ELECTRICAL ENGINEER'S POCKET-BOOK:

A HAND-BOOK
OF USEFUL DATA FOR ELECTRICIANS AND
ELECTRICAL ENGINEERS.

BY

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SEVENTH EDITION, REVISED

NEW YORK:
D. VAN NOSTRAND COMPANY
1918.

PREFACE TO THE FIFTH EDITION.

In appreciation of the very cordial reception accorded the earlier editions of this book, and in recognition of the fact that vast changes and advances have occurred in every branch of electrical engineering since the original publication, the author feels called upon to issue the present revised and enlarged edition.

The book as now presented, exceeds the previous editions in magnitude by about 600 pages, while the subject matter of every section has been either completely revised and brought up to date, or entirely re-written. The aim throughout has been to supply in exhaustive and condensed form, the data essential to the engineer engaged in any of the branches of the vast domain of electrical engineering. While our conception of the fundamental principles of electrical science can of necessity have undergone no very considerable alteration, those essential details which in effect constitute the working data of the practicing engineer have so altered and grown that books published only a few years ago are already obsolete. It is believed that a stage in the progress of electrical engineering standardization has now been reached wherein a compilation such as the present can be accepted as embodying the vital element to which future advances will appear to a degree in the relation of superficial alterations.

The original plan of dividing the subject into a number of sections and having each revised by an eminent specialist in that particular field has again been followed. Aside from the easy accessibility afforded, this plan of construction is valuable only in proportion to the weightiness of the authorities entrusted with the revision of the several divisions, and it is confidently believed that a perusal of the names heading the sections will lead to the conviction that a more approved and authoritative organization could not have been wished for. The several contributors are widely known and recognized as among the first of their respective specialties, and it is believed that the general average of excellence assured by their collaboration surpasses that of any compilation of the kind previously attempted.

Each section is complete in itself, but needless repetition has been avoided by the free use of cross references through the medium of the very extensive index.

Attention is directed to the large quantity of new matter, appearing for the first time in print, in the several sections. In the section on Conductors, e.g., the tables of Inductance, Capacity and Impedance, will be found new and original. Many sections, e.g., Street Railways, Photometry, Conductors, Lighting, Roentgen Rays, etc., are pointed out as examples of exhaustive though condensed presentation. The mechanical section has been treated with the same care and attention as the electrical.

The matter has been confined to the requirements of the electrical trades and sciences, the inclusion of the usual mathematical tables and data found in the commonly used handbooks having been avoided. These tables being easily accessible, and the present edition being already of great magnitude, this exclusion will be appreciated.

An important feature of the present volume will be found in the voluminous and studiously developed index and table of contents. The index is as complete as the limitations of manipulative facility will permit, and is calculated to render the finding of the particular phase of the subject sought a matter of least possible labor. The table of contents is designed to supplement and extend the use of the index, and in conjunction with the marginal thumb-index will render instantaneous the location of sections and subdivisions.

The careful and lengthy work of revision and search leads the author to believe that the number of errors cannot be large, and he ventures to express the hope that readers discovering any will have the kindness to bring them to his attention.

In conclusion the author begs to express his gratitude to the many contributors for their coöperation, and to the publishers for their painstaking effort and generosity in making so handsome and substantial a volume.

HORATIO A. FOSTER.

100 Broadway, New York.
June 1, 1908.

PREFACE TO THE SEVENTH EDITION.

No attempt has been made in this edition to add new matter nor to make radical changes in the old, but in a few cases substitution has been made, as in the latest revision of the Standardization Rules of the Am. Inst. E. E., and some changes in the text and cuts in the chapter on Switchboards. A number of typographical and other errors have been corrected.

HORATIO A. FOSTER.

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SYMBOLS, UNITS, INSTRUMENTS.

CHAPTER I.

ELECTRICAL ENGINEERING SYMBOLS.

The following list of symbols has been compiled from various sources as being those most commonly in use in the United States. Little variation will be found from similar lists already published except the elimination of some that may be considered exclusively foreign. The list has been revised by competent authorities and may be considered as representing the best usage.

Fundamental.

l, Length. c.m. = centimeter; in., or ″ = inch, ft. or ′ = foot.
M, Mass. gr. = mass of 1 gramme; kg. = 1 kilogramme.
T, *t*, Time. *s* = second.

Derived: *geometric.*

S, *s*, Surface.
V, Volume.
α, *β*, Angle.

Mechanical.

v, Velocity.
m, Momentum.
ω, Angular velocity.
a, Acceleration.
g, Acceleration due to gravity = 32.2 feet per second.
F, *f*, Force.
W, Work.
P, Power.
δ, Dyne, 10 δ = 10 dynes.
ε, Ergs.
ft. lb., Foot-pound.
H.p., h.p.; HP, Horse-power.
I.H.P., Indicated horse-power.
B.H.P., Brake horse-power.
E.H.P., Electrical horse-power.
J, Joules' equivalent.
p, Pressure.
K, Moment of inertia.

Derived Electrostatic.

q, Quantity.
i, Current.
e, Potential Difference.
r, Resistance.
k, Capacity.
sk, Specific Inductive capacity.

Derived Magnetic.

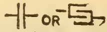
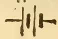
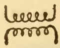
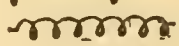
m, Strength of pole.
𝔐 Magnetic moment.
ℑ Intensity of magnetization.
ℑ, Intensity of magnetization.
ℋ, Horizontal intensity of earth's magnetism.
ℋ, Field intensity.
Φ, Magnetic Flux.
ℬ, Magnetic flux density or magnetic induction.
ℋ, Magnetizing force.
ℱ, Magnetomotive force.
ℛ, Reluctance, Magnetic resistance.
μ, Magnetic permeability.
κ, Magnetic susceptibility.
ν, Reluctivity (specific magnetic resistance).

Derived electromagnetic.

R, Resistance, Ohm.
Ω, do, megohm.
E, Electromotive force, volt.
U, Difference of potential, volt.
I, Intensity of current, Ampere.
Q, Quantity of electricity, Ampere-hour; Coulomb.
C, Capacity, Farad.
W, Electric Energy, Watt-hour; Joule.
P, Electric Power, Watt; Kilowatt.
ρ, Resistivity (specific resistance), Ohm-centimeter.
G, Conductance, Mho.
γ, Conductivity (specific conductivity.
Y, Admittance, mho.
Z, Impedance, ohm.
X, Reactance, ohm.
B, Susceptance, mho.
L, Inductance (coefficient of Induction), Henry.
v, Ratio of electro-magnetic to electrostatic unit of quantity $= 3 \times 10^{10}$ centimeters per second approximately.

Symbols in general use.

D, Diameter.
r, Radius.
t, Temperature.
θ, Deflection of galvanometer needle.

N, *n*,	Number of anything.
π,	Circumference $\div$ diameter : 3.141592.
ω,	$2\pi N = 6.2831 \times$ frequency, in alternating current.
$\sim f$,	Frequency, periodicity, cycles per second.
G,	Galvanometer.
S,	Shunt.
N, n,	North pole of a magnet.
S, s,	South pole of a magnet.
A.M.	Ammeter.
V.M.	Voltmeter.
A.C.	Alternating current.
D.C.	Direct current.
P.D.	Potential difference.
C.G.S.	Centimeter, Gramme, Second system.
B. & S.	Brown & Sharpe wire gauge.
B.W.G.,	Birmingham Wire gauge.
R.p.m.,	Revolutions per minute
C.P.	Candlepower.
—o—	Incandescent lamp.
	Arc lamp.
	Condenser.
	Battery of cells.
	Dynamo or motor, d.c.
	Dynamo or motor, a.c.
	Converter.
	Static transformer.
	Inductive resistance.
	Non-inductive resistance.

CHAPTER II.

ELECTRICAL ENGINEERING UNITS.

Index Notation.

Electrical units and values oftentimes require the use of large numbers of many figures both as whole numbers and in decimals. In order to avoid this to a great extent the index method of notation is in universal use in connection with all electrical computations.

In indicating a large number, for example, say, a million, instead of writing 1,000,000, it would by the index method be written 10^6; and 35,000,000 would be written 35×10^6.

A decimal is written with a minus sign before the exponent, or, $\frac{1}{100} = .01 = 10^{-2}$; and .00048 is written 48×10^{-5}.

The velocity of light is 30,000,000,000 cms. per sec., and is written 3×10^{10}.

In multiplying numbers expressed in this notation the significant figures are multiplied, and to their product is annexed 10, with an index equal to the *sum* of the indices of the two numbers.

In dividing, the significant figures are divided, and 10, with an index equal to the *difference* of the two indices of the numbers is annexed to the dividend.

Fundamental Units.

The physical qualities, such as force, velocity, momentum, etc., are expressed in terms of *length*, *mass*, *time*, and for electricity the system of terms in universal use is that known as the C. G. S. system,

viz.: The unit of length is the *Centimeter*.
The unit of mass is the *Gramme*.
The unit of time is the *Second*.

Expressed in more familiar units, the *Centimeter* is equal to .3937 inch in length; the *Gramme* is equal to 15.432 grains, and represents the *mass* or *quantity* of a cubic centimeter of water at 4° C, or 39.2° Fah.; the *Second* is the $\frac{1}{86164.09}$ part of a sidereal day, or the $\frac{1}{86400}$ part of a mean solar day.

These units are also often called *absolute units*.

Derived Geometric Units.

The unit of area or surface is the *square centimeter*.
The unit of *volume* is the *cubic centimeter*.

Derived Mechanical Units.

Velocity is the rate of change of position, and is uniform velocity when equal distances are passed over in equal spaces of time; unit velocity is a rate of change of *one centimeter per second*.

Angular Velocity is the angular distance about a center passed through in one second of time. Unit angular velocity is the velocity of a body moving in a circular path, whose radius is unity, and which would traverse a unit angle in unit time. Unit angle is 57°, 17′, 44.8″ approximately; i.e., an angle whose arc equals its radius.

Momentum is the quantity of motion in a body, and equals the *mass* times the *velocity*.

Acceleration is the rate at which velocity changes; the unit is an acceleration of one centimeter per second per second. The acceleration due to gravity is the increment in velocity imparted to falling bodies by gravity, and is usually taken as 32.2 feet per second, or 981 centimeters per second. This value differs somewhat at different localities. At the North Pole $g = 983.1$; at the equator $g = 978.1$; and at Greenwich it is 981.1.

Force acts to change a body's condition of rest or motion. It is that which tends to produce, alter, or destroy motion, and is measured by the time rate of change of momentum produced.

The unit of force is that force which, acting for one second on a mass of one gramme, gives the mass a velocity of one centimeter per second; this unit is called a *dyne*. The force of gravity or weight of a mass in dynes may be found by multiplying the mass in grammes by the value of g at the particular place where the force is exerted. The pull of gravity on one pound in the United States may be taken as 445,000 dynes.

Work is the product of a force into the distance through which it acts. The unit is the *erg*, and equals the work done in pushing a mass through a distance of one centimeter against a force of one dyne. As the "weight" of one gramme is 1×981, or 981 dynes, the work done in raising a weight of one gramme through a height of one centimeter against the force of gravity, or 981 dynes, equals $1 \times 981 = 981$ ergs.

One kilogramme-meter $= 100000 \times 981$ ergs.

Kinetic energy is the work a body is able to do by reason of its motion.

Potential energy is the work a body is able to do by reason of its position.

The unit of energy is the *erg*.

Power is the rate of working, and the unit is the *watt* $= 10^7$ ergs per sec. *Horse-power* is the unit of power in common use and, although a somewhat arbitrary unit, it is difficult to compel people to change from it to any other. It equals 33,000 lbs. raised one foot high in one minute, or 550 foot-pounds per second.

1 ft.-lb. $= 1.356 \times 10^7$ ergs.

1 watt $= 10^7$ ergs per second.

1 horse-power $= 550 \times 1.356 \times 10^7$ ergs $= 746$ watts. If a current of I amperes flow through R ohms under a pressure of E volts, then $\frac{EI}{746} = \frac{I^2R}{746} = \frac{E^2}{746\,R}$ represents the horse-power involved.

The French "*force de cheval*" $= 736$ watts $= 542.48$ ft. lbs. per sec. $= .9863$ H. P., and 1 H.P. $= 1.01389$ "*force de cheval*."

Heat. The Joule $WJ = 10^7$ ergs, and is the work done, or heat generated, by a watt second, or ampere flowing for a second through a resistance of an ohm.

If H = heat generated in gramme calories,
I = current in amperes,
E = e.m.f. in volts,
R = resistance in ohms, and
t = time in seconds,

then $H = 0.24 I^2Rt = 0.24\,EIt$. gramme *calories* or therms.

Then $$IEt = I^2Rt = \frac{E^2t}{R} = EQ = \text{Joules}.$$

or, as 1 horse-power = 550 foot-pounds of work per second,

$$\text{Joules} = \tfrac{550}{746} EQ = .7373\, EQ \text{ ft. lbs.}$$

Heat Units.

The *British Thermal Unit* is the amount of heat required to raise the temperature of one pound of water one deg. F. at or near its temp. of max. density, 39.1°; = 1 pound-degree-Fah. = 251.9 French calories.

The *Calorie* is the amount of heat required to raise the temperature of a mass of 1 gramme of water from 4° C. to 5° C. = 1 gramme-degree-centigrade.

Water at 4° C. is at its maximum density.

Joules equivalent, J, is the amount of energy equal to a heat unit.

For a B.T.U., or pound-degree-Fah., $J = 1.07 \times 10^{10}$ ergs., or $= 778$ foot-pounds.

For one pound-degree — Centigrade, $J = 1.93 \times 10^{10}$ ergs.

For a *calorie* $J = 4.189 \times 10^7$ ergs.

The heat generated in t seconds of time is

$$\frac{I^2Rt}{J} = \frac{EIt}{J}, \text{ where } J = 4.189 \times 10^7,$$

and I, R, and E are expressed in practical units.

Electrical Units.

There are two sets of electrical units derived from the fundamental C. G. S. units; viz., the *electrostatic* and the *electromagnetic*. The first is based on the force exerted between two quantities of electricity, and the second upon the force exerted between a current and a magnetic pole. The ratio of the *electrostatic* to the *electromagnetic* units has been carefully determined by a number of authorities, and is found to be some multiple or sub-multiple of a quantity represented by v, whose value is approximately 3×10^{10} centimeters per second. Convenient rules for changing from one to the other set of units will be stated later on in this chapter.

Electrostatic Units.

As yet there have been no names assigned to these. Their values are as follows:

The unit of quantity is that quantity of electricity which repels with a force of *one dyne* a similar and equal quantity of electricity placed at unit distance (one centimeter) in air.

Unit of current is that which conveys a unit of quantity along a conductor in unit time (one second).

Unit difference of potential or *unit electro-motive force* exists between two points when *one erg* of work is required to pass a unit quantity of electricity from one point to the other.

Unit of resistance is possessed by that conductor through which unit current will pass under unit electro-motive force at its ends.

Unit of capacity is that which, when charged by unit potential, will hold one unit of electricity; or that capacity which, when charged with one unit of electricity, has a unit difference of potential.

Specific inductive capacity of a substance is the ratio between the capacity of a condenser having that substance as a dielectric to the capacity of the same condenser using dry air at 0° C. and a pressure of 76 centimeters as the dielectric.

Magnetic Units.

Unit Strength of Pole (symbol m) is that which repels another similar and equal pole with unit force (one dyne) when placed at unit distance (one centimeter) from it.

Magnetic Moment (symbol $\mathfrak{M}$) is the product of the strength of either pole into the distance between the two poles.

Intensity of Magnetization is the magnetic moment of a magnet divided by its volume. (symbol $\mathfrak{J}$).

Intensity of Magnetic Field (symbol $\mathcal{H}$) is measured by the force it exerts upon a unit magnetic pole, and therefore the unit is that intensity of field which acts on a unit pole with a unit force (one dyne).

Magnetic Induction (symbol $\mathcal{B}$) is the magnetic flux or the number of magnetic lines per unit area of cross-section of magnetized material, the area being at every point perpendicular to the direction of flux. It is equal to the magnetizing force or field intensity $\mathcal{H}$ multiplied by the *permeability* μ: the unit is the *gauss*.

Magnetic Flux (symbol Φ) is equal to the average field intensity multiplied by the area. Its unit is the *maxwell*.

Magnetizing Force (symbol $\mathcal{H}$) per unit of length of a solenoid equals

$4\pi NI \div L$ where $N =$ the number of turns of wire on the solenoid; $L =$ the length of the solenoid in cms., and $I =$ the current in absolute units.

Magnetomotive Force (symbol $\mathfrak{F}$) is the total magnetizing force developed in a magnetic circuit by a coil, equals $4\pi NI$, and the unit is the *gilbert.*

Reluctance, or *Magnetic Resistance* (symbol $\mathcal{R}$), is the resistance offered to the magnetic flux by the material magnetized, and is the ratio of magnetomotive force to magnetic flux; that is, unit magnetomotive force will generate a unit of magnetic flux through unit reluctance: the unit is the *oersted;* i.e., the reluctance offered by a cubic centimeter of vacuum.

Magnetic Permeability (symbol μ) is the ratio of the magnetic induction $\mathcal{B}$ to the magnetizing force $\mathcal{H}$, that is $\frac{\mathcal{B}}{\mathcal{H}} = \mu$.

Magnetic Susceptibility (symbol κ) is the ratio of the intensity of magnetization to the magnetizing force, or $\kappa = \frac{\mathfrak{I}}{\mathcal{H}}$.

Reluctivity, or *Specific Magnetic Resistance* (symbol ν), is the reluctance per unit of length and of unit cross-section that a material offers to being magnetized.

Electromagnetic Units.

Resistance (symbol R) is that property of a material that opposes the flow of a current of electricity through it; and the unit is that resistance which, with an electro-motive force or pressure between its ends of one unit, will permit the flow of a unit of current.

The practical unit is the *ohm*, and its value in C.S.G. units is 10^9. The standard unit is a column of pure mercury at 0° C., of uniform cross-section, 106.3 centimeters long, and 14.4521 grammes weight. For convenience in use for very high resistances the prefix *meg* is used; and the *megohm*, or million ohms, becomes the unit for use in expressing the insulation resistances of submarine cables and all other high resistances.

Electro-motive Force (symbol E) is the electric pressure which forces the current through a resistance, and unit E.M.F. is that pressure which will force a unit current one ampere through a unit resistance. The unit is the volt, and the practical standard adopted by the international congress of electricians at Chicago in 1893 is the Clark cell, directions for making which will be given farther on. The E.M.F. of a Clark cell is 1.434 volt at 15° C.

The value of the volt in C.G.S. units is 10^8. For small E.M.F's. the unit millivolt, or one-thousandth volt, is used.

The International Volt is 1.1358 B. A. volts; and the ratio of B. A. volt to the International volt is .9866.

Difference of Potential, as the name indicates, is simply a difference of electric pressure between two points. The unit is the *volt.*

Current (symbol I) is the intensity of the electric current that flows through a circuit. A unit current will flow through a resistance of one ohm, with an electro-motive force of one volt between its ends. The unit is the ampere, and is practically represented by the current that will electrolytically deposit silver at the rate of .001118 gramme per second. Its value in C.G.S. units is 10^{-1}. For small values the milliampere is used, and it equals one-thousandth of an ampere.

The Quantity of Electricity (symbol Q) which passes through a given cross-section of an individual circuit in t seconds when a current of I amperes is flowing is equal to It units. The unit is therefore the ampere-second. Its name is the *Coulomb*, and its value in C.G.S. units is 10^{-1}.

Capacity (symbol C) is the property of a material condenser for holding a charge of electricity. A condenser of unit capacity is one which will be charged to a potential of one volt by a quantity of 1 coulomb. The unit is the *farad*, its C.G.S. value is 10^{-9}; and this being so much larger than ever obtains in practical work, its millionth part, or the *micro-farad*, is used as the practical unit, and its value in absolute units is 10^{-15}. A condenser of one-third micro-farad capacity is the size in most common use in the U. S.

Electric Energy (symbol W) is represented by the work done in a circuit or conductor by a current flowing through it. The unit is the *Joule*, its absolute value is 10^7 ergs, and it reprepresents the work done by the flow for one second of unit current (1 ampere) through 1 ohm.

Electric Power (symbol P) is measured in *watts*, and is represented by a current of 1 ampere under a pressure of 1 volt, or 1 Joule per second. The

Symbols for Physical Quantities and Abbreviations for Units.

Recommended by the Committee on Notation of the International Electrical Congress of 1893, with additions of the International Electrical Congress of 1900.

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C. G. S. Units.	Abbreviations of the names of the C.G.S. Units.	Practical Units.	Abbreviations of the Practical Units.
Fundamental.							
Length	L, l	. . . . . .	L	Centimeter.	cm	Meter.	m
Mass	M	. . . . . .	M	Mass of 1 gramme.	g	Mass of a kilogram.	kg
Time*	T, t	. . . . . .	T	Second.	s	Minute; hour.	m; h
Geometric.							
Surface	S, s	$S = L.L$	L^2	Square centimeter.	cm^2	Square meter.	m^2
Volume	V	$V = L.L.L$	L^3	Cubic centimeter.	cm^3	Cubic meter.	m^3
Angle	α, β	$\alpha = \frac{\text{arc}}{\text{radius}}$	A number.	Radian.	. . .	Degree; minute; second; grade.	
Mechanical.							
Velocity	v	$V = \frac{L}{T}$	LT^{-1}	Centimeter per second.	cm : s	Meter per second.	m : s
Angular Velocity	ω	$\omega = \frac{v}{L}$	T^{-1}	Radian per second.	. . .	Revs. (turns) per minute.	t : m
Acceleration	a	$a = \frac{v}{T}$	LT^{-2}	Centimeter per second per second.	cm : s^2	Meter per second per second.	m : s^2
Force	F, f	$F = Ma$	LMT^{-2}	Dyne.	dyne	Gramme; kilogr'm.	g : kg
Work	W	$W = FL$	L^2MT^{-2}	Erg.	erg	Kilogrammeter.	kgm
Power	P	$P = \frac{W}{T}$	L^2MT^{-3}	Erg per second.	erg : s	Kilogrammeter per second.	kgm : s

* The International Bureau of Weights and Measures has established an important distinction in the notation of time, according as it refers to the *epoch* (date of time or day) or the *duration* of a phenomenon. In the former case the reference letters are used as indices, and in the latter they are on the same line with the numbers; for instance, an experiment began at $2^h\, 15^m\, 46^s$, lasted 2h. 15m. 46s., and ended at $4\ 31^m\, 32^s$. This method is to be recommended.

Pressure	p	$p=\frac{F}{S}$	$L^{-1}MT^{-2}$	Barie	dyne: cm²		
Moment of Inertia	K	$K=ML^2$	L^2M	Gramme-mass-centimeter-squared.	g-cm²		
Magnetic.							
Strength of Pole	m	$F=\frac{m^2}{L^2}$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$				
Magnetic Moment	$\mathfrak{M}$	$\mathfrak{M}=ml$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$				
Intensity of Magnetization .	$\mathfrak{I}$	$\mathfrak{I}=\frac{\mathfrak{M}}{V}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$				
Field Intensity	$\mathcal{H}$	$\mathcal{H}=\frac{F}{m}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	. . .	*Gauss.*	
Flux of (Magnetic) Force .	Φ	$\Phi=\mathcal{H}S$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$	*Maxwell.*	. . .	*Maxwell.*	
Magnetic Induction	$\mathcal{B}$	$\mathcal{B}=\mu\,\mathcal{H}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gauss.*	. . .	*Gauss.*	
Magnetizing Force† . . .	$\mathcal{H}$	$\mathcal{H}=\frac{4\pi NI}{L}$	$L^{-\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$				
Magnetomotive Force . . .	$\mathfrak{F}$	$\mathfrak{F}=4\pi NI$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	*Gilbert.*‡	. . .	1 Gilbert ‡ = 0.7958 ampere-turns	a-t
Reluctance (Magnetic Resistance)	$\mathcal{R}$	$\mathcal{R}=\nu\frac{L}{S}$	L^{-1}	*Oersted.*‡	. . .	*Oersted.*‡	
(Magnetic) Permeability . .	μ	$\mu=\frac{\mathcal{B}}{\mathcal{H}}$	A Number.				
(Magnetic) Susceptibility .	κ	$\kappa=\frac{\mathfrak{I}}{\mathcal{H}}$	A Number.				
Reluctivity (Specific Magnetic Resistance) . . .	ν	$\nu=\frac{1}{\mu}$	A Number.				
Electromagnetic.							
Resistance	R, r	$R=\frac{E}{I}$	LT^{-1}	absohm.	. . .	Ohm.	ohm
Electromotive Force . . .	E, e	$E=RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	abvolt.	Abv.	Volt.	v

† N is the number of turns and L the length of the solenoid generating the magnetizing force.
‡ Name provisionally adopted by the American Institute of Electrical Engineers.

Symbols for Physical Quantities and Abbreviations for Units. — *Continued*

Physical Quantities.	Symbols.	Defining Equations.	Dimensions of the Physical Quantities.	Names of the C. G. S. Units.	Abbreviations of the names of the C. G. S. Units.	Practical Units.	Abbreviations of the Practical Units.
Electromagnetic.—*Cont.*							
Difference of Potential . .	U, u	$U = RI$	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	abvolt.	Abv.	Volt.	v
Intensity of Current . . .	I, i	$I = \frac{E}{R}$	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	absampere.	Absamp.	Ampere.	
Quantity of Electricity . .	Q, q	$Q = IT$	$L^{\frac{1}{2}}M^{\frac{1}{2}}$	abcoulomb.	AbC.	Coulomb ; ampere-hour.	c ; a-h
Capacity	C, c	$C = \frac{Q}{E}$	$L^{-1}T^{2}$	abfarad.	AbF.	Farad.	F
Electric Energy	W	$W = EIT$	$L^{2}MT^{-2}$	abjoule or erg.	AbJ.	Joule ; watt-hour.	J ; w-h
Electric Power	P	$P = EI$	$L^{2}MT^{-3}$	abwatt or erg per second.	. . .	Watt ; kilowatt.	w ; kw
Resistivity (Specific Resistance)	ρ	$\rho = \frac{RS}{L}$	$L^{2}T^{-1}$	absohm-centimeter	. . .	Ohm-centimeter.	ohm-cm
Conductance	G, g	$G = \frac{1}{R}$	$L^{-1}T$	abmho.	. . .	Mho.	mho
Conductivity (Specific Conductance)	γ	$\gamma = \frac{1}{\rho}$	$L^{-2}T$	. . . .	. . .	. . . .	
Coefficient of Induction (Inductance)	L, l	$L = \frac{\Phi}{I}$	L	abhenry or centimeter.	AbH.	Henry.	H
Frequency	n	. . . . . .	T^{-1}	. . . .	. . .	~	
Admittance	Y	$Y = \frac{1}{Z}$	$L^{-1}T$*	abmho.	. . .	Mho.	mho
Impedance	Z	$Z = \sqrt{R^2 + X^2}$	LT^{-1}*	absohm.	. . .	Ohm.	ohm
Reactance	X	$X = 2\pi nL - \frac{1}{2\pi nC}$	LT^{-1}*	absohm.	. . .	Ohm.	ohm
Susceptance	B	$B = \sqrt{Y^2 - G^2}$	$L^{-1}T$*	abmho.	. . .	Mho.	mho

* Plane Vector Quantity.

watt equals 10^7 absolute units, and 746 watts equals 1 horse-power. In electric lighting and power the unit *kilowatt*, or 1000 watts, is considerably used to avoid the use of large numbers.

Resistivity (symbol ρ) is the specific resistance of a substance, and is the resistance in ohms of a centimeter cube of the material to a flow of current between opposite faces.

Conductance (symbol G) is that property of a metal or substance by which it conducts an electric current, and equals the reciprocal of its resistance. The unit proposed for conductance is the *Mho*, but it has not come into prominent use as yet.

Conductivity (symbol v) is the specific conductance of a material, and is therefore the reciprocal of its resistivity. It is often expressed in comparison with the conductivity of some standard metal such as silver or copper, and is then stated as a percentage.

Inductance (symbol L), or coefficient of self-induction, of a circuit is that coefficient by which the time rate of change of the current in the circuit must be multiplied in order to give the E.M.F. of self-induction in the circuit. The practical unit is the *henry*, which equals 10^9 absolute units, and exists in a circuit when a current varying 1 *ampere* per *second* produces a *volt* of electro-motive force in that circuit. As the *henry* is so large as to be seldom met with in practice, 1 thousandth of it, or the *milli-henry*, is the unit most in use.

Below will be found a few rules for reducing values stated in electrostatic units to units in the electro-magnetic system. To reduce

electrostatic *potential* to *volts*, multiply by 300;
" *capacity* to *micro-farads*, divide by 900,000;
" *quantity* to *coulombs*, divide by 3×10^9;
" *current* to *amperes*, divide by 3×10^9;
" *resistance* to *ohms*, multiply by 9×10^{11}.

INTERNATIONAL ELECTRICAL UNITS.

At the International Congress of Electricians, held at Chicago, August 21, 1893, the following resolutions met with unanimous approval, and being approved for publication by the Treasury Department of the United States Government, Dec. 27, 1893, and legalized by act of Congress and approved by the President, July 12, 1894, are now recognized as the International units of value for their respective purposes.

RESOLVED, That the several governments represented by the delegates of the International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following:

1. As a unit of *resistance*, the *International ohm*, which is based upon the ohm equal to 10^9 units of resistance of the C.G.S. system of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at a temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area, and of the length 106.3 centimeters.

2. As a unit of *current*, the *International ampere*, which is one-tenth of the unit of current of the C.G.S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, in accordance with the accompanying specification (A) deposits silver at the rate of 0.001118 gramme per second.

3. As a unit of *electro-motive force* the *international volt* which is the E.M.F. that, steadily applied to a conductor whose resistance is one International ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the E.M.F. between the poles or electrodes of the voltaic cell known as Clark's cell at a temperature of 15° C, and prepared in the manner described in the accompanying specification (B).

4. As the unit of *quantity*, the *International coulomb*, which is the quantity of electricity transferred by a current of one international ampere in one second.

5. As the unit of *capacity* the *international farad*, which is the capacity

of a conductor charged to a *potential* of one *international volt* by one international coulomb of electricity.

6. As the unit of *work*, the *joule*, which is 10^7 units of work in the C.G.S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

7. As the unit of *power*, the *watt*, which is equal to 10^7 units of power in the C.G.S. system, and which is represented sufficiently well for practical use by the work done at the rate of one joule per second.

8. As the unit of *induction*, the *henry*, which is the induction in the circuit when the E.M.F. induced in this circuit is one international volt, while the inducing current varies at the rate of one international ampere per second.

Specification A.

In employing the silver voltameter to measure currents of about one ampere, the following arrangements shall be adopted:

The kathode on which the silver is to be deposited shall take the form of a platinum bowl not less than 10 cms. in diameter, and from 4 to 5 cms. in depth.

The anode shall be a disk or plate of pure silver some 30 sq. cms. in area, and 2 or 3 cms. in thickness.

This shall be supported horizontally in the liquid near the top of the solution by a silver rod riveted through its center.

To prevent the disintegrated silver which is formed on the anode from falling upon the kathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance, besides that of the voltameter, should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a Measurement. — The platinum bowl is to be washed consecutively with nitric acid, distilled water, and absolute alcohol; it is then to be dried at 160° C., and left to cool in a desiccator. When cold it is to be weighed carefully.

It is to be nearly filled with the solution, and connected to the rest of the circuit by being placed on a clean copper support to which a binding-screw is attached

The anode is then to be immersed in the solution so as to be well covered by it, and supported in that position; the connections to the rest of the circuit are then to be made.

Contact is to be made at the key, noting the time. The current is to be allowed to pass for not less than half an hour, and the time of breaking contact observed.

The solution is now to be removed from the bowl, and the deposit washed with distilled water, and left to soak for at least six hours. It is then to be rinsed successively with distilled water and absolute alcohol, and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is to be weighed again. The gain in mass gives the silver deposited.

To find the time average of the current in amperes, this mass, expressed in grammes, must be divided by the number of seconds during which the current has passed and by 0.001118.

In determining the constant of an instrument by this method the current should be kept as nearly uniform as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time average of the current) can be found.

The current is calculated from the voltameter results, corresponding to this reading.

The current used in this experiment must be obtained from a battery and not from a dynamo, especially when the instrument to be calibrated is an electrodynamometer.

Specification B. — The Volt.

The cell has for its positive electrode, mercury, and for its negative electrode, amalgamated zinc; the electrolyte consists of a saturated solution of zinc sulphate and mercurous sulphate. The electromotive force is 1.434 volts at 15° C., and, between 10° C. and 25° C., by the increase of 1° C. in temperature, the electromotive force decreases by .00115 of a volt.

1. Preparation of the Mercury.—To secure purity it should be first treated with acid in the usual manner, and subsequently distilled in vacuo.

2. Preparation of the Zinc Amalgam.—The zinc designated in commerce as "commercially pure" can be used without further preparation. For the preparation of the amalgam one part by weight of zinc is to be added to nine (9) parts by weight of mercury, and both are to be heated in a porcelain dish at 100° C. with moderate stirring until the zinc has been fully dissolved in the mercury.

3. Preparation of the Mercurous Sulphate.—Take mercurous sulphate, purchased as pure, mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water and repeat the process at least twice. After the last washing, drain off as much of the water as possible. (For further details of purification, see Note A.)

4. Preparation of the Zinc Sulphate Solution.—Prepare a neutral saturated solution of pure re-crystallized zinc sulphate, free from iron, by mixing distilled water with nearly twice its weight of crystals of pure zinc sulphate and adding zinc oxide in the proportion of about 2 per cent by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved by the aid of gentle heat, but the temperature to which the solution is raised must not exceed 30° C. Mercurous sulphate, treated as described in 3, shall be added in the proportion of about 12 per cent by weight of the zinc sulphate crystals to neutralize the free zinc oxide remaining, and then the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. Preparation of the Mercurous Sulphate and Zinc Sulphate Paste.—For making the paste, two or three parts by weight of mercurous sulphate are to be added to one by weight of mercury. If the sulphate be dry, it is to be mixed with a paste consisting of zinc sulphate crystals and a concentrated zinc sulphate solution, so that the whole constitutes a stiff mass, which is permeated throughout by zinc sulphate crystals and globules of mercury.

If the sulphate, however, be moist, only zinc sulphate crystals are to be added; care must, however, be taken that these occur in excess, and are not dissolved after continued standing. The mercury must, in this case also, permeate the paste in little globules. It is advantageous to crush the zinc sulphate crystals before using, since the paste can then be better manipulated.

To set up the Cell.—The containing glass vessel, represented in the accompanying figure, shall consist of two limbs closed at bottom, and joined above to a common neck fitted with a ground-glass stopper. The diameter of the limbs should be at least 2 cms. and their length at least 3 cms. The neck should be not less than 1.5 cms. in diameter. At the bottom of each limb a platinum wire of about 0.4 mm. in diameter is sealed through the glass.

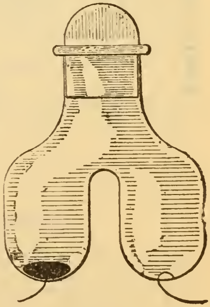


FIG 1.

To set up the cell, place in one limb mercury, and in the other hot liquid amalgam, containing 90 parts mercury and 10 parts zinc. The platinum wires at the bottom must be completely covered by the mercury and the amalgam respectively. On the mercury, place a layer one cm. thick of the zinc and mercurous sulphate paste described in 5. Both this paste and the zinc amalgam must then be covered with a layer of the neutral zinc sulphate crystals one cm. thick. The whole vessel must then be filled with the saturated zinc sulphate solution, and the stopper inserted so that it shall just touch it, leaving, however, a small bubble to guard against breakage when the temperature rises.

Before finally inserting the glass stopper, it is to be brushed round its upper edge with a strong alcoholic solution of shellac, and pressed firmly in place. (For details of filling the cell see Note B.)

Table of Equivalents of Units of Energy and Work.

	Erg.	Mega-erg.	Gram-degree C.	Kilo-gram-degree C.	Pound-degree C.	Pound-degree F.	Watt second.	Gram-centi-meter.	Kilo-gram-meter.	Foot-pound.	H. P. sec., Eng-lish.	H. P. sec., metric.
Erg	1	$\frac{1}{10^6}$	$\frac{23888}{10^{12}}$	$\frac{23888}{10^{15}}$	$\frac{527}{10^{13}}$	$\frac{948}{10^{13}}$	$\frac{1}{10^7}$	$\frac{101,979}{10^8}$	$\frac{101,97}{10^{13}}$	$\frac{737,612}{10^{13}}$	$\frac{13411}{10^{14}}$	$\frac{13596}{10^{14}}$
Mega-erg	10^6	1	$\frac{23888}{10^6}$	$\frac{23888}{10^9}$	$\frac{527}{10^7}$	$\frac{948}{10^7}$	0.1	1019.79	$\frac{101,979}{10^7}$	$\frac{737,612}{10^7}$	$\frac{13411}{10^8}$	$\frac{13596}{10^8}$
Gram-degree C. . .	41,861,700	41.8617	1	.001	.002205	.003968	4.18617	42,684.3	.426,843	3.08777	.005,614	.005692
Kilogram-degree C .	$41,862 \times 10^6$	41,861.7	1000	1	2.2046	3.9683	4186.17	42,684,300	426,843	3087.77	5.61412	5.692
Pound-degree C . .	$18,988 \times 10^6$	18,988.1	453.592	.453,592	1	1.8000	1898.81	19,363,900	193.639	1400.59	2.54652	2.58185
Pound-degree F . .	$10,549 \times 10^6$	10,549.	251.996	251,996	.555,556	1	1054.90	10,757,700	107.577	778.104	1.41474	1.43436
Watt-second . . .	10^7	10	.238,882	$\frac{238,882}{10^8}$	.000,527	.000948	1	10,197.9	.101,979	.737,612	.001,341	.001,359
Gram-centimeter . .	980.596	.000981	.000,023	$\frac{2342}{10^{11}}$	$\frac{5164}{10^{11}}$	$\frac{9296}{10^{11}}$	.000,098	1	.00001	$\frac{723,328}{10^5}$	$\frac{13151}{10^{11}}$	$\frac{13333}{10^{11}}$
Kilogram-meter . .	981×10^6	98.0596	2.34247	.002,342	.005164	.009296	9.80596	100,000	1	7.23328	.013,151	.013,333
Foot-pound	13,557,300	13.5573	.323,859	.000,324	.000714	.001,285	1.35573	13,825.5	.138,255	1	.001,818	.001,843
Horse-power sec., Eng.	$745,650 \times 10^4$	7456.50	178.122	.178122	.39292	.70684	745.650	7,604,040	76.0404	550	1	1.01383
Horse-power sec., met.	$73,545 \times 10^5$	7354.5	.175685	175.685	.38732	.69717	735.447	7,500,000	75	542.475	.986,356	1

Notes to the Specifications.

(*A*). **The Mercurous Sulphate.**—The treatment of the mercurous sulphate has for its object the removal of any mercuric sulphate which decomposes in the presence of water into an acid and a basic sulphate. The latter is a yellow substance—turpeth mineral—practically insoluble in water; its presence, at any rate in moderate quantities, has no effect on the cell. If, however, it be formed, the acid sulphate is also formed. This is soluble in water, and the acid produced affects the electromotive force. The object of the washings is to dissolve and remove this acid sulphate, and for this purpose the three washings described in the specification will suffice in nearly all cases. If, however, much of the turpeth mineral be formed, it shows that there is a great deal of the acid sulphate present; and it will then be wiser to obtain a fresh sample of mercurous sulphate, rather than to try by repeated washings to get rid of all the acid.

The free mercury helps in the process of removing the acid; for the acid mercuric sulphate attacks it, forming mercurous sulphate.

Pure mercurous sulphate, when quite free from acid, shows on repeated washing a faint yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate. The appearance of this primrose yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate, may be taken as an indication that all the acid has been removed; the washing may with advantage be continued until this tint appears.

(*B*). **Filling the Cell.**—After thoroughly cleaning and drying the glass vessel, place it in a hot-water bath. Then pass through the neck of the vessel a thin glass tube reaching to the bottom to serve for the introduction of the amalgam. This tube should be as large as the glass vessel will admit. It serves to protect the upper part of the cell from being soiled with the amalgam. To fill in the amalgam, a clean dropping-tube about 10 cms. long, drawn out to a fine point, should be used. Its lower end is brought under the surface of the amalgam heated in a porcelain dish, and some of the amalgam is drawn into the tube by means of the rubber bulb. The point is then quickly cleaned of dross with filter paper, and is passed through the wider tube to the bottom, and emptied by pressing the bulb. The point of the tube must be so fine that the amlagam will come out only on squeezing the bulb. This process is repeated until the limb contains the desired quantity of the amalgam. The vessel is then removed from the water-bath. After cooling, the amalgam must adhere to the glass, and must show a clean surface with a metallic luster.

For insertion of the mercury, a dropping-tube with a long stem will be found convenient. The paste may be poured in through a wide tube reaching nearly down to the mercury and having a funnel-shaped top. If the paste does not run down freely it may be pushed down with a small glass rod. The paste and the amalgam are then both covered with the zinc sulphate crystals before the concentrated zinc sulphate solution is poured in. This should be added through a small funnel, so as to leave the neck of the vessel clean and dry.

For convenience and security in handling, the cell may be mounted in a suitable case so as to be at all times open to inspection.

In using the cell, sudden variations of temperature should, as far as possible, be avoided, since the changes in electromotive force lag behind those of temperature.

CHAPTER III.

DESCRIPTION OF INSTRUMENTS.

Although no attempt will be made here to fully describe all the different instruments used in electrical testing, some of the more important will be named and the more common uses to which they may be put mentioned.

The four essential instruments for all electrical testing of which all other instruments are but variations, are: the *battery*, the *galvanometer*, the *resistance-box*, and the *condenser*, and following will be found a concise description of the more important types of each.

PRIMARY BATTERIES.

A Voltaic Battery is a device for converting chemical energy directly into electrical energy.

If a plate of chemically pure zinc and a plate of copper are immersed in dilute sulphuric acid no chemical action takes place. As soon, however, as the zinc and copper plates are connected by an electrical conductor outside of the liquid a vigorous chemical action is set up, the zinc dissolves in the acid, and hydrogen is liberated on the copper plate. As long as this action takes place an electric current passes from the zinc plate through the acid to the copper plate and through the conductor back to the zinc plate.

The chemical action in this simple voltaic cell soon becomes weaker, and at the same time the intensity of the electric current diminishes and finally becomes zero. The diminution of activity is chiefly due to the accumulation of hydrogen on the copper plate, causing what is known as "polarization." An agent introduced into a galvanic cell to prevent polarization is called a "depolarizer."

The chemical reaction of a voltaic cell is directly proportional to the quantity of electricity passing through it. The quantity (in grammes) of an element liberated or brought into combination electrolytically by one coulomb of electricity, is called its electrochemical equivalent. (See table on second page of section on "Electrochemistry.") The theoretical consumption of material in a voltaic battery doing a certain amount of work can be calculated from the electrochemical equivalent of the material. For example, in a battery doing work equivalent to one horse-power hour

$$\frac{746 \times 3600 \times .003387}{E}$$

grammes of zinc will be dissolved; E being the E.M.F. of the battery.

In practice the consumption of material in a galvanic cell is larger, due to local action. Commercial zinc always contains iron, carbon, or other impurities; as soon as these are exposed to the liquid, local closed circuits are formed resulting in the consumption of zinc. To prevent this wasteful action, the zinc must be amalgamated with mercury. The action of the mercury brings the pure zinc to the surface and in contact with the liquid. Amalgamated zinc is not attacked by diluted sulphuric acid.

Zinc is amalgamated by immersing it in dilute sulphuric or hydrochloric acid for a few minutes to give it a clean surface, then mercury is rubbed on with a hard brush or cloth fixed on the end of a piece of wood.

Primary Cells may be classified into two groups; closed circuit and open circuit.

Closed Circuit Cells. — Cells of this group must be capable of working on a closed circuit of moderate resistance for a long period without sensible polarization. They must, therefore, contain an effective depolarizer. The best depolarizers are copper sulphate $CuSO_4$, strong nitric acid HNO_3, chromic acid CrO_3, oxide of copper CuO, and chloride of silver $AgCl$.

The following table contains data on the representative types of closed circuit cells.

Name.	+Plate.	Electrolyte.	Depolarizer.	−Plate.	E.M.F.	R.
Daniell	Zinc	Sulphuric Acid	Cop. sulphate	Copper	1.08	1.
Grove	"	" "	Nitric Acid	Platinum	1.9	.15
Bunsen	"	" "	" "	Carbon	1.8	.2
Peggendorff	"	" "	Bichromate of Potassium-Sulp. acid	"	2.	.2
Lande	"	Caustic Potash	Copper Oxide	Iron	1.	.1
Davy	"	Ammonium Chloride	Silver Chloride	Silver	1.1	4.5

The values given as electromotive force and internal resistance of the different types of cells are approximate only. The E.M.F. depends upon the purity of the materials, the concentration of the solution; the internal resistance, furthermore, depends upon the dimensions and general arrangement of the cells.

Open Circuit Cells.— Cells of this group are only suitable for use when the circuit is to be closed for a few seconds at a time, as for example for call bells, annunciators, etc. Such batteries do not need to contain a quick acting polarizer, as the effect of polarization can be taken care of during the intervals of rest, either by a slow acting depolarizer or even without any polarizer. It is, however, of the greatest importance that no local action takes place in these cells on open circuit.

The following table contains data on the representative types of open circuit cells:

Name.	+Plate.	Electrolyte.	Depolarizer	— Plate.	E.M.F.	R.
Leclanché	Zinc	Sol. of Sal-ammoniac	Binoxide of Manganese	Carbon	1.48	.5
Law	Zinc	" " "	None	Carbon	1.37	.4
Gassner	Zinc	Oxide of Zinc, sal-ammoniac, Chloride of zinc, plaster	"	Carbon	1.3	.2

The Gravity Cell.

The elements are copper and zinc; the solution is sulphate of copper, or "bluestone," dissolved in water. The usual form (see Fig. 2) is a glass jar, about 8 inches high and 6 inches diameter. The copper is made of two or more layers fastened in the middle, spread out, and set on edge in the bottom of the cell, the terminal being a piece of gutta-percha insulated copper wire extending up through the solution.

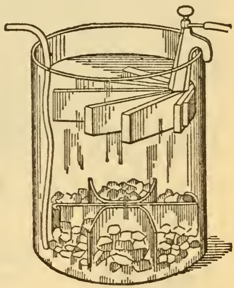


FIG. 2.

The zinc is usually cast with fingers spread out, and a hook for suspending from the top of the jar as shown, the terminal being on top of the hook. This form of zinc is commonly called "crowfoot," and the battery often goes by that name. Sometimes star-shaped zincs are suspended from a tripod across the top of the jar. The "bluestone" crystals are placed in the bottom of the jar about the copper, the jar then being filled with water to just above the "crowfoot" or zinc. A tablespoonful of sulphuric acid is added. A saturated solution of copper sulphate forms around the copper; and, after use, a zinc sulphate solution is formed around the zinc, and floats upon the copper sulphate solution. The line of separation between the two solutions is called the *blue line.* As the two solutions are kept separate because of their different specific gravities, the name "gravity cell" is employed.

This cell does not polarize, and the E.M.F. is practically constant or uniform at about 1 volt on a closed circuit. If the circuit is not closed, and the cell does not have work enough to prevent mixing of the two solutions, the copper sulphate coming in contact with the zinc will become decomposed; the oxygen forming oxide of zinc, and the copper depositing on the zinc having an appearance like black mud.

Care of the Gravity Cell. — For ordinary "local work" about three pounds of "bluestone" per cell is usually found best. When this is gone it is better to clean out the cell and supply new solution than to try to replenish. "Bluestone" crystals should not be smaller than a pea nor as large as an egg. In good condition the solution at the bottom should be a bright blue, changing to water-color above. A brownish color in any part denotes deterioration.

To prevent evaporation of the solution it is well to pour a layer of good mineral oil over the top when the cell is first set up. This oil should be odorless, free from naphtha or acid, and non-inflammable under 400° F. If oil is not used, dipping the top of the jar in melted paraffin for about an inch will prevent the salts of the solution from climbing over the edge. In starting a new battery it is best to short circuit the cells for twenty-four or forty-eight hours to form zinc sulphate and lower the internal resistance, The internal resistance of the ordinary gravity cell is 2 to 3 ohms, depending on a number of conditions, such as the size of plates, the nearness together, and the nature of the solution.

Never let the temperature of gravity cells get below 65° or 70° F., as the internal resistance increases very rapidly with a decrease in temperature.

The Leclanché Cell.

This cell is one of the most commonly used outside of telegraphy, and up to the advent of the so-called dry cell was practically the only one in use for house and telephone work. The elements are zinc and carbon, with peroxide of manganese about the carbon plate for a depolarizing agent. As usually constructed — for there are many modifications of the type — the jar is of glass, about 7 inches high and 5 inches in diameter, or sometimes square. The zinc is in the form of a stick, about a half inch diameter by 7 inches long, and is placed in one corner of the jar in a solution of sal-ammoniac. The carbon plate is placed in a porous cup within the jar, and the space around the carbon in the cup is filled with small pieces of carbon and granulated peroxide of manganese. The sal-ammoniac solution passes through the porous cup and moistens the contents. This cell will polarize if worked hard or short circuited, but recuperates quickly if left on open circuit for a while. The resistance of the Leclanché cell varies with its size and condition, but is generally less than one ohm. The initial E.M.F. is about 1.5 volt. It is desirable not to use too strong a solution of sal-ammoniac, as crystals will be deposited on the zinc; and not to let the solution get too weak, as chloride of zinc will form on the zinc; both conditions will materially increase the internal resistance of the cell and impair its efficiency. Without knowing the dimensions of cells it is not possible to state the amount of sal-ammoniac to use; but perhaps as good a way as any is to add it to the water until no more will dissolve, then add a little water so that the solution will be weaker than saturation. Keep all parts clean, and add sal-ammoniac and water when necessary.

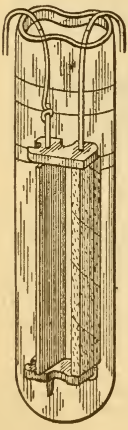


Fig. 3.

Chloride of Silver Dry Cell Battery.

This cell is extensively used for testing insulation of cables, etc., and its elements are a plate of chemically pure zinc and a cast plate of chloride of silver in an electrolyte paste.

As ordinarily constructed the jar is of glass about $2\frac{1}{2}''$ long by $\frac{3}{4}''$ diameter with the zinc and silver plates set in as per Fig. 3. The paste is poured in and the cell is then hermetically sealed. The terminals are led through fiber tops to posts thereon.

The small size of the cell renders it possible to construct a battery of from fifty to two hundred and twenty cells within a small compass.

The containing box is provided with a pole-changing switch in the cover and with selecting cords and tips so that the operator may select any number of cells desired. Fig. 4 shows a portable testing battery of fifty of these cells complete ready for use.

The E.M.F. of the chloride of silver cell is .9 of a volt, the internal resistance being about 4 ohms. The current supplied is quite constant until within a few moments of its exhaustion ; they will not dry out in any climate, have a long life, and there is no local action developed when the cells are not in use.

Fuller Cell.

The elements of this cell are zinc in a dilute solution of sulphuric acid and carbon in a solution of electropoin. Electropoin consists of three parts

FIG. 4. Chloride of Silver Cells.

bichromate of potash, one part sulphuric acid, and nine parts water. Dissolve the bichromate in the water at boiling, and when cool add the sulphuric acid slowly. The zinc plate is in the form of a cone, and is placed in the bottom of a porous cup inside a glass jar. The carbon plate is outside the porous cup.

About two ounces of mercury are placed in the porous cup with the zinc, for amalgamation, and the cup is filled with a dilute solution of sulphuric acid. The outside jar is filled with the electropoin. In this the carbon plate is immersed.

The E.M.F. is 2 volts, and the internal resistance is about half an ohm. The solution is originally of an orange color. When this becomes bluish in tint, add more crystals. Should the color be normal and the cell be weak, add fresh sulphuric acid.

Edison-Lalande Cell.

The elements of this cell (see Fig. 5) are zinc and copper oxide in a water solution of caustic potash. The plates are suspended side by side from the cover of the jar. The copper oxide, which is plated with a thin film of metallic copper to reduce the resistance when the cell is first started, is held in a frame attached to the cover. A layer of oil is poured on top of the solution to prevent creeping salts. The E.M.F. is low, starting at .78 volt, and after working for a time it decreases. The internal resistance is also low, being about .025 ohm for the largest cell. Very strong currents can be taken from this cell: for instance the cell having an E.M.F. of .75 volt and resistance of .025 ohm will produce 30 amperes on short circuit. The makers advise, in setting up the cell, that only one half of the sticks of caustic potash be placed in the jar first, and that water be then poured in up to within about an inch of the top of the jar. Then stir until the potash is dissolved, when one may add the remainder of the potash sticks, stirring as before.

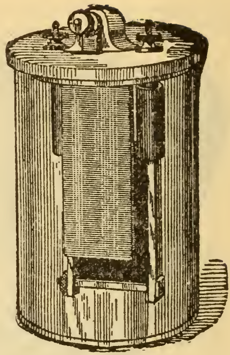


FIG. 5.

Dry Batteries.

The general appearance of a cell of dry battery is shown in Fig. 6, and the construction varies slightly in the different makes. *The Burnley dry cell* is made of a zinc tube (see Fig. 6) as one element, which acts also as the containing jar, a carbon cylinder is the negative element, and an exciting solution composed of 1 part sal-ammoniac, 1 part chloride of zinc, 3 parts plaster, .87 parts flour, and 2 parts water. In constructing the cell a plunger somewhat larger than the carbon element is placed in the middle of

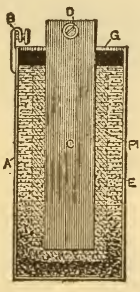


FIG. 6.

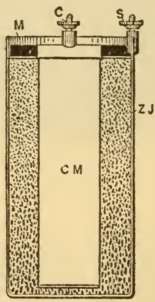


FIG. 7.

the zinc jar, and the above solution mixture poured in around it, quickly becoming stiff, after which the plunger is withdrawn, the carbon inserted in place, and the surrounding space filled with another mixture consisting of 1 part sal-ammoniac, 1 part chloride of zinc, 1 part peroxide of manganese, 1 part granulated carbon, 3 parts plaster, 1 part flour, and 2 parts water. After the ingredients are all in place the top is sealed with bitumen or other suitable compound. A terminal is fastened to the zinc cup, and another to the carbon plate. The E.M.F. of the Burnley cell is 1.4 volt; the internal resistance about .3 ohm, and it gives practically constant E.M.F. during its life. *The Gasner dry cell*, shown in Fig. 7, consists of a zinc cup as the positive element, a cylinder composed of carbon and manganese for the negative element, and an exciting solution which becomes comparatively hard, made up of the following ingredients, viz.: 1 part by weight of oxide of zinc, 1 part sal-ammoniac, 3 parts plaster, 1 part chloride of zinc, and 2 parts water.

The E.M.F. and resistance are about the same as for the cell last described.

Standard Cells.

Clark Cell.— The form of cell called Clark, specifications for making which will be found in the chapter on units, is the one adopted as the standard of E.M.F. by the International Electrical Congress at Chicago in 1893. The positive element is mercury, and the negative is amalgamated zinc, the electrolytes being saturated solutions of sulphate of zinc and mercurous sulphate.

At 15° C. the E.M.F. is 1.434 international volts, and between the temperatures 10° and 25° C., the increase of 1° C. decreases the E.M.F. .00115 volt.

Later investigations by the Physikalisch Technische Reichsanstalt give the value of the E.M.F. as 1.4328 volts at 15° C.; the change due to temperature is expressed by the following formula:

$$E = 1.4328 - 0.00119\ (t - 15°\ C.) - 0.000007\ (t - 15°\ C.)^2 \text{ volts.}$$

In making accurate measurements with the Clark cell great care must be taken on account of the large temperature coefficient and from the fact that the E.M.F. lags behind the temperature change.

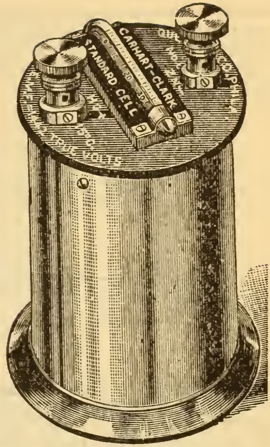


Fig. 8. Carhart-Clark Standard Cell.

Carhart-Clark Cell. — This cell has the same elements as Clark, but the solution of zinc sulphate is saturated at 0° C. The E.M.F. is 1.440 volt, and the temperature coefficient about half that of the Clark cell.

Weston Cadmium Cell. — The elements of this cell are cadmium and mercury, the electrolytes being the sulphates of cadmium and mercury.

If the cadmium sulphate crystals are in excess, the E.M.F. at any temperature is

$$E = 1.0194 - 0.000038\ (t - 20°\ C.) - 0.00000065\ (t - 20°\ C.)^2 \text{ Int. volts.}$$

In the cell as made by the Weston Company the cadmium sulphate solution is saturated at 4° C. and has an E.M.F. = 1.01985 Int. volts with a zero temperature coefficient. The E.M.F. remains constant for years if no currents in excess of .0001 amp. be passed through the cell.

The Weston cell has largely superseded the Clark cell as a working standard on account of its constancy and its freedom from temperature coefficient.

Grouping of Battery Cells.

Series.— When it is desired to obtain an E.M.F. greater than that of one cell, two or more are connected together in series; that is, the positive terminal of one cell is connected to the negative terminal of the next, and so on until the number of cells required to produce the E.M.F. wanted are connected. For example, the E.M.F. of one cell of Leclanché is 1.47 volt; then 10 cells connected in series as in Fig. 9 would give an E.M.F. at the extreme terminals of 14.7 volts.

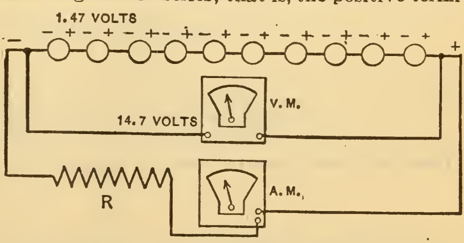


Fig. 9. Battery Cells in Series.

Multiple. — If it be desired to obtain more current strength, i.e., more amperes without change of E.M.F., then more cells must be placed along side the others, that is, in parallel with the first row; each row or series of cells producing the same E.M.F. and joined together at the ends, positive terminals to positive terminals, and negative to negative, adding their currents together at the same E.M.F. as in Fig. 10 below.

If still more current strength be needed, another series of cells may be added, and their current added to the circuit, making three times the current of one series.

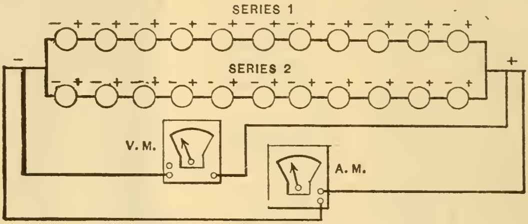


FIG. 10. Battery Cells in Multiple

The reason for this is, that when two or more resistances are placed in parallel or multiple, the equivalent resistance is decreased, as is shown in another chapter. If the resistance of one series be 10 ohms, the resistance of two series in multiple would be one-half of ten, or 5 ohms; that of three series in parallel, one-third, or 3.33 ohms; and of four series, 2.5 ohms.

Let $E =$ E.M.F. of a single cell,
$r =$ internal resistance of one cell,
$R =$ external resistance in a circuit.

Then for n cells arranged in *series*, the current which will flow will be represented by the formula,

$$I = \frac{nE}{nr + R} = \frac{E}{r + \frac{R}{n}}.$$

If R is very small as compared with nr, then $I = \frac{E}{r}$, or the current is the same as that from one cell on short circuit.

If, as in telegraph work, nr is very small as compared with R, then $I = \frac{nE}{R}$, or the current increases in proportion to the number of cells.

The value of r is nearly inversely proportional to the area of the plates when fronting each other in the liquid, and directly as their distance apart. Therefore, if the area of the plate is increased a times, for one cell

$$I = \frac{E}{\frac{r}{a} + R} = \frac{aE}{r + aR}.$$

Let $N =$ the total number of cells in the battery,
$n_s =$ number of cells in each series,
$n_p =$ number of sets or series in parallel.

Then the internal resistance of the whole battery

$$= \frac{n_s r}{n_p}.$$

To find the best arrangement of a given number of cells (N) to obtain a maximum current (I) working through an external resistance (R), make $\frac{n_s r}{n_p} = R$, or the internal resistance of the whole battery equal to R.

In any circuit $I = \frac{\text{total E.M.F.}}{\text{total resist.}}$, and for any arrangement

$$I = \frac{n_s E}{\frac{n_s r}{n_p} + R} = \frac{n_p n_s E}{n_s r + n_p R}.$$

When arranged for maximum current through a given external resistance R,

$$n_s = \sqrt{\frac{NR}{r}} \text{ and } np = \sqrt{\frac{Nr}{R}}.$$

To find the greatest current that can be obtained from a given number of cells (N) through a given external resistance (R),

$$I = \frac{E}{2} \sqrt{\frac{N}{Rr}}.$$

To find the number of cells in series (n_s) and in parallel (n_p) required to give a current (I) through an external resistance (R) and to have an efficiency (F).

$$\text{Efficiency } F = \frac{\text{External work}}{\text{Total work}}$$

$$= \frac{I^2 R}{I^2 \left(\frac{n_s r}{n_p} + R\right)} = \frac{R}{\frac{n_s r}{n_p} + R}.$$

The internal resistance of the whole battery is

$$\frac{n_s r}{n_p} = \frac{R(1-F)}{F} \quad \text{and } I = \frac{n_s E F}{R}$$

$$n_s = \frac{IR}{EF} \qquad n_p = \frac{Ir}{E(1-F)}.$$

ELECTRICAL MEASURING INSTRUMENTS.

The electrical measuring instruments most used in practice are galvanometers, resistance boxes, condensers, voltmeters, ammeters, and wattmeters, with variations of the same, such as millivoltmeters, milliammeters, etc.

Galvanometers.

These are instruments for measuring the magnitude or direction of electric currents. The term galvanometer can also be properly applied to the many types of indicating instruments, such as voltmeters and ammeters, where a needle or pointer is under the influence of some directive force, such as the earth's field, a spring, a weight, a permanent magnet, or other means, and is deflected from zero by the passing of an electric current through its coils.

Nearly all galvanometers can be separated into two classes. The first is the *moving-needle* class. A magnetized needle of steel is suspended with its axis horizontal so as to move freely in a horizontal plane. The suspension is by means of a pivot or fiber of silk, of quartz, or of other material. The needle normally points in a north and south direction under the influence of the earth's magnetic field, or in the direction of some other field due to auxiliary magnets. Near to the needle, and frequently surrounding it, is placed a coil of wire whose axis is at right angles to the normal direction of the needle. When a current is passed through the coil the needle tends to turn into a new position, which lies between the direction of the original field and the axis of the coil.

The second class is the *moving coil* or d'Arsonval class. A small coil is suspended by means of a fine wire between the poles of a magnet. Its axis is normally at right angles with the lines of the field. Current is led into the coil by means of the suspension wire, and leaves the coil by a flexible wire attached underneath it.

The *figure of merit* of a galvanometer is (a) the current strength required to cause a deflection of one scale division; or (b) it is the resistance that must be introduced into the circuit that one volt may cause a deflection of one scale division. This expression for the delicacy of a galvanometer is insufficient unless the following quantities are also given: the resistance of the galvanometer, the distance of the scale from the mirror, the size of the scale divisions, and the time of vibration of the needle.

The *sensitiveness* of a galvanometer is the difference of potential necessary to be impressed between the galvanometer terminals in order to produce a deflection of one scale division.

Moving-Needle Galvanometers.

(*a*.) *The Tangent Galvanometer.* If the inside diameter of the coil which surrounds a needle, held at zero by the earth's field, be at least 12 times the length of the needle, then the deflections of the needle which correspond to different current strengths sent through the coils, will be such that the current strengths will vary directly as the tangents of the angles of deflection. Such an instrument is called a tangent galvanometer. It was formerly much used for the absolute measurement of current. It has, however, many correction factors, some of which are of uncertain magnitude; and, furthermore, for accuracy in the results yielded by it one must have an exact knowledge of the value of the horizontal component of the earth's magnetism. This quantity is continually changing, and is affected much by the presence of large masses of iron and the existence of heavy currents in the vicinity.

Let $r =$ the radius of a tangent galvanometer coil, in centimeters
$n =$ the number of turns in the coil,
$H =$ the horizontal intensity of the earth's magnetism,
$I =$ the current flowing in the coil in absolute units, and
$\theta =$ the deflection of the needle, then

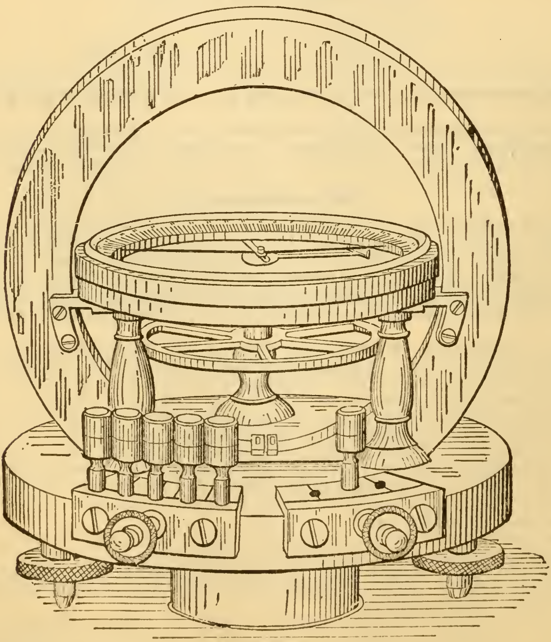


FIG. 11. Tangent Galvanometers.

$$I = \frac{r}{2\pi n} H \tan \theta.$$

For convenience the term $\frac{2\pi n}{r}$ i.e., the strength of the field produced at the center of the coil by the unit of current, is called the *constant* of the galvanometer, and is represented by G, whence

$$I = \frac{H}{G} \tan \theta$$

The current in amperes equals 10 I.

(*b*.) *Kelvin Galvanometers*. The most sensitive galvanometers made are of a type due to Lord Kelvin. Fig. 12 shows one form of this instrument. The moving system consists of a slender quartz rod, to the center of which is fastened a small glass mirror. Parallel to the plane of the mirror, and at one end of the quartz tube, is fastened a complex of carefully selected minute magnetic needles. The north ends of those needles all point in the same direction. At the other end of the quartz tube is fastened a similar complex with the polarity reversed. Were the two complexes of exactly equal magnetic moment, then, when suspended in the earth's field, no directive action would be felt. In fact, this action is very small. The combination forms what is called an *astatic* system. Each magnetic complex is inclosed between two wire coils. The four coils are supplied with binding-posts, so as to permit of connection in series or in parallel. Current is sent through them in the proper direction, to produce in each case deflections the same way. Quartz fiber, which exhibits no elastic fatigue and which is very strong, is used as a suspension. An adjustable magnet is mounted on the top of the galvanometer. By means of it the directive action of the earth's field can be modified to any extent. Under weak directive force the sensitiveness increases greatly, and the period of oscillation of the needle becomes long. The limit of sensitiveness is largely influenced by the patience of the observer.

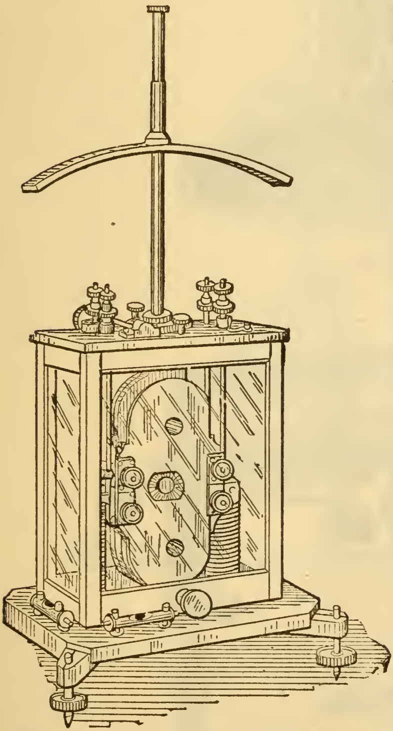


FIG. 12. — Kelvin Reflecting Astatic Galvanometer with Four Coils.

For very precise work the deflections of the needle are observed by means of a telescope and scale. Fig. 13 shows such an instrument. The moving mirror reflects an image of the scale into the objective of the telescope. Continuous work with the telescope is apt to injure the eyes, and is certainly tiresome. Where much galvanometer work is being done by the same person, a ray of light from a small electric, gas, or oil lamp is so directed as to be reflected from the mirror on the needle upon a divided scale. Such a lamp and scale is shown in Fig. 14. In order to bring the needle quickly to rest when under the in-

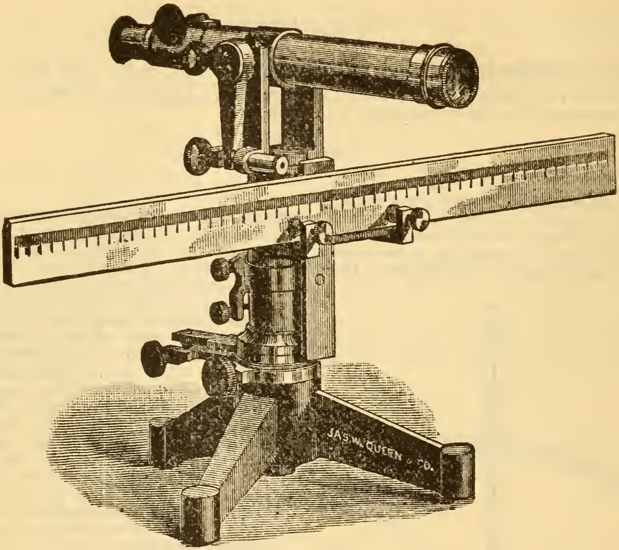


FIG. 13.

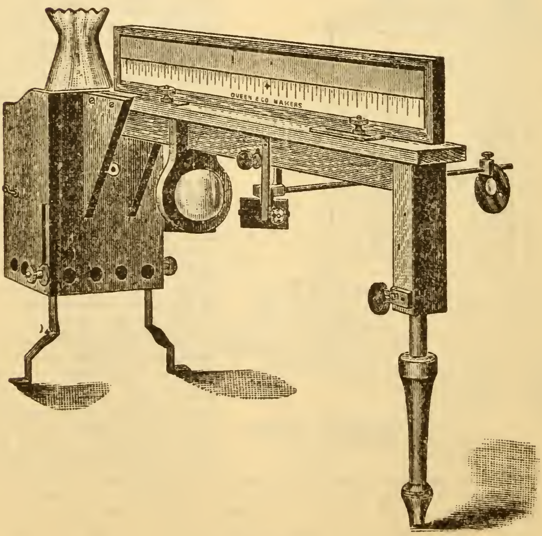


FIG. 14.

fluence of a current, some method of damping must be employed. One method is to attach a mica vane to the moving system, and allow it to swing in an inclosed chamber which contains air or oil. Sometimes the moving needle is inclosed in a hollow made in a block of copper. The eddy currents induced by the moving needle react upon it and stop its swinging.

Moving-Coil Galvanometers.

These galvanometers are to be preferred in all cases except where the utmost of delicacy is required. In the most sensitive form, with permanent magnetic field, they can be made to deflect one millimeter with a scale distance of one meter, when one microvolt is impressed between the terminals of the coil. This is sufficient for nearly all purposes. The sensitiveness can be further increased by using an electromagnetic field. The moving-coil

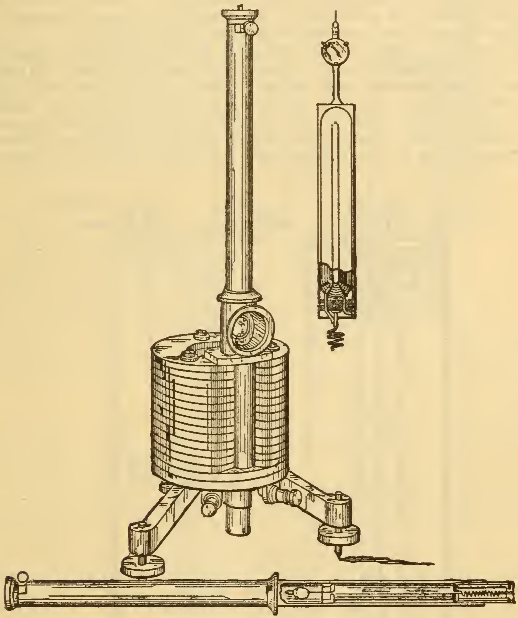


FIG. 15.

form of galvanometer has the following good points: its readings are but slightly affected by the presence of magnetic substances in the vicinity, and are practically independent of the earth's field; the instrument can be easily made dead-beat; and many forms are not much affected by vibrations. Fig. 15 shows a form of D'Arsonval galvanometer of high sensibility. The coil (shown at the right) is inclosed in an aluminum tube. Eddy currents are induced in this tube when the coil swings. They cause damping, and, with a proper thickness of tube, the system may be made aperiodic.

Ballistic Galvanometers.

Ballistic galvanometers are used for measuring or comparing quantities of electricity such as flow in circuits when a condenser is discharged or magnetic flux linkages are disturbed. The time of oscillation of the needle must in such cases be long as compared with the duration of the discharge. If there be no damping of the needle the quantities of electricity are proportional to the sines of half the angle of the first throws of the needle. All galvanometers have some damping. The comparison of quantities of electricity can easily be made with galvanometers of moderate or even strong damping. Absolute determination of quantity by means of the ballistic galvanometer requires great experimental precautions. (See the *Galvanometer*, by E. L. Nichols.)

Instrument for the Measurement of Alternating Currents, by E. F. Northrup.

(Abstract from Trans. A. I. E. E.)

The instrument here described was developed to meet the frequent need of means for easily and accurately calibrating alternating-current instruments, ammeters and voltmeters, whatever their capacity.

(*a*) It is used as a *zero instrument*, and does not depend upon any calibration or determination of any constant of the instrument; (*b*) it operates with extreme sensitiveness, and being perfectly "dead-beat" is adapted to work with fluctuating currents; (*c*) it may be used with or without low. resistance shunts; when used with them it has an unlimited upward range of current measurement; and when used without them its lower range is down to from two to five milliamperes; (*d*) as the operation of the instrument depends upon the heating effect of currents it is wholly independent of wave-form and frequency.

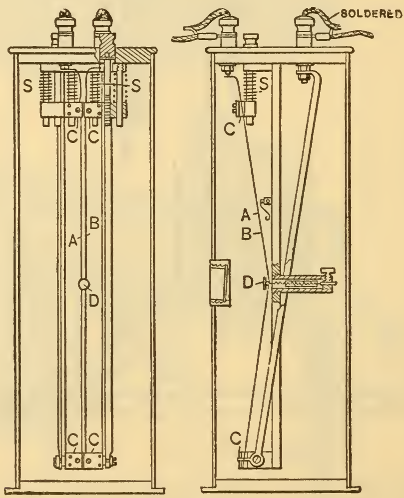


Fig. 16.

Referring to Fig. 16, two small wires, *AB*, of No. 33 hard-drawn silver wire when shunts are used, lie parallel to each other at a distance of 0.158 in., being held near their extremities by ivory clamps, *CC*. Each of the ends of the two wires are connected to binding posts through the medium of heavy leads and soldered joints.

One face of a small circular disk of ivory, *D*, rests against the two wires at their middle point, a 0.5-in. circular mirror being fastened to the other face. Fastened at the center of the ivory disk and half way between the wires, when the disk is in position on the wires, is a small hook. To this, through the medium of a thread, is fastened a small adjustable spiral spring. The small ivory disk maintains its position by friction and the tension of the spring. The wires bend back under the tension of the spring about 0.875 in. from the vertical. The ivory disk does not rest directly upon the wires but bears upon each wire through the medium of a small agate stud shaped like the head of a screw, each wire being in the slot of the agate stud which rests upon it.

The two ivory clamps holding the wires near their upper extremity are made separately adjustable in a vertical direction by means of thumbscrews which pass through the hard-rubber top of the instrument. Springs *s s* prevent lost motion when the ivory clamps are screwed up or down.

The arrangement of parts above described is supported by a brass frame and a circular hard-rubber top. This frame drops into a circular nickel-plated brass case (Fig. 17). The case has a window in it directly in front of the mirror on the small ivory disk. Fig. 17 shows clearly the arrangement of parts and the appearance of the instrument.

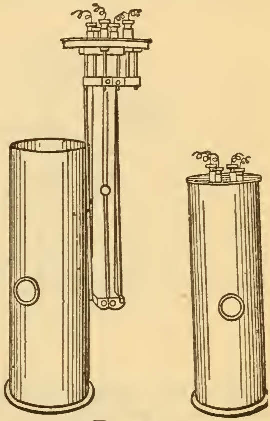


Fig. 17.

By means of the adjusting screws the tension of the two wires may be so adjusted that the plane of the mirror will be vertical to a line drawn in the direction of the spring which holds the mirror against the wires. Now if any elongation occurs in the wire on the right, that side of the mirror will be drawn down or back by the spring, or a deflection to the right is obtained. Likewise, if an elongation takes place in the wire on the left, the mirror will deflect to the left. If, however, an exactly equal elongation occurs in both wires at the same time, the plane of the mirror will not tilt but simply move back keeping parallel to itself.

If the mirror is observed with a telescope and scale, say at a distance of one meter, very minute angular deflections of the mirror will be easily observed, while a sinking back of the plane of the mirror away from the scale will not be observable.

Now if an alternating current of unknown strength be sent through the wire A, the wire will elongate, deflecting the mirror toward the left. Pass an adjustable direct current, which can be measured, through the wire B, until the deflection is reversed and brought back to zero on the scale. If when the deflection is zero, and certain precautions to be stated later have been observed, the strength of the direct current is known, the strength of the alternating current will also be known; for it is exactly equal to the direct current. This, however, is on the assumption that equal currents through the wires A and B produce equal elongations of the wires. Previously to comparing the currents, connect the wires A and B in series, and send a current through the circuit; if under these conditions the mirror be not deflected at all, or only slightly, it proves that the two wires are practically equally elongated by the same current strength. The limit of this possible small deflection may be taken as the true zero of the instrument. If this zero is maintained under working conditions, it means that the strength of the alternating current in the wire A, is equal to the strength of the adjustable and measured direct current in the wire B.

The arrangement of the complete circuits for measuring a large alternating current for the purpose of calibrating an alternating current ammeter A is shown diagrammatically in Fig. 18. An important accessory to the instrument is a quick-acting double-throw switch, marked S in the diagram. W_a and W_d represent the two wires of the instrument and m the mirror. R is a low-resistance shunt, preferably of manganin, having a negligible temperature coefficient, furnished with tap-off points c and d, between which the resistance R has previously been determined. The ammeter indicated in the diagram will measure from one to two amperes of direct current; r_3 is a slide wire resistance along which a slider p may be moved, thereby varying the pressure difference at a-b from zero to the value of the electromotive force of the storage battery.

The points a, b, on the direct-current side of the circuits have leads attached to them which go either to an accurately calibrated direct-current laboratory standard voltmeter, or to a potentiometer.

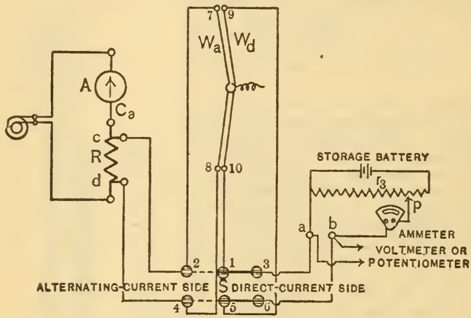


FIG 18.

When the instrument is installed, a permanent adjustment of the resistances at any convenient temperature of the wires and leads must be made as follows: (see Fig. 18.)

The resistances, 9 to 10 = 7 to 8,
10 to 1 + 9 to 5 = 8 to 4 + 7 to 2 and
2 to c + 4 to d = 3 to a + 6 to b.

Thus while this gives the over-all resistance from a through the wire W_d to b equal to the over-all resistance from d through the wire W_a to c, the different portions of the circuit must be matched in resistance as stated above.

When the switch S is closed on the alternating-current side the two wires W_a and W_d are thrown in parallel, and the two parallel-connected circuits have the same resistance, by construction, and that to these parallel circuits at the points 2 and 4 is applied the same potential difference, this potential difference being the drop on the low resistance R carrying the alternating current. The drop over R, inasmuch as it is a low resistance, is only slightly lowered by being shunted by the two wires of the instrument and their leads, and this lowering of the potential is not appreciably greater when the two wires in parallel shunt the resistance R than when only one wire with its leads shunts the resistance. Disregarding the slight lowering of the potential, both wires will now have passing through them equal currents, each current being nearly the same as would pass through the one wire W_a if the switch S were open, and only this wire could receive current.

With the resistances of the parallel circuits correctly adjusted to equality, both wires will get equal currents, both will elongate equally or very nearly so, and the mirror m instead of rotating will move back, maintaining its plane parallel to the position which it has with no current passing.

When the switch S is thrown to the direct-current side, the potential drop over the resistance R is now applied to the wire W_d only; and the direct potential difference between the points a and b is applied to the wire W_d.

This drop between *a* and *b* can be varied by the slider *p* and measured by a voltmeter or potentiometer applied at *a*, *b*. The ammeter gives the current taken by the wire *Wd*.

The shunt resistance *R* may be designed to carry any current, however large. The same resistance *R*, or a combination of resistances, may be designed with several tap-off or potential points, so that the instrument may always have approximately the same potential applied to its alternating-current side, whatever the strength of the current to be measured. This potential drop is best made between 0.25 and 0.5 volt. The necessary drop of potential being so low, the energy dissipated in the shunts is small, and therefore they may be of very moderate size. It is also easy to make them practically non-inductive.

Galvanometer Shunt Boxes.

It is often desirable to use a galvanometer of high sensibility for work demanding a much lower sensibility. Again, it may be convenient to calibrate a galvanometer of low sensibility, while it would be inconvenient to calibrate a more sensitive one It is therefore useful to be able to change the sensibility in a known ratio. Convenience dictates that simple ratios be used, and those almost universally taken are 10, 100, and 1000; that is $\frac{1}{9}$, $\frac{1}{99}$, or $\frac{1}{999}$, part of the current flowing is allowed to go through the galvanometer while the remainder is diverted through a shunt. In Fig. 19 let

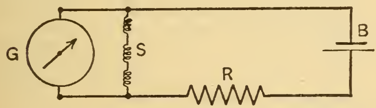


FIG. 19.

G = the resistance of the galvanometer, and
S = the resistance of the shunt,

then the joint resistance of the two is $\frac{G\ S}{G+S}$.

If I = the total current flowing in the circuit, and
if I_1 = the part flowing through the galvanometer,

then $\frac{I}{I_1} = \frac{G+S}{S} = \frac{G}{S} + 1 =$ the *Multiplying power* of the shunt.

The resistance of a shunt which will give a certain multiplying power, *n*, is equal to $\frac{G}{n-1}$. Fig. 20 shows a form of shunt used with a galvanometer, although it is perfectly feasible to use an ordinary resistance box for the purpose. Messrs. Ayrton & Mather have developed a new shunt, which can be used with any galvanometer irrespective of its resistance: following is a diagram of it.

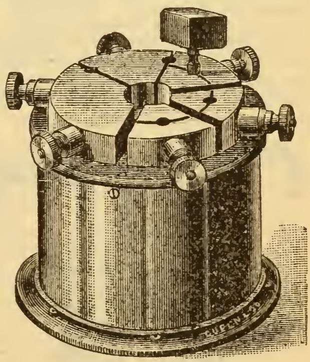


FIG. 20.

A and B are terminals for the galvanometer connections. B and C are the ingoing and outgoing terminals for battery circuit. To short circuit G, place plugs in j and f. To throw all the current through G, put a plug in f only. To use the shunts, place a plug in h, and leave it there until through using. In this method it is not necessary to know the resistance of either G or *r*. The shunt box can therefore be used with any galvanometer. Temperature variations make no difference, provided they do not take place during one set of tests. The resistance *r* may be any number of ohms, but in order not to decrease the sensibility too much *r* should be at least as large as G. The resistance *r* is divided for use as follows: permanent attachments to the various blocks are made at points in the coil corresponding with $\frac{r}{1000}$, $\frac{r}{100}$, $\frac{r}{10}$ ohms.

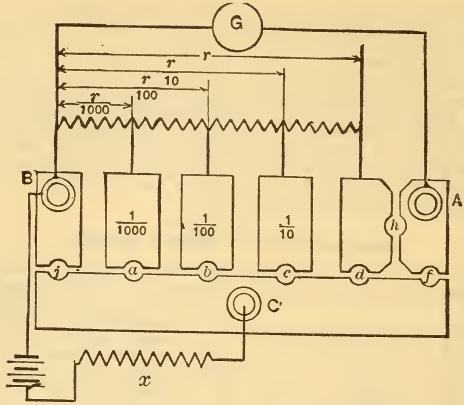


Fig. 21. Ayrton & Mather's Universal Shunt.

PRACTICAL STANDARDS OF RESISTANCE.

The unit of resistance, the international ohm, is represented by the resistance of a uniform column of mercury 106.3 cm. long and 14.4521 grammes in mass, at 0° C; but in practice it is not convenient to compare resistances with such a standard, and therefore secondary standards of resistance are made up and standardized with a great degree of precision. These secondary standards are made of wire. The material must possess permanency of constitution and of resistivity, must have a small temperature coefficient of resistivity, must have a small thermo-electric power when compared with copper, and should have a fairly high resistivity. Manganin when properly treated possesses all of these qualities (see "Properties of Conductors"). Platinoid is also frequently used. An assemblage of standards of various convenient magnitudes in a single case is called a resistance box, or rheostat.

Fig. 22 shows the pattern adopted by the Physikalisch Reichsanstalt and now in general use. For very low resistances having a high current-carrying capacity a larger form is used shown in Fig. 23. These are immersed in oil and cooled by water circulating through coiled pipe. They are made

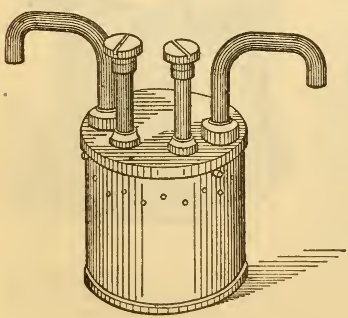


Fig. 22.

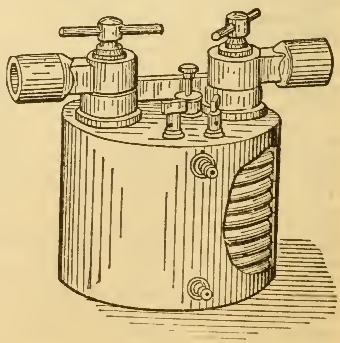


Fig. 23.

in values of .01, .001 and .0001 ohm, the resistances being that between the two small binding posts called the potential terminals.

Wheatstone Bridge.

The form of resistance box most frequently met with is some type of "Wheatstone's bridge," the theory of which is described elsewhere.

The coils are usually of silk insulated wire wound non-inductively on spools, with the ends attached to brass blocks, so arranged that brass plugs can be inserted in a hole between two blocks, thus short-circuiting the resistance of the particular bobbin over which the plug is placed. By non-inductive winding is meant that the wire is first doubled, then the closed end is placed on the bobbin and the wire wound double about the bobbin. By this method any electromagnetic action in one wire is neutralized by an equivalent action in the other, and there is no inductive effect when the circuit is opened or closed.

The post-office pattern of Wheatstone bridge is one of the most commonly used, a diagram of its connections being shown in Fig. 24.

One arm of the bridge has separate resistances of the following values: 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1000, 2000, 3000, and 4000 ohms. Another arm is left open for the unknown resistance, x, which is to be measured. The remaining two arms each have three resistance coils of 10, 100, and 1000 ohms respectively. Two keys are supplied with the P.O. bridge, one for closing the battery circuit, and the other for closing the galvanometer circuit. The battery key should be closed first; and in some

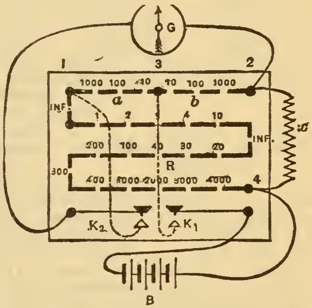


Fig. 24.

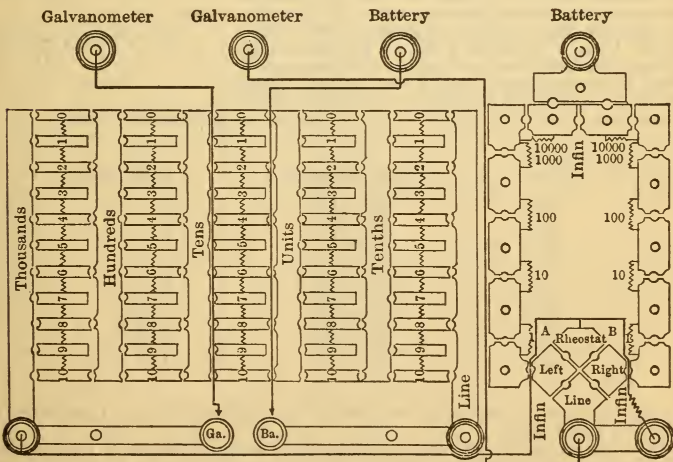


Fig. 25. Diagram of Anthony Bridge.

instruments the two keys are arranged with the battery key on top of the galvanometer key, so that but one finger and one pressure are necessary.

Prof. Anthony has devised a resistance box in which there are 10 one ohm coils, 10 tens, 10 hundreds, and 10 thousands. Any number of any group can be connected either in series or in multiple. The means of accomplishing this are seen clearly in the cut.

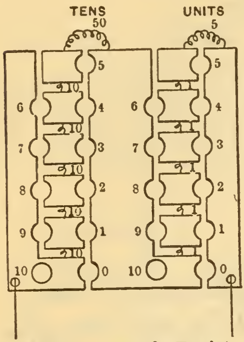


FIG. 26. Decade Resistance Box.

Decade Methods.

The Wheatstone bridge arrangement has the disadvantage of requiring a large number of plugs to short-circuit the resistances not in use, which introduces an element of uncertainty as to resistance of the plug contacts and the necessity of adding up the values of all the unplugged resistances in order to determine the value.

Fig. 26 shows the Weston arrangement of coils requiring but one plug per decade and a small number of coils.

In a later decade arrangement by Leeds & Northrup, 1, 3, 3′, and 2 ohm coils are connected in series as shown in Fig. 27.

Let the terminal of the 1 ohm coil and the 2 ohm coil and the points of union of the coils be numbered (1), (2), (3), (4), (5) as shown in Fig. 27. The current enters at point (1) and leaves the coils at the point (5) traversing 1, 3, 3′, $2 = 9$ ohms in all. If this series is multiplied by any factor n, then $n\,(1 + 3 + 3' + 2) = n$ 9 ohms. It will be seen that if the points (1) and (5) are connected all the coils are short-circuited and that the current will traverse zero resistance. If the points (2) and (5) are connected the 3, 3^1, and 2 ohm will be short-circuited and the current will traverse 1 ohm. By extending this process so that we connect two and only two points at a time, it is possible to obtain the regular succession of values n (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) the last value being obtained when no points are connected. The following table shows the points which must be connected to obtain each of the above values and the coils which will be in circuit for giving each value:

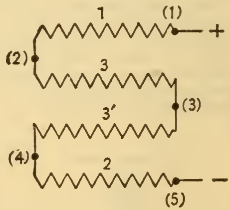


FIG. 27.

Value.	Points Connected.	Coils Used.
0 =	(5 — 1)	0
1 =	(2 — 5)	1
2 =	(4 — 1)	2
3 =	(2 — 4)	1, 2
4 =	(3 — 5)	1, 3
5 =	(1 — 3)	3′, 2
6 =	(2 — 3)	1, 3′, 2
7 =	(5 — 4)	1, 3, 3′
8 =	(1 — 2)	3, 3′, 2
9 =	(0)	1, 3, 3′, 2

Fig. 28 shows a method of connecting these points two at a time with the use of a single plug.

The circles in the diagram represent two rows of ten brass blocks each. To the first two blocks at the top of the rows, the points 5 and 1 of diagram 3 are connected. to the second two points 2 and 5 are connected and so on, no points being connected at the last pair of blocks. It is evident that if a plug be inserted between the blocks 1 and 5, the points 1 and 5 of diagram 3 are connected giving the value 0; if between the blocks 2 and 5, the points 2 and 5 are connected giving the value 1, and so on. The value 9 is obtained when the plug is disposed of by being inserted in the last pair of blocks which have no connections.

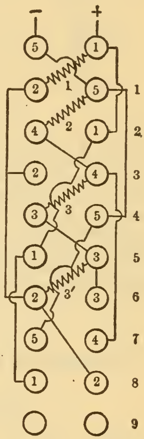


FIG. 28.

WATER RHEOSTATS.

In testing dynamos and other electrical apparatus producing large amounts of energy, it is necessary to have resistances of a capacity sufficient to absorb the energy developed, and this is almost invariably done by the use of the WATER RHEOSTAT, which in its simplest form consists of a box or barrel of wood, in which are placed two metal electrodes which can be adjusted in relation to each other so as to increase the resistance by separating them, or decrease it by approaching them to each other. Coils of galvanized iron wire in running water are much used, and when still water is used it is the practice to increase its conductivity by adding soda or common salt.

H. S. Webb in *American Electrician*, February, 1898, gives results of a number of experiments:

(*a*) Daniel jar (6¼″ dia., 8″ deep) horizontal sheet iron electrodes and water from faucet. With plates ¾ inch apart would not carry 4 amperes more than fifteen or twenty minutes without becoming too hot. P. D. 200 volts. With 2 amperes at 71 volts for one hour, temperature rose to 167° F.

Result: safe cross section in 30.7 sq. in. for 2 to 2½ amperes, with clear water and horizontal electrodes, watts absorbed per cu. in. of water, 10.

(*b*) Same jar and electrodes as above, but saturated solution of salt water used: 11 amperes, 7 volts, electrodes 7¾″ apart; in three hours temperature rose to 122° F. and was slowly rising when stopped. Watts absorbed per cu. in. of liquid, .4.

(*c*) Wooden trough 42″ × 6½″ × 8″, vertical sheet iron electrodes; cross section of liquid, 44 sq. in. With 10% solution of salt water, and 10 amperes flowing, temperature at end of run 95° F. Electrodes 41¾″ apart. P. D. 20 volts. Current density, about ¼ amp. per sq. in.; watts absorbed, .11 watt per cu. in., would probably carry 13 to 15 amperes safely.

It is apparent that salt increases the current carrying capacity, but decreases watts absorbed per cu. in.

(*d*) Whiskey barrel filled with clear water. Electrodes were horizontal circular iron plates 3/16″ thick. Plates 26⅜″ apart, P. D. of 486 volts gave current of 2.6 amperes. With plates ⅞″ apart, P. D. of 228 volts gave 35.5 amperes at the end of one hour. When temperature of the water had reached 175° F., much gas was given off. Current density .12 amp. per sq. in., and watts absorbed 30.5 per cu. in.

With large current density and direct current there is much decomposition of the electrodes with either clear or salt water. Horizontal electrodes are not to be recommended unless a large number of holes are drilled through the top plate to allow escape of gas. It is seldom necessary to use stronger solution than 2 or 3 per cent of salt, and in adding salt to the rheostat it is best to dissolve it thoroughly in a separate vessel and then add to the liquid as needed. Liquid rheostats seem to be more satisfactory for use in connection with alternating currents than with direct, as no decomposition of electrodes takes place and a given cross section of liquid seems to possess a greater current-carrying capacity.

Merrill in *American Electrician*, December, 1897, gives results of experiments on small rheostats with about 20 amperes of current.

Results are based upon a volume of solution 1 ft. long and 1 sq. ft. cross section.

Water and Dilute Sulphuric Acid.

Per Cent Acid by Weight.	Resistance in Ohms.
.174	4.12
.435	1.75
.724	1.10
.985	.85

Water and Common Table Salt.

Per Cent Salt by Weight.	Resistance in Ohms.
.23	7.84
.46	4.65
.70	3.12
.93	2.38
1.16	1.90
1.39	1.48

Use of salt solution is cheap and convenient, but very untrustworthy for accurate work.

For the sake of convenience in choosing proper sizes and lengths of iron wire for submerged rheostats, the accompanying table is given. The safe carrying capacities are the currents the wires can safely stand for a continuous run. If the apparatus is to be used for short periods, as in the case of a starting rheostat for a large motor, these values may be doubled.

Water should be kept circulating through the barrel, enough water being used to keep the temperature below 200° F.

Properties of Galvanized Iron Wire. For Submerged Rheostats.

Wire Numbers; B. & S. Gauge.	Safe carrying Capacity; Amperes.	Minimum Length in Feet for Safe carrying Capacity at Different Voltages.				Feet per Ohm, hot.
		100	110	220	500	
20	36	22.8	25	50	114	8.5
19	42	24.6	27	54	123	10.4
18	50	26.4	29	58	132	13.5
17	60	27.2	30	60	136	17.1
16	71	29.0	32	64	145	21.5
15	88	31.0	34	68	155	27.2
14	103	32.7	36	72	164	34.2
13	122	34.5	38	76	173	43.2
12	145	36.4	40	80	182	54.3
11	173	38.2	42	84	191	68.6
10	205	41.0	45	90	205	86.5
9	245	42.8	47	94	214	109.1
8	293	46.9	52	103	235	137.5
7	347	50.1	55	110	250	173.5
6	412	53.1	59	117	266	219.0
5	489	56.4	62	124	282	276.0
4	584	59.5	66	131	298	348.0

CONDENSERS.

If one terminal of a source of E.M.F. be connected to a conductor, and the other terminal be connected to another conductor adjacent to the first but insulated from it, it will be found that the two conductors exhibit a capacity for absorbing a charge of electricity that is somewhat analogous to the filling of a pipe with water before a pressure can be exerted. The charge will remain in the conductors after the removal of the source of supply. This capacity of the conductors to hold under a given E.M.F. a charge of electricity is governed by the amount of surface exposed, by the nearness of the surfaces to each other, by the quality of the insulating material, and by the degree of insulation from each other. If the terminals of a battery be connected through a battery and sensitive galvanometer to a long submarine cable conductor and to the earth, it will be found that a very considerable time will elapse before the needle will settle down to a steady point. This shows that the cable insulation has been *filled* with electricity; and it is common in so measuring the insulation resistance of a cable to assume a standard length of time, generally three minutes, during which time such electrification shall take place.

A *condenser* is an arrangement of metallic plates and insulation so made up that it will take a standard charge of electricity at a certain pressure. The energy represented by the charge seems to be stored up in the insulation between the conducting plates in the form of a stress. This property of insulating materials to take on a charge of static electricity is known as *inductive capacity*, and the following table shows the specific inductive capacities of different substances.

Specific Inductive Capacity of Gases.

(From Smithsonian Physical Tables.)

WITH THE EXCEPTION OF THE RESULTS GIVEN BY AYRTON AND PERRY, FOR WHICH NO TEMPERATURE RECORD HAS BEEN FOUND, THE VALUES ARE FOR 0° C. AND 760 M.M. PRESSURE.

Gas.	Sp. Ind. Cap.		Authority.
	Vacuum = 1.	Air = 1.	
Air	1.0015	1.0000	Ayrton and Perry.
Air	1.00059	1.0000	Klemencic.
Air	1.00059	1.0000	Boltzmann.
Carbon disulphide	1.0029	1.0023	Klemencic.
Carbon dioxide, CO_2	1.0023	1.0008	Ayrton and Perry.
Carbon dioxide, CO_2	1.00098	1.00039	Klemencic.
Carbon dioxide, CO_2	1.00095	1.00036	Boltzmann.
Carbon monoxide, CO	1.00069	1.00010	Klemencic.
Carbon monoxide, CO	1.00069	1.00010	Boltzmann.
Coal gas (illuminating)	1.0019	1.0004	Ayrton and Perry.
Hydrogen	1.0013	0.9998	Ayrton and Perry.
Hydrogen	1.00026	0.99967	Klemencic.
Hydrogen	1.00026	0.99967	Boltzmann.
Nitrous oxide, N_2O	1.00116	1.00057	Klemencic.
Nitrous oxide, N_2O	1.00099	1.00040	Boltzmann.
Sulphur dioxide	1.0052	1.0037	Ayrton and Perry.
Sulphur dioxide	1.00955	1.00896	Klemencic.
Vacuum 5 mm. pressure	1.0000	0.9985	Ayrton and Perry.
Vacuum 0.001 mm. pressure about	1.0000	0.94	Ayrton and Perry.
Vacuum	1.0000	0.99941	Klemencic.
Vacuum	1.0000	0.99941	Boltzmann.

Specific Inductive Capacity of Solids (Air Unity).

Substance.	Sp. Ind. Cap.	Authority.
Calcspar parallel to axis . . .	7.5	Romich and Nowak.
Calcspar perpendicular to axis	7.7	Romich and Nowak.
Caoutchouc	2.12–2.34	Schiller.
Caoutchouc, vulcanized . . .	2.69–2.94	Schiller.
Celluvert, hard gray	1.19	Elsas.
Celluvert, hard red	1.44	Elsas.
Celluvert, hard black	1.89	Elsas.
Celluvert, soft red	2.66	Elsas.
Ebonite	2.08	Rosetti.
Ebonite	3.15–3.48	Boltzmann.
Ebonite	2.21–2.76	Schiller.
Ebonite	2.72	Winkelmann.
Ebonite	2.56	Wullner.
Ebonite	2.86	Elsas.
Ebonite	1.9	Thomson (from Hertz's vibrations).
Fluor spar	6.7	Romich and Nowak.
Fluor spar	6.8	Curie.
Glass,* density 2.5 to 4.5. . .	5–10	Various.
Double extra dense flint, density 4.5	9.90	Hopkinson.
Dense flint, density 3.66 . . .	7.38	Hopkinson.
Light flint, density 3.20 . . .	6.70	Hopkinson.
Very light flint, density 2.87 .	6.61	Hopkinson.
Hard crown, density 2.485 . .	6.96	Hopkinson.
Plate, density ——	8.45	Hopkinson.
Mirror	5.8–6.34	Schiller.
Mirror	6.46–7.57	Winkelmann.
Mirror	6.88	Donle.
Mirror	6.44–7.46	Elsas.
Plate	3.31–4.12	Schiller.
Plate	7.5	Romich and Nowak.
Plate	6.10	Wullner.
Guttapercha	3.3–4.9	Submarine cable data.
Gypsum	6.33	Curie.
Mica	6.64	Klemencic.
Mica	8.00	Curie.
Mica	7.98	Bouty.
Mica	5.66–5.97	Elsas.
Mica	4.6	Romich and Nowak.
Paper, dry	1.25–1.75	Abbott.
Paraffin	2.32	Boltzmann.
Paraffin	1.98	Gibson and Barclay.
Paraffin	2.29	Hopkinson.
Paraffin, quickly cooled translucent.	1.68–1.92	Schiller. †
Paraffin, slowly cooled white .	1.85–2.47	Schiller.
Paraffin	2.18	Winkelmann.
Paraffin	1.96–2.29	Donle, Wullner.
Paraffin fluid, pasty	1.98–2.08	Arons and Rubens.
Paraffin, solid	1.95	Arons and Rubens.

* The values here quoted apply when the duration of charge lies between 0.25 and 0.00005 of a second. J. J. Thomson has obtained the value 2.7 when the duration of the charge is about $\frac{1}{25} \times 10^6$ of a second; and this is confirmed by Blondlot, who obtained for a similar duration 2.8.

† The lower values were obtained by electric oscillations of duration of charge about 0.00006 second. The larger values were obtained when duration of charge was about 0.02 second.

Specific Inductive Capacity of Solids (Air Unity). — *Cont.*

Substance.	Sp. Ind. Cap.	Authority.
Porcelain	4.38	Curie.
Quartz, along the optic axis	4.55	Curie.
Quartz, transverse	4.49	Curie.
Resin	2.48–2.57	Boltzmann.
Rock salt	18.0	Hopkinson.
Rock salt	5.85	Curie.
Selenium	10.2	Romich and Nowak.
Shellac	3.10	Winkelmann.
Shellac	3.67	Donle.
Shellac	2.95–3.73	Wullner.
Spermaceti	2.18	Rosetti.
Spermaceti	2.25	Felici.
Sulphur	3.84–3.90	Boltzmann.
Sulphur	2.88–3.21	Wullner.
Sulphur	2.24	J. J. Thomson.
Sulphur	2.94	Blondlot.
Sulphur	2.56	Trouton and Lilly.

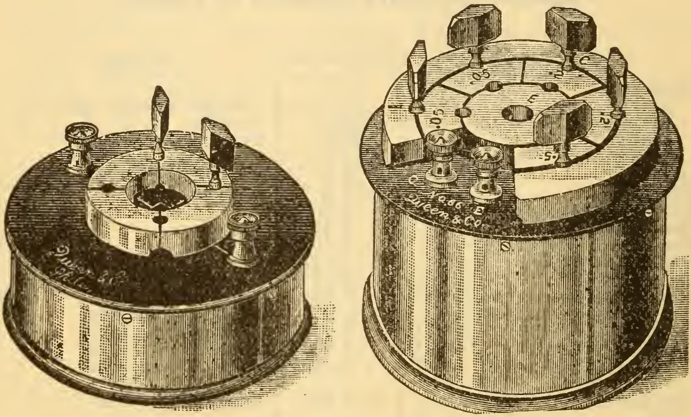
Specific Inductive Capacity of Liquids.

Substance.	Sp. Ind. Cap.	Authority.
Alcohols:		
Amyl	15–15.9	Cohn and Arons; Tereschin.
Ethyl	24–27	Various.
Methyl	32.65	Tereschin.
Propyl	22.8	Tereschin.
Anilin	7.5	Tereschin.
Benzene	1.93–2.45	Various.
Benzene average about	2.3	
Benzene at 5° C.	2.1898	Negreano.
Benzene at 15° C.	2.1534	Negreano.
Benzene at 25° C.	2.1279	Negreano.
Benzene at 40° C.	2.1103	Negreano.
Hexane, between 11° and 13° C.	1.859	Landholt and Jahn.
Octane, between 13° .5–14° C.	1.934	Landholt and Jahn.
Decane, between 13° .5–14° .2 C.	1.966	Landholt and Jahn.
Amylene, between 15° –16° .2 C.	2.201	Landholt and Jahn.
Octylene, between 11° .5–13° .6 C.	2.175	Landholt and Jahn.
Decylene, between 16° .7 C.	2.236	Landholt and Jahn.
Oils:		
Arachid	3.17	Hopkinson.
Castor	4.6–4.8	Various.
Colza	3.07–3.14	Hopkinson.
Lemon	2.25	Tomaszewski.
Neatsfoot	3.07	Hopkinson.
Olive	3.08–3.16	Arons and Rubens; Hopkinson.
Petroleum	2.02–2.19	Various.
Petroleum ether	1.92	Hopkinson.
Rape-seed	2.2–3.0	Various.
Sesame	3.17	Hopkinson.
Sperm	3.02–3.09	Hopkinson; Rosa.
Turpentine	2.15–2.28	Various.
Vaseline	2.17	Fuchs.
Ozokerite	2.13	Hopkinson
Toluene	2.2–2.4	Various.
Xylene	2.3–2.6	Various.

Specific Inductive Capacity. — Definition: The specific inductive capacity of a substance is the ratio of the capacity of a condenser when its plates are separated by this substance to the capacity of the same condenser when its plates are separated by air. Therefore while the capacity of a condenser is rated as compared with a similar one made up with air insulation it is possible to get a greater capacity in the same space by the use of some substance other than air. If it take k coulombs of electricity to produce a P. D. of one volt between the terminals of an air condenser, then if the same condenser be insulated by some other substance it will take $k \times$ the specific inductive capacity of the substance with which it is now insulated to produce a P. D. of one volt. The foregoing are tables of specific inductive capacities taken from "Smithsonian Tables."

The specific inductive capacity of paper cables varies from 3 to 4, according to the type of paper and mixture adopted. The inductive capacity of paper is about 2; that of rosin 2 to 3, according to its origin; and mixtures of rosin, oil, paraffin, ozokerite, and other materials have a capacity of 3 to 4, or even more. For example, lubricating oil 55 parts, rosin 560, paraffin 224, ozokerite 160, has a standard inductive capacity of 3.6; oxidized linseed oil 90, rosin 370, Arkangel pitch 70, have 4.4; Arkangel pitch itself has 5.9; a mixture with Gallipot, instead of rosin — for example, Gallipot 600, Arkangel pitch 110, and linseed oil 130 — has 4.8; a mixture of lubricating oil 9, rosin 52, black ozokerite 23, white ozokerite 16, has only 3.55.

The unit of *capacity* is the international *farad*, which is defined as the capacity of a condenser which requires one coulomb (1 ampere for 1 second) to raise its potential from zero to one volt.



Figs. 29 and 30. Standard Condensers.

As the *farad* is far larger than ever is met in practice, the practical unit is taken as one-millionth farad or the micro-farad.

The commercial standard most in use is the ⅓ micro-farad, although adjustable condensers are often used, arranged so as to combine into many micro-farads or fractions of the same. Fig. 29 shows the ordinary ⅓ micro-farad condenser, and Fig. 30 one that is adjustable for different values. Diagram 31 shows an outline of the connections inside an adjustable condenser. The ordinary commercial condenser is most usually made up of sheets of tin foil separated from each other by some insulator such as paraffined paper or mica. Every alternate sheet of foil is connected to a common terminal. As the capacity of a condenser depends upon the nearness of the conductors to each other, and upon the area of the same, the insulating material is made as thin as possible, and still be safe from leakage or puncture. Many sheets of foil are joined together as described to make up the area. A condenser of 1 mfd. capacity contains about 3600 sq. in. of tin foil. In adjustable condenser, the sheets are separated into bundles,

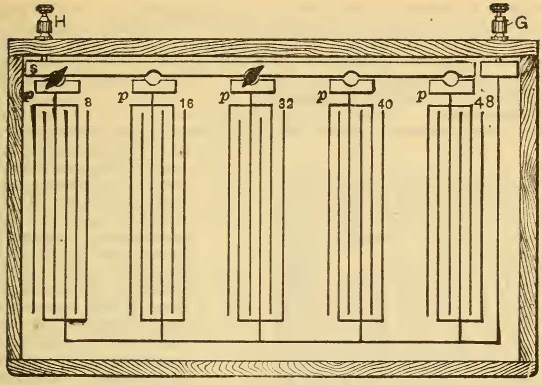


FIG. 31.

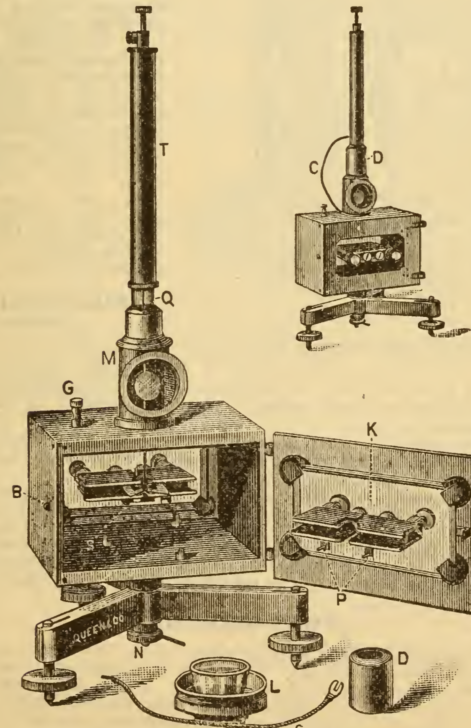


FIG. 32. Modified Mascart Electrometer.

and arranged so that any of them can be plugged in or out to add to or lessen the total capacity. If connected in multiple as shown, or if the positive side of one condenser be connected to the negative side of another, or a number of them are thus added together, then the condensers are said to be arranged in "cascade" or in series. This is seldom done unless it be to obtain greater variation in capacity.

Electrometer. — Another instrument used where the measurement of electrostatic capacities or potentials is common, is the *electrometer*. A type of electrometer commonly used is the quadrant electrometer, for which we are indebted to Lord Kelvin. The needle is a thin, flat piece of aluminium suspended in a horizontal position by a thin metallic wire, in close proximity to four quadrants of thin sheet brass, that are supported on insulators without touching each other. Opposite quadrants are connected by fine wires. A charge of electricity is given the needle by connecting the suspension filament with a Leyden jar or other condenser.

If the needle be charged positively it will be attracted by a negative charge and repelled by a positive charge. If, therefore, there be a difference of potential between the pairs of quadrants, the needle will be deflected from zero. The usual mirror, scale, and lamp are used with this instrument, as in the case of the reflecting galvanometer. A form is shown in Fig. 32.

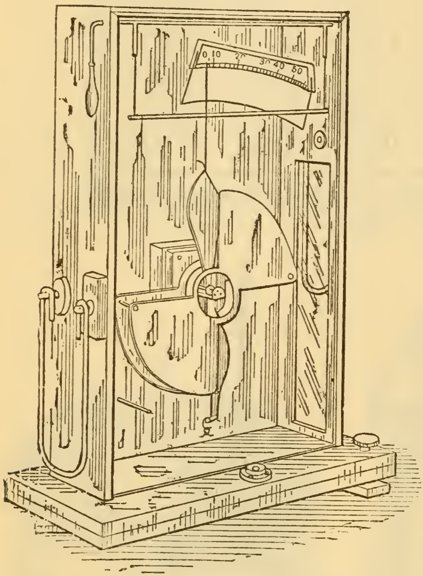


Fig. 33. Kelvin's Electrostatic Voltmeter.

Electrostatic Voltmeter.

A modification of the electrometer, used for indicating high, and in some cases low, alternating current potentials is the electrostatic voltmeter of Lord Kelvin. It is constructed on the principle of an air condenser.

In the high potential instrument, Fig. 33, the needle is made of a thin aluminium plate suspended vertically on delicate knife-edges, with a pointer extending from the upper part to a scale.

On either side of the needle, and parallel to its face, are placed two quadrant plates metallically connected and serving as one terminal of the circuit to be measured, while the needle serves as the other and opposite terminal. Any electrical potential difference between the needle and the plates will deflect the needle out of its neutral position. Calibrated weights can be hung on the bottom of the needle to change the value of the scale indications.

VOLTMETERS.

These are indicating instruments which show the electromotive force impressed upon their terminals. They are, in nearly all cases, calibrated galvanometers of constant high resistance. When connected across the terminals of any source of electromotive force, currents will flow through them which are directly proportional to the impressed voltages. A pointer connected to the moving element moves over a scale which is empirically graduated to show the impressed voltage. The resistance of commercial voltmeters in ohms varies from 10 to 150 times the full scale reading in volts; thus, a voltmeter of Weston's make having a range of 150 volts may have a resistance of from 15000 to 325,000 ohms. The resistance should be wound non-inductively and of a wire possessing a negligible temperature coefficient. The controlling or directive forces to bring the pointer back to zero are generally obtained from springs or gravity and occasionally from magnets.

There are several types of voltmeters in commercial use, those developed by Edward Weston being perhaps the best known. For direct-current measurements in either switchboard or portable forms the moving coil type constructed on the general principle of the d'Arsonval galvanometer with pivoted coil is most frequently used. They can be constructed so as to have high resistances and perfect damping and are but little affected by external fields, especially if shielded with iron casing, as is often done with switchboard instruments.

For alternating-current measurements the electromagnetic or soft iron instrument is very commonly used for switchboard work. In this instrument a mass of soft iron is so placed in a solenoid that it will be drawn from the center to the edge of the solenoid, or drawn into the solenoid from an outside point. These instruments are correct only for the particular frequency for which they were calibrated and corrections should be made for any change of frequency. When properly calibrated they may be used on direct-current circuits.

Portable voltmeters for alternating-current measurements frequently employ a system based upon the electro-dynamometer. This instrument has the advantage of being independent of frequency variations or wave form. It can also be used for direct-current measurements if correction for external fields is made.

In addition to the above types, voltmeters are constructed on the hot wire principle in which the passage of the current causes heating and a consequent expansion of the wire through which it passes. The expansion of the wire is taken up by a spring which causes a pointer to move acrcss a graduated scale.

Ammeters.

The scale of a voltmeter may be graduated and marked so as to indicate the value of the currents passing through it instead of the volts impressed upon its terminals. It will then be an ammeter. To be of value its resistance must be small. Many ammeters consist of moving-coil millivoltmeters connected to the terminals of shunts through which the currents to be measured are passed. The shunts are made of a high resistance low temperature coefficient alloy and, since the resistance remains constant, the drop in potential between its terminals will be proportionate to the current flowing through it. The scales are graduated so as to indicate the currents passing through the shunts. The shunt type of instrument is particularly applicable to switchboards, but is adapted for direct-current measurements only.

For alternating-current measurements the electromagnetic system is generally employed, the total current to be measured passing through a low-resistance solenoid, or the current flowing through the ammeter may be reduced by inserting the primary of a series transformer in the main circuit and connecting the ammeter across the terminals of the secondary. Since the ratio of current in the primary to that in the secondary is constant, the ammeter may be calibrated in terms of the primary, but need have only the small secondary current flowing through it.

Soft Iron Instruments. — If a piece of soft iron be placed in a magnetic field it becomes itself magnetic. This fact is utilized in the so-called "soft iron" instruments in which the movable system consists of a soft iron needle pivoted within a coil and normally placed oblique to the directions of its magnetic field. When a current passes through the coil the needle tends to assume a position parallel to the lines of force, and being controlled by a spring or other controlling force, the deflection is a measure of the current passing.

This type of instrument is used to some extent for switchboard work, but cannot be used in measurements where great accuracy is required on account of magnetic lag in the iron.

The Electro-Dynamometer.

If currents be sent through two coils of wire, which are capable of movement as regards each other, they will tend to place themselves in such a position as to bring the lines of force of their magnetic fields parallel to each other and in the same direction. The Siemen's electro-dynamometer acts according to this principle.

Fig. 34 below shows the form most used. It consists of a fixed coil usually having two divisions, — one of a few turns of heavy wire for heavy currents and another of many turns of finer wire for smaller currents. Outside of this fixed coil, and at right angles thereto, is suspended a movable coil of few turns. A carefully wound helical spring joins the movable coil to a torsion screw above the dial. A pointer on this torsion screw shows on the dial the degrees of angle through which it may be twisted. The lower ends of the movable coil dip into mercury cups to make connection with the fixed coil. If current flows through the two coils in series, the movable coil is turned from its position at right angles with the fixed coil and tries to arrange itself in the same plane as the latter, according to above law.

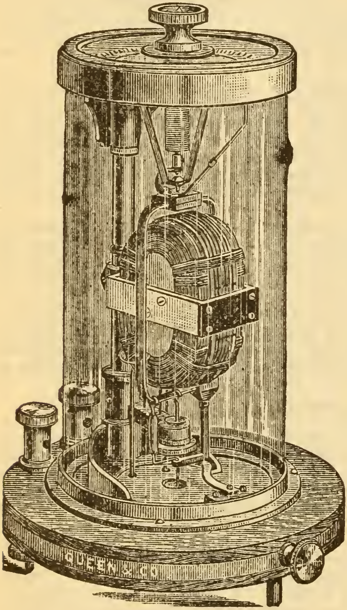


FIG. 34. Siemen's Electro-Dynamometer.

The torsion screw is then turned in the opposite direction until the force of the spring overcomes the electrodynamic action of the coils, and the movable coil is brought to zero.

If A be a constant depending upon the character of the torsion spring, I be the current, and d be the angle of deflection of the torsion screw to return the movable coil to zero, then

$$I = A\sqrt{d}.$$

The electro-dynamometer is suited to measure alternating currents of ordinary frequencies, also direct currents.

Wattmeter. — If the movable coil of the electro-dynamometer be of very fine wire, and have a coil of very high and non-inductive resistance in series with it, and if the fixed coil be of heavy wire, then the instrument may be used for measuring the work of a circuit in watts, by connecting the fixed coil in series with the circuit under test, and the movable coil across the terminals of the circuit. In this case, if the voltage current be i_1 and the series current in the fixed coil be i_2, then the power equals Ki_1i_2, where K is a constant of the instrument. The two currents are supposed to be in phase with each other. If the movable coil be not brought back to zero, but a pointer connected with it be permitted to move over a graduated scale, the scale can be calibrated directly in watts.

Weston's well-known wattmeter is constructed substantially on this principle.

In order that a wattmeter (electro-dynamometer) may be reliable for measuring alternate-current power, it is needful that the fine-wire circuit, which is to be connected as a shunt to the apparatus under measurement, should have as little self-induction as possible in proportion to its resistance. The latter may be increased by adding auxiliary non-inductive resistances. The instrument must itself be so constructed that there shall be no eddy currents set up by either circuit in the frames, supports, or case; otherwise the indications will be false.

Kelvin's Composite Electric Balance.

This instrument is employed to a considerable extent as a standard for comparison of instruments for both direct and alternating currents, although for direct-current work it has been almost entirely superseded by the direct reading laboratory standard instrument, which is more sensitive, and equally accurate throughout the scale, as is not the case with the Kelvin balance, since its indications vary as the square of the current. It can be used as voltmeter, ampere meter, or wattmeter. The principle of its action is similar to that of the electro-dynamometer. The attraction and repulsion between the stationary and movable coils is balanced by the attraction of gravity on a sliding weight connected with the movable coils.

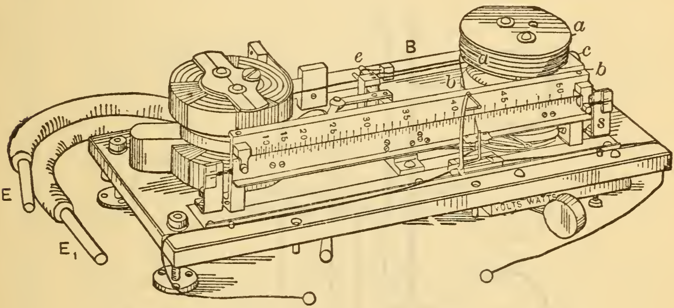


Fig. 35. Kelvin's Standard Composite Balance.

Above is a cut of the instrument in its latest form, and the diagram following shows the theory on which the instrument works.

In both cut and diagram the same letters indicate the same parts: *a* and *b* are two coils of silk-covered copper wire placed one above the other as shown with their planes horizontal, and the whole being mounted on a slab of slate which is supported on leveling screws.

Two coils *c* and *d*, of similar wire, are made in rings that are secured to the ends of a balance beam *B*, which is suspended at its center by two flat ligaments of fine copper wire.

When for use with direct currents two other coils, *g* and *h*, made of strip copper, and of cross section heavy enough to carry large currents, say 500 amperes, are secured to the base plate at the left in the same relative position as are the coils *a* and *b* at the right. When the instrument is to be used in the measurement of alternating currents the coils *g* and *h* are made of two or three turns of a stranded copper conductor, each wire of which is insulated; and, to as far as possible annul the effects of induction, the strand is given one turn or twist for each turn around the coil.

The coils *c* and *d* of the balance are suspended equidistant between the right and left pairs of coils with planes parallel to their planes and centers coinciding with their centers.

To Set the Balance. — Level the instrument with the adjustable legs, turn the stop screws back out of contact with the cross trunnions and front plate of the beam, leaving it free.

To Use as Voltmeter or Centi-ampere Meter. — Connect the instrument to the circuit or source of E.M.F. through a non-inductive resistance R, as shown in the following diagram, the resistance terminal to T and the other terminal to T_1; throw the switch H to the right to the "volt" contact.

One of the weights $v\,w_1$, $v\,w_2$, $v\,w_3$, is then used on the scale beam, and a is balance obtained. The current flowing in the instrument is then calculated by a comparison of the scale-reading with the certificate accompanying the instrument. The volts E.M.F. at the terminals are calculated from the current flowing and the resistance in circuit, including the non-inductive resistance used, by Ohm's law, $v = IR$.

To Use as Hekto-ampere Meter. — Turn the switch H to "watts," insert the thick wire coils in circuit with the current in such a way that the right-hand end of the beam rises. Use the "sledge" alone or the weight marked *w. w.*

Terminals E and E_1 are then introduced into the circuit, and a measured current passed through the suspended coils g and h; and the constants given in the certificate for the balance used in this way are calculated on the assumption that this current is .25 ampere. Any other current may be used, say I ampere, then the constant becomes $I \div .25$ or $4I$.

The current flowing in the suspended coils g and h may be measured by the instrument itself, arranged for the measurement of volts. To do this, first measure the current produced by the applied E.M.F. through the coils

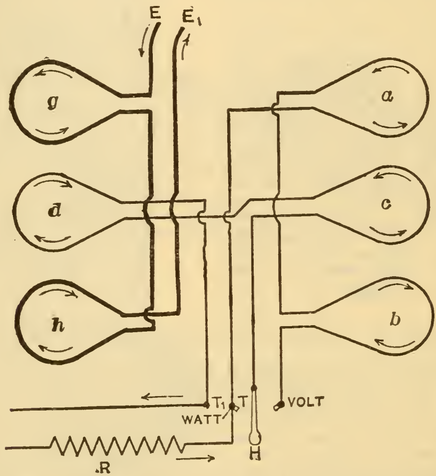


Fig. 36. Diagram of the Kelvin Composite Balance.

of the instrument and the external resistance, then turn the switch H to "watt," and introduce into the circuit a resistance equal to that of the fixed coils.

To Use as a Wattmeter. — Insert the thick wire coils in the main circuit; then join one end of the non-inductive resistance R to one terminal of the fine wire coils, and the other end of R to one of the leads; the other terminal of the fine wire coils is connected to the other lead. The current flowing and the E.M.F. may now be determined by the methods described above. The watts can then be calculated from the E.M.F. of the leads, and the current flowing in the thick wire coils by the formula,

$$P_w = VI = i\ IR,$$

Where $i =$ current in the suspended coil circuit.
$I =$ current in the thick wire coils.
$R =$ resistance in the circuit.

When working with alternating currents the non-inductive resistance R must be large enough to prevent any difference of phase of the current flowing in the fine wire coils and the E.M.F. of the circuit.

Table of Doubled Square Roots for Lord Kelvin's Standard Electric Balances.

	0	100	200	300	400	500	600	700	800	900	
0	0.000	20.00	28.28	34.64	40.00	44.72	48.99	52.92	56.57	60.00	0
1	2.000	20.10	28.35	34.70	40.05	44.77	49.03	52.95	56.60	60.03	1
2	2.828	20.20	28.43	34.76	40.10	44.81	49.07	52.99	56.64	60.07	2
3	3.464	20.30	28.50	34.81	40.15	44.86	49.11	53.03	56.67	60.10	3
4	4.000	20.40	28.57	34.87	40.20	44.90	49.15	53.07	56.71	60.13	4
5	4.472	20.49	28.64	34.93	40.25	44.94	49.19	53.10	56.75	60.17	5
6	4.899	20.59	28.71	34.99	40.30	44.99	49.23	53.14	56.78	60.20	6
7	5.292	20.69	28.77	35.04	40.35	45.03	49.27	53.18	56.82	60.23	7
8	5.657	20.78	28.84	35.10	40.40	45.08	49.32	53.22	56.85	60.27	8
9	6.000	20.88	28.91	35.16	40.45	45.12	49.36	53.25	56.89	60.30	9
10	6.325	20.98	28.98	35.21	40.50	45.17	49.40	53.29	56.92	60.33	10
11	6.633	21.07	29.05	35.27	40.55	45.21	49.44	53.33	56.96	60.37	11
12	6.928	21.17	29.12	35.33	40.60	45.25	49.48	53.37	56.99	60.40	12
13	7.211	21.26	29.19	35.38	40.64	45.30	49.52	53.40	57.03	60.43	13
14	7.483	21.35	29.26	35.44	40.69	45.34	49.56	53.44	57.06	60.46	14
15	7.746	21.45	29.33	35.50	40.74	45.39	49.60	53.48	57.10	60.50	15
16	8.000	21.54	29.39	35.55	40.79	45.43	49.64	53.52	57.13	60.53	16
17	8.246	21.63	29.46	35.61	40.84	45.48	49.68	53.55	57.17	60.56	17
18	8.485	21.73	29.53	35.67	40.89	45.52	49.72	53.59	57.20	60.60	18
19	8.718	21.82	29.60	35.72	40.94	45.56	49.76	53.63	57.24	60.63	19
20	8.944	21.91	29.66	35.78	40.99	45.61	49.80	53.67	57.27	60.66	20
21	9.165	22.00	29.73	35.83	41.04	45.65	49.84	53.70	57.31	60.70	21
22	9.381	22.09	29.80	35.89	41.09	45.69	49.88	53.74	57.34	60.73	22
23	9.592	22.18	29.87	35.94	41.13	45.74	49.92	53.78	57.38	60.76	23
24	9.798	22.27	29.93	36.00	41.18	45.78	49.96	53.81	57.41	60.79	24
25	10.000	22.36	30.00	36.06	41.23	45.83	50.00	53.85	57.45	60.83	25
26	10.198	22.45	30.07	36.11	41.28	45.87	50.04	53.89	57.48	60.86	26
27	10.392	22.54	30.13	36.17	41.33	45.91	50.08	53.93	57.52	60.89	27
28	10.583	22.63	30.20	36.22	41.38	45.96	50.12	53.96	57.55	60.93	28
29	10.770	22.72	30.27	36.28	41.42	46.00	50.16	54.00	57.58	60.96	29
30	10.954	22.80	30.33	36.33	41.47	46.04	50.20	54.04	57.62	60.99	30
31	11.136	22.89	30.40	36.39	41.52	46.09	50.24	54.07	57.65	61.02	31
32	11.314	22.98	30.46	36.44	41.57	46.13	50.28	54.11	57.69	61.06	32
33	11.489	23.07	30.53	36.50	41.62	46.17	50.32	54.15	57.72	61.09	33
34	11.662	23.15	30.59	36.55	41.67	46.22	50.36	54.18	57.76	61.12	34
35	11.832	23.24	30.66	36.61	41.71	46.26	50.40	54.22	57.79	61.16	35
36	12.000	23.32	30.72	36.66	41.76	46.30	50.44	54.26	57.83	61.19	36
37	12.166	23.41	30.79	36.72	41.81	46.35	50.48	54.30	57.86	61.22	37
38	12.329	23.49	30.85	36.77	41.86	46.39	50.52	54.33	57.90	61.25	38
39	12.490	23.58	30.92	36.82	41.90	46.43	50.56	54.37	57.93	61.29	39
40	12.649	23.66	30.98	36.88	41.95	46.48	50.60	54.41	57.97	61.32	40
41	12.806	23.75	31.05	36.93	42.00	46.52	50.64	54.44	58.00	61.35	41
42	12.961	23.83	31.11	36.99	42.05	46.56	50.68	54.48	58.03	61.38	42
43	13.115	23.92	31.18	37.04	42.10	46.60	50.71	54.52	58.07	61.42	43
44	13.266	24.00	31.24	37.09	42.14	46.65	50.75	54.55	58.10	61.45	44
45	13.416	24.08	31.30	37.15	42.19	46.69	50.79	54.59	58.14	61.48	45
46	13.565	24.17	31.37	37.20	42.24	46.73	50.83	54.63	58.17	61.51	46
47	13.711	24.25	31.43	37.26	42.28	46.78	50.87	54.66	58.21	61.55	47
48	13.856	24.33	31.50	37.31	42.33	46.82	50.91	54.70	58.24	61.58	48
49	14.000	24.41	31.56	37.36	42.38	46.86	50.95	54.74	58.28	61.61	49
50	14.142	24.49	31.62	37.42	42.43	46.90	50.99	54.77	58.31	61.64	50

	0	100	200	300	400	500	600	700	800	900	
51	14.283	24.58	31.69	37.47	42.47	46.95	51.03	54.81	58.34	61.68	51
52	14.422	24.66	31.75	37.52	42.52	46.99	51.07	54.85	58.38	61.71	52
53	14.560	24.74	31.81	37.58	42.57	47.03	51.11	54.88	58.41	61.74	53
54	14.697	24.82	31.87	37.63	42.61	47.07	51.15	54.92	58.45	61.77	54
55	14.832	24.90	31.94	37.68	42.66	47.12	51.19	54.95	58.48	61.81	55
56	14.967	24.98	32.00	37.74	42.71	47.16	51.22	54.99	58.51	61.84	56
57	15.100	25.06	32.06	37.79	42.76	47.20	51.26	55.03	58.55	61.87	57
58	15.232	25.14	32.12	37.84	42.80	47.24	51.30	55.06	58.58	61.90	58
59	15.362	25.22	32.19	37.89	42.85	47.29	51.34	55.10	58.62	61.94	59
60	15.492	25.30	32.25	37.95	42.90	47.33	51.38	55.14	58.65	61.97	60
61	15.620	25.38	32.31	38.00	42.94	47.37	51.42	55.17	58.69	62.00	61
62	15.748	25.46	32.37	38.05	42.99	47.41	51.46	55.21	58.72	62.03	62
63	15.875	25.53	32.43	38.11	43.03	47.46	51.50	55.24	58.75	62.06	63
64	16.000	25.61	32.50	38.16	43.08	47.50	51.54	55.28	58.79	62.10	64
65	16.125	25.69	32.56	38.21	43.13	47.54	51.58	55.32	58.82	62.13	65
66	16.248	25.77	32.62	38.26	43.17	47.58	51.61	55.35	58.86	62.16	66
67	16.371	25.85	32.68	38.31	43.22	47.62	51.65	55.39	58.89	62.19	67
68	16.492	25.92	32.74	38.37	43.27	47.67	51.69	55.43	58.92	62.23	68
69	16.613	26.00	32.80	38.42	43.31	47.71	51.73	55.46	58.96	62.26	69
70	16.733	26.08	32.86	38.47	43.36	47.75	51.77	55.50	58.99	62.29	70
71	16.852	26.15	32.92	38.52	43.41	47.79	51.81	55.53	59.03	62.32	71
72	16.971	26.23	32.98	38.57	43.45	47.83	51.85	55.57	59.06	62.35	72
73	17.088	26.31	33.05	38.63	43.50	47.87	51.88	55.61	59.09	62.39	73
74	17.205	26.38	33.11	38.68	43.54	47.92	51.92	55.64	59.13	62.42	74
75	17.321	26.46	33.17	38.73	43.59	47.96	51.96	55.68	59.16	62.45	75
76	17.436	26.53	33.23	38.78	43.63	48.00	52.00	55.71	59.19	62.48	76
77	17.550	26.61	33.29	38.83	43.68	48.04	52.04	55.75	59.23	62.51	77
78	17.664	26.68	33.35	38.88	43.73	48.08	52.08	55.79	59.26	62.55	78
79	17.776	26.76	33.41	38.94	43.77	48.12	52.12	55.82	59.30	62.58	79
80	17.889	26.83	33.47	38.99	43.82	48.17	52.15	55.86	59.33	62.61	80
81	18.000	26.91	33.53	39.04	43.86	48.21	52.19	55.89	59.36	62.64	81
82	18.111	26.98	33.59	39.09	43.91	48.25	52.23	55.93	59.40	62.67	82
83	18.221	27.06	33.65	39.14	43.95	48.29	52.27	55.96	59.43	62.71	83
84	18.330	27.13	33.70	39.19	44.00	48.33	52.31	56.00	59.46	62.74	84
85	18.439	27.20	33.76	39.24	44.05	48.37	52.35	56.04	59.50	62.77	85
86	18.547	27.28	33.82	39.29	44.09	48.41	52.38	56 07	59.53	62.80	86
87	18.655	27.35	33.88	39.34	44.14	48.46	52.42	56.11	59.57	62.83	87
88	18.762	27.42	33.94	39.40	44.18	48.50	52.46	56.14	59.60	62.86	88
89	18.868	27.50	34.00	39.45	44.23	48.54	52.50	56.18	59.63	62.90	89
90	18.974	27.57	34.06	39.50	44.27	48.58	52.54	56.21	59.67	62.93	90
91	19.079	27.64	34.12	39.55	44.32	48.62	52.57	56.25	59.70	62.96	91
92	19.183	27.71	34.18	39.60	44.36	48.66	52.61	56.28	59.73	62.99	92
93	19.287	27.78	34.23	39.65	44.41	48.70	52.65	56.32	59.77	63.02	93
94	19.391	27.86	34.29	39.70	44.45	48.74	52.69	56.36	59.80	63.06	94
95	19.494	27.93	34.35	39.75	44.50	48.79	52.73	56.39	59.83	63.09	95
96	19.596	28.00	34.41	39.80	44.54	48.83	52.76	56.43	59.87	63.12	96
97	19.698	28.07	34.47	39.85	44.59	48.87	52.80	56.46	59.90	63.15	97
98	19.799	28.14	34.53	39.90	44.63	48.91	52.84	56.50	59.93	63.18	98
99	19.900	28.21	34.58	39.95	44.68	48.95	52.88	56.53	59.97	63.21	99
100	20.000	28.28	34.64	40.00	44.72	48.99	52.92	56.57	60.00	63.25	100

The Potentiometer.

In its simplest form the potentiometer may be represented by the diagram, Fig. 37.

A B is a resistance in which a constant current from the battery *W* is maintained. The regulating resistance *R* is used to compensate for variations in the E.M.F. or internal resistance of the battery *W*. The constancy of the current in *A B* is checked by seeing that the drop in potential between two points chosen in it is equal to the E.M.F. of a standard cell. The standard cell is introduced into the circuit *M. E. M.'* at *E*, and the regulating resistance *R* adjusted until the sensitive galvanometer *G* shows no deflection. Assuming *A B* to have a uniform resistance throughout its length, and the current in it to remain constant, it is obvious that any other voltage not greater than the drop between *A* and *B* can be measured by introducing it at *E* and shifting the points *MM'* until the galvanometer again comes to a balance. Further, a direct reading scale may be placed between *A* and *B*. For most potentiometer work the drop between *A* and *B* is made about 1.5 volts, as this is about the E.M.F. of a standard Clark cell. That the instrument may have a wide range and make measurements to a sufficiently high degree of accuracy, it is necessary that it be possible to sub-divide this resistance, so as to read voltage to at least the fifth decimal place. Since the current must be kept constant the total resistance in the circuit must not be varied by raising the resistance between *M* and *M'*.

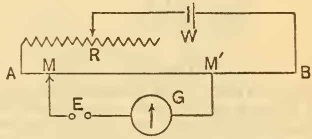


FIG. 37.

Range. — To meet general laboratory requirements the potentiometer must measure directly as high as 1.5 volts so that all kinds of standard cells may be compared with each other; and it must measure as low as .00001 volt so that reasonably low resistance standards may be used in measuring current. An example will make this point clear. To measure 1000 amperes the current must flow through a standard low resistance and the drop in E.M.F. across its terminals be measured on the potentiometer. With a potentiometer reading only to .0001 volt the drop across the low resistance must be at least .1 volt in order that it may be read to an accuracy of $\frac{1}{10}$%. If 1000 amperes is the maximum current to be used on the particular low resistance it should be so designed as to give proper readings with a minimum current at least as low as 100 amperes. 100 amperes must consequently give a drop of .1 volt, which fixes the resistance at .001 ohm. .001 ohm to carry 1000 amperes must be able to dissipate 1000 watts, and in order to remain a standard it must do this without heating enough to vary the resistance outside of small limits. With a potentiometer reading to .00001 volt the same range of current can be handled on a resistance of .0001 ohm and can be measured to the same degree of accuracy. To carry 1000 amperes it will only have to dissipate 100 watts. To maintain the same degree of accuracy while a current is flowing it can consequently be made of a very much smaller size and with $\frac{1}{10}$ the radiating surface.

Methods of Using the Standard Cell. — The standard cell is used to measure the current flowing through the potentiometer, which is done by making the drop in E.M.F. across a known resistance in the circuit equal to that of the standard cell.

1st Method. — The standard cell may be used as indicated in Fig. 38. The galvanometer is permanently in circuit with the points *MM'*, and by means of the double-throw switch *U* the standard cell *S*, or an unknown E.M.F. *E*, may be thrown into the same circuit. If the resistance *A B* is provided with a scale by means of which it is sub-divided into, for example, 15,000 equal parts, the points *MM'* may be set to a reading corresponding to the E.M.F. of the standard cell and the current from the battery *W* regulated by the resistance *R* until there is a balance, the standard cell being in circuit with the galvanometer and points *MM'*. There will then be such a current flowing that for any other position of the points *MM'*, producing a balance with the unknown E.M.F. in circuit, the reading from the scale will be direct in volts. This method is open to the objection that it requires a resetting of the points *MM'* to make a check measurement of the current flowing. In making accurate measurements these check measurements have to be made frequently and are especially inconvenient by this method when the points MM' are multiplied from two to four or five as they generally are.

2d Method. — A method of measuring and checking the currents which avoids this objection is shown in Fig. 39. It is not necessary that the resistance which furnishes the drop, against which the E.M.F. of the standard

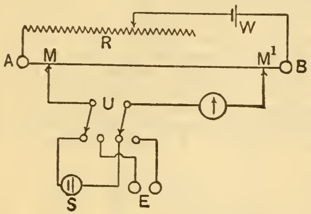


FIG. 38.

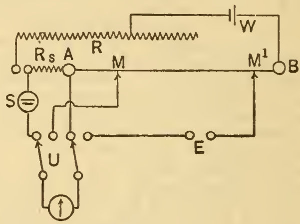


FIG. 39.

cell is balanced, be between the points A B, which limit the motion of MM'. If placed at R_s and properly chosen with reference to the E.M.F. of the standard cell and the resistance of the wire A B, the current which produces a drop across it equal to the E.M.F. of the standard cell will make the scale of A B direct reading in volts. In this case the double-throw switch is arranged so as to throw the galvanometer either into the circuit containing the standard cell and the resistance R_s, or into the circuit containing the points MM' and the unknown E.M.F. This method is, however, open to a serious objection from the standpoint of accuracy, which is avoided by the first. To illustrate this by a numerical example, assume in both cases all the resistances adjusted to an accuracy of $\frac{1}{50}$ of 1% and the error to be in such a direction as to produce the worst result. In the second method if the resistance R_s were $\frac{1}{50}$% high the current flowing through the potentiometer would be $\frac{1}{50}$% lower than it should be. If now the resistances of A B were $\frac{1}{50}$% low this would introduce a second error of the same amount in the same direction and the resulting error in measurement would be $\frac{1}{25}$%. In other words the measurement accuracy throughout the range of the potentiometer may be only half so good as the adjustment accuracy. In the first method, since the standard cell E.M.F. and the unknown E.M.F. are balanced against the drop across the same resistances in measuring an E.M.F. nearly equal to that of the standard cell, inaccuracies in the resistance are the same in both cases and balance each other.

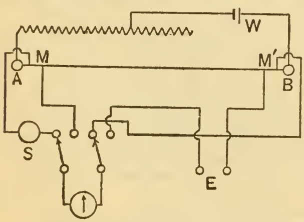


FIG. 40.

Consequently by this method measurements are bound to be more accurate than the adjustment of the resistances. In a potentiometer arranged to be used with a Clark cell using the first method of applying the standard cell and with resistances adjusted to $\frac{1}{50}$% it can be shown by calculation that the maximum error in measurement will vary with the value of the E.M.F. under measurement. For E.M.F. of 1.5 volts this error will be less than .003%. For E.M.F. of 1.2 volts it will be about .01%. For E.M.F. of .8 volts it will be about .02%. For E.M.F. of .3 to .1 volts it will be .04%, and in no case will be larger than this. To sum up the contrast in accuracy between the two methods: in the second the errors may be twice as great as the adjustment errors throughout the range, while in the first method they only become this large for .3 volt and under, and for higher voltages have increasing accuracy becoming equal to that of the adjustment at .8 volts and much better as they approach the E.M.F. of the standard cell; at exactly the E.M.F. of the standard cell the accuracy of comparison becomes independent of the accuracy of adjustment of the resistance.

3d Method.—A third method combines with the accuracy of the first, the convenience of the second. It is illustrated in Fig. 40. The E.M.F. of the standard cell is balanced against the drop across a part of the potentiometer wire *AB* as in method No. 1, but the terminals of this resistance are found, not by setting the points M M′, but they are permanently fixed, and the double-throw switch *U* throws the galvanometer into one circuit or the other as desired.

The Brooks Deflection Potentiometer.

While the potentiometer is very accurate, it is slow in working and can be used only with steady current or voltage. The deflection potentiometer, designed by H. B. Brooks of the National Bureau of Standards, combines in large measure the accuracy and reliability of the null potentiometer with the speed and convenience of portable deflection instruments. It consists of a

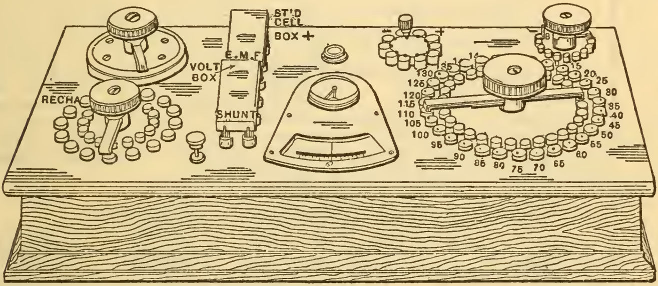


FIG. 40a. The Brooks' Deflection Potentiometer.

one-dial potentiometer having a pivoted moving-coil galvanometer with calibrated scale. The deflection of the galvanometer gives the last few figures of the result, which are read from the slide wire in some forms of potentiometer. As the galvanometer is quick and dead beat, the value of a fluctuating current or voltage may be followed. The deflection potentiometer is intended as a standard instrument for central stations, instrument and meter factories, and other service requiring accuracy combined with speed.

Description of Instrument.

Figure 4 shows a plan of circuits of the Model 3 potentiometer, which has been designed for general measurements of current and voltage in laboratories whose requirements include a reasonable degree of accuracy combined with speed of working.

The main dial has 30 steps of 5 ohms each. In series with it is a coil of 1.80 ohms and a standard-cell dial of 10 steps of 0.01 ohm each. The Weston portable unsaturated standard cell only is used; it is balanced around the last two-thirds (100 ohms) of the main dial, plus the 1.80-ohm coil and the standard-cell dial. Thus it is possible to use standard cells whose values are from 1.0180 to 1.0190 volts inclusive. This covers the range of variation of these unsaturated cells sufficiently well, as cells may be bought with the specification that they shall fall within this range, and within several units of the lower end of the dial, to provide for the slight decrease of E.M.F. to be expected in a period of years. The standard current through the main dial coils is thus 0.01 ampere; it is furnished by a storage cell. The series rheostat r_3 has a minimum value of 20.85 ohms, and increases by 15 steps of 0.1 ohm each. The shunt rheostat (r_6) has a minimum value of 88.9 ohms, and increases by 15 steps to a maximum of 123.4 ohms. A fine rheostat of 0.5 ohm in the battery circuit covers any step of the coarse rheostat, and has a compensating resistance of 0.3 ohm in the galvanometer circuit. The circuits are so designed that the compensating resistance (r_4) of the main dial repeats at 90, 95, . . . 150 the values for 80, 75, . . . 20; hence a number of coils are saved by using cross connections.

The galvanometer key has a protective resistance of 2,400 ohms, which is in circuit on the first contact and is cut out on full depression. The total resistance in the galvanometer circuit under working conditions is 60 ohms between the binding posts marked "Volt Box," which with 40 ohms resultant

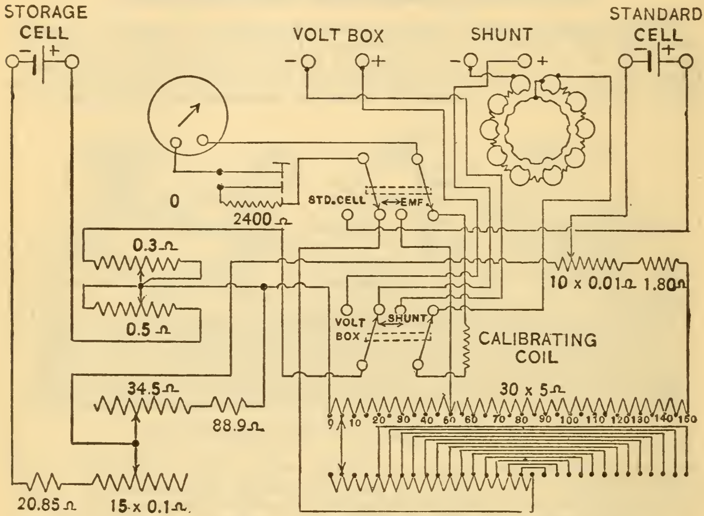


FIG. 40b. Plan of Circuit, Model 3 Brooks' Deflection Potentiometer.

resistance in the volt box makes up the normal total of 100 ohms. The total resistance measured between the binding posts marked "Shunt" is 100 ohms when the circular plug rheostat near these posts is plugged at the extreme right, and is less than this by amounts of 0.1, 0.2, 0.5 . . . 40 ohms when the plug is placed in succession toward the left. This allows the total resistance to be kept 100 ohms when using shunts of the values just given, the resistance of the shunt being counted in the total.

INSTRUMENTS AND METHODS FOR DETERMINATION OF WAVE FORM OF CURRENT AND ELECTROMOTIVE FORCE.

THERE are numerous methods of determining wave form, those used in the laboratory experiments commonly making use of the ballistic galvanometer. Of the simple methods used in shop practice, R. D. Mershon, Consulting Engineer, has applied the telephone to an old ballistic method in such a manner as to make it quite accurate and readily applied.

Mershon's Method. — The following cut shows the connections. A telephone receiver, shunted with a condenser, is connected in the line from the source of current, the wave form of which it is wished to determine. A contact-maker is placed in the other leg, and an external source of steady current, as from a storage battery, is opposed to the alternating current, as shown. The pressure of the external current is then varied until there is no sound in the telephone, when the pressures are equal and can be read from the voltmeter. The contact-maker being revolved by successive steps, points may be determined for an entire cycle.

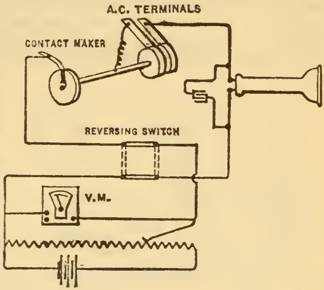


FIG. 41. Mershon's method of determining Wave Form.

Duncan's Method. — Where it is desirable to make simultaneous determinations it will ordinarily require several contact-makers, as well as full sets of instruments. Dr. Louis Duncan has devised a method by which one contact-maker in connection with a dynamometer for each curve will enable all readings to be taken at once. The following cut shows the connections. The fixed coils of all the dynamometers are connected to their respective circuits, and the fine wire movable coils of about 1,000 ohms each are connected in series with a contact maker and small storage battery. The contact-maker is made to revolve in synchronism with the alternating current source. Now, if alternating currents from the different sources are passed through the fixed coils, and at intervals of the same frequency current from the battery is passed through the movable coils, the deflection or impulse will be in proportion to the instantaneous value of the currents flowing in the fixed coils, and the deflections or the movable coils will take permanent position indicating that value, if the contact-maker and sources of alternating current are revolved in unison.

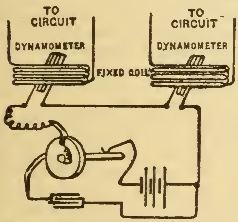


FIG. 42. Duncan's method of determining curves of several circuits at the same time.

The dynamometers are calibrated first by passing continuous currents of known value through the fixed coils, while the regular interrupted current from the battery is being passed through the movable coils.

Ryan's Method. — Prof. Harris J. Ryan, of Leland Stanford University, designed a special electrometer for use in connection with a very fine series of transformer tests. This instrument will be found described and illustrated in the chapter on description of instruments.

The method of using it is shown in the cut below, in which the contact-maker shown is made to revolve in synchronism with the source of alternating current. The terminals d d_1, of the indicating instruments can be connected to any one of the three sets of terminals, a a_1, b b_1, c c_1.

The terminals, a a_1, are for reading the instantaneous value of the primary impressed E.M.F.; b b_1, the same value of the current flowing through the small non-inductive resistance, R; and c c_1 the same value of the secondary impressed E.M.F.; the secondary current being read from the ammeter shown. Of course if the contact-maker be cut out, then all the above values will be $\sqrt{\text{mean}^2}$.

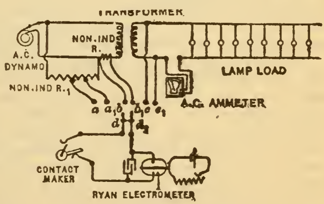


FIG. 43. Prof. Ryan's Method of obtaining Curves of Wave Form for studying Transformers.

Rosa Curve Tracer.

This instrument consists of a hard-rubber cylinder upon which is wound a single layer of bare wire. A constant current from a small storage battery is sent through this coil causing a uniform drop of potential between its ends. (See Diagram, Fig. 44.) A voltmeter connected between the terminals indicates the drop, and the resistance R in series with the battery serves to regulate this drop. The current to be plotted passes through the non-inductive resistance $A B$ and the problem is to measure the instantaneous values of the drop between these two points at successive instants throughout the period of a wave. The point B is joined to the middle point Q of the spiral wire $M N$. A is joined through the revolving contact-maker $C M$ to a sliding contact P.

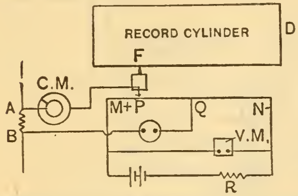


Fig. 44. Rosa Curve Tracer.

The contact-maker is joined to the shaft of the alternator, or is at least driven in synchronism with it; then every time the contact is completed at any particular phase of the wave, the current has the same value and the galvanometer will show a deflection. If the sliding contact P be adjusted so that the galvanometer shows no deflection, then the potential difference between the points P and Q is the same as that between the points A and B. This value is proportional to the distance $P Q$, and is positive on one side and negative on the other side of Q.

For making the record, a cylinder is arranged opposite the potentiometer wire and slider, upon which the paper for the record is wound. A tripping point is attached to the slider in such manner that when the galvanometer has been brought to zero by the adjustment of the resistance R, the pointer is tripped and a point impressed on the record paper through a typewriter ribbon, and at the same time the record cylinder is advanced a notch or series of them as may be required, ready for the next record. By this means the plotting of a curve of current or potential takes but a few seconds.

Oscillograph. — This form of instrument devised by Blondel and others is much used for the analysis of wave forms of current and electromotive force, and for the study of potentials and other properties of alternators or other forms of dynamos and motors. It is extremely sensitive and will detect and show either on a screen or a photograph, the most minute variations in current and potential. The *Blondel* type described below will serve to show all the principles of the instrument. *Duddell* has somewhat improved upon this one, and the *General Electric Co.* has designed another that is especially adapted to workshop practice.

The engraving (Fig. 45) shows the general appearance of the oscillograph. The apparatus is mounted in a box (Fig. 46) with an arc lamp at one end. Above is a ground-glass screen upon which the wave forms are traced by a spot of light. The magnet is mounted on the left in an inverted position. It is a permanent magnet and made up of six horseshoe pieces. Between the poles are placed two similar sets of vibrating bands, separated by an iron bridge-piece which renders each one an independent unit. In this way two wave forms can be taken at once, such as the electromotive force and current, and are seen on the screen in their relative positions.

The arrangement of mounting will be seen in Fig. 47; the band is a very fine and narrow strip of soft iron about one thirty-second of an inch wide and one five-hundredth of an inch thick. This band is held in a movable support in a vertical position between the poles of the magnet. It is stretched on the support between two ivory bridge-pieces and is attached at a to a sliding piece which moves in a rectangular groove. The slider carries a rod n above, which passes to the top and has a nut S on the end. Below S is a spring contained in a tube, so that by turning the nut the band stretches more or less between the bridges. The band carries a small, mirror m in the center. The mirror support is mounted in an oil box T of ivory, which fits into place between the magnet poles and can be turned about by the collar D. At P are two iron pieces inserted in the cylinder which serve to concentrate the field; at L is a lens placed in front of the mirror. In this way the soft iron piece vibrates without the use of pivots or suspension. Each horizontal element of the band acts like a small magnet, and the deflections produced by the coils accumulate from the extremities to the center of the band, thus increasing its sensitiveness considerably. The total deflections indicated by the mirror are proportional to the current. Owing to the properties peculiar to vibrating bands a very high

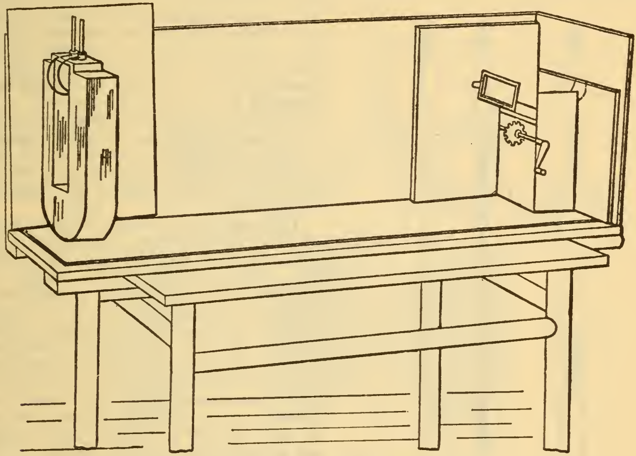


FIG. 45. Blondel Oscillograph, 1902 Model, Interior View.

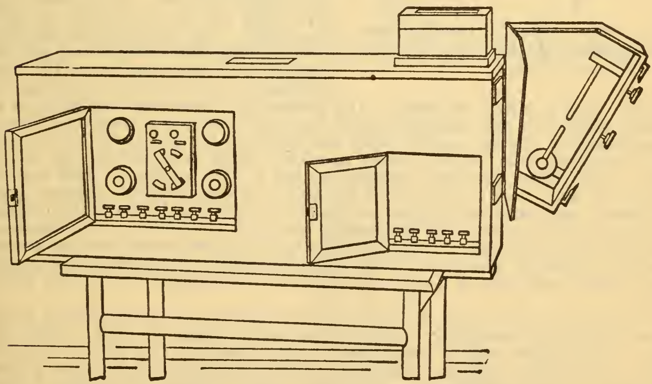


FIG. 46. Blondel Oscillograph, 1902 Model, Mounted in Case.

frequency is obtained and this is further increased by the tension which is given to it and by its position in the magnetic field. Where the wave form contains small irregularities it is of course important that these should not be affected by the vibration proper to the mirror, and the higher this rate of vibration the more correctly will the wave form be indicated

The method of mounting is seen in Fig. 48. The current coils are generally made up of thin copper strip. At $P P'$ are the pole-pieces, built of laminated iron, for concentrating the effect on the strip. There are two similar vibrating sets separated by an iron partition in the center, thus forming two different oscillographs which are quite independent of each other; even three sets can be mounted in this way. The oil tube T containing the mirror may be slid up and down by the lower screw v and may be turned horizontally by the endless screw V. On the left is seen the complete mounting; the front coil has an elliptical opening to allow the light to pass. At M is an adjustable mirror which gives a permanent spot of light to form the base line of the curves.

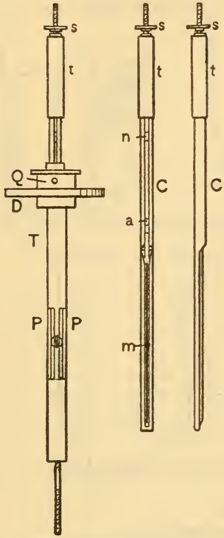


Fig. 47. Blondel Oscillograph, showing Method of mounting Vibrating Band.

By using the vibrating band, a period of 50,000 vibrations per second has been reached, representing the oscillation period proper to the band. In this case the instrument is sufficiently sensitive, although it may be made much more sensitive by using a band having 15,000 to 20,000 vibrations, which will answer in most cases where the wave forms are not too irregular. The sensitiveness in the latter case answers to a displacement of the spot of light of 100 millimeters per ampere on a screen one meter distant. The use of soft iron pole-pieces to concentrate the effect gives a high magnetic intensity to the band, and in fact it is generally brought to saturation owing to its small volume. It is found that the band has an advantage in being saturated. The sensitiveness increases at first while the band is not yet saturated, then decreases when the magnetization of the piece increases less rapidly than the field strength. The number of vibrations continues to increase, rapidly at first, then slowly, as the band becomes saturated. The results depend in a great measure upon the quality of the iron used for the band.

The mirrors must be very small and light when mounted on such a thin strip. They have now been reduced as low as 0.2 millimeter wide and 0.5 millimeter high, with a thickness of but 0.05 to 0.1 millimeter. Silvered glass or mica is used, and the mirrors are fastened to the bands with shellac before the latter are mounted. As the band is enclosed in an oil box it is free from rust and well protected. The sensitiveness of the instrument may be greatly varied by using an iron yoke which is placed against the poles of the permanent magnet and acts as a shunt to diminish the strength of the field at the poles.

To the right of the box will be seen the arrangement of the oscillating mirror which gives the to-and-fro motion to the spot of light in order to form the wave. The device will be understood by the diagram, Fig. 49. S is an arc lamp which throws a beam of light by means of the lens X and shutter F upon the mirror of the oscillograph n; this beam is then reflected and passes through the lens I, falling on the oscillating mirror m placed behind it. The latter is given a to-and-fro motion by a small synchronous motor. The beam of light thus far has two movements, one by the mirror n of the oscillograph and the other by the mirror m, and the resultant of the two gives the wave form which is projected above on the ground-glass screen P. The to-and-fro movement of the mirror is obtained by a cam fixed to the motor-shaft. During two complete periods of the wave the mirror must be moved at a continuous

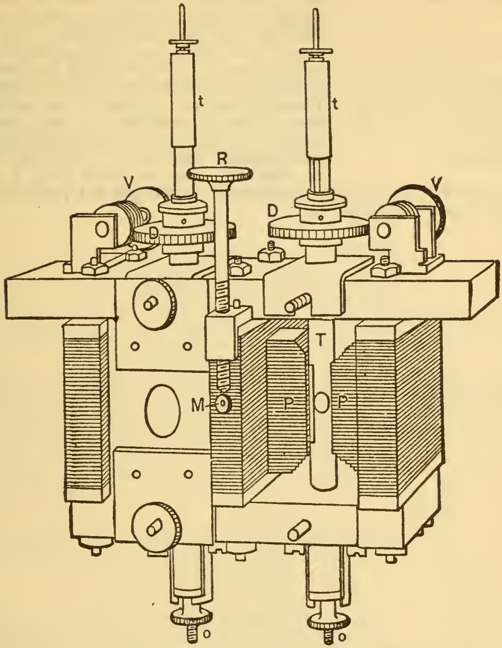


FIG. 48. Blondel Oscillograph, showing the Arrangement of the Magnet

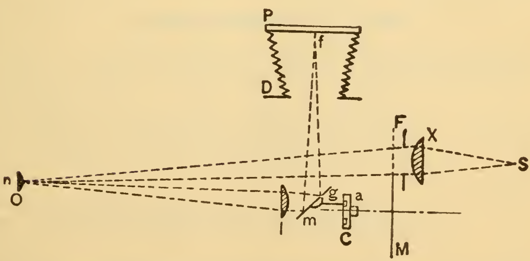


FIG. 49. Diagram showing the Arrangement of the Apparatus in the Blondel Oscillograph.

rate from top to bottom, and during the next period it must be able to return so as to continue the movement (as will be noticed on the photograph two complete waves are thrown on the screen). This is carried out by the profile of the cam which is such that the mirror has a uniform movement during two cycles of the wave, and the next cycle is occupied by the return of the mirror (during this time an electrically operated shutter placed at *F* cuts off the light), so that the eye perceives only a continuous trace of the wave. To observe phenomena which are not periodic the motor is replaced by a pendulum device.

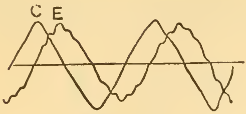


FIG. 50.

MEASUREMENTS.

REVISED BY W. N. GOODWIN, JR., AND PROF. SAMUEL SHELDON.

ELEMENTARY LAWS OF ELECTRICAL CIRCUITS.

Ohm's Law is the fundamental law of electrical circuits and is expressed in the following equations.

$$I = \frac{E}{R}$$
$$E = IR$$
$$R = \frac{E}{I}$$

where $I =$ Current strength in amperes,
$R =$ Resistance in ohms,
$E =$ Electromotive Force in volts.

The conductance of a conductor is the reciprocal of its resistance, and the unit is called a *mho*, so that Ohm's law may be stated as follows:

$$I = EG$$

where $G =$ conductance in *mhos.*

Multiple Circuits. — The conductance of any number of circuits in parallel is equal to the sum of the conductances of the individual circuits, which is, as stated above, the reciprocal of their resistances. The combined resistance then is the reciprocal of the conductance thus found.

Thus in Fig. 1, if r and r_1 be two resistances in parallel, the combined resistance $= \frac{1}{\frac{1}{r} + \frac{1}{r_1}} = \frac{rr_1}{r + r_1}$.

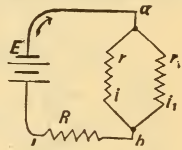


FIG. 1.

The joint resistance of any number of resistances in parallel as a, b, c, and d is $\frac{1}{\frac{1}{a}+\frac{1}{b}+\frac{1}{c}+\frac{1}{d}+ \text{etc.}}$.

Current in a Multiple Circuit is divided among the separate circuits in direct proportion to their respective conductances, or inversely as their resistances.

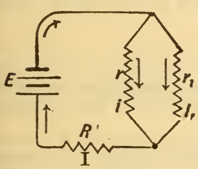


FIG. 2.

In Fig. 2, the total resistance of circuit

$$= R + \frac{rr_1}{r + r_1}$$

total current $I = \frac{E\,(r + r_1)}{Rr + Rr_1 + rr_1}$,

and $i = \frac{Er_1}{Rr + Rr_1 + rr_1}$ $\quad i_1 = \frac{Er}{Rr + Rr_1 + rr_1}$.

KIRCHOFF'S LAWS.

First Law. — If in any circuit a number of currents meet at a point, the sum of those flowing toward that point is equal to the sum of those flowing away from it.

Second Law. — In any closed circuit, the algebraic sum of the products formed by multiplying the resistance of each part by the current passing through it is equal to the sum of the electromotive forces in the circuit.

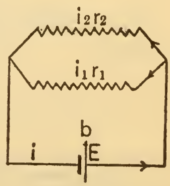


FIG. 3.

By means of these laws, the current in any part of an intricate system of conductors can be found if the resistances of the different parts and the electromotive forces are given.

Thus in Fig. 3, according to the first law $i = i_1 + i_2$ and from the second law $i = i_1 + i_2$ and from the second law $E = i_1 r_1$ and $i_1 r_2 = i_1 r_1$.

From these three formulæ, the three unknown currents can be deduced The same method can be applied to more complex circuits.

RESISTANCE MEASUREMENTS.

Substitution Method. — This is the simplest method of measuring resistance. The resistance to be measured is inserted in series with a galvanometer and some constant source of current, and the galvanometer deflection noted; then a known adjustable resistance is substituted for the unknown and adjusted until the same deflection is again obtained. Then this value of the adjustable resistance is equal to that of the resistance to be measured.

Differential Galvanometer Method. — In galvanometers having two coils wound side by side, separate currents sent through them in opposite directions exert a differential action on the movable system. In a differential galvanometer the two coils are equal in their magnetic action on the movable system for equal currents, so that equal currents sent through them in opposite directions will not deflect the needle. If the currents are unequal, then the deflection is a measure of their difference. This form of galvanometer may be used to measure resistance by inserting the unknown resistance in circuit with one coil of the galvanometer and a known adjustable resistance with the other, both circuits being connected in multiple. Then when the resistance is adjusted until no deflection is produced the resistances in the two circuits are equal.

The method is often used in the comparison of the conductivity of wire, and where rapid measurements not requiring great accuracy are desired.

Wheatstone's Bridge. — For accurate measurements of resistance the Wheatstone Bridge method is almost universally used; Fig. 4 is a diagram of the connections in which a, b, and R are known resistances and x the unknown resistance to be measured. G is the galvanometer, and B is a battery of several cells, the number of which may be varied according to the value of the resistance x. R is adjusted until there is no deflection of the galvanometer needle when both keys are closed.

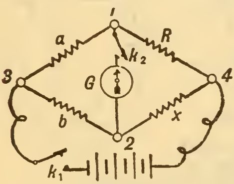


FIG. 4.

The battery key should always be closed before the galvanometer key is depressed or there will be a "kick" in the galvanometer due to the self inductance or capacity of the circuit under test.

When a balance is established $\frac{x}{R} = \frac{b}{a}$, or $x = R\frac{b}{a}$.

The resistances a and b are, in practice, made even multiples of 10, so that x can be read directly from R, the proper number of figures being pointed off decimally.

If $a = b$ the value of x is the same as R. If x be greater than the capacity of R, or low in comparison to it, then a and b must be so chosen that their ratio respectively multiplies or divides R.

For example, let $\left.\begin{matrix} a = 10 \\ b = 1000 \\ R = 243 \end{matrix}\right\}$ then $x = \frac{b}{a}, R = \frac{1000}{10} \times 243 = 24{,}300.$

The ratio of a to b being 100, any reading as R is multiplied by 100, or again let

$$\left.\begin{matrix} a = 1000 \\ b = 10 \\ R = 243 \end{matrix}\right\} \text{ then } x = \frac{10}{1000} \times 243 = 2.43.$$

The ratio of a to b being $\frac{1}{100}$, any reading as R should be divided by 100.

A commercial form of Wheatstone Bridge of the Weston Model is shown diagrammatically in Fig. 5. This type, called the "plug in" type, or some modification of it, is most commonly used. It has the advantage over the "plug out" type in that fewer plugs are required, there being but one plug needed for each decade; this reduces the plug error to a minimum.

Direct Reading Ohmmeter. — Another form of instrument used for measuring resistances is known as the direct reading ohmmeter. Briefly described it is simply a slide wire bridge, the wire forming two of the arms of the bridge, a known resistance a third arm, and the unknown resistance

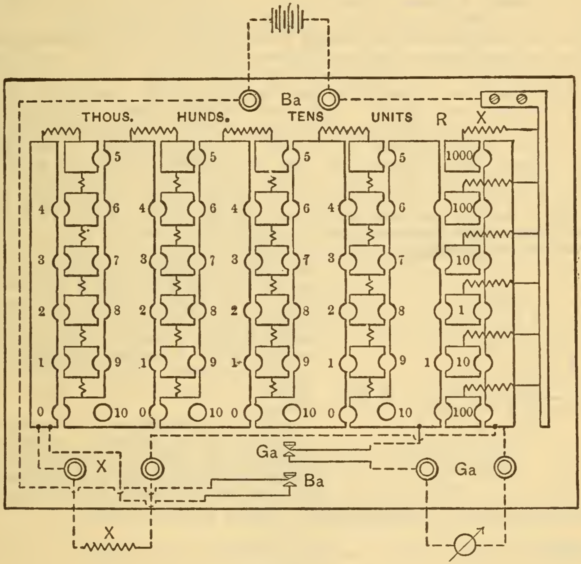


FIG. 5.

the fourth. The slide wire is graduated to read directly in ohms, and is printed with numbers in black and red. The black numbers refer to a low reading scale which is used when the single plug of the instrument is fitted into the hole marked black, and the red numbers refer to a higher scale

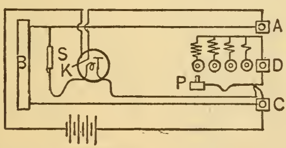


FIG. 6.

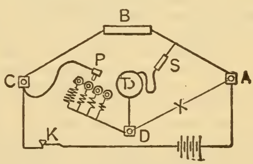


FIG. 7.

Fig. 6 shows diagrammatically the connections of this Ohmmeter, and Fig. 7 gives the same ones expanded into the conventional Bridge Form.

when the plug is inserted in the hole marked red. This instrument usually has four scales, although it is sometimes made with three and five. The slide wire is doubled back on itself by means of a heavy cross block of practically zero resistance.

The detector circuit comprises a detecting instrument ordinarily a telephone receiver, and a stylus, which is touched at various points along the slide wire until the detector by silence indicates a balance, when the result is read directly in ohms. In some of the instruments the battery is equipped with a small induction coil which provides alternating current. In this form the instrument is useful for measuring electrolytic resistance and other resistances containing electromotive forces that may be developed by the presence of current therein, and by the use of a suitable condenser in place of the known resistance, capacities can be compared.

Directions for Use of Sage Direct Reading Ohmmeter.— *To Measure Resistance.* Connect the terminals of the circuit to be measured to the posts, *A* and *D*. Place the telephone receiver to the ear and close the battery key, *K*, located in the receiver. Hold the stylus, *S*, in the hand in the same manner as a pencil, and with it touch the straight wires along their entire length until a point is reached where gently tapping the stylus on the wire produces no sound in the telephone. The resistance sought is then that indicated by the scale under that point of the wire. During these readings the plug, *P*, must be in one of the sockets at the right-hand end of the rubber cross-bar. When in the socket marked "red" the scale numerals printed in red should be used. When in the socket marked "blue" the blue numbers should be read, etc.

Slide-wire Bridge. — A very convenient form of bridge for ordinary use where extreme accuracy is not demanded is the slide-wire bridge, shown in Fig. 8. It consists of a wire 1 meter long and about 1.5 mm. diameter stretched parallel with a meter scale divided into millimeters. A contact key is so arranged as to be moved along the wire so that contact with it can be made at any point.

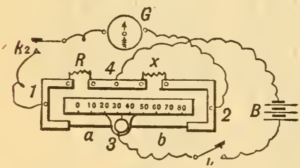


FIG. 8.

A known resistance R is connected as shown; x is the unknown resistance; the galvanometer and the battery are connected as shown in the figure; after closing the key k_1 the contact 3 is then moved along the wire until the galvanometer needle returns to zero;

then again; $$a : b :: R : x,$$

and $$x = \frac{bR}{a}.$$

The Carey-Foster Method. — For the very precise comparison of nearly equal resistances of from 1 to 100 ohms this method yields exquisite results. In Fig. 9, S_1 and S_2 represent the two nearly equal resistances to be compared, and R_1, R_2 represent nearly equal resistances, which, for best results, should not differ much in magnitude from S_1 and S_2. S_1 and S_2 are connected by a slide wire whose resistance per unit length ρ is known. The battery and galvanometer are connected as in the diagram. A balance is obtained by moving the contact c along the stretched wire. Suppose the length of the wire on the left-hand side to the point of contact to be a units. Then exchange S_1 and S_2 for each other without altering any other connections in the circuit. Upon producing a new balance, let a_1 be the length of wire to the left of the contact.

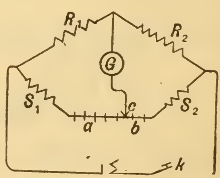


FIG. 9. Carey-Foster Bridge.

Then $$S_1 = S_2 + (a - a_1)\,\rho.$$

Special commutators are upon the market which have for their purpose the easy exchange of S_1 and S_2.

To avoid thermal effects, which are quite considerable with resistances made of some materials, the battery should be commutated for each position of the resistances to be compared. The readings for the two balances accompanying the battery commutation should be averaged.

Measurements of Low Resistances.

Kelvin's Double Bridge. — If a Wheatstone bridge be used to compare resistances having a value much less than one ohm, the terminal and contact resistances produce a considerable error in the results. In conductors having such low resistance, the value of the resistance given or to be measured is considered as lying between two definite points. In standard resistances these points are connected to two terminals called potential terminals.

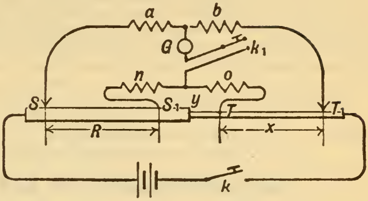


FIG. 10. Kelvin's Double Bridge.

Kelvin has designed a modified form of Wheatstone bridge in which the above-mentioned errors are eliminated. The method is shown diagrammatically in Fig. 10, in which R and x, the resistances to be compared, lie between S and S_1 on one and between T and T_1 of the other, and are connected together at y; n and o are auxiliary resistances also adjustable. A galvanometer is connected through a key, as shown, to two points, one at the junction of n and o; the other at the junction of a and b. If n and o be so adjusted that $n : o :: R : x$, and a and b be adjusted so that the galvanometer is balanced, then

$$a : b :: R : x,$$

or

$$x = \frac{bR}{a}.$$

In practice, n and o may be changed during the adjustment of a and b so as to maintain the ratio of n to o the same as that of a to b, either by changing n and o, on standard rheostats, or by opening the circuit at y and adjusting n and o, as in a regular bridge, for a balance after each trial value of a and b; then when a balance is obtained in the galvanometer with circuit at y both open and closed the above equation holds good.

Another Method For Comparison of Low Resistances. — For comparing the resistances of ammeter shunts, etc., with standard side terminal resistances of the Reichsanstalt form, the method of Sheldon yields very accurate results. The unknown resistance x, Fig. 11, which may be assumed to be supplied with branch potential points a b, is connected by heavy conductors in series with a standard resistance R, having potential points c d. From the two free terminals T T^1 of these resistances are shunted two 10,000 ohm resistance boxes S P, adjusted to the same normal temperature, and wound with wire of the same or negligable temperature coefficient, and connected in series. From the point of connection e, between the two boxes, connection is made to one terminal of the galvanometer g, the other terminal being connected successively with the potential points a, b, c, and d. At the outset all the plugs are removed from the box S, and all are in place in the box P. After connecting T and T^1 with a source of heavy current, plugs are transferred from one box to the corresponding holes in the other box (this keeps the total resistance in the two boxes constant) until no deflection is observed in the galvanometer. This operation is repeated for each of the potential points a, b, c, and d. Representing the resistances in the box S on the occasion of each of these balances by S_a, S_b, S_c, and S_d respectively, we have the following expression for the value of the unknown resistance:

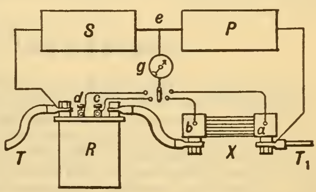


FIG. 11. Precise Measurement.

$$x = \frac{S_a - S_b}{S_c - S_d} R.$$

NOTE. — Mr. E. F. Northrup gives the following formula as handy in determining the percentage conductivity of metal wires. This conductivity is generally expressed as a certain per cent conductivity of Matthiessen's standard. To determine the conductivity, a resistance R of a sample is usually determined at a temperature 20° C and of a length l. From this measurement the per cent conductivity may be expressed as follows:

$$\text{Percentage conductivity} = \frac{l^2 \times d \times 100}{R_{20} \times W \times 581{,}054},$$

where l = length in centimeters, W = weight in grams, R_{20} = resistance in ohms at 20° C, d = specific gravity.

RESISTANCE OF GALVANOMETERS.

When a second galvanometer is available, by far the most simple and satisfactory method is to measure the resistance of the galvanometer by any of the ordinary Wheatstone's bridge methods. Take the temperature at the same time, and, if the instrument has a delicate system, remove the needle and suspension.

Half Deflection Method. — Connect the galvanometer in series with a resistance r and battery as in the following figure. Note the deflection d; then increase r so that the new deflection d_1 will be one-half the first, or $\frac{d}{2} = d_1$; call the new resistance r_1; then

Resistance of Galvanometer $= r_1 - 2r$.

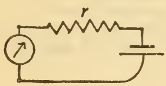


FIG. 12.

If the instrument be a tangent galvanometer, then d and d_1 should represent the tangents of the deflections.

Kelvin's Method. — Connect the galvanometer, as x in a Wheatstone's bridge, as in Fig. 13. Adjust r until the deflection of G is the same, whether the key is closed or open.

$$G = r\frac{b}{a}.$$

The result is independent of the resistance of the battery. The battery should be connected from the junction of the two highest resistances to that of the two lowest.

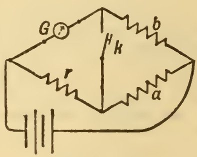


FIG. 13.

RESISTANCE OF BATTERIES.

Condenser Method. — For this test is needed a condenser C, a ballistic galvanometer G, a double contact key k_1, a resistance R, of about the same magnitude as the supposed resistance of the battery B, and a single contact key k_2. Connect as in the following figure. With the key k_2 open, press the key k_1, and observe the throw θ_1 in the galvanometer. Then, after the needle has come to rest, with key k_2 closed, repeat the operation observing the throw θ_2. Then the resistance of the battery

$$x = R\frac{\theta_1 - \theta_2}{\theta_2}.$$

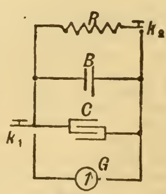


FIG. 14.

Reduced Deflection Method. — Connect the battery B in circuit with a galvanometer G and a resistance r as in Fig. 15. Note the deflection d, and then increase r to r_1 and note the smaller deflection d_1; then, if the deflections of the galvanometer be proportional to the currents,

$$B = \frac{r_1 d_1 - rd}{d - d_1} - G.$$

If r_1 is such that $d_1 = \frac{d}{2}$,

then $B = r_1 - (2r + G)$.

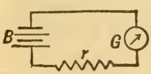


FIG. 15.

The E.M.F. of the battery is supposed to remain unaltered during the measurement.

Mance's Method. — Connect the battery as x in Wheatstone's bridge as in Fig. 16. Adjust r until the deflection of G is the same whether the key be closed or open.

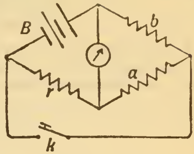


FIG. 16.

Then $$B = r\frac{b}{a}.$$

The galvanometer should be placed between the junction of the two highest resistances and that of the two lowest.

Resistance of Battery while Working. — Connect the battery B with a resistance r, and also in parallel with a condenser C, galvanometer G, and key k; shunt the battery through s with key k_1, as in Fig. 17.

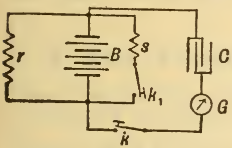


FIG. 17.

Close the key k, and note the deflection d of the galvanometer, keeping k closed, close k_1 and note d_1, the deflection in the opposite direction. Then the battery resistance

$$B = s\frac{d_1}{d - d_1 - \frac{d_1 s}{r}}.$$

If r be large, the term $\frac{d_1 s}{r}$ is negligible, and

$$B = s\frac{d_1}{d - d_1},$$

s being the multiplying power of the shunt.

Workshop Method, Applicable as well to Dynamos. — With dynamo or battery on open circuit, take the voltage across the terminals with a voltmeter, and call it d; take another reading d_1 at the same points with the battery or dynamo working on a known resistance r: then the internal resistance $$R = \frac{d - d_1}{d_1}r.$$

In the case of storage batteries, if the current I be read from an inserted ammeter when charging, the resistance of the battery is

$$B = \frac{d_1 - d}{I},$$

and when discharging $$B = \frac{d - d_1}{I}.$$

RESISTANCE OF AËRIAL LINES OR HOUSE CIRCUITS.

Conductor Resistance. — When the circuit has metallic return, it is easily measured by any of the Wheatstone's bridge methods, or, if the circuit conductor can be supplied with current through an ammeter, then the fall of potential across the ends of the conductor will give a measure of the resistance by ohms law, viz.,

$$\text{Resistance} = \frac{\text{drop in volts}}{\text{current}}.$$

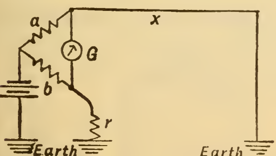


FIG. 18.

If the circuit has earth return as in telegraph and some telephone circuits, then place far end of the line to earth, and connect with bridge as in Fig. 18.

Then the total resistance x of the line and earth, is $$x = r\frac{b}{a}.$$

If a second line be available, the resistance of the first line can be determined separated from that of earth, as well as the resistance of earth.

Let r = resistance of first line,
r_1 = resistance of second line,
r_2 = resistance of earth.

First connect the far end of r and r_1 together, and get the total resistance R; connect r and r_2, and measure the resistance R_1, connect r_1 and r_2, and get total resistance R_2. Then if

$$T = \frac{R + R_1 + R_2}{2}$$
$$r = T - R_2,$$
$$r_1 = T - R_1,$$
$$r_2 = T - R.$$

This test is particularly applicable to finding the resistance of trolley wires, feeders, and track.

For other methods for resistance measurements see under "Tests with Voltmeter."

MEASUREMENT OF ELECTROMOTIVE FORCE.

Of Batteries. — This can usually be measured closely enough for all practical purposes by a high class low-reading voltmeter (see Tests with a Voltmeter).

Wheatstone's Method. — Connect the cell or battery to be compared in circuit with a galvanometer and high resistance r, and note the deflection d; then add another high resistance r_1 (about equal to r), and note the deflection d_1. Next, connect the cell with which the first is to be compared in circuit with the galvanometer, and connect in resistance until the galvanometer deflection is the same as d; then add further resistance R until the galvanometer deflection is the same as d_1; then, if e equals the E.M.F. of the first cell, and E equals the E.M.F. of the cell with which it is compared,

$$r_1 : R :: e : E,$$

and $$E = \frac{Re}{r_1}.$$

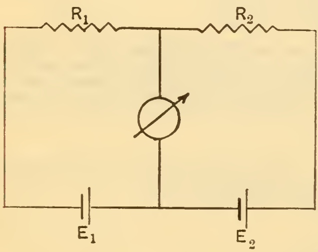


FIG. 19.

Or, the electromotive forces are proportional to the respective resistance which must be added to reduce the deflection the same amount.

Lumsden's Method. — The two cells E_1 and E_2 to be compared are arranged as shown in Fig. 19. R_1 and R_2 are adjustable resistances which are large as compared with the resistances of the cells. R_1 and R_2 are changed until the deflection in the galvanometer is reduced to zero.

Then $$\frac{E_1}{E_2} = \frac{R_1}{R_2}.$$

If greater accuracy be required than that obtained by the above methods, some potentiometer method may be used, in which the cell to be measured is compared directly with a standard cell.

Lord Rayleigh's Compensation Method. — In the following diagram let R and R_1 be two 10,000-ohm rheostats, B be the battery of larger E.M.F. than either of the cells to be compared, B_1 be one of the cells under test, G be a sensitive galvanometer, HR be a high resistance to protect the standard cell, and k be a key. Obtain a balance, so that the galvanometer shows no deflection on closing the key k, by trans-

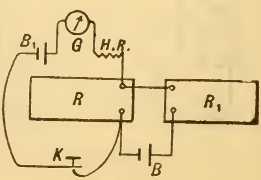


FIG. 20.

ferring resistance from one box to the other, being careful to keep the sum of the resistances in the boxes equal to 10,000 ohms. Observe the resistance in R and call it R_1. Repeat with the other cell B_2, and call the resistance R_2. Then the E.M.F.'s of the two cells

$$E_1 : E_2 = R_1 : R_2.$$

NOTE. — Special boxes are on the market which automatically change the resistances R and R_1, maintaining the sum of the resistances constant, the value of the resistance being read directly from the dials.

Direct Reading Potentiometer. — There are many forms of potentiometers available, which are used in connection with a standard cell, and on which the potential difference to be measured is read directly from the switch dials of the instrument when it is balanced as shown by a galvanometer. Such potentiometers generally read to 1.5 volts. To measure higher voltages than this a *volt box* must be used, which is simply a high resistance, across which the voltage to be measured is connected. Connections are brought out from the resistance so as to include a known portion of it, having such a value that the potential difference across it will be less than 1.5 volts. This is then measured on the potentiometer, and the value found multiplied by the constant of the *volt box*.

Measurement of Current by Potentiometer. — The current to be measured is passed through a standard low resistance, say, .01 or .001 ohm, and the difference of potential across its potential terminals measured by means of a potentiometer. Then the current is by Ohm's law

$$I = \frac{E}{R}$$

where E is the difference of potential as measured, and R the resistance of the standard.

MEASURING CAPACITY.

Arrangement of Condensers. In Parallel. — Join like poles of the several condensers together as in the figure; then, the joint capacity of the set is equal to the sum of the several capacities.

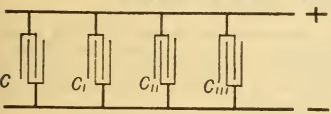


FIG. 21.

Total capacity $= c + c_{/} + c_{//} + c_{///}$.

Condensers in Series. — Join the unlike poles as if connecting up battery cells in series as in Fig. 22, then the joint capacity of all is the reciprocal of the sum of the reciprocals of the several capacities.

$$\text{Capacity } C = \frac{1}{\frac{1}{c} + \frac{1}{c_{/}} + \frac{1}{c_{//}} + \frac{1}{c_{///}}}.$$

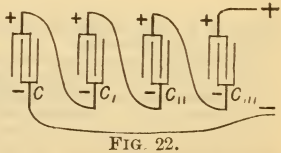


FIG. 22.

Capacity by Direct Discharge. — Charge a standard condenser, Fig. 23, C_s by a battery E for a certain time, say 30 seconds; then discharge it through a ballistic galvanometer G; note the throw d.

Next charge the condenser to be measured, C_1, by the same battery and for the same length of time, and discharge this through the same galvanometer noting the throw d_1;

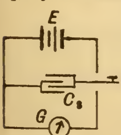


FIG. 23.

Then $$C_s : C_1 :: d : d_1.$$

and $$C_1 = C\frac{d_1}{d}.$$

For Kelvin's and Gott's methods see pages 326–327, "Cable Testing."

Bridge Method. — For comparing the capacities of two condensers, C_s and C, which are approximately the same, connect as in Fig. 24 through two rather high inductionless resistances R_1 and R_2 to the key k which makes and breaks contacts at each end. E is a battery. A galvanometer is inserted between the ends of the condensers where they join the resistances. Adjust the resistances so that no deflection results when the key is manipulated.

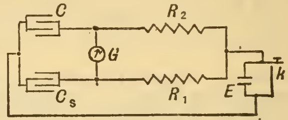


FIG. 24.

Then $$C = C_s \frac{R_1}{R_2}.$$

Loss of Potential Method. — The capacity of a condenser may be determined by the following formula:

$$C = \frac{t}{2.303\ R\ \log \frac{E}{e}}$$

where C is the electrostatic capacity, in microfarads, of a condenser, the potential of whose charge falls from E to e when it is discharged during t seconds through a resistance of R megohms.

If C is the known and R the unknown quantity, then

$$R = \frac{t}{2.303\ k \log \frac{E}{e}}.$$

In measuring the insulation resistance of a short cable by this method, the discharge deflection E, compared with the discharge deflection obtained with the same battery from a standard condenser, would give the value of k. For long cables, however, this does not give correct results, and the capacity must be determined by other methods.

ELECTROMAGNETIC INDUCTION.

Law of Induction. — When the magnetic induction or flux interlinked with an electrical circuit is changed in any manner, an electromotive force is induced in that circuit which is proportional in amount to the rate of change of the flux, and acts in a direction which would, by producing a current, tend to oppose that change.

Symbolically expressed the induced electromotive force in volts is

$$e = -\frac{n}{10^8}\frac{d\phi}{dt},$$

where ϕ is the magnetic flux through the circuit, n the number of turns of wire, and t the time.

Self-induced electromotive forces are those induced in a circuit by change in the current in the circuit itself.

Coefficient of Self-Induction. — The practical unit of self-induction is the *henry*, and is equal to 10^9 absolute units.

The self-induction in *henrys* of any coil or circuit is equal numerically to the electromotive force in volts induced by a current in it changing at the rate of one ampere per second. Thus the electromotive force in volts produced in a circuit by a varying current is

$$e = -L\frac{di}{dt},$$

where L is the self-induction in *henrys* and i the current in amperes.

If $\phi_1 = n, \phi$ represent the flux turns in the circuit,

then $$\phi_1 = Li \times 10^8.$$

Foı example. if a coil have 150 turns of wire, carrying a current of two amperes, producing 200,000 lines of force, or 200 kilogausses through it, the flux turns equal $200{,}000 \times 150 = 30{,}000{,}000$, and the self-induction is therefore

$$L = \frac{\phi_1}{10^8 i} = \frac{30{,}000{,}000}{2 \times 100{,}000{,}000} = .15 \text{ henry.}$$

If the current of 2 amperes die out uniformly in one second, then the electromotive force induced is

$$e = L\frac{di}{dt} = .15 \times 2 = .30 \text{ volt.}$$

Coefficient of Self-Induction of a Long Solenoid.

$$L = \frac{4\,\pi n n^1 A}{10^9}$$

when the permeability is unity.

Where n = total number of turns of wire,
n^1 = number of turns per centimeter length,
A = area of cross section of solenoid.

For magnetic substances the above equation must be multiplied by μ, the permeability of the medium.

Measurements of The Coefficient of Induction.

Comparison with Known Capacity. — The coefficient of self-

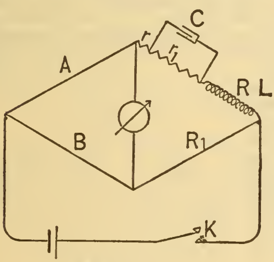


FIG. 25.

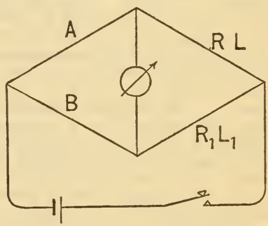


FIG. 26.

induction may be determined by means of a Wheatstone bridge as follows: Let A and B, in Fig. 25, be the bridge ratio arms, R_1 the adjustable rheostat. Connect the circuit to be measured as RL in series with a variable non-inductive resistance r and r_1 a portion of which r_1 is shunted by a standard condenser of capacity C. First balance the bridge for steady currents by adjusting R_1, that is, when the key K is closed continuously. Then alter the proportion of non-inductive resistance r_1, shunting the condenser until no deflection occurs in the galvanometer when the key K is open and closed. Then the self-inductance

$$L = C r_1^2.$$

Comparison with Known Self-Inductance. — Arrange in form of bridge as shown in Fig. 26, L being the unknown and L_1 the standard self-inductance. Adjustable non-inductive resistances are connected in series with them. Call the resistances in each arm R and R_1, A and B are non-inductive resistances. First adjust to a balance for steady currents by changing R and R_1, then adjust A and B until no throw of the galvanometer is observed when the galvanometer key is closed before closing the battery key. Then R and R_1 must be again adjusted for steady currents, and so on until a balance is obtained for both steady and transient currents.

Then $$\frac{L}{L_1}=\frac{A}{B}=\frac{R}{R_1}.$$

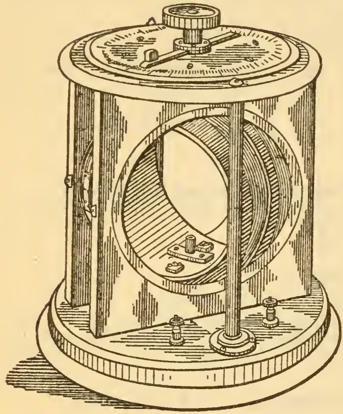


FIG. 27. Ayrton and Perry's Variable Standard of Self-Induction.

If L_1 be one of Ayrton and Perry's adjustable standards of self-induction (see Fig. 27), then the bridge can be balanced in the regular way for steady current, and for transient currents by varying the self-induction standard.

As shown in the illustration this instrument consists of two coils wound on sections of concentric spherical surfaces, the inside one of which can be rotated with reference to the outside one, and thus their coefficient of induction varied without changing their resistance. The scale is divided to read in millihenrys on one side and in degrees on the other. Its range is approximately from 3.5 to 42 millihenrys.

Telephone Method. — A modification of the above, which is quicker and more practical, is by using a telephone in place of the galvanometer, and a source of alternating or rapidly interrupted direct current for the battery, as shown in Fig. 28. The part ab is a slide wire with telephone contact at K; the self-inductances L and L_1 are connected as in the previous method with adjustable non-inductive resistances. S is a source of alternating current. The return circuit should be run parallel and close to the slide wire to reduce inductive errors. The contact K is moved along the wire and placed in a position where the minimum sound is heard in the telephone and R and R_1 are changed to reduce this sound to a lower minimum. These operations are repeated until finally a point is reached where the minimum of sound is very sharply defined or silence occurs.

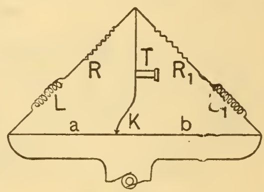


FIG. 28.

Then $$\frac{L}{L_1}=\frac{a}{b}.$$

Measurement of Self-Inductance with an Alternating Current of Known Frequency.

For this test is needed a high resistance or electrostatic alternating current voltmeter, a direct current ammeter, and a non-inductive resistance.

Connect as in Fig. 29, where R_1 is an inductive resistance to be measured, and S a switch for short-circuiting the ammeter; the A. C. dynamo of frequency n is so arranged that its terminals may be disconnected, and a battery be substituted therefor.

With the connections as in Fig. 29, close the switch S, and take the drop with the voltmeter from a to b and the drop from a to C; then disconnect the A. C. dynamo, and connect the battery B; open the switch s, and vary the continuous current until the drop from a to C is the same as with the alternating current, both measurements being made with the same voltmeter; then note the current shown by the ammeter, and measure the drop from a to b with the voltmeter. Call the drop across R_1 from a to b, with alternating current, E, and the same with continuous current, E_1, and the reading of the ammeter with the latter, I.

Then $$L = \frac{\sqrt{E^2 - E_1^2}}{2\pi n I}.$$

If the resistance R_1 be known, and the ammeter be suitable for use with

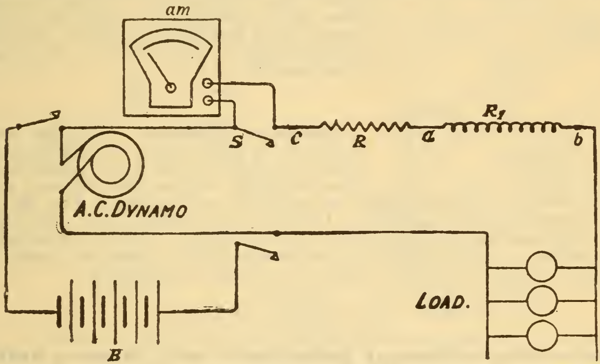


FIG. 29.

alternating currents, the switch and non-inductive resistance may be dispensed with. We then have $L = \frac{\sqrt{E^2 - R_1^2 I_1^2}}{2\pi n I}$, where I_1 is the value of the alternating current.

NOTE. — The resistance of the voltmeter must be high enough to render its current negligible as compared with that through the resistance R_1.

Measurement of Mutual Inductance.

Connect the two coils whose mutual inductance is to be determined, first in series and then in opposition to each other. The self-induction of each combination is then measured by any suitable method.

Let M = the mutual inductance between the two coils.
L = the self-inductance of one coil.
$L_{\prime}$ = the self-inductance of the other coil.
$L_{\prime\prime}$ = the self-inductance of both coils in series.
$L_{\prime\prime\prime}$ = the self-inductance of both coils in opposition.

Then since $L_{\prime\prime} = L + L_{\prime} + 2M$
and $L_{\prime\prime\prime} = L + L_{\prime} - 2M$.

Then the coefficient of mutual inductance desired is

$$M = \frac{L_{\prime\prime} - L_{\prime\prime\prime}}{4}.$$

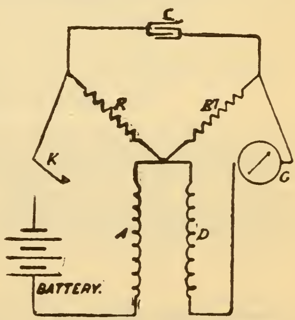


FIG. 30.

Comparison with a Known Capacity. — Connect as shown in Fig. 30 where A and D are two coils whose mutual inductance M is required. R and R_1 are two adjustable non-inductive resistances and C a standard condenser placed in shunt to R and R_1. Vary the resistances R and R_1 until no deflection is observed on the galvanometer when the key is opened or closed. Then the mutual inductance is

$$M = CRR_1.$$

Comparison with Known Self-Induction by Bridge. — In this method the mutual inductance of two coils is compared with the known self-inductance of one of them. The coil whose self-inductance is known is connected as R in Fig. 31. The other coil is connected in the battery circuit with its magnetic circuit opposed to that of the other coil. Then by adjusting the other arms of the bridge to a balance for both steady and transient currents, as in the methods for self-inductance, the mutual inductance is

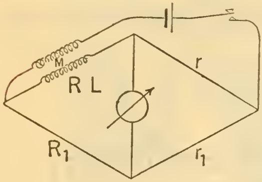


FIG. 31.

$$M = -\frac{Lr_1}{r + r_1}.$$

Another Method. — In order that a balance may be obtained without the inconvenience of trial and approximation as in the foregoing method, the battery circuit may be shunted by non-inductive resistance as S shown in Fig. 32. The other connections are similar to those of the previous test. The bridge is first balanced for steady currents in the regular way by adjusting the resistances R_1, r, and r_1, and then S is changed until no deflection occurs when the key is opened or closed. Then the mutual inductance is

$$M = -\frac{LR_1S}{(R_1 + R)\,S + (R + r)\,R_1}.$$

Comparison of Mutual Inductance with Known Self-Inductance of Another Coil. — Connections are made as shown in Fig. 33. One of the two coils whose mutual inductance is to be measured is con-

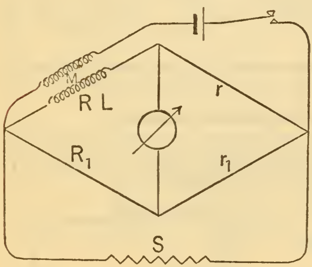


FIG. 32.

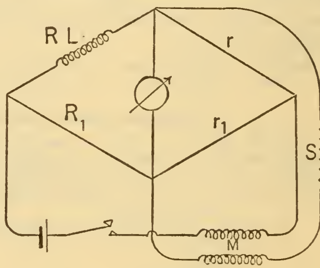


FIG. 33.

nected in the battery circuit, and the other in series with an adjustable non-inductive resistance as a shunt to the galvanometer. The known self-inductance L is connected in the bridge as R. The bridge is first balanced, as before, for steady current, then the resistance S is changed until no deflection occurs when the key is opened or closed. Then if S be the total resistance in the shunt circuit, the mutual inductance is

$$M = -\frac{LR_1S}{(R + R_1)^2}.$$

Telephone Method. — As in measurements of self-inductance, a telephone may be used in measurements of mutual inductance, as shown in Fig. 34. The coil of known self-inductance L is connected in one arm of the bridge, as shown at R. The other coil is connected in opposition to that coil in the main current circuit, the current supplied being either alternating or a rapidly interrupted direct current. The non-inductive resistance and the telephone circuit contact are varied until silence occurs in the telephone in a manner similar to that described for self-inductance.

Then if ρ is the resistance of the slide wire for unit length, and the position for a balance is a units from the right as shown, then the mutual inductance is

$$M = -\frac{La\rho}{R_1 + a\rho}.$$

Secohmmeter. — In measurements of inductance, when balancing for transient currents the galvanometer deflects in one direction when the battery key is closed, and in the opposite direction when it is opened. To increase the sensibility of such tests, Ayrton and Perry have devised the secohmmeter. The battery and galvanometer circuits are each commuted

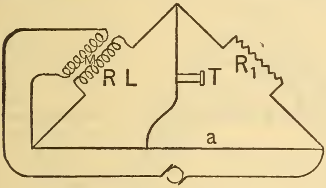


FIG. 34.

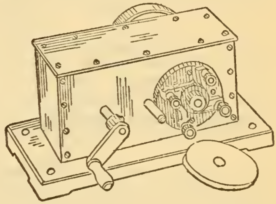


FIG. 35. Ayrton and Perry's Secohmmeter.

so as to produce a galvanometer deflection in one direction, and increased in amount. This apparatus may be used in connection with any of the above tests where galvanometers are used, the balance being obtained when the deflection is reduced to zero. Below is given a description of the apparatus as shown in Fig. 35.

This instrument serves the purpose of making an alternating current to use in measurements of self-induction, and of commuting such portion of this current as flows in the galvanometer circuit to a direct current.

The instrument consists of two rotating commutators mounted on one axis and a train of gears for rapidly driving them. The commutators are on the two sides of a cast metal case, one only being shown in the illustration. They are electrically insulated from each other. The brushes of one commutator are mounted on a disk, which can be rotated through an angle of 90° around the axis. The brushes can accordingly be set so that they will reverse the circuits in which they are connected at the same time, or so that one will reverse at any desired fraction of a period after the other. The driving handle may be attached at two places on the train of gears, thus giving two speeds. A pulley wheel is also provided, which may be used in place of the handle and the apparatus be driven by a motor.

MEASUREMENT OF POWER IN ALTERNATING CURRENT CIRCUITS.

In alternating current circuits having inductance in any part of the circuit, such as motors, unloaded transformers, and the self-inductance of the line itself, the product of the values of the current and the E.M.F. as shown by an ammeter and voltmeter does not give the power in the circuit, since the current is not in phase with the E.M.F.

The power at any instant of time in any alternating current circuit is equal to the product of the instantaneous values of the current and E.M.F. This is shown graphically in (Cut A) Fig. 36. The mean power in the circuit is

$$P = EI,$$

where E is the effective E.M.F. and I the effective current. The effective values of E.M.F. and current are the square roots of the mean squares of their respective instantaneous values, or numerically, their maximum values divided by $\sqrt{2}$ or 1.41. Alternating current measuring instruments of either the "hot wire" or dynamometer type indicate effective values.

If the current is not in phase with the E.M.F., and the angular difference in phase is ϕ, then the power is

$$P = EI \cos \phi.$$

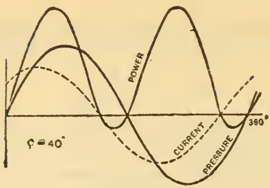


Fig. A.

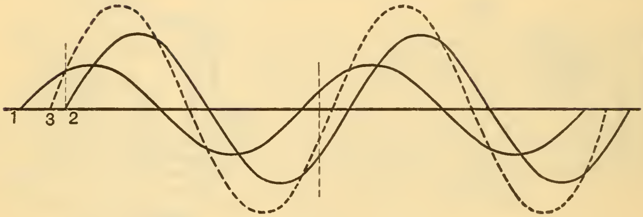


Fig. B.

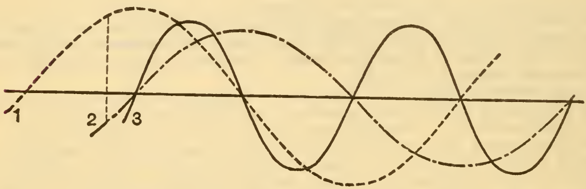


Fig. C.

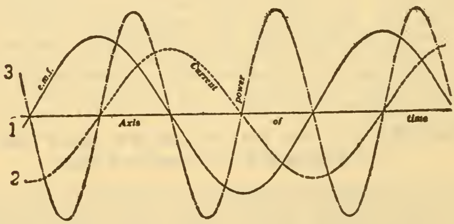


Fig. D.

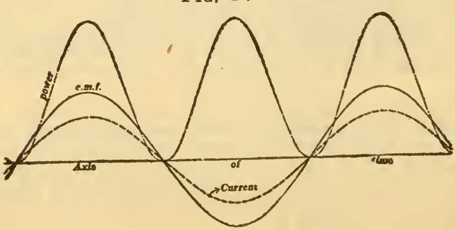


Fig. E.

Fig. 36.

Cos ϕ is called the power factor, since it is the factor by which the apparent power EI must be multiplied to obtain the true power.

Suppose that curve No. 1 in Fig. B, page 70, represents the various values of the impressed voltage throughout a cycle, and that curve No. 2 represents the various values of the self-induced voltage. Curve No. 2, it will be noted, is not in phase with curve No. 1. Its highest value comes at a later time than that of curve No. 1, because the self-induced electromotive force is never in phase with the impressed electromotive force, as the self-induced electromotive force is obviously at its highest point when the lines of force induced by the coil are changing most rapidly. This occurs when the current is rapidly increasing or diminishing, and not when it is maintaining a momentarily steady value at its highest point.

Current will flow in the circuit in proportion to, and in phase with, the resultant of the two curves, and the ordinates of this resultant will be the algebraical sum of the corresponding ordinate of the two curves. Curve No. 3 shows the resultant curve constructed in this way. It will be found to be similar to the other curves but of a different maximum value, also lagging behind the curve of impressed E.M.F., but occurring earlier than the curve of self-induced E.M.F.

In Fig. C are shown the curves representing the impressed E.M.F. and the resulting current, and as will be seen the current lags behind. If the values of these curves be combined by multiplying them together, ordinate by ordinate, this curve representing power will result. This will be the true curve of power, as it obviously represents the power at every instant, the instantaneous voltage being multiplied by the instantaneous current, and consequently takes account of the fact that their maxima are shifted with reference to one another.

If the current and voltage curves are arranged as shown in Fig. D, in which the maximum value of the voltage occurs at the same time as does the minimum value of the current, the result will be as shown, and no power will be produced.

If the current is in phase with the electromotive force as shown in Fig. E, the power curve will appear above the zero line, and the true power will also be the apparent power.

Three Voltmeter Method. Ayrton & Sumpner.

This method is good where the voltage can be regulated to suit the load.

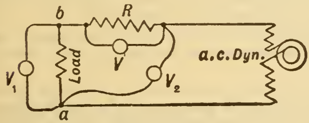


FIG. 37.

In figure 37 let the non-inductive resistance R be placed in series with the load $a\ b$; take the voltage V across the terminals of R; V_1 across the load $a\ b$, and V_2 across both, or from a to c. Then the

$$\text{True watts} = \frac{V_2^2 - V_1^2 - V^2}{2R}.$$

The best conditions are when $V = V_1$, and, if $R = \frac{1}{2}$ ohm,

then $$W = V_2^2 - V_1^2 - V^2.$$

Combined Voltmeter and Ammeter Method.

This method, devised also by Fleming, is quite accurate, and enables the accuracy of instruments in use to be checked. In Fig. 38 R is a non-inductive resistance connected in shunt to the inductive load $a\ b$, and the voltmeter V measures the $p.\ d.$ across $x\ y$. A and A_1 are ammeters connected as shown; then

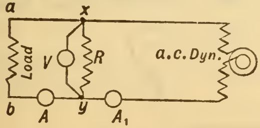


FIG. 38.

$$\text{True watts} = \frac{R}{2}\left(A_1^2 - A^2 - \left(\frac{V}{R}\right)^2\right).$$

If the voltmeter V takes an appreciable amount of current, it may be tested as follows: disconnect R and V at y, and see that A and A_1 are alike; then connect R and V at y again, and disconnect the load $a\ b$. Then A_1 = current taken by R and V in multiple.

WATTMETER METHODS.

(Contributed by W. N. Goodwin, Jr.)

For measurement of power in electric circuits, the wattmeter gives the quickest and most accurate results. Since the instrument mechanically integrates the products of the instantaneous values of current and E.M.F., the power is indicated directly, regardless of the power factor.

When a wattmeter is connected to a circuit, the instrument itself requires current and, therefore, some power is consumed in it. This error must be calculated and subtracted from the observed readings. Weston wattmeters are compensated for this error by means of a coil wound in opposition to the field coil and adjusted with it. The following are a few of the important tests with a wattmeter used in power measurements.

Fig. 39 shows the connections for measurement of power in either a direct or single phase alternating-current circuit. The power consumed by *L* is read directly from the instrument.

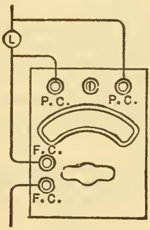


FIG. 39.

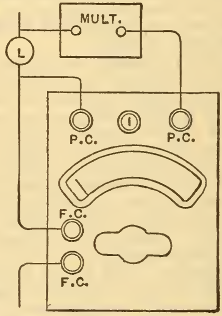


FIG. 40.

In direct current measurements, to eliminate the effect of the earth's magnetic field, two readings must be taken; either the connections must be reversed for the second reading, or the instrument turned 180° from its first position; the mean of the two readings gives the true power.

If the instrument have a multiplier, it should be connected as shown in Fig 40, so that the difference of potential between the stationary and movable coils shall be a minimum.

Checking Wattmeters.— In checking wattmeters either directly with other wattmeters, or by means of a voltmeter and ammeter, the wattmeter should be connected so as not to include its compensating coil. In a Weston wattmeter the "independent" binding post should be used, shown in Fig 39, the pressure circuits being connected in parallel and the field or current coils in series.

Three-Phase Power Measurements. — In unbalanced systems two wattmeters are required, connected as shown in Fig. 41. The total power transmitted is then the algebraic sum of the readings of the two wattmeters. If the power factor is greater than .50, the power is the arithmetical sum, and if it is less than .50, the power is the arithmetical difference of the readings.

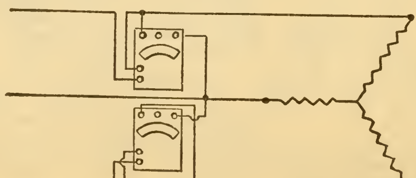


FIG. 41.

Balanced Three-Phase Systems. — One wattmeter may be used in three-phase circuits in which the current lag is the same for all parts of the circuit and the load is uniformly distributed. The connections are shown in Fig. 42. The current coil of the wattmeter is connected in one

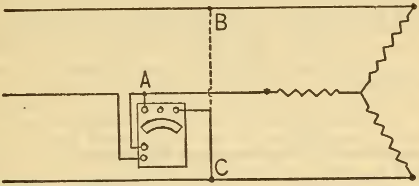


FIG. 42.

of the leads as A; one end of the pressure circuit to the same lead, the other end is connected successively to each of the other leads as B and C, a reading being taken in each position. The power is then the sum of the separate readings.

Second Method for Balanced Circuits. — Another method may be used by which the power may be obtained from a single reading of the instrument, as shown in Fig. 43. The current coil of the wattmeter is connected in one lead as A; one end of the pressure circuit is connected to the same lead.

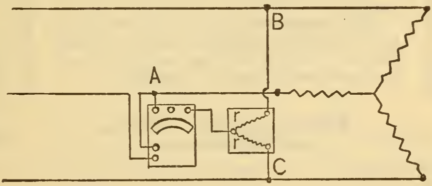


FIG. 43.

The other end of the pressure circuit is connected to the junction of two resistances r and r, each equal in resistance to that of the wattmeter; the ends of these resistances are connected to the other two leads as shown at B and C. The power is then

$$P = 3\,p$$

where p is the instrument reading.

If it be desired to use the instrument for higher voltages than that for which it was designed, then a resistance R must be added to the instrument branch, of such a value that $\frac{R+r}{r}$ is equal to the multiplying constant m desired.

Each of the other two branches must be increased to $R + r$.

Then the power is

$$P = 3\,mp.$$

The Weston "Y box" multiplier, which may be made for any multiplying constant, is constructed according to this principle.

Any of the above methods can be used equally well for the delta as for the star connection.

TESTS WITH A VOLTMETER.

The following are a few of the more important tests for which voltmeters and ammeters are especially adapted. With some changes and additions they have mostly been condensed from an article by H. Maschke, Ph.D., of the Western Laboratory published in the *Electrical World* in April, 1892.

The scales of the better known portable instruments read, in general, from 0 to 150, or some even multiple or fraction of this value. Voltmeters are available having scales ranging from 1.5 volts to 750 volts for a full scale deflection, and when used with multipliers for any higher range. Two or more ranges may be had on the same instrument, so that by simply transferring connections from one binding post to another, voltages differing greatly in amount may be measured on one instrument. Millivoltmeters may be had reading as low as 20 millivolts for a full scale deflection.

Instruments with Permanent Magnets should not be placed on or near the field magnets of motors or generators, nor should they be used for measurements in very strong magnetic fields, such as those produced in the vicinity of conductors carrying heavy currents. If the fields be not too strong, then the error produced in the instrument from this cause may be eliminated by taking the mean of two readings, one in position, and the other when the instrument is turned 180° from that position around its vertical axis.

Electromotive Force of Batteries.

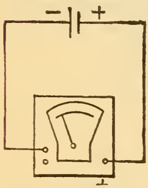


FIG. 44.

The positive post of voltmeters is usually at the right, and marked +. In a battery the zinc is commonly negative, and should therefore be connected to the left or negative binding post.

For single cells or a small number, a low-reading voltmeter, say one reading to 15 volts, will be used, the connections being as per diagrams.

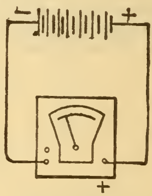


FIG. 45.

Electromotive Force of Dynamos.

For voltage within range of the instrument available for the purpose, it is only necessary to connect one terminal of the voltmeter to a brush of one polarity, and the other terminal to a brush of the opposite polarity, and read direct from the scale of the instrument. As continuous current voltmeters usually deflect forward or back according to which pole is connected, it is necessary sometimes to reverse the lead wires, in which case the polarity of the dynamo is also determined. Of course the voltage across any circuit may be taken in the same way, or the dynamo voltage may be taken at the switchboard, in which case the drop in the leads sometimes enters into the calculations. Following are diagrams of the connections to bipolar and multipolar dynamos :

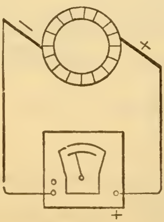


FIG. 46.

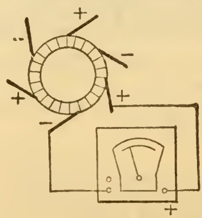


FIG. 47.

In the case of arc dynamos or other machines giving high voltage, it is necessary to provide a multiplier in order to make use of the ordinary instrument; and the following is the rule for determining the resistance which, when placed in series with the voltmeter, will provide the necessary multiplying power.

Let $e =$ upper limit of instrument scale, for example 150 volts,
$E =$ upper limit of scale required, for example 750 volts,
$R =$ resistance of the voltmeter, for example 18,000 ohms,
$r =$ additional resistance required, in ohms.

Then $r = R\frac{E-e}{e}$ or $r = 18{,}000\,\frac{750-150}{150} = 72{,}000$ ohms.

The multiplying power $= \frac{E}{e}$ or $\frac{750}{150} = 5$.

Should the exact resistance not be available, then with any available resistance r_1 the regular scale readings must be multiplied by $\left(\frac{r_1}{R}+1\right)$.

Importance of High Resistance for Voltmeters.

It is highly important, as reducing the error in measurement, that the internal resistance of a voltmeter be as high as practicable, as is shown in the following example:

Let E in the figure be a dynamo, battery, or other source of electric energy, sending current through the resistance r; and *vm.* be a voltmeter indicating the pressure in volts between the terminals A and B. Before the *vm.* is connected to the terminals A and B there will be a certain difference of potential, which will be less when the voltmeter is connected, owing to the lessening of the total resistance between the two points; if the resistance of the *vm.* be high, this difference will be very small, and the higher it is the less the error. Following are the formulas and computations for determining the error.

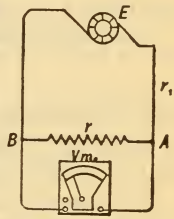


FIG. 48.

In Fig. 48 let E be the E.M.F. of the generator, r the resistance of the circuit across A and B when the difference of potential is to be measured, r_1 the resistance of the leads, generator, etc., and R the resistance of the voltmeter. Before the *vm.* is connected the difference of potential between A and B is

$$V = \frac{rE}{r+r_1}.$$

With the voltmeter connected the difference of potential indicated by the instrument is

$$V_1 = \frac{rRE}{rR + r_1r + r_1R}.$$

The voltage across A and B is, therefore, reduced by the introduction of the voltmeter by the amount of

$$V - V_1 = \frac{rr_1V_1}{(r+r_1)R}.$$

The error is

$$P = 100\left(\frac{V-V_1}{V_1}\right) = \frac{100rr_1}{(r+r_1)R}.$$

The error is inversely proportional to the resistance R of the voltmeter

Example.

Let $E = 10$ volts,
$r = 10$ ohms,
$r_1 = 2$ ohms,
$R = 500$ ohms.

Then the reading of the voltmeter is

$$V_1 = \frac{10 \times 500 \times 10}{(10 \times 500) + (2 \times 10) + (2 \times 500)} = 8.3056 \text{ volts},$$

and the error is

$$V - V_1 = \frac{10 \times 2 \times 8.3056}{(10 + 2)\,500} = .0277 \text{ volts.}$$

and the percentage error is

$$P = \frac{100 \times 10 \times 2}{(10 + 2) \times 500} = .333\%.$$

If R be made 1000 ohms, then

$$V_1 = \frac{10 \times 1000 \times 10}{(10 \times 1000) + (2 \times 10) + (2 \times 1000)} = 8.32 \text{ volts}$$

and the error is

$$V_1 - V = \frac{10 \times 2 \times 8.32}{(10 + 2)\,1000} = .01387$$

and the percentage error is

$$p = \frac{100 \times 10 \times 2}{(10 + 2) \times 1000} = .166\%$$

or just one-half the error with $R = 500$ ohms.

If the error of measurement is not to exceed a stated per cent p, then r and r_1 must be such that

$$\frac{rr_1}{r + r_1} \text{ is less than } \frac{pR}{100}.$$

If the circuit is closed by a resistance r_1, and it be desired to measure the E.M.F. of the generator by connecting the voltmeter between any two points as A and B, then $E = \left(\frac{R + r_1}{R}\right) V_1$, where V_1 = reading on *vm.*

The error between the true value of the E.M.F. of the generator and that shown by the voltmeter is

$$E - V = \frac{r_1 V_1}{R}$$

and the percentage error $p = 100 \left(\frac{r_1}{R}\right)$.

If the error is not to exceed p per cent, then the resistance of the generator, cables, etc., must not exceed $\frac{pR}{100}$.

For example, with a voltmeter having 15,000 ohms for 150 volts; if p must be less than $\frac{1}{5}\%$, then r_1 may be as great as $\frac{\frac{1}{5} \times 15000}{100} = 30$ ohms.

Comparison of E.M.F. of Batteries.

Wheatstone's Method. — To compare E.M.F. of two batteries, A and X, with low-reading voltmeters, let E be the E.M.F. of A, and E_1 the E.M.F. of X.

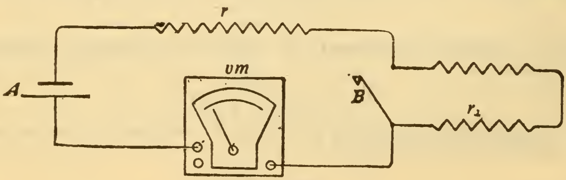


FIG. 49.

First connect battery A in series with the voltmeter and a resistance r, switch B being closed, and note the deflection V; then open the switch B, and throw in the resistance r_1, and note the deflection V_1. Now connect battery X in place of A, and close the switch B, and vary the resistance r until the same deflection V of voltmeter is obtained and call the new resistance r_2; next open the switch B, or otherwise add to the resistance r_2 until the deflection V_1 of the voltmeter is produced; call this added resistance r_3, then

$$E : E_1 :: r_1 : r_3.$$

If E be smaller than E_1, the voltmeter resistance R may be taken as r, and it is better to have r_1 about twice as large as the combined resistance of r and the resistance of A.

It is not necessary that the internal resistance of the cells be small as compared with R.

Poggendorff's Method Modified by Clark.

To Compare the E.M.F. of a battery cell or element with a standard cell.
Let S be a standard cell,
T be a cell for comparison with the standard,
B be a battery of higher E.M.F. than either of the above elements.

A resistance r is joined in series with the battery B and a slide wire $A D$. A millivoltmeter is connected as shown, both its terminals being connected to the like poles of the battery B and the Standard S.

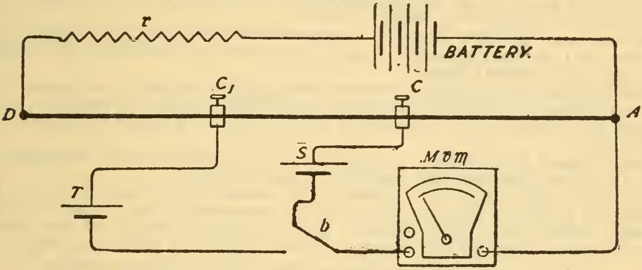


FIG. 50.

Move the contact C along the wire until the pointer of the instrument stands at zero, and let r_1 be the resistance of A C.

Throw the switch b so as to cut out the standard S, and cut in the cell T; now slide the contact C_1 along the wire until the pointer again stands at zero, and call the resistance of A C_1 r_2,

Then the E.M.Fs. of the two cells

$$T : S :: r_2 : r_1.$$

If a meter bridge or other scaled wire be used in place of $A D$, the results may be read directly in volts by arranging the resistance r so that with the pointer at zero the contact C is at the point 144 on the wire scale, or at 100 times the E.M.F. of the standard S, which may be supposed to be a Clark cell. All other readings will in this case be in hundredths of volts; and should the location of C_1 be at 175 on the scale when the pointer is at zero on the millivoltmeter then the E.M.F. of the cell, being compared, will be 1.75 volts.

Measuring Current Strength with a Voltmeter.

If the resistance of a part of an electric circuit be known, taking the drop in potential around such resistance will determine the current flowing by ohms law viz., $I = \frac{E}{R}$.

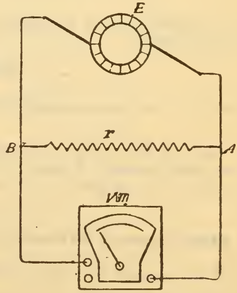


FIG. 51.

In the figure let r be a known resistance between the points A and B of the circuit, and I the strength of current to be determined; then if the voltmeter, connected as shown, gives a deflection of V volts, the current flowing in r will be

$$I = \frac{V}{r}.$$

For the corrections to be applied in certain cases, see the section on *Importance of High Resistance for Voltmeters*, page 75.

Always see that the resistance r has enough carrying capacity to avoid a rise of temperature which would change its resistance.

If the reading is exact to $\frac{1}{p}$ volt the measurement of current will be exact to $\frac{1}{p \times r}$ amperes. If $r = .5$ ohm, and the readings are taken on a low-reading voltmeter, say ranging from 0 to 5 volts, and that can be read to $\frac{1}{300}$ volt, then the possible error will be

$$\frac{1}{300 \times .5} = \frac{1}{150} \text{ ampere.}$$

If r be made equal to 1 ohm, then the volts read also mean amperes.

Measurement of Current with a Millivoltmeter. — This is the method generally used in practice for the measurements of currents, and is the same principle as the one outlined above with the substitution of a millivoltmeter for the voltmeter.

As the drop is much lower, a comparatively low resistance shunt may be used, so that heavy currents may be measured without the shunt becoming disproportionately large.

For portable instruments, detachable shunts are generally adjusted with the instrument so that the instrument scale reads directly in amperes. The snunts are constructed of resistance alloy having a negligible temperature coefficient.

Switchboard instruments also have shunts with slotted terminals so that they may be connected directly to the bus-bars.

In some cases where the currents to be measured are very large the instruments are adjusted to the drop across a portion of the copper bus-bar through which the current passes. To compute the length of the copper bar of a given cross section to give a certain drop for a given current,

let A = the area of the cross section of bar in square inches,
I = current in amperes,
V = drop in millivolts desired for instrument for current I;

then, $$\text{length in feet} = \frac{AV \times 119}{I} \text{ at } 20^\circ \text{ C.}$$

Measuring Resistance with a Voltmeter.

General Methods.—In the figure, let X = the unknown resistance that is to be measured, r = a known resistance, E, the dynamo or other steady source of E.M.F.

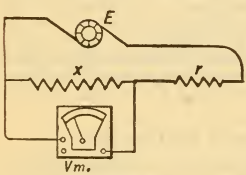


FIG. 52.

When connected as shown in the figure, let the voltmeter reading be V; then connect the voltmeter terminals to r in the same manner and let the reading be V_1; then

$$X : r :: V : V_1$$

and $$X = \frac{r \times V}{V_1}.$$

If, for instance, $r = 2$ ohms and $V = 3$ volts and $V_1 = 4$ volts then

$$X = \frac{2 \times 3}{4} = 1.5 \text{ ohms.}$$

If readings can be made to $\frac{1}{p}$ volt, the error of resistance measurement will then be

$$100 \times \frac{1}{p}\left(\frac{1}{V} + \frac{1}{V_1}\right) \text{ per cent.}$$

and for the above example would be

$$1\,(\tfrac{1}{3} + \tfrac{1}{4}) = 0.58\%.$$

Should there be a considerable difference between the magnitudes of the two resistances X and r, it might be better to read the drop across one of them from one scale, and to read the drop across the other on a lower scale.

Resistance Measurement with Voltmeter and Ammeter.

The most common modification of the above method is to insert an ammeter in place of the resistance r in the last figure, in which case $X = \frac{V}{I}$ where I is the current flowing in amperes as read from the ammeter.

If the readings of the voltmeter be correct to $\frac{1}{p}$ and the ammeter readings be correct to the same degree, the possible error becomes :

$$100 \times \frac{1}{p}\left(\frac{1}{V}+\frac{1}{I}\right) \text{ per cent.}$$

Measurement of very Small Resistances with a Millivoltmeter and Ammeter.

By using a millivoltmeter in connection with an ammeter, very small resistances, such as that of bars of copper, armature resistance, etc., can be accurately measured.

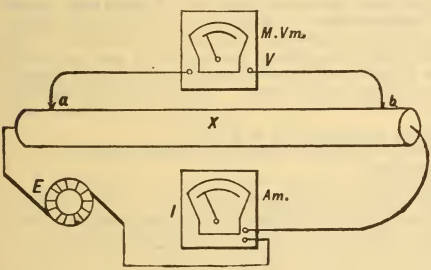


FIG. 53.

In order to have a reasonable degree of accuracy in measuring resistance by the "drop" method, as this is called, it is necessary that as heavy currents as may be available be used. Then, if E be the dynamo or other source of steady E.M.F., X be the required resistance of a portion of the bar, V be the drop in potential between the points a and b, and I be the current flowing in the circuit as indicated by the ammeter, then

$$X=\frac{V}{I}.$$

The applications of this method are endless, and but a few, to which it is especially adapted, need be mentioned here. They are the resistance of armatures, the drop being taken from opposite commutator bars and not from the brush-holders, as then the brush-contact resistance is taken in ; the resistance of station instruments and all switchboard appliances, such as the resistance of switch contacts ; the resistance of bonded joints on electric railway work, as described in the chapter on railway testing.

Measurement of High Resistances.

With the ordinary voltmeter of high internal resistance, let R be the resistance of the voltmeter, X be the resistance to be measured. Connect them up in series with some source of electromotive force as in the following figure.

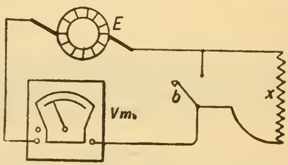


FIG. 54.

Close the switch b, and read the voltage V with the resistance of the voltmeter alone in circuit ; then open the switch, thus cutting in the resistance X, and take another reading of the voltmeter, V_1.

Then $$X=R\left(\frac{V}{V_1}-1\right).$$

If the readings of the voltmeter be correct to $\frac{1}{p}$ of a volt the error of the above result will be $100 \times \frac{1}{pV_1}\left(\frac{V+V_1}{V-V_1}\right)$ per cent.

Very High Resistance. — For the measurement of very high resistances a more sensitive voltmeter will give much better results for the reason that the reading V_1 when the switch b is opened, becomes so small with the ordinary voltmeter that the error is relatively very great. Instruments are on the market having a sensibility of 1600 ohms per volt or about 250,000 ohms for 150 volts.

For example if $x = 1$ megohm and an ordinary voltmeter be used
$R = 15{,}000$ ohms for 150 volts,
and $E = 120$ volts,

$$V_1 \text{ would be } \frac{ER}{X + R} = \frac{120 \times 15{,}000}{1{,}000{,}000 + 15{,}000} = 1.772 \text{ volts;}$$

while if R were 250,000 ohms,

$$V_1 \text{ would be } \frac{120 \times 250{,}000}{1{,}000{,}000 + 250{,}000} = 24 \text{ volts,}$$

that is with the high resistance instrument, with the same accuracy of the instrument scales, the percentage error is about $\frac{1}{14}$ as great as with the lower resistance instrument.

Measuring the Insulation Resistance of Lighting and Power Circuits with a Voltmeter. — For the measurement of insulation resistance, a high resistance sensitive voltmeter is needed. For rough measurements where the exact insulation resistance is not required but it is wished to determine if such resistance exceeds some stated figure, then a voltmeter of ordinary sensibility will answer. The methods in general are as follows:

Let X = insulation resistance to ground as in Fig. 55,
X_1 = insulation resistance to ground of opposite lead,
R = resistance of voltmeter,
V = potential of dynamo E,
V_1 = reading of voltmeter, as connected in figure,
V_2 = reading of voltmeter, when connected to opposite lead.

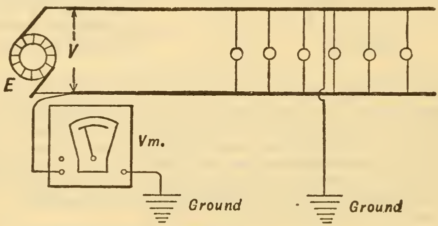


FIG. 55.

Then
$$X = R\left(\frac{V}{V_{\prime}} - 1\right),$$
and
$$X_{\prime} = R\left(\frac{V}{V_{\prime\prime}} - 1\right).$$

The above formula can be modified to give results more nearly correct by taking into account the fact that the path through the resistance R of the voltmeter is in parallel with the leak to ground on the side to which it is connected as shown in the following figure:

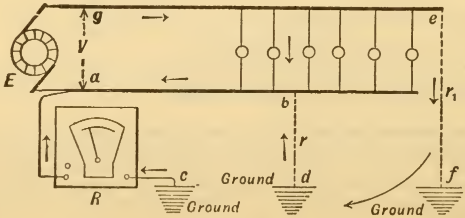


FIG. 56.

In this case the voltage V of the circuit will not only send current through the lamps, but through the leaks $e\ f$ to ground, and through the ground to d and c, thence through d to b, and c to a, these two last paths being in parallel, therefore having less resistance than if one alone was used; thus if r be the resistance of the ground leak $b\ d$, and r_1 be the resistance of the leak $e\ f$, and R be the resistance of the voltmeter, then the total resistance by way of the ground, between the conductors, would be

$$\frac{R \times r}{R + r} + r_1,$$

and if $V =$ voltage of the circuit,
$v =$ reading of voltmeter from a to c,
$v_, =$ reading of voltmeter from g to c.

Then $$r = R \left(\frac{V - (v + v_,)}{v_,} \right),$$

and $$r_1 = R \left(\frac{V - (v + v_,)}{v} \right).$$

The sum of the resistance $r + r_1$ will be $= R \left(\frac{(v + v_,)\,(V - (v + v_,))}{v v_,} \right)$.

Insulation Resistance of Arc Light Circuits.

Arc lamps are to a great extent run in series, and the insulation resistance of their circuits is found in a manner similiar to that for multiple circuits, but the formula differs a little. Let the following figure be a typical arc circuit, with a partial ground at c.

First find the total voltage V between a and b of the circuit. This can most handily be done with a voltmeter having a high resistance in a separate box and so calibrated with the voltmeter as to multiply its readings by

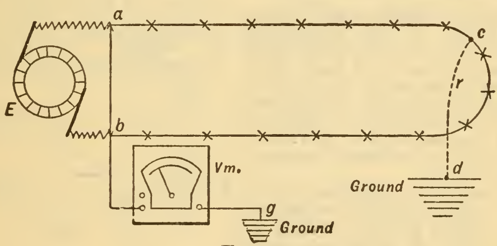


FIG. 57.

some convenient number. For convenience in locating the ground, get the average volts per lamp by dividing the total volts V by the number of lamps on the circuit; the writer has found 48 volts to be a good average for the ordinary 10 ampere lamp. With the 16 lamps shown in the above figure, V would probably be about 768 volts.

Next take a voltmeter reading from each end of the circuit to ground. Call the reading from a to ground v, and from b to ground $v_,$, R being the resistance of voltmeter as before, and r the insulation resistance required.

Then $$r = R \left(\frac{V - (v + v_,)}{v + v_,} \right),$$

and the location of the ground, provided there be but one and the general insulation of the circuit be good, will be found closely proportional to the readings v and $v_,$; in the above figure say we find the voltmeter reading from a to ground to be 28, and from b to ground to be 36; then the distance of the ground c from the two ends of the circuit will be in proportion to the readings 28 and 36 respectively.

There being 16 lamps on the circuit, the number of lamps between a and c

would be $28 \div (28 + 36) = \frac{28}{64}$ of $16 = 7$, and from b to c would be $36 \div (28 + 36) = \frac{36}{64}$ of $16 = 9$; that is, the ground would most likely be found between the seventh and eighth lamps, counting from a.

Insulation across a Double Pole Fuse Block or Other Similar Device where Both Terminals are on the Same Base.

Let $f\,f$ be fuses in place on a base,
V = potential of circuit,
R = resistance of voltmeter,
v = reading of voltmeter,
required the resistance r across the base $a\,a_1$ to $b\,b_1$.

Then $$r = R\frac{V - v}{v}.$$

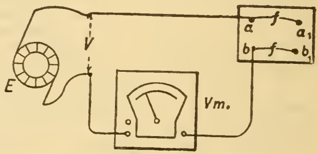


FIG. 58.

MEASUREMENT OF THE INSULATION RESISTANCE OF AN ELECTRIC WIRING SYSTEM WITH THE POWER ON.

The following methods have been devised by Dr. Edwin F. Northrup for the measurement of insulation resistance of a circuit where it is impracticable to shunt off the current.

1.—Voltmeter Method.

Let A (Fig. 59) represent any wiring system in which X_1 and X_2 are the insulation resistances between the bus-bars, B_1 and B_2 and the earth (the gas or water pipes being taken as at the potential of the earth). In Fig. 59, I, II, and III are equivalent diagrams in which y represents the unknown resistance of all the lamps, motors, etc., across the line.

If direct current is supplied to the bus-bars, a direct-current voltmeter should be used. If the current is alternating, then an alternating-current voltmeter will be required. The resistances, X_1 and X_2, are determined by knowing g, the resistance of the voltmeter, and by taking three voltmeter readings.

1st. Measure the voltage, which we will call E, across the bus-bars (Fig. 59) I.

2d. Connect the voltmeter between the bus-bar, B_1, and the earth and take its reading, which we will call V_1 (Fig. 59) II.

3d. Connect the voltmeter between the bus-bar, B_2, and the earth and take its reading, which we will call V_2 (Fig. 59) III.

If the readings in either of the two latter cases are only a fraction of a scale division, then the insulation resistance is too high to be measured by this method and we may resort to

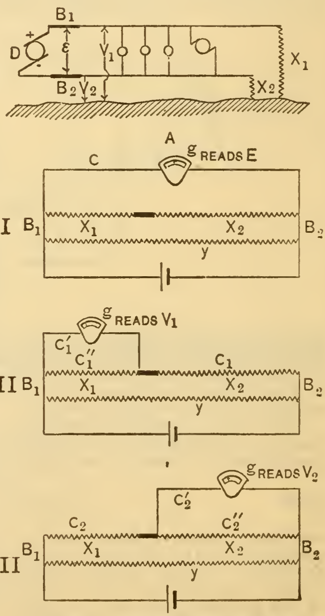


FIG. 59. Voltmeter Method.

the second method to be described. Having taken the above three readings, it can be shown that

$$X_1 = \frac{g\,(E - V_1 - V_2)}{V_2} \tag{1}$$

$$X_2 = \frac{g\,(E - V_1 - V_2)}{V_1}. \tag{2}$$

The current I, which leaks to the ground will be,

$$I = \frac{E}{X_1 + X_2}.$$

For example, the insulation resistance of the wiring system of a large office building was determined by means of a Weston voltmeter, the following readings and resistances were obtained:

$$\begin{aligned} g &= 12{,}220 \text{ ohms,} \\ E &= 113 \text{ volts,} \\ V_1 &= 1 \text{ volt,} \\ V_2 &= 4 \text{ volts.} \end{aligned}$$

$$X_1 = \frac{12{,}220\,(113 - 1 - 4)}{4} = 329{,}940 \text{ ohms,}$$

$$X_2 = \frac{12{,}220\,(113 - 1 - 4)}{1} = 1{,}319{,}760 \text{ ohms.}$$

The above example shows that where the sum of the resistances, X_1 and X_2, are not over one or two million ohms, the voltmeter method is sufficiently accurate for the purpose. If one side of the line is grounded — that is, if $X_2 = 0$ — then from (2) $E = V_1 + V_2 = V_1$, as $V_2 = 0$, and the method fails to give X_1.

Expressions (1) and (2) above are obtained as follows: The meaning of the letters used are indicated in I, II, and III (Fig. 59), C_1, C_2, etc., being currents and g the resistance of the voltmeter.

$$C_1 = \frac{E}{X_2 + \dfrac{gX_1}{X_1 + g}},$$

$$C_2 = \frac{E}{X_1 + \dfrac{gX_2}{X_2 + g}},$$

$$C_1^1 = \frac{X_1}{g + X_1}\,C_1 = \frac{V_1}{g}, \text{ or } C_1 = \frac{V_1\,(g + X_1)}{X_1\,g},$$

$$C_2^1 = \frac{X_2}{g + X_2}\,C_2 = \frac{V_2}{g}, \text{ or } C_2 = \frac{V_2\,(g + X_2)}{X_2\,g}.$$

Hence, we have the two relations,

$$\frac{E}{X_2 + \dfrac{gX_1}{X_1 + g}} = \frac{V_1\,(g + X_1)}{X_1\,g}, \text{ and } \frac{E}{X_1 + \dfrac{gX_2}{X_2 + g}} = \frac{V_2\,(g + X_2)}{X_2\,g},$$

from which the values for X_1 and X_2 are obtained as given above in equations (1) and (2).

Any instrument, as a galvanometer, in which the deflections are proportional to the currents, may be substituted for a voltmeter. In such a case, if D, d_1, and d_2 are deflections corresponding to the readings E, V_1, and V_2, and G is the total resistance in series with the instrument, we have as before:

$$X_1 = \frac{G\,(D - d_1 - d_2)}{d_2} \tag{3}$$

and

$$X_2 = \frac{G\,(D - d_1 - d_2)}{d_1} \tag{4}$$

If two or more electric lamps are connected in series, their resistances, while carrying current, can be determined by means of three readings, as above.

If $X_2 = \infty$, $V_1 = 0$, and $X_1 = \frac{g\,(E - V_2)}{V_2}$, which is the ordinary expression used in measuring a resistance with a voltmeter by reading the voltmeter with the resistance in series with it and again with the resistance cut out.

II. — Galvanometer Method.

This method may be used when greater accuracy is required or when the insulation resistance to earth, of at least one side of the line, is over a megohm.

The wiring system is represented in 1 of Fig. 60, and 2 of Fig. 60 gives equivalent circuits.

The method consists in connecting across the bus-bars a moderately high resistance and finding on this resistance a point, *p*, where the potential due to the generator is the same as that of the earth, and then with

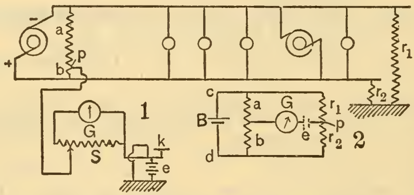


Fig. 60. Galvanometer Method.

the aid of a sensitive galvanometer and an external source of E.M.F., measuring the resistances, r_1 and r_2, to earth in the following manner: *k* is a key and *S* an Ayrton universal shunt. This latter may be omitted if the source of E.M.F. can be varied in a known manner.

It is evident from Fig. 60 that a balance will be had when $\frac{a}{b} = \frac{r_1}{r_2}$, the key, *k*, being in its upper position. If *k* is now depressed, the resistance, *R*, encountered by the current generated by the source, *e*, will be

$$R = g_1 + \frac{1}{\frac{1}{b + r_2} + \frac{1}{a + r_1}}$$

where g_1 is the resistance of the galvanometer; but in comparison with r_1 and r_2, g_1, a and b can be neglected, and

$$R = \frac{r_1 r_2}{r_1 + r_2}.$$

By construction, $\frac{r_1}{r_2} = \frac{a}{b} = N$, a known ratio. From the last two relations we deduce

$$r_2 = \frac{R\,(N + 1)}{N}$$

and

$$r_1 = R\,(N + 1).$$

Taking *d* as the deflection of the galvanometer and *K* as the galvanometer constant, the current through the galvanometer is

$$\frac{e}{R} = \frac{d}{K}, \text{ or } R = \frac{eK}{d}.$$

K should be defined as the resistance which must be inserted in circuit with the galvanometer (including its own resistance), so that it will give, with one volt, a scale deflection of one scale division at the distance at which the scale is placed from the mirror during the test, usually taken as one meter.

Then we will have:

$$r_2 = \frac{eK\,(N+1)}{Nd}$$

and

$$r_1 = \frac{eK\,(N+1)}{d}.$$

Taking $K = 10^8$ as an average value for an ordinary D'Arsonval galvanometer and $e = 100$, $n = 2$, and $d = 100$, we have:

$$r_2 = \frac{100 \times 10^8\,(2+1)}{2 \times 100} = 150 \text{ megohms},$$

$$r_1 = \frac{100 \times 10^8\,(2+1)}{100} = 300 \text{ megohms}.$$

This example shows that a galvanometer of very moderate sensibility will measure in this way a very high insulation resistance. If, on the other hand, the insulation is low, small battery power may be used or the deflection of the galvanometer can be cut down to $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, or $\frac{1}{10000}$ by the Ayrton shunt. The only difficulty likely to be experienced in applying the above method is that, while making the test, the relative values of r_1 and r_2 will keep changing, due to motors or lights being thrown on or off the line. In this event it is only possible to obtain a sort of average value for the resistance to earth of each side of the line.

Insulation Resistance of Electric Circuits in Buildings.

In the United States it is quite common to specify that the entire installation when connected up shall have an insulation resistance from earth of at least one megohm.

The National Code gives the following:

The wiring of any building must test free from grounds; i.e., each main supply line and every branch circuit should have an insulation resistance of at least 100,000 ohms, and the whole installation should have an insulation resistance between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to 5 amperes	4,000,000.
Up to 10 amperes	2,000,000.
Up to 25 amperes	800,000.
Up to 50 amperes	400,000.
Up to 100 amperes	200,000.
Up to 200 amperes	100,000.
Up to 400 amperes	50,000.
Up to 800 amperes	25,000.
Up to 1,600 amperes	12,500.

All cut-outs and safety devices in place in the above.

Where lamp-sockets, receptacles, and electroliers, etc., are connected, one-half of the above will be required.

Professor Jamison's rule is:

$$\text{Resistance from earth} = 100{,}000 \times \frac{\text{E.M.F.}}{\text{number of lamps}}.$$

Kempe's rule is:—

$$\text{Resistance in megohms} = \frac{75}{\text{number of lamps}}.$$

A rule for use in the U. S. Navy is:

$$\text{Resistance} = 300{,}000 \times \frac{\text{E.M.F.}}{\text{number of outlets}}.$$

Institution of Electrical Engineers' rule is :

$$R = \frac{7900 \times \text{E.M.F.}}{\text{number of lamps}}.$$

Phœnix Fire Office rule for circuits of 200 volts is that

$$\text{the least } R = \frac{12.5 \text{ megohms}}{\text{number of lamps}}.$$

Twenty-five English insurance companies have a rule that the leakage from a circuit shall not exceed $\frac{1}{20000}$ part of the total working current.

Below is a table giving the approximate insulation allowable for circuits having different loads of lamps.

For a circuit having—

25 lamps, insulation should exceed . . 500,000 ohms.
50 lamps, insulation should exceed . . 250,000 ohms.
100 lamps, insulation should exceed . . 125,000 ohms.
500 lamps, insulation should exceed . . 25,000 ohms.
1000 lamps, insulation should exceed . . 12,000 ohms.

All insulation tests of lighting circuits should be made with the working current. (See page 80, voltmeter test.)

In the following table Uppenborn shows the importance of testing with the working voltage.

Table I. shows the resistance between the terminals of a slate cut out.

Table II. shows the resistance between two cotton-covered wires twisted.

I.		II.	
VOLTS.	MEGOHMS.	VOLTS.	MEGOHMS.
5	68	5	281
10	53	10	188
13.6	45	16.9	184
27.2	24	27.2	121

Measuring the Insulation of Dynamos.

The same formula as that used for measuring high resistances (see Fig. 55) applies equally well to determining the insulation of dynamo conductors from the iron body of the machine.

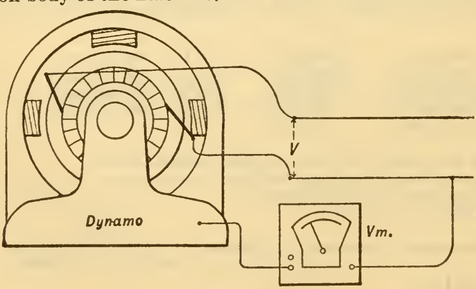


FIG. 61.

Connect, as in Fig. No. 61, all symbols having the same meaning as before.

Let $r =$ insulation resistance of dynamo, then

$$r = R\left(\frac{V}{V.} - 1\right).$$

Measuring the Insulation Resistance of Motors.

Where motors are connected to isolated plant circuits with known high insulation, the formula used for insulation of dynamos applies; but where the motors are connected to public circuits of questionable insulation it is necessary to first determine the circuit insulation, which can be done by using the connections shown in Fig. 56. Fig. 62 shows the connections to motor for determining its insulation by current from an operating circuit.

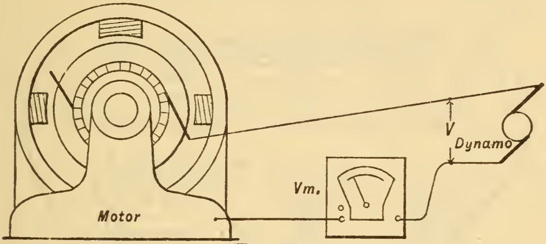


FIG. 62.

Here, as before, the insulation r of the total connected devices $= R\left(\frac{V}{V_{\prime}} - 1\right)$.

If $r =$ total resistance of circuit and motor in multiple to ground, and $r_{\prime}$ is the insulation of the circuit from ground, then X, the insulation of the motor will be

$$X = \frac{r_{\prime} \times r}{r_{\prime} - r}.$$

Measurement of the Internal Resistance of a Battery.

In the following figure (No. 63), let E be the cell or battery whose resistance is to be measured, K be a switch, and r a suitable resistance.

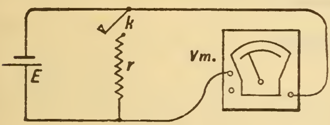


FIG. 63.

Let $V =$ the reading of voltmeter with the key, K, open (this is the E.M.F. of the battery), and

$V_{\prime} =$ the reading of voltmeter with key, K, closed (this is the drop across the resistance r),

Then the battery resistance

$$r_{\prime} = r \times \frac{V - V_{\prime}}{V_{\prime}} \text{ ohms.}$$

The same method can be used to measure the internal resistance of dynamos. An ammeter may be connected in the r circuit, in which case $r_1 = \frac{V - V_1}{I}$ where I is the reading in amperes.

Conductivity with a Millivoltmeter.

This is a quick and convenient method of roughly comparing the conductivity of a sample of metal with that of a standard piece.

In Fig. 64, R is a standard bar of copper of 100% conductivity at 70° F.; this bar may be of convenient length for use in the clamps, but of known cross section. X is the piece of metal of unknown conductivity, but of the same cross section as the standard. E is a source of steady current, and if a storage battery is available it is much the better for the purpose. M is a millivoltmeter with the contact device d. The distance apart of the two points may be anything, so long as it remains unaltered and will go between the clamps on either of the bars.

Now with the current flowing through the two bars in series the fall of potential between two points the same distance apart and on the same flow-

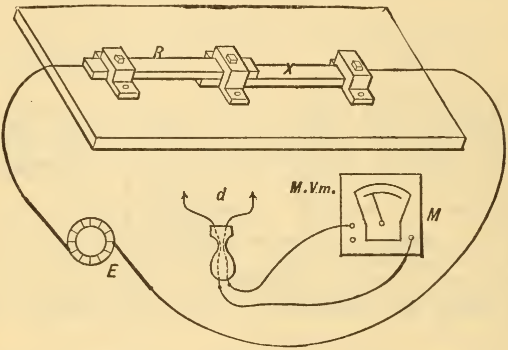


FIG. 64.

line will, on either bar, be in proportion to the resistance, or in inverse proportion to the conductivity; therefore by placing the points of d on the bars in succession, the readings of the millivoltmeter will give the ratio of the conductivities of the two pieces.

For example:

if the reading from $R = 200$ millivolts,
and the reading from $X = 205$ millivolts,
then the percentage conductivity of X as compared with R is

$$205 : 200 :: 100 : \text{conductivity of } X,$$

or

$$\frac{200 \times 100}{205} = 97.5\%.$$

MAGNETIC PROPERTIES OF IRON.

REVISED BY TOWNSEND WOLCOTT.

WITH a given excitation the flux Φ or flux-density $\mathcal{B}$ of an electromagnet will depend upon the quality of the iron or steel of the core, and is usually rated as compared with air.

If a solenoid of wire be traversed with a current, a certain number of magnetic lines of force, $\mathcal{H}$, will be developed per square centimetre of the core of air. Now, if a core of iron be thrust into the coil, taking the place of the air, many more lines of force will flow; and at the centre of the solenoid these will be equal to $\mathcal{B}$ lines per square centimetre.

As iron or steel varies considerably as to the number of lines per square centimetre $\mathcal{B}$ which it will allow to traverse its body with a given excitation, its conductivity towards lines of force, which is called its *permeability*, is numerically represented by the ratio of the flux-density when the core is present, to the flux-density when air alone is present. This permeability is represented by μ.

The permeability μ of soft wrought iron is greater than that of cast iron; and that for mild or open-hearth annealed steel castings as now made for dynamos and motors is nearly, and in some cases quite, equal to the best soft wrought iron.

The number of magnetic lines that can be forced through a given cross-section of iron depends, not only on its permeability, but upon its saturation. For instance, if but a small number of lines are flowing through the iron at a certain excitation, doubling the excitation will practically double the lines of force; when the lines reach a certain number, increasing the excitation does not proportionally increase the lines of force, and an excitation may be reached after which there will be little if any increase of lines of force, no matter what may be the increase of excitation.

Iron or steel for use in magnetic circuits must be tested by sample before any accurate calculations can be made.

Data for $\mathcal{B}$-$\mathcal{H}$ Curves.

Average First Quality American Metal.

(Sheldon.)

$\mathcal{H}$	Ampere turns per cent. length.	Ampere turns per inch length.	Cast Iron.		Cast Steel.		Wrought Iron		Sheet Metal.	
			$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per sq. in.
10	7.95	20.2	4.3	27.7	11.5	74.2	13.0	83.8	14.3	92.2
20	15.90	40.4	5.7	36.8	13.8	89.0	14.7	94.8	15.6	100.7
30	23.85	60.6	6.5	41.9	14.9	96.1	15.3	98.6	16.2	104.5
40	31.80	80.8	7.1	45.8	15.5	100.0	15.7	101.2	16.6	107.1
50	39.75	101.0	7.6	49.0	16.0	103.2	16.0	103.2	16.9	109.0
60	47.70	121.2	8.0	51.6	16.5	106.5	16.3	105.2	17.3	111.6
70	55.65	141.4	8.4	53.2	16.9	109.0	16.5	106.5	17.5	112.9
80	63.65	161.6	8.7	56.1	17.2	111.0	16.7	107.8	17.7	114.1
90	71.60	181.8	9.0	58.0	17.4	112.2	16.9	109.0	18.0	116.1
100	79.50	202.0	9.4	60.6	17.7	114.1	17.2	110.9	18.2	117.3
150	119.25	303.0	10.6	68.3	18.5	119.2	18.0	116.1	19.0	122.7
200	159.0	404.0	11.7	75.5	19.2	123.9	18.7	120.8	19.6	126.5
250	198.8	505.0	12.4	80.0	19.7	127.1	19.2	123.9	20.2	130.2
300	238.5	606.0	13.2	85.1	20.1	129.6	19.7	127.1	20.7	133.5

$\mathcal{H}$ = 1.257 ampere turns per cm. = .495 ampere turns per inch.

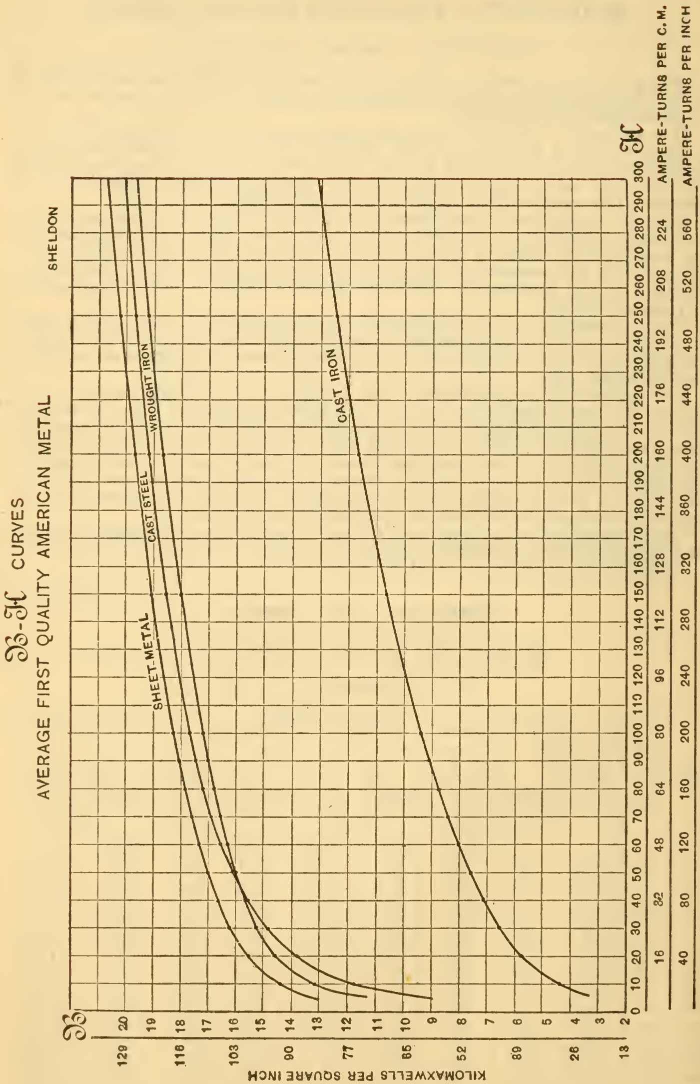


FIG. 1. Magnetic Properties of Iron.

In large generators, having toothed armatures and large flux densities in the air-gap, the flux is carried chiefly by the teeth. This results in a very high tooth flux density, and a correspondingly reduced permeability. The related values of $\mathcal{B}$, $\mathcal{H}$, and μ are given in the following table. These values are for average American sheet metal.

Permeability at High Flux Densities.

$\mathcal{H}$	Ampere Turns per cm. Length.	Ampere Turns per Inch Length.	$\mathcal{B}$ Kilo-gausses.	Kilomax-wells per Square in.	μ
200	159	404	19.8	127	99.0
400	318	808	21.0	135	52.5
600	477	1212	21.5	138	35.8
800	637	1616	21.8	140	27.3
1000	795	2020	22.0	142	22.0
1200	954	2424	22.3	144	1.8
1400	1113	2828	22.5	145	1.6

METHODS OF DETERMINING THE MAGNETIC QUALITIES OF IRON AND STEEL.

The methods of determining the magnetic value of iron or steel for electro-magnetic purposes are divided by Prof. S. P. Thompson into the following classes: *Magnetometric*, *Balance*, *Ballistic*, and *Traction*.

The first of these methods, now no longer used to any extent, consists in calculating the magnetization of a core from the deflection of a magnetometer needle placed at a fixed distance.

In the *Balance* class, the deflection of the magnetometer needle is balanced by known forces, or the deflection due to the difference in magnetization of a known bar and of a test bar is taken.

The *Ballistic* method is most frequently used for laboratory tests, and for such cases as require considerable accuracy in the results. There are really two ballistic methods, the *Ring method* and the *Divided-bar method*.

In either of these methods the ballistic galvanometer is used for measuring the currents induced in a test coil, by reversing the exciting current, or cutting the lines of force.

Ring Method. — The following cut shows the arrangement of instruments for this test, as used by Prof. Rowland. The ring is made of the sample of iron which is to undergo test, and is uniformly wound with the

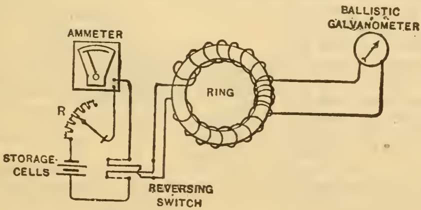


FIG. 2. Connections for the Ring Method.

exciting coil or circuit, and a small exploring coil is wound over the exciting coil at one point, as shown. The terminals of the latter are connected to the ballistic galvanometer.

The method of making a test is as follows: —

The resistance, R, is adjusted to give the highest amount of exciting current. The reversing switch is then commutated several times with the galvanometer disconnected. After connecting the galvanometer the switch is suddenly reversed, and the throw of the galvanometer, due to the reversal of the direction of magnetic lines, is recorded. The resistance, R, is then adjusted for a somewhat smaller current, which is again reversed, and the galvanometer throw again recorded. The test is carried on with various exciting currents of any desired magnitude. In every case the exciting current and the corresponding throw of the galvanometer are noted and recorded.

If $i =$ amperes flowing in the exciting coil,
$n_1 =$ number of turns of wire in exciting coil,
$l =$ length in centimetres of the mean circumference of the ring,
then the magnetizing force

$$\mathcal{H} = \frac{4\pi}{10} \times \frac{n_1 i}{l} \text{ or } 1.257 \times \frac{n_1 i}{l}.$$

If $l'' =$ length of the ring in inches, then

$$\mathcal{H}'' = .495 \times \frac{n_1 i}{l''}.$$

If $\theta =$ the throw of the galvanometer,
$K =$ constant of the galvanometer,
$R =$ resistance of the test coil and circuit,
$n_2 =$ number of turns in the test coil,
$a =$ area of cross-section of the ring in centimetres, then

$$\mathcal{B} = \frac{10^8 R K \theta}{2 a n_2}.$$

To determine K, the constant of the galvanometer, discharge a condenser of known capacity, which has been charged to a known voltage, through it, and take the reading θ^1, then

If $c =$ capacity of the condenser in microfarads,
$e =$ volts pressure to which the condenser is charged,

then the quantity passing through the galvanometer upon discharge in coulombs is $Q = \frac{c\,e}{1{,}000{,}000}$,

and the galvanometer constant

$$K = \frac{c\,e}{1{,}000{,}000\,\theta^1}.$$

Divided-Bar Method. — As it is often inconvenient or impossible to obtain samples in the form of a ring, and still more inconvenient to wind the coils on it, Hopkinson devised the divided-bar method, in which the sample is a long rod ½″ diameter, inserted in closely fitting holes in a heavy wrought iron yoke, as shown in Fig. 3.

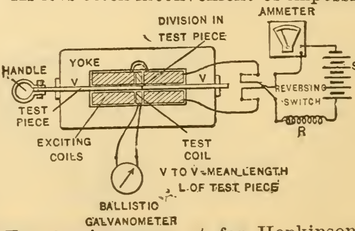


FIG. 3. Arrangement for Hopkinson's divided-bar method of measuring permeability.

In the cut the exciting coils are in two parts, and receive current from the battery and through the ammeter, resistance, and reversing switch, as shown.

The test bar is divided near the centre at the point indicated in the cut, and a small light test coil is placed over it, and so arranged with springs as to be thrown clear out of the yoke when released by pulling out the loose end of the test bar by the handle shown.

In operation, the exciting current is adjusted by the resistance R, the test bar suddenly pulled out by the handle, thus releasing the test coil and producing a throw of the galvanometer. As the current is not reversed, the induced pressure is due to N only, and the equation for $\mathcal{B}$ is

$$\mathcal{B} = \frac{10^8 \, R K \theta}{a n_2}, \text{ and}$$

$$\mathcal{H} = \frac{4\pi}{10} \times \frac{n_1 i}{L} = 1.257 \frac{n_1 i}{L},$$

Where $L =$ the mean length of the test rod as shown in the cut.

In using the divided-bar method, a correction must be made, for the reason that the test coil is much larger than the test rod, and a number of lines of force pass through the coil that do not through the rod. This correction can easily be determined by taking a reading with a wooden test rod in place of the metal one.

An examination of the cut will show that the bar and yoke can also be used for the method of reversals.

Magnetic Square Method. — G. F. C. Searle (*Journal I. E. E.*, December, 1904), has suggested another method of avoiding the use of the Rowland ring arrangement. The apparatus consists of a square, with strips laid overlapping at the edges. To obtain accurate results, the dimensions of the square must be large, as compared with the width of the strips. The same is true, but in a somewhat less degree, with the Rowland ring. According to A. Press, when the relative dimensions are correctly adjusted the ballistic galvanometer will give repeatable results, if the iron be first effectively demagnetized by means of an alternating current gradually reduced to zero, and then subjected to a series of reversals, from 50 to 200 with normal magnetizing current, before actual readings are taken.

Traction Method.

The following cut shows the method with sufficient clearness. A heavy yoke of wrought iron has a small hole in one end through which the test rod is pushed, through the exciting coil shown, and against the bottom of the yoke, which is surfaced true and smooth, as is the end of the test rod.

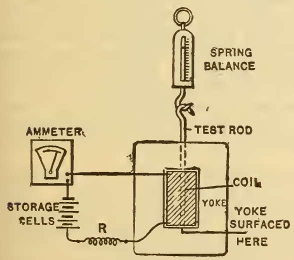


FIG. 4. S. P. Thompson's permeameter.

In operation, the exciting current is adjusted by the resistance R, and the spring balance is then pulled until the sample or test rod separates from the yoke, at which time the pull in pounds necessary to pull them apart is read. Then

$$\mathcal{B} = 1{,}317 \times \sqrt{\frac{P}{A}} + \mathcal{H}.$$

Where $P =$ pull in pounds as shown on the balance,

$A =$ area of contact of the rod and yoke in square inches.

$\mathcal{H}$ is found as in the Hopkinson method preceding this.

Following is a description of a practical adaptation of the *permeameter* to shop-work as used in the factory of the Westinghouse Electric and Manufacturing Co. at Pittsburgh, Pa.

The Permeameter, as used by the Westinghouse Electric and Mfg. Co.

DESIGN AND DESCRIPTION PREPARED BY MR. C. E. SKINNER.

A method of measuring the permeability of iron and steel known as the "Permeameter Method" was devised by Prof. Silvanus P. Thompson, and is based on the law of traction as enunciated by Clerk Maxwell. According to this law the pull required to break any number of lines of force varies as the square of the number of lines broken. (A complete discussion of the theory of the permeameter, with the derivation of the proper formula for calculating the results from the measurements will be found in the "Electro Magnet," by Prof. S. P. Thompson.)

A permeameter which has been in use for several years in the laboratory of the Westinghouse Electric and Manufacturing Company, and which has given excellent satisfaction, is shown in Figs. 5 and 6. The yoke, *A*, consists of a piece of soft iron 7″ x 8½″ x 2½″, with a rectangular opening in the center 2½″ x 4″. The sample, *X*, to be tested is ⅝″ in diameter and 7½″ long, and is introduced into the opening through a ⅝″ hole in the yoke, as shown in the drawing. The test sample is finished very accurately to ⅝″ in diameter, so that it makes a very close fit in the hole in the yoke. The lower end of the opening in the yoke and the lower end of the sample are accurately faced so as to make a perfect joint. The upper end of the sample is tapped to receive a ¼″ screw ⅜″ long, twenty threads per inch, by means of which a spring balance is attached to it. The magnetizing coil, *C*, is wound on a brass spool, *S*, 4″ long, with the end flanges turned up so that it may be fastened to the yoke by means of the screws. The axis of the coil coincides with the axis of the yoke and opening. The coil has flexible leads, which allow it to be easily removed from the opening for the inspection of the surface where contact is made between the yoke and the test sample.

The spring balance, *F*, is suspended from an angle iron fastened to the upright rack, *I*, which engages with the pinion, *J*. The balance is suspended exactly over the centre of the yoke through which the sample passes, to avoid any side pull. A spring buffer, *K*, is provided, which allows perfectly free movement of the link holding the sample for a distance of about ⅛″, and then takes up the jar consequent upon the sudden release of the sample. The frame, *B*, which supports the pulling mechanism, is made of brass, and has feet cast at the bottom, by means of which the complete apparatus is fastened to the table. Two spring balances are provided, one reading to 30 lbs. and the other to 100 lbs. These spring balances are of special construction, having comparatively long scales. (They were originally made self-registering; but this was found unnecessary, as a reading could be taken with greater rapidity and with sufficient accuracy without the self-registering mechanism.) Any good spring balance may be used. The spring should be carefully calibrated from time to time over its whole range; and if there is a correction it will be found convenient to use a calibration curve in correcting the readings. With a sample ⅝″ in diameter, or ⅓ of a square inch area cross-section, the maximum pull required for cast iron is about 25 lbs., and for mild cast steel about 70 lbs.

With the number of turns on the coil given above, the current required for obtaining a magnetizing force of $\mathcal{H} = 300$, is about 12.5 amperes. This is as high a value as is ever necessary in ordinary work. For furnishing the current a storage battery is ordinarily used, and the variations made by means of a lamp board which has in addition a sliding resistance, so that variations of about .01 ampere may be obtained over the full range of current from 0.1 ampere to 12.5 amperes.

The operation of the permeameter is as follows:—

The sample to be tested is first demagnetized by introducing it into the field of an electro-magnet with a wire core, through which an alternating current is passing, and gradually removing it from the field of this electro-magnet. The sample is then introduced into the opening in the yoke, care being taken to see that it can move without friction. Measurements are taken with the smallest current to be used first, gradually increasing to the highest value desired. In no case should a reading be taken with a current of less value than has been reached with the sample in position, unless the sample is thoroughly demagnetized again before reading is taken. It is usually most convenient to make each successive adjustment of current with the sample out of position, then introduce the sample and give it a half turn, to insure perfect contact between the sample and the yoke. The lower end of the sample and the surface on which it rests should be carefully inspected to see that no foreign matter of any kind is present which might introduce serious errors in the measurements. The pull is made by turning the pinion slowly by means of a handle, *E*, carefully noting each

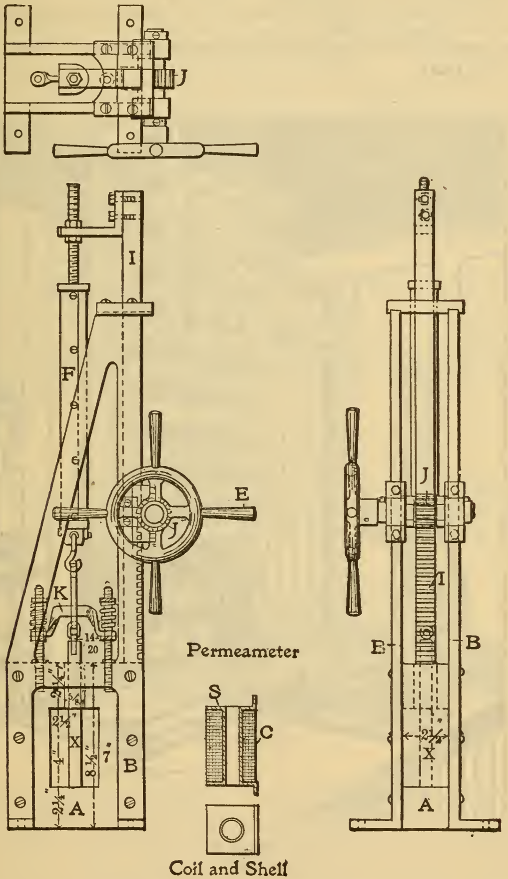


FIG. 5.

position of the index of the spring balance as it advances over the scale, and noting the point of release. The mean of three or four readings is usually taken as the corrected value for pull, the current in the coil remaining constant. With practice the spring balance can be read to within less than 1%; and as the square root of the pull is taken, the final error becomes quite small, especially with high readings.

The evaluation of the results for the above permeameter is obtained by the use of the following formula :

$$\text{The magnetizing force } \mathcal{H} = \frac{4\pi n_1 i}{10\, l}.$$

Where n_1 = number of turns in the magnetizing coil = 223,
i = current in amperes,
l = length of magnetic circuit in centimeters, estimated in this case as 11.74.

Substituting the known values in the above formula we have

$\mathcal{H} = 23.8\, i$.

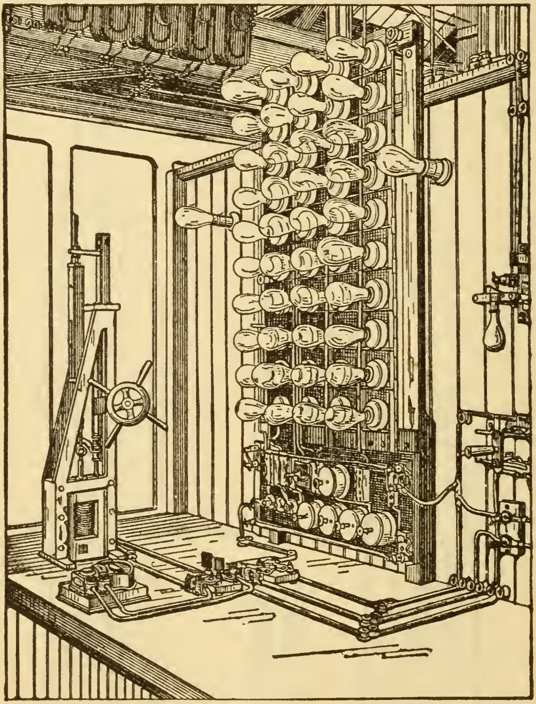


FIG. 6.

The number of lines of force per square centimeter

$$\mathcal{B} = 1{,}317 \sqrt{\frac{P}{A}} + \mathcal{H}\,.$$

Where P = pull in lbs.
A = area of the sample in square inches = 0.3068.
$\mathcal{H}$ = value of the magnetizing force for the given pull.

Substituting the value of A in the above formula we have

$$\mathfrak{B} = 2{,}380 \sqrt{P} + \mathfrak{H}$$

There are several sources of error in measurements made by the permeameter which should be carefully considered, and eliminated as far as possible.

a. The unavoidable air gap between the sample and the yoke where it passes through the hole in the upper part of the yoke, together with the more or less imperfect contact at the lower end of the sample, increases the magnetic reluctance and introduces errors for which it is impossible to make due allowance. By careful manipulation, however, these can be reduced to a minimum, and be made practically constant.

b. As the magnetization becomes greater the leakage at the lower end of the sample increases more rapidly; and there is considerable error at very high values from this source, as the leakage lines are not broken with the rest.

c. Errors in the calibration and reading of the spring balance. None but the best quality of spring balance should be used, and the average of several readings taken with the current remaining perfectly constant for each point on the $\mathfrak{B}$-$\mathfrak{H}$ curve. As the square root of the pull is taken, the errors due to reading the spring balance make a larger and larger percentage error in $\mathfrak{B}$ as P approaches zero, thus preventing accurate determinations being made at the beginning of the curve.

From the above it will be seen that the permeameter is not well adapted for giving the absolute values of the quality of iron and steel, but is especially suitable for comparative values, such as are noted in ordinary work, where a large number of samples are to be quickly measured. A complete curve can be taken and plotted in ten minutes. By suitable comparison of known samples measured by more accurate methods, the permeameter readings may be evaluated to a sufficient degree for use in the calculations of dynamo electric machinery.

Drysdale's Permeameter.

This instrument is designed to enable one to test the magnetic quality of iron or steel magnet castings and forgings under commercial conditions, by drilling it with a special drill. A testing plug is inserted in the hole thus drilled and the magnetization or permeability is then directly meas-

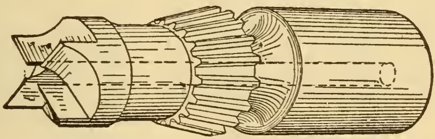


FIG. 7.

ured on an instrument attached, without any calculations, by simply throwing over a reversing switch.

Fig. 7 shows the special form of drill employed. It has four cutting edges at the lower end, which cut a cylindrical hole in the specimen. The drill is, however, made hollow, so that a thin rod or pin of the material is left standing in the center of the hole, as shown in Fig. 8, which shows a cast steel pole piece, and some small specimens of iron and steel actually drilled. In addition, cutting edges are provided at the top of the drill, which give a conical shape to the top of the hole drilled. The hole is about $\frac{3}{4}$ in. deep and $\frac{1}{2}$ in. in its largest diameter, while the pin is $\frac{1}{10}$ in. in diameter. Such a hole may be drilled in any position where a bolt hole is afterwards to be made in the back of a pole piece, or face of a joint, or otherwise in projections left specially for the purpose, which may be cut off the casting or forging on delivery and sent to the test room.

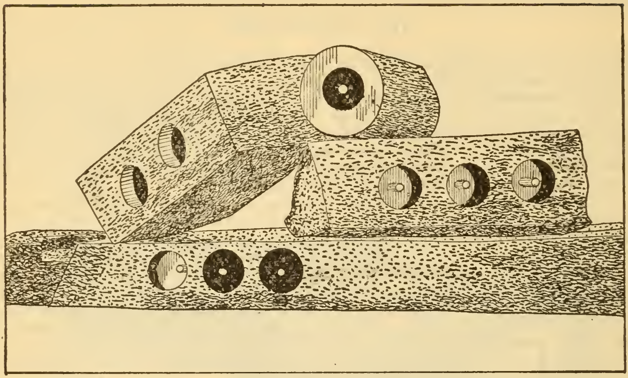


FIG. 8. Specimens Showing Holes and Pins.

In this hole is inserted the testing plug, Fig. 9, which consists of a soft iron plug, accurately fitting the conical portion of the hole cut by the drill, and having a central hole fitting over the pin. The plug is also split lengthwise, so that on forcing it into the conical hole the sides yield slightly and grip the pin, so making a very perfect magnetic joint. If the pin is magnetized the lines of force pass through the pin into the plug, and thence round the mass of the metal to the pin again, as shown in Fig. 9. The pin is magnetized by current in a coil wound round it, and the magnetization produced is tested by use of a second or search coil. On making or breaking or reversing the current in the first or magnetizing coil, the lines of force passing through the search coil are altered, and if this coil is connected to a galvanometer, kicks or throws of the galvanometer will be obtained proportional to the change in the magnetization of the pin.

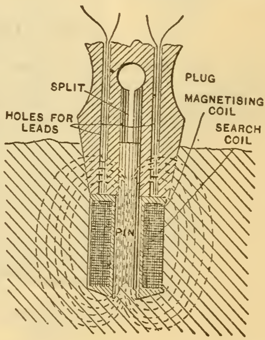


FIG. 9. Section through Plug and Specimen.

CORE LOSSES.

These result from *Hysteresis* and *Eddy currents*.

Professor Ewing has given the name *Hysteresis* to that quality in iron which causes the lagging of the *induction* behind the magnetic force. It causes a loss when the direction of the induction is reversed, and results in a heating of the iron. It increases in direct proportion to the number of reversals, and according to Steinmetz, as the 1.6th power of the maximum value of the induction in the iron core. The heat produced has to be dissipated either by radiation or conduction, or by both. Steinmetz gives the following formula for hysteresis loss in ergs per cubic centimeter, of iron per cycle; $h = \eta \mathfrak{B}_{max}{}^{1.6}$, where η = a constant depending upon the kind of iron. Taking η at .002 and retaining $\mathfrak{B}$ in gausses, the loss in watts per cubic inch of material P_h will be, $P_h = .338\ \mathfrak{B}_{max}{}^{1.6}\ f\ 10^{-8}$, in which f = cycles per second.

It is to be observed that, in practice, considerable variations in the magnetic density take place in parts where the magnetomotive force is a constant, due to the differences in the lengths of the lines of flux. This will not only affect the measured hysteresis losses, but the eddy currents as well. For this reason, machines of geometrically different form will not obey quite the same law of losses. Considerable question has been raised regarding the constancy of the hysteresis index. According to A. Press, the experiments of Mordey and Hansard with transformer iron imply that the hysteresis index for the range taken should be at least 2. Lancelot Wild gave the index as 2.7 for densities varying from $\mathfrak{B} = 200$ to $\mathfrak{B} = 400$, W. E. Sumpner states that the index varies 1.475 to 2.7, depending upon the range of the density, and Prof. Ewing gives the index as varying from 1.9 to 2 with densities $\mathfrak{B} = 200$ to $\mathfrak{B} = 500$, depending upon the sample.

Hysteretic Constants for Different Materials.

Material.	Hysteretic Constant. η.
Best annealed transformer sheet metal . .	.001
Very soft iron wire	.002
Thin good sheet iron	.003
Thick sheet iron	.0033
Most ordinary sheet iron	.004
Transformer cores	.003
Soft annealed cast steel	.008
Soft machine steel	.0094
Cast steel	.012
Cast iron	.016
Hardened cast steel	.025

Hysteresis Loss Factors.

$\mathfrak{B}_{max}$ in Gausses.	$\mathfrak{B}_{max}{}^{1.6}$	$\eta\,\mathfrak{B}_{max}{}^{1.6}$		
		$\eta = 0.002$	$\eta = 0.003$	$\eta = 0.004$
1,000	63,100	126	189	252
2,000	191,300	382	573	765
3,000	365,900	731	1,096	1,463
4,000	580,000	1,160	1,740	2,320
5,000	828,800	1,657	2,486	3,315
6,000	1,111,000	2,222	3,333	4,444
7,000	1,420,000	2,840	4,260	5,680
8,000	1,758,000	3,516	5,274	7,032
9,000	2,122,000	4,244	6,366	8,488
10,000	2,511,000	5,022	7,533	10,044

Eddy Currents are the local currents in the iron core caused by the E.M.F.'s generated by moving the cores in the field, and increase as the square of the number of revolutions per second. The cure is to divide or laminate the core so that currents cannot flow. These currents cause heating, and unless the core be laminated to a great degree are apt to heat the armature core so much as to char the insulation of its windings.

Wiener gives tables showing the losses by Hysteresis and Eddy currents at one cycle per second, under different conditions. These are changed into any number of cycles by direct proportion. The formula for eddy current loss is:

$$P_e = 42\,\mathfrak{B}''^2\,t^2 f^2\,10^{-18},$$

in which P_e = watts per cu. in., $\mathfrak{B}_{max}''$ = maximum value of the magnetic density per sq. in., t = thickness of plate in mils, and f = frequency.

Hysteresis Factors for Different Core Densities.

Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated at a Frequency of One Complete Magnetic Cycle per Second.				Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated at a Frequency of One Complete Magnetic Cycle per Second.			
	$\eta = .002$		$\eta = .003$			$\eta = .002$		$\eta = .003$	
	Per cu. ft.	Per lb.	Per cu. ft.	Per lb.		Per cu. ft.	Per lb.	Per cu. ft.	Per lb.
10,000	0.713	.0015	1.069	.0023	66,000	14.68	.0305	22.02	.0458
15,000	1.37	.0027	2.055	.0041	67,000	15.01	.0313	22.52	.0470
20,000	2.16	.0045	3.24	.0068	68,000	15.39	.0321	23.05	.0482
25,000	3.09	.0064	4.64	.0096	69,000	15.76	.0329	23.64	.0494
30,000	4.06	.0086	6.09	.0129	70,000	16.13	.0337	24.19	.0506
31,000	4.39	.0091	6.59	.0137	71,000	16.50	.0345	24.75	.0517
32,000	4.62	.0096	6.93	.0144	72,000	16.87	.0352	25.31	.0528
33,000	4.85	.0101	7.28	.0152	73,000	17.25	.0360	25.88	.0540
34,000	5.08	.0106	7.62	.0159	74,000	17.61	.0368	26.41	.0552
35,000	5.32	.0111	7.98	.0167	75,000	17.99	.0376	26.99	.0564
36,000	5.56	.0116	8.34	.0174	76,000	18.41	.0384	27.62	.0576
37,000	5.82	.0121	8.73	.0182	77,000	18.78	.0392	28.17	.0588
38,000	6.08	.0126	9.12	.0189	78,000	19.19	.0400	28.78	.0600
39,000	6.30	.0131	9.45	.0197	79,000	19.58	.0408	29.37	.0612
40,000	6.59	.0136	9.89	.0204	80,000	19.93	.0416	29.90	.0624
41,000	6.87	.0142	10.31	.0213	81,000	20.37	.0424	30.55	.0636
42,000	7.11	.0148	10.67	.0222	82,000	20.77	.0432	31.15	.0648
43,000	7.39	.0154	11.09	.0231	83,000	21.18	.0440	31.77	.0660
44,000	7.67	.0160	11.51	.0240	84,000	21.60	.0448	32.40	.0672
45,000	7.95	.0166	11.93	.0249	85,000	21.98	.0456	32.98	.0684
46,000	8.24	.0172	12.36	.0258	86,000	22.40	.0465	33.60	.0697
47,000	8.53	.0178	12.80	.0267	87,000	22.85	.0474	34.27	.0711
48,000	8.81	.0184	13.22	.0276	88,000	23.26	.0483	34.87	.0724
49,000	9.10	.0190	13.65	.0285	89,000	23.65	.0492	35.47	.0738
50,000	9.40	.0196	14.10	.0294	90,000	24.10	.0501	36.15	.0751
51,000	9.70	.0202	14.55	.0303	91,000	24.51	.0510	36.76	.0765
52,000	10.00	.0208	15.00	.0312	92,000	24.97	.0519	37.44	.0778
53,000	10.31	.0214	15.46	.0321	93,000	25.41	.0528	38.11	.0793
54,000	10.68	.0221	15.97	.0332	94,000	25.86	.0538	38.79	.0808
55,000	10.98	.0228	16.47	.0342	95,000	26.30	.0548	39.45	.0823
56,000	11.28	.0235	16.92	.0353	96,000	26.84	.0558	40.26	.0838
57,000	11.60	.0242	17.40	.0363	97,000	27.30	.0568	40.95	.0853
58,000	11.94	.0249	17.91	.0374	98,000	27.73	.0578	41.59	.0868
59,000	12.27	.0256	18.41	.0384	99,000	28.19	.0588	42.28	.0883
60,000	12.61	.0263	18.91	.0395	100,000	28.55	.0598	42.85	.0898
61,000	12.95	.0270	19.42	.0405	105,000	30.86	.0643	46.29	.0965
62,000	13.30	.0277	19.95	.0416	110,000	33.20	.0694	49.80	.1041
63,000	13.63	.0284	20.45	.0426	115,000	35.70	.0746	53.55	.1119
64,000	13.99	.0291	20.98	.0437	120,000	38.20	.0796	57.30	.1194
65,000	14.31	.0298	21.47	.0447	150,000	40.83	.0850	60.25	.1275

The Step-by-Step Method of Hysteresis Test.

The samples for hysteresis tests, being generally of sheet iron, are made in the form of annular disks whose inner diameters are not less than $\frac{5}{8}$ of their external diameter. A number of these disks are stacked on top of each other, and the composite ring is wound with one layer of wire forming the magnetizing coil of n_1 turns. This coil is connected through a reversing switch to an ammeter in series with an adjustable resistance, and a storage battery. A secondary test coil of n_2 turns is connected with a ballistic galvanometer, as shown in Fig. 10.

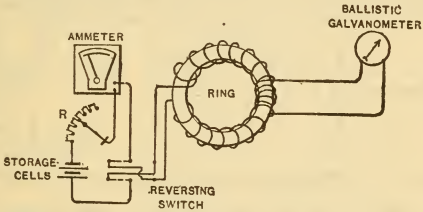


FIG. 10.

To make the test, adjust the resistance for the maximum exciting current. Reverse the switch several times, the galvanometer being disconnected. Then connect the galvanometer, and reduce the current by moving the contact arm of the rheostat up one step. This rheostat must be so constructed that an alteration in resistance can be made *without opening the circuit even for an instant.* Note the throw in the galvanometer corresponding to the change in exciting current. Follow this method by changing resistance step-by-step until the current reaches zero. Reverse the direction, and increase step-by-step up to a maximum and then back again to zero. Reverse once more, and increase step-by-step to the original maximum. In every case note and record the value of the exciting current i, and the corresponding throw of the galvanometer, θ. Form a table having the following headings to its columns: —

i, $\mathcal{H}$, θ, change of $\mathcal{B}$, $\mathcal{B}$.

Values of H are obtained from the formula,

$$\mathcal{H} = \frac{4\pi\, n_1\, i}{10\, l},$$ when l = average circumference of the test ring.

Change of $\mathcal{B}$ is obtained by the formula,

$$\frac{10^8\, R\, K\, \theta}{a\, n_2},$$

where all letters have the same significance as in the formula on page 92. Remember that we started in our test with a maximum *unknown* value of $\mathcal{B}$, and that we gradually decreased this by steps measurable by the throw of the galvanometer, and that we afterwards raised the $\mathcal{B}$ in an opposite direction to the same maximum *unknown* value, and still further reduced this to zero, and after commutation produced the original maximum value. According to this, if due consideration be paid to the sign of the $\mathcal{B}$ which is determined by the direction of the galvanometer throw, the algebraic sum of the changes in $\mathcal{B}$ should be equal to zero; the algebraic sum of the first or second half of the changes in $\mathcal{B}$ should be equal to twice the value of the original maximum, $\mathcal{B}$. Taking this maximum value as the first under the column of the table headed $\mathcal{B}$, and applying algebraically to this the changes in $\mathcal{B}$ for successive values, we obtain the completed table. Plot a curve of $\mathcal{H}$ and $\mathcal{B}$. The area enclosed represents the energy lost in carrying the sample through one cycle of magnetization between the maximum limits $+\mathcal{B}$ and $-\mathcal{B}$. Measure this area, and express it in the same units as is employed for the co-ordinate axes of the curve. This area divided by 4π

gives the number of ergs of work performed per cycle upon one cubic centimeter of the iron, the induction being carried to the limits $+\mathfrak{B}$ and $-\mathfrak{B}$.

The Wattmeter Method of Hysteresis Tests.

Inasmuch as the iron, a sample of which is submitted for test, is generally to be employed in the manufacture of alternating-current apparatus, it is desirable to make the test as nearly as possible under working conditions. If the samples be disks, as in the previous method, and these be shellacked on both sides before being united into the composite test-ring in order to avoid as much as possible foucault current losses, the test can be quickly made according to the method outlined in the following diagram :

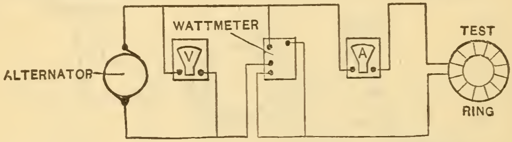


FIG. 11. Wattmeter Test for Hysteretic Constant.

Alternating current of f cycles per second is sent through the test-ring. Its voltage, E, and current strength, i, are measured by the alternating-current voltmeter, V, and ammeter, A. If r be the resistance of the test-ring coil of n_1 turns, then the watts lost in hysteresis W, is equal to the wattmeter reading $W' - i^2r$. If the volume of the iron be V cubic centimeters, and the cross section of the iron ring be a square centimeters, then Steinmetz's hysteretic constant

$$\eta = \frac{10^7\, W}{V f}\left(\frac{\sqrt{2}\pi\ n_1 f a}{E\ 10^8}\right)^{1.6}.$$

Foucault current losses are neglected in this formula, and the assumption is made that the current is sinusoidal.

Ewing's Hysteresis Tester.—In this instrument, Fig. 12, the test sample is made up of about seven pieces of sheet iron $\frac{5}{8}''$ wide and $3''$ long. These are rotated between the poles of a permanent magnet mounted on knife edges.

The magnet carries a pointer which moves over a scale. Two standards of known hysteresis properties are used for reference. The deflections corresponding to these samples are plotted as a function of their hysteresis losses, and a line joining the two points thus found is referred to in subsequent tests, this line showing the relation existing between deflection and hysteresis loss. The deflections are practically the same, with a great variation in the thickness of the pile of test-pieces, so that no correction has to be made for such variation. This instrument has the advantage of using easily prepared test samples.

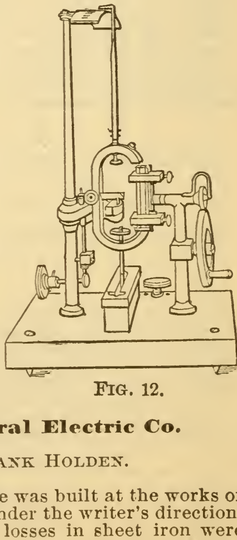


FIG. 12.

Hysteresis Meter, Used by General Electric Co.

DESIGNED AND DESCRIBED BY FRANK HOLDEN.

During the last few weeks of the year 1892 there was built at the works of the General Electric Company, in Lynn, Mass., under the writer's direction, an instrument, shown in Fig. 13, by which the losses in sheet iron were determined by measuring the torque produced on the iron, which was punched in rings, when placed between the poles of a rotating electro-magnet. The rings were held by a fibre frame so as to be concentric with a vertical shaft which worked freely on a pivot bearing at its lower end. They had a width of 1 centimeter, an outside diameter of 8.9 centimeters, and enough were used to make a cylinder about 1.8 centimeters high. The top part of this instrument, which rested on a thin brass cylinder surrounding the rings, was movable. On the upper surface was marked a degree scale, over which passed a pointer, with which the upper end of a helical spring rotated. It was so constructed that when the vertical shaft with the rings and the upper part of the instrument with the spring was put in place, the lower end of the spring engaged with the shaft, and consequently rotated with the rings. A pointer moving with the lower end of the spring reached to the zero of the degree scale when the apparatus was ready for use. By this arrangement it was found what distortion it was necessary to give the spring in order to balance the effect of the rotating magnet, and the spring having been calibrated, the ergs spent on the rings per cycle were determined by multiplying the degrees distortion by a constant.

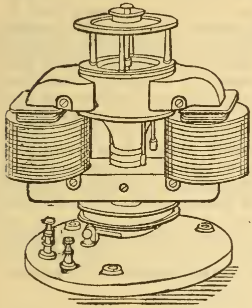


FIG. 13. Hysteresis Meter.

A coil, so arranged that it surrounded but did not touch the rings, made contact at its ends with two fixed brushes that rested in diametrically opposite positions on a two-part commutator, which revolved with a magnet. The segments were connected each to a collector ring against which rubbed a brush, the latter two brushes being joined through a sensitive Weston voltmeter. If this were so arranged that the coil was at right angles to the

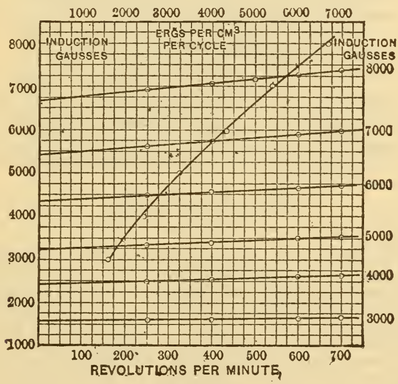


FIG. 14.

induction, when the brushes changed contact from one segment to the other, it is evident, the self-induction of the circuit being negligible, that the mean value of the current in the circuit was proportional to the total flux through the coil. Knowing the constant of the voltmeter, the deflection was easily calculated from the speed of the magnet, the number of turns in the coil, cross-section of the rings, and the resistance of the circuit. From an induction of 2,000 gausses to at least 10,000 gausses, the leakage across the interior space of the rings was negligible.

Carried on the shaft below the magnet was a pulley around which passed a flat belt driven with a pulley of the same size on an electric motor, so that the speed of the magnet could be found by observing that of the motor. In operating, the deflections to be produced on the voltmeter at a certain speed, with the desired induction in the rings, were first calculated. Five hundred revolutions per minute was generally adopted as the speed in this case. The motor being run at the desired speed, the magnetizing current was adjusted until the calculated deflection was produced on the voltmeter. Keeping the magnetizing current constant, the speed was changed successively in value to certain values, and the corresponding distortions of the spring necessary to balance the effect of the magnet noted. When this process was carried out at different induction values, and the ergs expended per cycle on the rings plotted as a function of the speed, a series of lines was produced, as shown in Figs. 14 and 15. It was found that the slope of the lines decreased very rapidly with the decrease in thickness of the iron sheet used so as to indicate that had it been thin enough the slope would have been zero between 100 and 800 revolutions per minute, which was about the highest speed permissible. From this it would seem that, in these tests, the total loss per cycle had two components; one remaining constant, due to hysteresis, and the other varying as the speed of the magnets, due to currents induced in the iron.

Fig. 18 gives observations of eddy current loss and thickness of iron sheet on this assumption. The line drawn is a parabola, so that it would appear that with the range of observations made the loss varied about as the square of the thickness of the sheets.

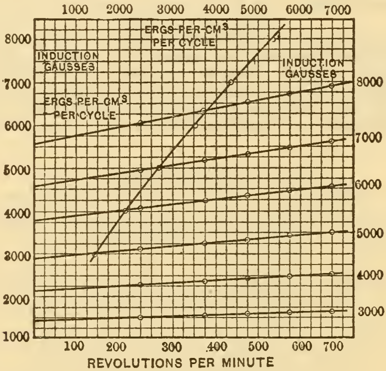


FIG. 15.

Fig. 14 gives lines from iron .04 centimeters thick. Speed readings were not taken lower than 250 revolutions per minute, as it had been found that the lines were always straight, and speeds below this value could not be read with the tachometer available for this particular test. Plotting the hysteresis as a function of the induction, in this case the points are all quite close to a curve whose equation is, Ergs $= A$ constant $\times$ (Density per square centimeter)$^{1.47}$, three points in the latter calculated curve being shown by the crosses. The iron, a test on which is shown in Fig. 15, was .1 centimeter thick, and shows a greater eddy current loss. The equation for the hysteresis curve for this sample is, Ergs $= A$ constant $\times$ (Density per square centimeters)$^{1.4}$, some points in the latter curve being shown by crosses, as before.

The eddy current losses for these two samples are plotted as functions of the induction in Fig. 17. The curves drawn are parabolas; showing that in these cases the eddy current loss varied approximately as the square of the induction, although there were often greater variations from that law than these two samples show. The average exponent for the hysteresis curves was a little over 1.5, although it varied from 1.4 to 1.7. Rings tested in this manner were wound and tested with a ballistic galvanometer, using the step-by-step method. There were discrepancies of as much as 4 per cent between the two results, but an average of ten tests showed the ballistic galvanometer method gave results 2.5 per cent lower than the other. This difference is easily attributable to experimental errors.

It being noticed that for a given induction in the rings, the magnetizing currents for different samples did not vary much, it was planned shortly after completing the above apparatus to construct a modified instrument which would use electro-magnets of such high reluctance that the variations of the rings would be negligible, and induction be dependent only on the current. By making the electro-magnets of suitable iron and of about one-third the cross-section of the rings used, the iron may be so highly saturated that the induction will remain quite constant under considerable variation in the magnetizing current, thus rendering unnecessary any accurate comparisons of magnetizing currents, and the rings can be at about their maximum permeability when thus magnetized. Such an instrument is shown in Fig. 13 in its original experimental form, with the rings in position ready for test. A modified form is shown in Fig. 16. The rings are here allowed to rotate in opposition to the action of a spring and carry a pointer over a scale, so that it is quite direct reading. Twenty-five compar-

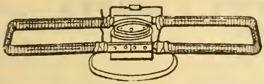


FIG. 16. Modified Hysteresis Meter.

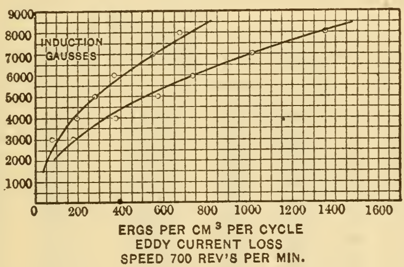


FIG. 17.

isons of this instrument with the original one gave results that agreed within 6 per cent in all cases, and more than half were within 2 per cent of agreement. Permanent magnets had been previously tried, but the attempt seemed to show that the instrument would not, in that case, compare samples of iron widely different in character ; and the writer not being able to

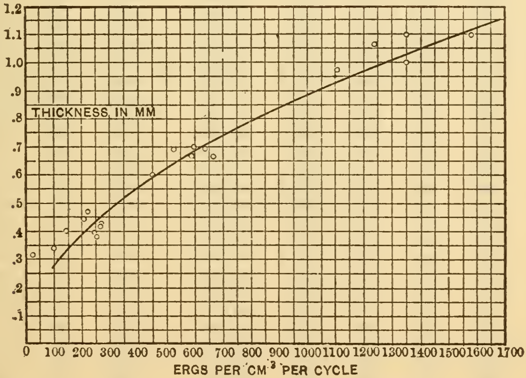


FIG. 18.

give any attention to the matter, no further investigations in that direction were attempted.

The instrument first described has been in use continuously since its completion at the works of the General Electric Company, in Schenectady.

EDDY CURRENT FACTORS FOR DIFFERENT CORE DENSITIES AND FOR VARIOUS LAMINATIONS.

(Wiener.)

Maximum Value of the Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated per cubic foot of iron at a frequency of 1 cycle per second. Thickness of lamination, δ				Maximum Value of the Magnetic Density in Armature Core. Lines of Force per sq. in.	Watts dissipated per cubic foot of iron at a frequency of 1 cycle per second. Thickness of lamination, δ			
	.010″	.020″	.040″	.080″		.010″	.020″	.040″	.080″
10,000	.0007	.003	.012	.046	66,000	.0315	.126	.503	2.013
15,000	.0016	.007	.026	.104	67,000	.0325	.130	.519	2.075
20,000	.0029	.012	.046	.185	68,000	.0335	.134	.534	2.137
25,000	.0045	.018	.072	.288	69,000	.0345	.138	.550	2.200
30,000	.0065	.026	.104	.416	70,000	.0355	.142	.566	2.265
31,000	.0070	.028	.111	.444	71,000•	.0365	.146	.582	2.330
32,000	.0074	.030	.118	.472	72,000	.0375	.150	.599	2.396
33,000	.0079	.032	.126	.503	73,000	.9385	.154	.616	2.463
34,000	.0084	.034	.134	.534	74,000	.0396	.158	.633	2.530
35,000	.0089	.036	.142	.567	75,000	.0407	.163	.650	2.600
36,000	.0094	.038	.150	.600	76,000	.0418	.167	.668	2.670
37,000	.0099	.040	.158	.633	77,000	.0429	.171	.685	2.740
38,000	.0104	.042	.167	.667	78,000	.0440	.176	.703	2.810
39,000	.0110	.044	.176	.703	79,000	.0451	.180	.721	2.883
40,000	.0116	.046	.185	.740	80,000	.0462	.185	.740	2.958
41,000	.0122	.049	.194	.777	81,000	.0474	.190	.758	3.033
42,000	.0128	.051	.204	.815	82,000	.0486	.194	.777	3.108
43,000	.0134	.054	.214	.855	83,000	.0498	.199	.796	3.184
44,000	.0140	.056	.224	.896	84,000	.0510	.204	.815	3.260
45,000	.0146	.059	.234	.937	85,000	.0523	.209	.835	3.340
46,000	.0153	.061	.245	.979	86,000	.0535	.214	.855	3.420
47,000	.0160	.064	.256	1.022	87,000	.0548	.219	.875	3.500
48,000	.0167	.067	.267	1.066	88,000	.0560	.224	.895	3.580
49,000	.0174	.070	.278	1.110	89,000	.0573	.229	.916	3.662
50,000	.0181	.072	.289	1.055	90,000	.0586	.234	.937	3.745
51,000	.0188	.075	.300	1.200	91,000	.0599	.240	.958	3.830
52,000	.0195	.078	.312	1.248	92,000	.0612	.245	.979	3.915
53,000	.0202	.081	.324	1.297	93,000	.0625	.250	1.000	4.000
54,000	.0210	.084	.337	1.346	94,000	.0638	.255	1.021	4.085
55,000	.0218	.087	.349	1.397	95,000	.0651	.261	1.043	4.170
56,000	.0226	.091	.362	1.448	96,000	.0665	.266	1.064	4.257
57,000	.0234	.094	.375	1.500	97,000	.0679	272	1.086	4.345
58,000	.0242	.097	.389	1.555	98,000	.0693	.277	1.109	4.436
59,000	.0251	.101	.403	1.610	99,000	.0707	.283	1.132	4.528
60,000	.0260	.104	.416	1.665	100,000	.0722	.289	1.156	4.622
61,000	.0269	.108	.430	1.720	105,000	.0797	.319	1.274	5.095
62,000	.0278	.111	.444	1.776	110,000	.0875	.350	1.398	5.593
63,000	.0287	.115	.458	1.833	115,000	.0955	.382	1.528	6.113
64,000	.0296	.118	.473	1.891	120,000	.1040	.416	1.664	6.655
65,000	.0305	.122	.486	1.951	125,000	.1128	.451	1.806	7.222

SPECIFIC ENERGY DISSIPATION IN ARMATURE CORE.

Maximum Magnetic Density.		Hysteresis Loss for Sheet Iron at Frequency of One Magnetic Cycle per Second (in Watts) ($\eta = 0.002$).				Eddy-Current Loss in Watts for .030″ (.075 cm.) Lamination, at One Cycle per Second Proportional to Square of Frequency.			
Gausses.	Lines of force per sq. in.	Per cm.³	Per cu. ft.	Per kg.	Per lb.	Per cm.³	Per cu. ft.	Per kg.	Per lb.
2,000	12,900	.000039	1.13	.0052	.0023	.0000004	.011	.000051	.000023
3,000	19,350	.000073	2.09	.0080	.0044	.0000009	.026	.000119	.000054
4,000	25,800	.000116	3.28	.0153	.0069	.0000016	.046	.000212	.000096
5,000	32,250	.000166	4.68	.0216	.0098	.0000025	.071	.000327	.000148
6,000	38,700	.000222	6.31	.0291	.0131	.0000036	.102	.000471	.000213
7,000	45,150	.000288	8.08	.0372	.0169	.0000049	.139	.000640	.000290
8,000	51,600	.000352	10.00	.0461	.0208	.0000064	.181	.000833	.000377
9,000	58,050	.000424	11.94	.0551	.0249	.0000081	.229	.001054	.000478
10,000	64,500	.000500	14.06	.0648	.0294	.0000100	.283	.001303	.000590
11,000	70,950	.000586	16.17	.0745	.0337	.0000121	.343	.001580	.000715
12,000	77,400	.000672	18.91	.0871	.0394	.0000144	.408	.001878	.000850
13,000	83,850	.000765	21.65	.0997	.0452	.0000169	.479	.002204	.000998
14,000	90,300	.000869	24.40	.1123	.0509	.0000196	.555	.002553	.001157
15,000	96,750	.000959	27.18	.1254	.0566	.0000225	.637	.002923	.001328
16,000	103,200	.001065	30.23	.1396	.0638	.0000256	.725	.003340	.001512
17,000	109,650	.001175	33.33	.1537	.0694	.0000289	.818	.003770	.001708
18,000	116,100	.001287	36.40	.1675	.0758	.0000324	.917	.004220	.001911
19,000	122,550	.001406	39.76	.1830	.0828	.0000361	1.022	.004710	.002130
20,000	129,000	.001523	43.20	.1978	.0900	.0000400	1.133	.005225	.002362

Iron Loss Determinations. — Since, in different types of electrical apparatus, uniformity or similarity of the flux distribution is not approached, the determination of iron losses from actual machines, when possible, is the best way of obtaining loss constants for the design of other machines of the same type.

ELECTROMAGNETS.

PROPERTIES.

REVISED BY TOWNSEND WOLCOTT AND PROF. SAMUEL SHELDON.

Residual Magnetism is the magnetization remaining in a piece of magnetic material after the magnetizing force is discontinued.

Retentiveness is that property of magnetizable materials which is measured by the residual magnetism.

Coercive Force is the magnetizing force necessary to remove all residual magnetism.

Permanent magnetism is residual magnetism in a material of great coercive force, as hard steel, which has little retentiveness; while soft iron has great retentiveness but little coercive force.

The following paragraphs are condensed from S. P. Thompson's "The Electromagnet:"

Magneto-Motive Force. — The magneto-motive force, or magnetizing power of an electro-magnet is proportional to the number of turns of wire and the amperes of current flowing through them; that is, one ampere flowing through ten coils or turns will produce the same *magneto-motive force* as ten amperes flowing through one coil or turn.

If $n =$ number of turns in the coil,

$I =$ amperes of current flowing,

$$1.257 = \frac{4\pi}{10} \text{ (to reduce to C. G. S. units).}$$

Magneto-motive force $= 1.257 \times nI = \mathfrak{F}$.

Intensity of Magnetic Force. — Intensity of magnetic force in an electro-magnet varies in different parts of the magnet, being strongest in the middle of the coil, and weaker toward the ends. In a long electro-magnet, say a length 100 times the diameter, the intensity of magnetic force will be found nearly uniform along the axis, falling off rapidly close to the ends.

In a long magnet, such as described above, and in an annular ring wound evenly over its full length, the value of the magnetic force, $\mathcal{H}$, is determined by the following expression: —

$$\mathcal{H} = 1.257 \frac{nI}{l}, \text{ in which } l = \text{centimeters.}$$

If the length is given in inches, then

$$\mathcal{H} = .495 \frac{nI}{l_{\prime\prime}}, \text{ in which } l_{\prime\prime} = \text{inches.}$$

If intensity of the magnetic force is to be expressed in lines per sq. inch,

$$\mathcal{H}_{\prime\prime} = 3.193 \times \frac{nI}{l_{\prime\prime}}.$$

Value of $\mathcal{H}$ at the centre of a Single-turn of Conductor. — In a single ring or turn of wire of radius r, carrying I amperes of current

$$\mathcal{H} = \frac{2\pi}{10} \times \frac{I}{r} = .6284 \times \frac{I}{r}.$$

Force on Conductor (carrying current) in a Magnetic Field. — A conductor carrying current in a magnetic field is repelled from the field by a certain mechanical force acting at right angles both to the conductor itself and to the lines of force in the field; see Fig. 1.

The magnitude of this repelling force is determined as follows, assuming the field to be uniform:

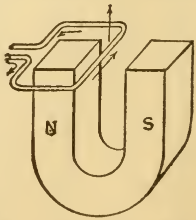


FIG. 1. Action of Magnetic Field, on Conductor carrying current.

$\mathcal{H} =$ magnetizing force, or intensity of the field.
$l =$ length of conductor across the field in c.m.
$l_{\prime\prime} =$ ditto in inches.
$I =$ amperes of current flowing in the conductor.
$F =$ repelling force.

F in dynes $= \frac{\mathcal{H} l I}{10}$. F in dynes $= \frac{\mathcal{H}_{\prime\prime} l_{\prime\prime} I}{25.4}$. F in grains $= \frac{\mathcal{H}_{\prime\prime} l_{\prime\prime} I}{16146}$.

Work done by Conductor (carrying Current) in moving across a Magnetic Field.

If the conductor described in the preceding paragraph be moved across the field of force, the work done will be determined as follows: in addition to the symbols there used, let b = breadth of field in and across which the conductor is moved; w = work done in ergs.

$$w = Fb = \frac{b\mathcal{H}lI}{10},$$

$$bl = \text{area of field},$$

$$N = bl \times \phi = \text{number of lines of force cut},$$

$$w = \frac{NI}{10}.$$

Rotation of Conductor (carrying current) around a Magnet Pole.

If a conductor (carrying current) be so arranged that it can rotate about the pole of a magnet, the force producing the rotation, called *torque*, will be determined as follows: The whole number of lines of force radiating from the pole will be 4π times the pole strength m.

$$w = \frac{4\pi\ mI}{10} = 1.257\ mI.$$

Dividing by the angle 2π, the *torque*, T, is

$$T = \frac{2\,mI}{10} = .2\ mI.$$

Every electric circuit tends to place itself so as to embrace the maximum flux.

Two electric conductors carrying currents tend to place themselves in position such that their mutual flux may be maximum; otherwise stated: if two currents run parallel and in the same direction, each produces a field of its own, and each conductor tends to move across the other's field.

In two coils or conductors lying parallel to each other, as in a tangent galvanometer, the mutual force varies directly in proportion to the product of their respective nI, and inversely as the axial distance they are apart.

Principle of the Magnetic Circuit.—The resistance that a magnetic circuit offers to the passage or flow of *magnetic lines of force* or *flux*, has been given the name of *reluctance*, symbol $\mathcal{R}$, and is analogous to *resistance*, to the flow of electric current in a conductor.

The *magnetic flux* or lines of force are treated as current flowing in the magnetic circuit, and denoted by the symbol ϕ.

The above two factors, together with the *magneto-motive force* described in the early part of this chapter, bear much the same relation to each other as do resistance, current, and E.M.F. of electric circuits, and are expressed as follows:—

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{reluctance}}.$$

$$\phi = \frac{\mathcal{F}}{\mathcal{R}}.$$

$$\mathcal{F} = \frac{4\pi\ nI}{10} = 1.257\,nI.$$

$$\mathcal{R} = \frac{l}{A\mu}.$$

$$\phi = \frac{1.257\ nI}{\frac{l}{A\mu}}.$$

$$nI = \frac{\phi\,\frac{l}{A\mu}}{1.257}.$$

If dimensions are in inches, and A is in square inches, then

$$nI = \phi \frac{l_{''}}{A_{''}\mu} \times .3132.$$

$$\text{and } \phi = \mathfrak{B}'' A''.$$

The Law of Traction. — The formula for the *pull* or lifting-power of an electromagnet when the poles are in actual contact with the armature or keeper is as follows:

$$\text{Pull (in dynes)} = \frac{\mathfrak{B}^2 A}{8\pi}.$$

$$\text{Pull (in grammes)} = \frac{\mathfrak{B}^2 A}{8\pi \times 981}.$$

$$\text{Pull (in pounds)} = \frac{\mathfrak{B}^2 A}{11{,}183{,}000}.$$

$$\text{In inch measure: Pull (in pounds)} = \frac{\mathfrak{B}^2_{''} A''}{72{,}134{,}000}.$$

Traction.

This proportionality to the square of the induction accounts for some anomalous peculiarities in the way that the keeper of a magnet holds fast to the poles. If the pole faces be perfectly true and flat and the face of the keeper the same, the keeper is actually held with less force than when the pole faces are very slightly convex. Or, again, if the keeper be slid to one side until only its sharp edge and that of the poles are in contact, it will be found to adhere more firmly than when placed squarely and centrally on the poles. In general, a magnet holds tighter to a slightly uneven surface than to one which perfectly fits the poles. The reason is that, when the area of contact is decreased, the intensity of the induction through the remaining contact is increased by the crowding together of the lines of induction; and, as the traction is proportional to the product of the area and the square of the intensity of the induction, so long as there is sufficient crowding of the lines so that the square of their intensity increases more than the area is diminished, the traction is increased by reducing the area of contact.

The amount of the traction is usually determined by the formula, $T = \frac{\mathfrak{B}^2}{8\pi}$, in which T is the traction per square centimeter expressed in dynes: to express the traction in grammes, this figure is of course divided by 981, or for pounds avoirdupois per square inch it should be divided by 69090. This formula is correct for the force required to separate the halves of a straight bar magnet cut in the middle, if the winding be also in halves and these halves separate at the same time as their respective halves of the core and if, further, the winding fit the core closely. It is also correct for the separating force when the magnetism is residual; as in the case of a permanent magnet. In other cases, for example, where an ordinary keeper is pulled away from a magnet, the formula is not strictly accurate on account of the keeper being attracted partly by the core of the magnet and partly by the current in the winding directly. However, the attraction exerted by the coil is usually small as compared to that exerted by the core; and the formula is not very much in error.

The attraction between the two parts of the iron is always $2\pi\mathfrak{J}^2$ dynes per square centimeter, $\mathfrak{J}$ being the intensity of magnetization, that is the number of units of free magnetism per square centimeter. But $\mathfrak{B} = 4\pi\mathfrak{J} + \mathfrak{H}$ so when $\mathfrak{H} = 0$, that is when there is no magnetizing force, $2\pi\mathfrak{J}^2 = \frac{\mathfrak{B}^2}{8\pi}$, which is evidently correct, as there is no attraction except between the two parts of the iron. When $\mathfrak{H}$ is not equal to zero, that is, when the magnetism is not residual, there is a force between the coil and the part of the iron that is moved away from the coil equal to $\mathfrak{H}\mathfrak{J}$ dynes per square centimeter, so that the whole force of separation is $2\pi\mathfrak{J}^2 + \mathfrak{H}\mathfrak{J}$. When there is a coil on each part of the magnet and both parts of the magnet and both coils are just alike, there are two of these $\mathcal{H}\mathcal{I}$ forces, because each coil attracts the other part of the iron; but as in this case $\mathcal{H}$ represents the intensity of the magnetizing force of the whole coil each half now attracts the other part of the iron with a force of $\frac{\mathcal{H}\mathcal{I}}{2}$ and both forces together equal $\mathcal{H}\mathcal{I}$. The two coils attract each other with a force of $\frac{\mathcal{H}^2}{8\pi}$ per square centimeter, so the whole force is $2\pi\mathcal{I}^2 + \mathcal{H}\mathcal{I} + \frac{\mathcal{H}^2}{8\pi}$, which may be written $\frac{1}{8\pi}(16\pi^2\mathcal{I}^2 + 8\pi\mathcal{H}\mathcal{I} + \mathcal{H}^2) = \frac{1}{8\pi}(4\pi\mathcal{I} + \mathcal{H})^2 = \frac{\mathcal{B}}{8\pi}$ per square centimeter, so in this case also the traction is proportional to the square of the intensity of the induction. If the coils be loose upon the cores so that their areas are sensibly greater than those of the cores, the whole force of separation is greater than that given by the equation; but, in practical cases, the error is usually small. In all cases, the attraction between the iron parts is $2\pi\mathcal{I}^2$ per square centimeter.

Magnetization and Traction of Electromagnets.

$\mathcal{B}$. Lines per sq. cm.	$\mathcal{B}''$ Lines per sq. inch.	Dynes per sq. cm.	Grammes per sq. cm.	Kilogs per sq. cm.	Pounds per sq. inch.
1,000	6,450	39,790	40.56	.04056	.577
2,000	12,900	159,200	162.3	.1623	2.308
3,000	19,350	358,100	365.1	.3651	5.190
4,000	25,800	636,600	648.9	.6489	9.228
5,000	32,250	994,700	1,014	1.014	14.39
6,000	38,700	1,432,000	1,460	1.460	20.75
7,000	45,150	1,950,000	1,987	1.987	28.26
8,000	51,600	2,547,000	2,596	2.596	36.95
9,000	58,050	3,223,000	3,286	3.286	46.72
10,000	64,500	3,979,000	4,056	4.056	57.68
11,000	70,950	4,815,000	4,907	4.907	69.77
12,000	77,400	5,730,000	5,841	5.841	83.07
13,000	83,850	6,725,000	6,855	6.855	97.47
14,000	90,300	7,800,000	7,550	7.550	113.1
15,000	96,750	8,953,000	9,124	9.124	129.7
16,000	103,200	10,170,000	10,390	10.390	147.7
17,000	109,650	11,500,000	11,720	11.720	166.6
18,000	116,100	12,890,000	13,140	13.140	186.8
19,000	122,550	14,360,000	14,630	14.630	208.1
20,000	129,000	15,920,000	16,230	16.230	230.8

Exciting Power and Traction.—If we can assume that there is no magnetic leakage, the *exciting power* may be calculated from the following expression; all dimensions being in inches, and the *pull* in pounds:

$$nI = \frac{\mathcal{B}''l''}{\mu} \times .3132.$$

$$\mathcal{B}'' = \frac{\mu \times nI}{l'' \times .3132},$$

$$\text{also, } \mathcal{B}'' = 8494\sqrt{\frac{\text{Pull}}{\text{Area}''}}$$

$$nI = 2661 \times \frac{l''}{\mu} \times \sqrt{\frac{\text{Pull}}{\text{Area}''}}.$$

If dimensions are in metric measure,

$$nI = 3951\ \frac{l}{\mu}\sqrt{\frac{\text{Pull in kilos}}{\text{Area in sq. cms.}}}.$$

$$\mathcal{B} = 1316.6\sqrt{\frac{\text{Pull in lbs.}}{\text{Area in sq. ins.}}}. \qquad \mathcal{B} = 4965\sqrt{\frac{\text{Pull in kilos.}}{\text{Area sq. cm.}}}.$$

WINDING OF ELECTROMAGNETS.

The method used by Cecil P. Poole for predetermining magnet windings is as follows: Temporary test coils, of wire much larger than will probably be required in the permanent coils, are wound to occupy the space that it is estimated the permanent coil will occupy. Current is passed through the temporary coils in series with a water rheostat or finely graduated resistance, by means of which the excitation may be closely adjusted. The exciting current is adjusted until the desired magnet performance is obtained; the current producing this effect is represented by I_x. The current is then increased or decreased as may be required until the resistance per foot of the winding corresponds with the resistance per foot given by Table I herewith, after five hours. The current required to produce this result is indicated by I_h.

The size of wire required to produce a given number of ampere-turns under given conditions of mean length and voltage is

$$d^2 = \frac{KAtL_m}{V},$$

in which d^2 equals circular mils of the wire to be used, K is a coefficient depending upon the specific resistance of the wire, At equals the ampere-turns desired, L_m equals the mean length per turn of wire in inches, and V equals the volts at the terminals of the coil. With the best commercial grade of magnet wire, K becomes unity at a temperature of about 140° Fahr., since the resistance per mil-foot of the wire at that temperature is 12 ohms. The resistances of wires given by Table I are based on this temperature. Table II has been calculated from the foregoing formula for this temperature.

From the first test made with the temporary winding the desired ampere-turns are obtained, and from Table II may be obtained the size of wire required to give the nearest number of ampere-turns per volt corresponding to this test and the proposed working voltage.

Table I. — Resistance of Magnet Wire at 140° Temperature, Fahrenheit.

Wire No.	Resistance per Foot.	Wire No.	Resistance per Foot.
4	0.0002875	19	0.009316
5	0.0003625	20	0.01176
6	0.0004571	21	0.014814
7	0.00057662	22	0.018691
8	0.0007268	23	0.023575
9	0.0009168	24	0.0297
10	0.001156	25	0.0375
11	0.0014575	26	0.04725
12	0.001838	27	0.05956
13	0.0023175	28	0.0751
14	0.002922	29	0.0947
15	0.003684	30	0.1194
16	0.004646	31	0.1506
17	0.00586	32	0.1899
18	0.007389	33	0.2395

The number of turns of wire in the test coil will, of course, be known, and the product of this number and the current, I_x, is the required exciting force in ampere-turns. The mean length per turn of wire in the permanent winding will be the same as that in the test winding, subject to minor corrections that may prove necessary in rounding out the final results. Tentatively, at least, the mean length, L_m, will be equal to

$$\frac{G_t + g}{2},$$

in which G_t is the girth of the test coil and g the girth of the bobbin or form in which it was wound. Having the ampere-turns required, the mean length per turn of wire and the voltage that will be applied to the terminals of the coil (or each coil, if there are more than one), the size of wire that must be used in the permanent winding is obtainable by the application of Table II. It may happen that none of the mean length values in the table will be found to correspond with that of the test winding; in that event, the nearest table value may be adopted and the mean length per turn of the permanent winding made to conform to this. In many cases it will be found that both the excitation per volt and the mean length per turn of the test winding will differ from all values in the table; in such a case, the nearest mean length value in the table should be adopted which gives the nearest excitation per volt *in excess* of the desired value.

The table is worked out on the assumption that any two wires drawn to B. & S. gauge and differing in size by ten gauge numbers will have cross-sectional areas differing in the ratio of 1 to 10.163 or 10.163 to 1, according to which wire is considered first.

As stated in the note at the foot of the table, the ampere-turns per volt in column *a* apply to the wire sizes in line *A* across the top of the table; the ampere-turns per volt in column *b* apply to the wire sizes in line *B*, and those in column *c*, to the wires in line *C*. Thus, if a coil wound with No. 8 wire has a mean length of 45.11 inches per turn, its exciting force will be 366 ampere-turns for each volt at its terminals; a coil of the same mean length but wound with No. 18 wire will have 36 ampere-turns per volt, while a coil of No. 28 wire with the same mean length per turn will yield only 3.54 ampere-turns per volt of applied E.M.F. The table is calculated on the basis of the wire sizes in line *B* and the ampere-turns per volt in column *b*, hence the latter values are not numbers from which decimals have been dropped, but are exact.

If the winding is to operate at constant potential, as most magnet windings do, the watts dissipated will be exactly proportional to the current passing, and this will be inversely proportional to the length of the coil parallel with the magnet core if the girth and temperature remain constant. The temperature will be unchanged, of course, the value I_h, of the current necessary to produce the working temperature having been ascertained by trial, as previously described. If the girth of the permanent winding cannot be made identical with that of the test winding, the correction in dimensions will be simple. First, the proper length on the hypothesis of unchanged girth must be determined. As the temperature of the coil is a function of the heat dissipated per unit of effective radiating surface, and the radiating surface is approximately proportional to the length of the coil parallel with the core (assuming the girth fixed), the heat dissipated per unit of surface will be approximately proportional inversely to the square of the coil length. Therefore, if the girth of the permanent winding were identical with that of the test winding, the proper length of the permanent coil would be given by the equation.

$$L_t \times \sqrt{\frac{I_x}{I_h}} = L_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which L_t is the length of the test coil and L_c the *calculated* length of the permanent coil on the basis of unchanged girth. Table III (divided into four sections, IIIa, IIIb, IIIc and IIId,) gives the corrected coil length, L_c, corresponding to a considerable practical range of test coil lengths, L_t, and ratios of I_x to I_h. If no correction in the mean length per turn

Table II. — Relation between Wire Size, Mean Length per Turn, and Ampere-Turns per Volt of Applied E.M.F.

			A 4	5	6	7	8	9	10	11	12	13
a	*b*	*c*	*B* 14	15	16	17	18	19	20	21	22	23
			C 24	25	26	27	28	29	30	31	32	33
203	20	1.97	205.3	162.9	129.1	102.4	81.2	64.4	51.1	40.5	32.12	25.48
213	21	2.07	198.8	155.1	122.9	97.52	77.33	61.34	48.66	38.57	30.59	24.26
224	22	2.16	186.7	148.1	117.4	93.1	73.82	58.55	46.45	36.82	29.19	23.14
234	23	2.26	178.6	141.6	112.3	89.04	70.6	56.	44.43	35.22	27.91	22.13
244	24	2.36	171.1	135.7	107.6	85.33	67.66	53.66	42.58	33.75	26.75	21.2
254	25	2.46	164.25	130.25	103.3	81.9	64.96	51.52	40.88	32.4	25.68	20.36
264	26	2.56	157.95	125.35	99.34	78.77	62.46	49.53	39.3	31.15	24.69	19.57
274	27	2.66	152.1	120.6	95.66	75.85	60.14	47.7	37.85	30.	23.77	18.85
285	28	2.75	146.66	116.3	92.25	73.15	58.	46.	36.5	28.95	22.92	18.17
295	29	2.85	141.62	112.3	89.	70.62	56.	44.4	35.24	27.93	22.13	17.55
305	30	2.95	136.9	108.55	86.1	68.26	54.13	42.93	34.06	27.	21.4	16.96
325	32	3.15	128.35	101.78	80.72	64.	50.75	40.25	31.93	25.31	20.06	15.9
346	34	3.34	120.8	95.8	75.97	60.24	47.76	37.88	30.05	23.82	18.88	14.97
366	36	3.54	114.	90.47	71.75	56.89	45.11	35.77	28.38	22.5	17.83	14.13
386	38	3.74	108.	85.71	67.97	53.9	42.73	33.89	26.89	21.31	16.89	13.39
407	40	3.94	102.67	81.43	64.58	51.2	40.6	32.2	25.55	20.25	16.05	12.72
427	42	4.13	97.78	77.55	61.5	48.76	38.66	30.66	24.33	19.28	15.28	12.11
447	44	4.33	93.34	74.02	58.7	46.54	36.91	29.27	23.22	18.41	14.59	11.56
468	46	4.53	89.28	70.8	56.15	44.52	35.3	28.	22.21	17.61	13.95	11.06
488	48	4.72	85.56	67.86	53.82	42.67	33.83	26.83	21.29	16.87	13.37	10.6

508	50	4.92	82.14	65.14	51.66	40.96	32.48	25.76	20.44	16.2	12.84	10.18
559	55	5.41	74.67	59.22	46.96	37.23	29.52	23.41	18.58	14.72	11.67	9.25
610	60	5.9	68.45	54.28	43.05	34.13	27.06	21.46	17.03	13.5	10.7	8.48
661	65	6.4	63.19	50.11	39.74	31.51	24.98	19.81	15.72	12.46	9.87	7.83
712	70	6.89	58.67	46.53	36.9	29.25	23.2	18.4	14.6	11.57	9.17	7.27
762	75	7.38	54.76	43.43	34.44	27.3	21.65	17.17	13.62	10.8	8.56	6.78
813	80	7.87	51.34	40.71	32.29	25.6	20.3	16.1	12.77	10.12	8.02	6.36
864	85	8.36	48.32	38.32	30.39	24.09	19.1	15.15	12.02	9.53	7.55	5.98
915	90	8.85	45.63	36.19	28.7	22.75	18.04	14.31	11.35	9.	7.13	5.65
965	95	9.35	43.23	34.28	27.19	21.56	17.09	13.55	10.75	8.52	6.75	5.35
1016	100	9.84	41.07	32.57	25.83	20.48	16.24	12.88	10.22	8.1	6.42	5.09
1118	110	10.82	37.33	29.61	23.48	18.62	14.76	11.71	9.29	7.36	5.83	4.63
1220	120	11.81	34.22	27.14	21.52	17.06	13.53	10.73	8.51	6.75	5.35	4.24
1321	130	12.79	31.59	25.05	19.87	15.75	12.49	9.91	7.86	6.23	4.94	3.91
1423	140	13.77	29.33	23.26	18.45	14.63	11.6	9.2	7.3	5.78	4.58	3.63
1525	150	14.76	27.38	21.71	17.22	13.65	10.82	8.58	6.81	5.4	4.28	3.39
1626	160	15.74	25.67	20.35	16.14	12.8	10.15	8.05	6.38	5.06	4.01	3.18
1728	170	16.73	24.16	19.16	15.19	12.04	9.55	7.57	6.01	4.76	3.77	2.99
1830	180	17.71	22.81	18.09	14.35	11.37	9.02	7.15	5.67	4.5	3.56	2.82
1931	190	18.70	21.61	17.14	13.59	10.78	8.54	6.78	5.38	4.26	3.38	2.67

The above numbers (in the body of the table) are mean lengths per turn, in inches.

NOTE. — The figures in lines *A*, *B*, and *C* at the heads of the columns are Wire Numbers, in B. & S. Gauge. Those in the columns *a*, *b*, and *c* are Ampere-Turns per Volt $(At \div V)$; the numbers in column *a* correspond to the wire sizes in line *A*; those in column *b* correspond to the wire sizes in line *B* and those in column *c* to the wires in line *C*.

is necessary, this set of tables will, of course, give the proper length, L, of the permanent coil, which in such cases is identical with L_c. If a correction in mean length is necessary and is such as to alter materially the girth of the coil, and, therefore, the radiating surface per unit of length, after making the correction in mean length as explained in a preceding paragraph, and ascertaining the calculated length of coil, L_c, by means of Table III, the final value for the length (L) of the permanent coil may be obtained by means of the formula

$$\frac{L_c \times G_t}{G} = L \quad \ldots\ldots\ldots\ldots (2)$$

G being the girth that the permanent coil will have after correcting the mean length per turn, and G_t the girth of the test coil.

For convenience in making corrections in the mean length per turn and the girth of the finished coil, Table IV (divided into IVa to IVe inclusive) has been prepared. This gives the depth of coil that will be obtained with different numbers of layers of the standard sizes of magnet wire, single and double cotton covered.

The table is based on the insulation thicknesses used by the Roebling factory, and while the coil depths are given to the second and third decimal places, it will, of course, be understood that this is not intended as an intimation that coils can be wound in practice to any such degree of accuracy, even if the insulation ran absolutely uniform always, which it does not do. The full figures are given in this, as in Tables I and II, merely in order that one may see what the exact theoretical values are. The table has not been made to include very small sizes of wire, for the reason that any approach to accuracy in calculations based on the insulated diameters of such wires is impossible.

For coils wound around a continuously convex surface, such as that of a bobbin for a round magnet core or one of oval cross section, the mean length per turn of wire is readily obtained by means of the formula

$$g + \pi d = L_m \quad \ldots\ldots\ldots\ldots (3)$$

in which g is the girth of the bobbin or former in which the coil is wound and d is the depth of the winding (in inch measure, or whatever unit of linear measurement may be used; not in layers). The girth of the coil will be obtainable by means of the formula

$$g + 2\pi d = G. \quad \ldots\ldots\ldots\ldots (4)$$

The mean length per turn in a coil wound on a bobbin of substantially rectangular cross section will be greater than the value given this formula on account of the bulging of the wire away from the core in the parts of the winding which cover the straight surfaces of the bobbin or former. This is also true, and to a greater extent, of the girths of the finished coil.

Table IIIa. — For correcting Length of Magnet Coil.

$\frac{Ix}{Ih}$	Length of Test Coil, *Lt*.											
	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞
.4	.95	1.03	1.11	1.19	1.27	1.35	1.43	1.5	1.58	1.66	1.74	1.82
.425	.98	1.06	1.14	1.22	1.31	1.39	1.47	1.55	1.63	1.71	1.8	1.87
.45	1.01	1.09	1.17	1.26	1.34	1.43	1.51	1.6	1.68	1.76	1.85	1.93
.475	1.03	1.12	1.21	1.29	1.38	1.47	1.55	1.64	1.72	1.81	1.9	1.98
.5	1.06	1.15	1.24	1.33	1.42	1.5	1.59	1.68	1.77	1.86	1.95	2.03
.525	1.09	1.18	1.27	1.36	1.45	1.54	1.63	1.72	1.81	1.9	1.99	2.08
.55	1.12	1.21	1.3	1.39	1.48	1.58	1.67	1.76	1.86	1.95	2.04	2.13
.575	1.14	1.23	1.33	1.42	1.52	1.61	1.71	1.8	1.9	1.99	2.09	2.18
.6	1.16	1.26	1.36	1.45	1.55	1.65	1.74	1.84	1.94	2.03	2.13	2.23
.625	1.18	1.29	1.38	1.48	1.58	1.68	1.78	1.88	1.98	2.08	2.17	2.27
.65	1.21	1.31	1.41	1.51	1.61	1.71	1.82	1.92	2.02	2.12	2.22	2.32
.675	1.23	1.34	1.44	1.54	1.64	1.75	1.85	1.95	2.05	2.16	2.26	2.36
.7	1.26	1.36	1.47	1.57	1.67	1.78	1.88	1.99	2.09	2.2	2.3	2.41
.725	1.28	1.38	1.49	1.6	1.7	1.81	1.92	2.02	2.13	2.24	2.34	2.45
.75	1.3	1.41	1.52	1.62	1.73	1.84	1.95	2.06	2.17	2.27	2.38	2.49
.8	1.34	1.46	1.57	1.68	1.79	1.9	2.01	2.13	2.24	2.35	2.46	2.57
.85	1.39	1.5	1.61	1.73	1.85	1.96	2.08	2.19	2.31	2.42	2.54	2.65
.9	1.42	1.54	1.66	1.78	1.9	2.02	2.14	2.25	2.37	2.49	2.61	2.73
.95	1.46	1.58	1.71	1.83	1.95	2.07	2.19	2.32	2.44	2.56	2.68	2.8
1.	1.5	1.63	1.75	1.88	2.	2.13	2.25	2.38	2.5	2.63	2.75	2.88
1.05	1.54	1.67	1.79	1.92	2.05	2.18	2.31	2.44	2.56	2.69	2.82	2.95
1.1	1.57	1.71	1.84	1.97	2.1	2.23	2.36	2.49	2.62	2.75	2.88	3.02
1.2	1.64	1.78	1.92	2.05	2.19	2.33	2.47	2.6	2.74	2.88	3.01	3.15
1.3	1.71	1.85	1.99	2.14	2.28	2.42	2.57	2.71	2.85	3.	3.14	3.28
1.4	1.78	1.92	2.07	2.22	2.37	2.51	2.66	2.81	2.96	3.11	3.25	3.4
1.5	1.84	1.99	2.14	2.3	2.45	2.6	2.76	2.91	3.06	3.22	3.37	3.52
1.6	1.9	2.06	2.21	2.37	2.53	2.69	2.85	3.01	3.16	3.32	3.48	3.64
1.7	1.96	2.12	2.28	2.45	2.61	2.77	2.93	3.1	3.26	3.42	3.59	3.75
1.8	2.01	2.18	2.35	2.52	2.68	2.85	3.02	3.19	3.35	3.52	3.69	3.86
1.9	2.07	2.24	2.41	2.59	2.76	2.93	3.1	3.27	3.45	3.62	3.79	3.96
2.	2.12	2.3	2.48	2.65	2.83	3.	3.18	3.36	3.54	3.71	3.89	4.07
2.1	2.17	2.36	2.54	2.72	2.9	3.08	3.26	3.44	3.62	3.81	3.99	4.17
2.2	2.23	2.41	2.6	2.78	2.97	3.15	3.34	3.52	3.71	3.89	4.08	4.27
2.3	2.28	2.47	2.65	2.84	3.03	3.22	3.41	3.6	3.79	3.98	4.17	4.36
2.4	2.32	2.52	2.71	2.91	3.1	3.29	3.49	3.68	3.87	4.07	4.26	4.46

The above numbers (in the body of the table) are corrected lengths, *Lc*.

Table IIIb.—For correcting Length of Magnet Coil.

$\frac{Ix}{Ih}$	Length of Test Coil, *Lt.*											
	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜
.4	1.9	1.98	2.06	2.14	2.22	2.3	2.37	2.45	2.53	2.61	2.69	2.77
.425	1.96	2.04	2.12	2.2	2.28	2.36	2.45	2.53	2.61	2.69	2.77	2.85
.45	2.01	2.1	2.18	2.26	2.35	2.43	2.52	2.6	2.68	2.77	2.85	2.94
.475	2.07	2.15	2.24	2.33	2.41	2.5	2.58	2.67	2.76	2.84	2.93	3.02
.5	2.12	2.21	2.3	2.39	2.48	2.56	2.65	2.74	2.83	2.92	3.01	3.09
.525	2.18	2.26	2.36	2.45	2.54	2.63	2.72	2.81	2.9	2.99	3.08	3.17
.55	2.23	2.32	2.41	2.5	2.60	2.69	2.78	2.87	2.97	3.06	3.15	3.23
.575	2.28	2.37	2.46	2.56	2.65	2.75	2.84	2.94	3.03	3.13	3.22	3.31
.6	2.32	2.42	2.52	2.62	2.71	2.81	2.91	3.	3.1	3.2	3.29	3.39
.625	2.37	2.47	2.57	2.67	2.77	2.87	2.97	3.06	3.16	3.26	3.36	3.46
.65	2.42	2.52	2.62	2.72	2.82	2.92	3.02	3.13	3.23	3.33	3.43	3.53
.675	2.46	2.57	2.67	2.77	2.88	2.98	3.08	3.19	3.29	3.39	3.49	3.59
.7	2.51	2.62	2.72	2.82	2.93	3.03	3.14	3.24	3.35	3.45	3.56	3.66
.725	2.56	2.66	2.77	2.87	2.98	3.09	3.19	3.3	3.41	3.51	3.62	3.73
.75	2.6	2.71	2.81	2.92	3.03	3.14	3.25	3.36	3.46	3.57	3.68	3.79
.8	2.68	2.8	2.91	3.02	3.13	3.24	3.35	3.47	3.58	3.69	3.8	3.91
.85	2.77	2.88	3.	3.11	3.23	3.34	3.46	3.57	3.69	3.81	3.92	4.03
.9	2.84	2.97	3.09	3.2	3.32	3.44	3.56	3.68	3.8	3.91	4.03	4.15
.95	2.92	3.05	3.17	3.29	3.41	3.53	3.66	3.78	3.9	4.02	4.14	4.26
1.	3.	3.13	3.25	3.38	3.5	3.63	3.75	3.88	4.	4.13	4.25	4.38
1.05	3.07	3.2	3.33	3.46	3.59	3.72	3.84	3.97	4.1	4.23	4.36	4.48
1.1	3.14	3.28	3.41	3.54	3.67	3.8	3.93	4.06	4.2	4.33	4.46	4.59
1.15	3.21	3.35	3.49	3.62	3.75	3.89	4.02	4.16	4.29	4.42	4.56	4.69
1.2	3.28	3.44	3.58	3.72	3.85	3.99	4.13	4.27	4.4	4.54	4.68	4.82
1.25	3.35	3.49	3.63	3.77	3.91	4.05	4.19	4.33	4.47	4.61	4.75	4.89
1.3	3.42	3.56	3.71	3.85	3.99	4.13	4.28	4.42	4.56	4.7	4.85	4.99
1.35	3.49	3.68	3.78	3.92	4.07	4.21	4.36	4.5	4.65	4.79	4.94	5.08
1.4	3.55	3.7	3.85	3.99	4.14	4.29	4.44	4.59	4.73	4.88	5.03	5.18
1.45	3.61	3.76	3.91	4.07	4.22	4.37	4.52	4.67	4.82	4.97	5.12	5.27
1.5	3.67	3.83	3.98	4.13	4.29	4.44	4.59	4.75	4.9	5.05	5.21	5.36
1.6	3.85	3.95	4.11	4.27	4.43	4.59	4.75	4.9	5.06	5.22	5.38	5.53
1.7	3.91	4.08	4.24	4.4	4.56	4.73	4.89	5.05	5.22	5.38	5.54	5.71
1.8	4.02	4.19	4.36	4.53	4.7	4.86	5.03	5.2	5.37	5.54	5.7	5.87
1.9	4.14	4.31	4.48	4.65	4.83	5.	5.17	5.34	5.51	5.69	5.86	6.03
2.	4.25	4.42	4.6	4.77	4.95	5.13	5.31	5.48	5.66	5.83	6.01	6.19

The above numbers (in the body of the table) are corrected lengths, *Lc.*

Table IIIc.—For correcting Length of Magnet Coil.

$\frac{Ix}{Ih}$	Length of Test Coil, *Lt.*											
	4½	4⅝	4¾	4⅞	5	5⅛	5¼	5⅜	5½	5⅝	5¾	5⅞
.5	3.18	3.27	3.36	3.45	3.54	3.62	3.71	3.8	3.89	3.98	4.07	4.16
.525	3.26	3.35	3.44	3.53	3.62	3.71	3.81	3.9	3.99	4.08	4.17	4.26
.55	3.34	3.43	3.52	3.62	3.71	3.8	3.9	3.99	4.08	4.17	4.27	4.36
.575	3.41	3.51	3.6	3.7	3.79	3.89	3.98	4.08	4.17	4.27	4.36	4.46
.6	3.49	3.58	3.68	3.78	3.87	3.97	4.07	4.16	4.26	4.36	4.46	4.55
.625	3.56	3.66	3.76	3.86	3.95	4.05	4.15	4.25	4.35	4.45	4.55	4.65
.65	3.63	3.73	3.83	3.93	4.03	4.13	4.23	4.33	4.43	4.54	4.64	4.74
.675	3.7	3.8	3.9	4.01	4.11	4.21	4.31	4.42	4.52	4.62	4.72	4.83
.7	3.77	3.87	3.97	4.08	4.18	4.29	4.39	4.5	4.6	4.71	4.81	4.92
.725	3.83	3.94	4.04	4.15	4.26	4.37	4.47	4.58	4.68	4.79	4.9	5.0
.75	3.9	4.01	4.11	4.22	4.33	4.44	4.55	4.66	4.76	4.87	4.98	5.09
.775	4.01	4.07	4.18	4.29	4.4	4.51	4.62	4.73	4.84	4.95	5.06	5.17
.8	4.03	4.14	4.25	4.36	4.47	4.58	4.7	4.81	4.92	5.03	5.14	5.25
.825	4.09	4.2	4.32	4.43	4.54	4.66	4.77	4.88	5.	5.11	5.22	5.34
.85	4.15	4.27	4.38	4.5	4.61	4.73	4.84	4.96	5.07	5.19	5.3	5.42
.875	4.21	4.33	4.44	4.56	4.68	4.8	4.91	5.03	5.15	5.26	5.38	5.5
.9	4.27	4.39	4.51	4.63	4.74	4.86	4.98	5.1	5.22	5.34	5.46	5.57
.925	4.33	4.45	4.57	4.69	4.81	4.93	5.05	5.17	5.29	5.41	5.53	5.65
.95	4.39	4.51	4.63	4.75	4.87	5.	5.12	5.24	5.36	5.48	5.61	5.73
1.	4.5	4.63	4.75	4.88	5.	5.13	5.25	5.38	5.5	5.63	5.75	5.88
1.05	4.61	4.74	4.87	5.	5.12	5.25	5.38	5.51	5.64	5.76	5.89	6.02
1.1	4.72	4.85	4.98	5.11	5.25	5.38	5.51	5.64	5.77	5.9	6.03	6.16
1.15	4.83	4.96	5.09	5.23	5.36	5.5	5.63	5.76	5.9	6.03	6.17	6.3
1.2	4.96	5.07	5.2	5.34	5.48	5.61	5.75	5.89	6.03	6.16	6.3	6.44
1.25	5.03	5.17	5.31	5.45	5.59	5.73	5.87	6.01	6.15	6.29	6.43	6.57
1.3	5.13	5.27	5.42	5.56	5.7	5.84	5.99	6.13	6.27	6.41	6.56	6.7
1.35	5.23	5.37	5.52	5.67	5.81	5.96	6.1	6.25	6.39	6.54	6.68	6.83
1.4	5.33	5.47	5.62	5.77	5.92	6.07	6.21	6.36	6.51	6.66	6.81	6.95
1.45	5.42	5.57	5.72	5.87	6.02	6.17	6.32	6.47	6.62	6.77	6.93	7.08
1.5	5.51	5.67	5.82	5.97	6.12	6.28	6.43	6.58	6.74	6.89	7.04	7.2
1.55	5.6	5.76	5.91	6.07	6.23	6.38	6.54	6.69	6.85	7.	7.16	7.32
1.6	5.69	6.85	6.01	6.17	6.33	6.48	6.64	6.8	6.96	7.12	7.27	7.43
1.65	5.78	5.94	6.1	6.26	6.42	6.58	6.74	6.91	7.07	7.23	7.39	7.55
1.7	5.87	6.03	6.19	6.36	6.52	6.68	6.85	7.01	7.17	7.33	7.5	7.66
1.75	5.96	6.12	6.28	6.45	6.61	6.78	6.95	7.11	7.28	7.44	7.61	7.77
1.8	6.04	6.21	6.37	6.54	6.71	6.88	7.05	7.21	7.38	7.55	7.72	7.88
1.85	6.12	6.29	6.46	6.63	6.8	6.97	7.14	7.31	7.48	7.65	7.82	7.99
1.9	6.2	6.38	6.55	6.72	6.89	7.07	7.24	7.41	7.58	7.75	7.93	8.1
1.95	6.28	6.46	6.63	6.81	6.98	7.16	7.33	7.51	7.68	7.86	8.03	8.21
2.	6.37	6.54	6.72	6.9	7.07	7.25	7.42	7.6	7.78	7.96	8.13	8.31

The above numbers (in the body of the table) are corrected lengths, *Lc*.

Table IIId. — For correcting Length of Magnet Coil.

$\frac{Ix}{Ih}$	Length of Test Coil, *Lt.*											
	6	6⅛	6¼	6⅜	6½	6⅝	6¾	6⅞	7	7⅛	7¼	7⅜
.5	4.24	4.33	4.44	4.51	4.6	4.69	4.77	4.86	4.95	5.04	5.13	5.22
.525	4.35	4.44	4.53	4.62	4.71	4.8	4.89	4.98	5.07	5.16	5.25	5.34
.55	4.45	4.54	4.64	4.73	4.82	4.91	5.01	5.1	5.19	5.29	5.38	5.47
.575	4.55	4.65	4.74	4.83	4.93	5.02	5.12	5.21	5.31	5.4	5.5	5.59
.6	4.65	4.75	4.84	4.94	5.04	5.13	5.23	5.33	5.42	5.52	5.62	5.71
.625	4.75	4.84	4.94	5.04	5.14	5.24	5.34	5.44	5.53	5.63	5.73	5.83
.65	4.84	4.94	5.04	5.14	5.24	5.34	5.44	5.54	5.64	5.75	5.85	5.95
.675	4.93	5.03	5.14	5.24	5.34	5.44	5.55	5.65	5.75	5.85	5.96	6.06
.7	5.02	5.13	5.23	5.33	5.44	5.54	5.65	5.75	5.86	5.96	6.07	6.17
.725	5.11	5.22	5.32	5.43	5.53	5.64	5.75	5.86	5.96	6.07	6.17	6.28
.75	5.2	5.3	5.41	5.52	5.63	5.74	5.85	5.95	6.06	6.17	6.28	6.39
.775	5.28	5.39	5.5	5.61	5.72	5.83	5.94	6.05	6.16	6.27	6.39	6.49
.8	5.37	5.48	5.59	5.7	5.81	5.93	6.04	6.15	6.26	6.37	6.49	6.6
.825	5.45	5.56	5.68	5.79	5.91	6.02	6.13	6.25	6.36	6.47	6.59	6.7
.85	5.53	5.65	5.76	5.88	5.99	6.11	6.22	6.34	6.45	6.57	6.69	6.8
.875	5.61	5.73	5.85	5.96	6.08	6.2	6.31	6.43	6.55	6.67	6.78	6.9
.9	5.69	5.81	5.93	6.05	6.17	6.29	6.4	6.52	6.64	6.75	6.88	7.
.925	5.77	5.89	6.01	6.13	6.25	6.37	6.49	6.61	6.73	6.85	6.97	7.09
.95	5.85	5.97	6.09	6.21	6.34	6.46	6.58	6.7	6.82	6.95	7.07	7.19
1.	6.	6.13	6.25	6.38	6.5	6.63	6.75	6.88	7.	7.13	7.25	7.38
1.05	6.15	6.28	6.41	6.53	6.66	6.79	6.92	7.05	7.17	7.3	7.43	7.56
1.1	6.29	6.43	4.56	6.69	6.82	6.95	7.08	7.21	7.34	7.47	7.61	7.74
1.15	6.44	6.57	6.7	6.84	6.97	7.11	7.24	7.37	7.51	7.64	7.78	7.91
1.2	6.57	6.71	6.85	6.99	7.12	7.26	7.39	7.53	7.67	7.81	7.94	8.08
1.25	6.71	6.85	6.99	7.13	7.27	7.41	7.55	7.69	7.83	7.97	8.11	8.25
1.3	6.84	6.98	7.13	7.27	7.41	7.55	7.7	7.84	7.98	8.13	8.27	8.41
1.35	6.97	7.12	7.26	7.41	7.55	7.7	7.84	7.99	8.13	8.28	8.43	8.57
1.4	7.1	7.25	7.4	7.54	7.69	7.84	7.99	8.13	8.28	8.43	8.58	8.73
1.45	7.23	7.38	7.53	7.68	7.83	7.98	8.13	8.28	8.43	8.58	8.73	8.88
1.5	7.35	7.5	7.66	7.81	7.96	8.11	8.27	8.42	8.57	8.73	8.88	9.03
1.55	7.47	7.63	7.78	7.94	8.09	8.25	8.4	8.56	8.72	8.87	9.03	9.18
1.6	7.59	7.75	7.91	8.07	8.22	8.38	8.54	8.7	8.86	9.01	9.17	9.33
1.65	7.71	7.87	8.03	8.19	8.35	8.51	8.67	8.83	8.99	9.15	9.31	9.47
1.7	7.82	7.99	8.15	8.31	8.48	8.64	8.8	8.96	9.13	9.29	9.45	9.62
1.75	7.94	8.1	8.27	8.43	8.6	8.77	8.93	9.09	9.26	9.43	9.59	9.76
1.8	8.05	8.22	8.39	8.55	8.72	8.89	9.06	9.22	9.39	9.56	9.73	9.9
1.85	8.16	8.33	8.5	8.67	8.84	9.01	9.18	9.35	9.52	9.69	9.86	10.03
1.9	8.27	8.44	8.62	8.79	8.96	9.13	9.3	9.48	9.65	9.82	9.99	10.17
1.95	8.38	8.55	8.73	8.9	9.08	9.25	9.43	9.6	9.78	9.95	10.13	10.3
2.	8.49	8.66	8.84	9.02	9.19	9.37	9.55	9.72	9.9	10.08	10.25	10.43

The above numbers (in the body of the table) are corrected lengths, *Lc.*

Table IVa.—Linear Space occupied by Single Cotton-Covered Wires.

Turns or Layers.	Wire Numbers, B. & S. Gauge:										
	4	5	6	7	8	9	10	11	12	13	14
2 . .	0.432	0.388	0.344	0.308	0.274	0.244	0.216	0.194	0.174	0.16	0.14
3 . .	0.648	0.582	0.516	0.462	0.411	0.366	0.324	0.291	0.261	0.24	0.21
4 . .	0.864	0.776	0.688	0.616	0.548	0.488	0.432	0.388	0.348	0.31	0.28
5 . .	1.08	0.97	0.86	0.77	0.685	0.61	0.54	0.485	0.435	0.39	0.35
6 . .	1.296	1.164	1.032	0.924	0.822	0.732	0.648	0.582	0.522	0.47	0.42
7 . .	1.512	1.358	1.204	1.078	0.959	0.854	0.756	0.679	0.609	0.55	0.49
8 . .	1.728	1.552	1.376	1.232	1.096	0.976	0.864	0.776	0.696	0.63	0.56
9 . .	1.994	1.746	1.548	1.386	1.233	1.098	0.972	0.873	0.783	0.70	0.63
10 . .	2.16	1.94	1.72	1.54	1.37	1.22	1.08	0.97	0.87	0.78	0.7
11 . .	2.38	2.14	1.89	1.69	1.51	1.34	1.19	1.07	0.96	0.86	0.77
12 . .	2.59	2.33	2.07	1.85	1.64	1.47	1.3	1.17	1.05	0.94	0.84
13 . .	2.81	2.52	2.24	2.	1.78	1.59	1.41	1.26	1.13	1.02	0.91
14 . .	3.03	2.72	2.41	2.16	1.92	1.71	1.51	1.36	1.22	1.09	.98
15 . .	3.24	2.91	2.58	2.31	2.06	1.83	1.62	1.46	1.31	1.17	1.05
16 . .	3.46	3.11	2.75	2.47	2.19	1.95	1.73	1.55	1.39	1.25	1.12
17 . .	3.67	3.3	2.93	2.62	2.33	2.06	1.84	1.65	1.48	1.33	1.19
18 . .	3.89	3.49	3.1	2.77	2.47	2.2	1.95	1.75	1.57	1.44	1.26
19 . .	4.11	3.69	3.27	2.93	2.61	2.32	2.05	1.85	1.66	1.48	1.33
20 . .	4.32	3.88	3.44	3.08	2.74	2.44	2.16	1.94	1.74	1.56	1.4
21 . .	4.53	4.07	3.61	3.24	2.88	2.56	2.27	2.04	1.83	1.64	1.47
22 . .	4.75	4.27	3.78	3.39	3.02	2.69	2.38	2.14	1.92	1.72	1.54
23 . .	4.97	4.46	3.95	3.54	3.15	2.81	2.49	2.23	2.	1.8	1.61
24 . .	...	4.65	4.125	3.69	3.29	2.93	2.59	2.33	2.09	1.87	1.68
25 . .	...	4.85	4.3	3.85	3.43	3.05	2.7	2.43	2.18	1.95	1.75
26 . .	...	5.05	4.47	4.	3.56	3.17	2.81	2.52	2.26	2.03	1.82
27 . .	...	...	4.64	4.16	3.7	3.29	2.92	2.62	2.35	2.11	1.89
28 . .	...	...	4.81	4.31	3.83	3.41	3.03	2.72	2.44	2.19	1.96
29 . .	...	...	4.98	4.46	3.97	3.54	3.13	2.82	2.53	2.26	2.03
30 . .	...	...	5.16	4.62	4.11	3.66	3.24	2.91	2.61	2.34	2.1
31 . .	...	...	...	4.77	4.25	3.78	3.35	3.	2.7	2.42	2.17
32 . .	...	...	...	4.93	4.38	3.9	3.45	3.1	2.79	2.5	2.24
33 . .	...	...	...	5.08	4.52	4.02	3.56	3.2	2.87	2.58	2.31
34 . .	...	...	...	...	4.65	4.14	3.67	3.29	2.96	2.65	2.38
35 . .	...	...	...	...	4.79	4.27	3.78	3.39	3.04	2.73	2.45
36 . .	...	...	...	...	4.93	4.39	3.89	3.49	3.13	2.81	2.52
37 . .	...	...	...	...	5.07	4.51	3.99	3.59	3.22	2.89	2.59
38 . .	...	...	...	...	...	4.63	4.1	3.68	3.3	2.97	2.66
39 . .	...	...	...	...	...	4.76	4.21	3.78	3.39	3.04	2.73
40 . .	...	...	...	...	...	4.88	4.32	3.88	3.48	3.12	2.8
41 . .	...	...	...	...	...	5.	4.42	3.97	3.56	3.2	2.87
42 . .	. .	...	...	...	...	...	4.53	4.07	3.65	3.27	2.94
43 . .	...	...	...	...	...	...	4.64	4.17	3.74	3.35	3.01
44 . .	...	...	...	...	...	...	4.75	4.27	3.83	3.43	3.08
45 . .	...	...	...	...	...	...	4.86	4.36	3.91	3.51	3.15
46 . .	...	...	...	...	...	...	4.97	4.46	4.	3.59	3.22
47 . .	...	...	...	...	...	...	...	4.56	4.09	3.66	3.29
48 . .	...	...	...	...	...	...	...	4.66	4.18	3.74	3.36
49 . .	...	...	...	...	...	...	...	4.76	4.27	3.82	3.43
50 . .	...	...	...	...	...	...	...	4.85	4.35	3.95	3.5
52 . .	...	...	...	...	...	...	...	...	4.52	4.06	3.64
54 . .	...	...	...	...	...	...	...	...	4.7	4.22	3.78
56 . .	...	...	...	...	...	...	...	...	4.87	4.37	3.92
58 . .	...	...	...	...	...	...	...	...	...	4.52	4.06
60 . .	...	...	...	...	...	...	...	...	...	4.68	4.2
62 . .	...	...	...	...	...	...	...	...	...	...	4.34
64 . .	...	...	...	...	...	...	...	...	...	...	4.48

TABLE IVb.—Linear Space occupied by Single Cotton-Covered Wires.

Turns or Layers.	Wire Numbers, B. & S. Gauge:									
	15	16	17	18	19	20	21	22	23	24
6	0.38	0.34	0.31	0.28	0.25	0.23	0.2	0.19	0.17	0.15
7	0.44	0.4	0.36	0.32	0.29	0.27	0.24	0.22	0.2	0.17
8	0.5	0.46	0.41	0.37	0.34	0.3	0.27	0.25	0.22	0.2
9	0.57	0.51	0.46	0.41	0.38	0.34	0.31	0.28	0.25	0.22
10	0.63	0.57	0.51	0.46	0.42	0.38	0.34	0.31	0.28	0.25
11	0.69	0.63	0.56	0.51	0.46	0.42	0.37	0.34	0.31	0.27
12	0.75	0.68	0.61	0.55	0.5	0.46	0.41	0.37	0.34	0.3
13	0.82	0.74	0.66	0.6	0.55	0.49	0.44	0.4	0.36	0.33
14	0.88	0.8	0.71	0.64	0.59	0.53	0.48	0.43	0.39	0.35
15	0.95	0.85	0.76	0.69	0.63	0.57	0.51	0.46	0.42	0.38
16	1.01	0.91	0.82	0.74	0.67	0.61	0.54	0.5	0.45	0.4
17	1.07	0.97	0.87	0.78	0.72	0.65	0.58	0.53	0.48	0.42
18	1.13	1.03	0.92	0.83	0.76	0.68	0.61	0.56	0.5	0.45
19	1.2	1.08	0.97	0.87	0.8	0.72	0.65	0.59	0.53	0.47
20	1.26	1.14	1.02	0.92	0.84	0.76	0.68	0.62	0.56	0.5
21	1.32	1.2	1.07	0.97	0.88	0.8	0.71	0.65	0.59	0.52
22	1.39	1.25	1.12	1.01	0.92	0.84	0.75	0.68	0.62	0.55
23	1.45	1.31	1.17	1.06	0.97	0.87	0.78	0.71	0.64	0.57
24	1.51	1.37	1.22	1.1	1.01	0.91	0.82	0.74	0.67	0.6
25	1.57	1.42	1.27	1.15	1.05	0.95	0.85	0.78	0.7	0.62
26	1.64	1.48	1.33	1.2	1.09	0.99	0.88	0.81	0.73	0.65
27	1.7	1.54	1.38	1.24	1.13	1.03	0.92	0.84	0.76	0.67
28	1.76	1.6	1.43	1.29	1.18	1.06	0.95	0.87	0.78	0.7
29	1.83	1.65	1.48	1.33	1.22	1.1	0.99	0.9	0.81	0.72
30	1.89	1.71	1.53	1.38	1.26	1.14	1.02	0.93	0.84	0.75
31	1.95	1.77	1.58	1.43	1.3	1.18	1.05	0.96	0.87	0.77
32	2.02	1.82	1.63	1.47	1.34	1.22	1.09	0.99	0.9	0.8
33	2.08	1.88	1.68	1.52	1.39	1.25	1.12	1.02	0.93	0.82
34	2.14	1.94	1.73	1.56	1.43	1.29	1.16	1.05	0.95	0.85
35	2.2	2.	1.78	1.61	1.47	1.33	1.19	1.08	0.98	0.87
36	2.27	2.05	1.84	1.66	1.51	1.37	1.22	1.12	1.01	0.9
37	2.33	2.11	1.89	1.7	1.55	1.41	1.26	1.15	1.04	0.92
38	2.39	2.17	1.94	1.75	1.6	1.44	1.29	1.18	1.06	0.95
39	2.46	2.22	1.99	1.79	1.64	1.48	1.33	1.21	1.09	0.97
40	2.52	2.28	2.04	1.84	1.68	1.52	1.36	1.24	1.12	1.
41	2.58	2.34	2.09	1.89	1.72	1.56	1.39	1.27	1.15	1.02
42	2.65	2.39	2.14	1.93	1.76	1.6	1.43	1.3	1.18	1.05
43	2.71	2.45	2.19	1.98	1.81	1.63	1.46	1.33	1.2	1.07
44	2.77	2.51	2.24	2.02	1.85	1.67	1.5	1.36	1.23	1.1
45	2.83	2.56	2.29	2.07	1.89	1.71	1.53	1.39	1.26	1.12
46	2.9	2.62	2.35	2.12	1.93	1.75	1.56	1.43	1.29	1.15
47	2.96	2.68	2.4	2.16	1.97	1.79	1.6	1.46	1.32	1.17
48	3.02	2.73	2.45	2.21	2.02	1.82	1.63	1.49	1.34	1.2
49	3.09	2.79	2.5	2.25	2.06	1.86	1.67	1.52	1.37	1.22
50	3.15	2.85	2.55	2.3	2.1	1.9	1.7	1.55	1.4	1.25
52	3.27	2.96	2.65	2.39	2.18	1.98	1.77	1.61	1.46	1.3
54	3.4	3.08	2.75	2.48	2.27	2.05	1.84	1.67	1.51	1.35
56	3.53	3.19	2.86	2.58	2.35	2.13	1.9	1.74	1.57	1.4
58	3.65	3.31	2.96	2.67	2.44	2.2	1.97	1.8	1.62	1.45
60	3.78	3.42	3.06	2.76	2.52	2.28	2.04	1.86	1.68	1.5
62	3.91	3.53	3.16	2.85	2.6	2.36	2.11	1.92	1.74	1.55
64	4.03	3.65	3.26	2.94	2.69	2.43	2.18	1.98	1.79	1.6
66	4.16	3.76	3.37	3.04	2.77	2.51	2.24	2.05	1.85	1.65
68	4.28	3.88	3.47	3.13	2.86	2.58	2.31	2.11	1.9	1.7
70	4.41	3.99	3.57	3.22	2.94	2.66	2.38	2.17	1.96	1.75

Table IVc.—Linear Space occupied by Single Cotton-Covered Wires.

Turns or Layers.	Wire Numbers, B. & S. Gauge:							
	17	18	19	20	21	22	23	24
72	3.67	3.31	3.02	2.74	2.45	2.23	2.02	1.8
74	3.77	3.4	3.11	2.81	2.52	2.29	2.07	1.85
76	3.88	3.5	3.19	2.89	2.58	2.36	2.13	1.9
78	3.98	3.58	3.28	2.96	2.65	2.42	2.18	1.95
80	4.08	3.68	3.36	3.04	2.72	2.48	2.24	2.
82	4.18	3.77	3.44	3.12	2.79	2.54	2.3	2.05
84	4.28	3.86	3.53	3.19	2.86	2.6	2.35	2.1
86	4.39	3.96	3.61	3.27	2.92	2.67	2.41	2.15
88	4.49	4.05	3.7	3.34	2.99	2.73	2.46	2.2
90	4.59	4.14	3.78	3.42	3.06	2.79	2.52	2.25
92	....	4.23	3.86	3.5	3.13	2.85	2.58	2.3
94	....	4.32	3.95	3.57	3.2	2.91	2.63	2.35
96	....	4.42	4.03	3.65	3.26	2.98	2.69	2.4
98	....	4.51	4.12	3.72	3.33	3.04	2.74	2.45
100	....	4.6	4.2	3.8	3.4	3.1	2.8	2.5
102	....	....	4.28	3.88	3.47	3.16	2.86	2.55
104	....	....	4.37	3.95	3.54	3.22	2.91	2.6
106	....	....	4.45	4.03	3.6	3.29	2.97	2.65
108	....	....	4.54	4.1	3.67	3.35	3.02	2.7
110	....	....	....	4.18	3.74	3.41	3.08	2.75
112	....	....	....	4.26	3.81	3.47	3.14	2.8
114	....	....	....	4.33	3.88	3.53	3.19	2.85
116	....	....	....	4.41	3.94	3.6	3.25	2.9
118	....	....	....	4.48	4.01	3.66	3.3	2.95
120	....	....	....	4.56	4.08	3.72	3.36	3.

Table IVd.—Linear Space occupied by Double Cotton-Covered Wires.

Turns or Layers.	Wire Numbers, B. & S. Gauge:										
	4	5	6	7	8	9	10	11	12	13	14
2. . .	0.444	0.4	0.356	0.32	0.284	0.252	0.224	0.202	0.182	0.16	0.15
3. . .	0.666	0.6	0.534	0.48	0.426	0.378	0.336	0.303	0.273	0.24	0.22
4. . .	0.888	0.8	0.712	0.64	0.568	0.504	0.448	0.404	0.364	0.32	0.29
5. . .	1.11	1.	0.89	0.8	0.71	0.63	0.56	0.505	0.455	0.4	0.36
6. . .	1.332	1.2	1.068	0.96	0.852	0.756	0.672	0.606	0.546	0.49	0.44
7. . .	1.554	1.4	1.246	1.12	0.994	0.882	0.784	0.707	0.637	0.57	0.51
8. . .	1.776	1.6	1.424	1.28	1.136	1.008	0.896	0.808	0.728	0.65	0.58
9. . .	1.998	1.8	1.602	1.44	1.278	1.134	1.008	0.909	0.819	0.73	0.66
10. . .	2.22	2.	1.78	1.6	1.42	1.26	1.12	1.01	0.91	0.81	0.73
11. . .	2.442	2.2	1.958	1.76	1.562	1.386	1.232	1.111	1.001	0.89	0.8

Table IVd. — Linear Space occupied by Double Cotton-Covered Wires. — *Continued.*

Turns or Layers.	Wire Numbers, B. & S. Gauge: 4	5	6	7	8	9	10	11	12	13	14
12. . .	2.664	2.4	2.136	1.92	1.704	1.512	1.344	1.212	1.092	0.97	0.88
13. . .	2.886	2.6	2.314	2.08	1.846	1.638	1.456	1.313	1.183	1.05	0.95
14. . .	3.108	2.8	2.492	2.24	1.988	1.764	1.568	1.414	1.274	1.13	1.02
15. . .	3.33	3.	2.67	2.4	2.13	1.89	1.68	1.51	1.36	1.21	1.1
16. . .	3.55	3.2	2.85	2.56	2.27	2.01	1.79	1.62	1.46	1.3	1.17
17. . .	3.77	3.4	3.03	2.72	2.41	2.14	1.9	1.72	1.55	1.38	1.24
18. . .	4.	3.6	3.2	2.88	2.56	2.27	2.02	1.82	1.64	1.46	1.31
19. . .	4.22	3.8	3.38	3.04	2.77	2.39	2.13	1.92	1.73	1.54	1.39
20 . .	4.44	4.	3.56	3.2	2.84	2.52	2.24	2.02	1.82	1.62	1.46
21. . .	4.66	4.2	3.74	3.36	2.98	2.65	2.35	2.12	1.91	1.7	1.53
22. . .	4.88	4.4	3.92	3.52	3.12	2.77	2.46	2.22	2.	1.78	1.61
23. . .	...	4.6	4.09	3.68	3.27	2.9	2.58	2.32	2.09	1.86	1.68
24. . .	...	4.8	4.27	3.84	3.41	3.02	2.69	2.42	2.18	1.94	1.75
25. . .	...	5.	4.45	4.	3.55	3.15	2.8	2.53	2.28	2.03	1.83
26. . .	...	...	4.63	4.16	3.69	3.28	2.91	2.63	2.37	2.11	1.9
27. . .	...	...	4.81	4.32	3.83	3.4	3.02	2.73	2.46	2.19	1.97
28. . .	...	...	4.98	4.48	3.98	3.53	3.14	2.83	2.55	2.27	2.04
29. . .	...	...	...	4.64	4.12	3.65	3.25	2.93	2.64	2.35	2.12
30. . .	...	...	...	4.8	4.2	3.78	3.36	3.03	2.73	2.43	2.19
31. . .	...	...	...	4.96	4.4	3.91	3.47	3.13	2.82	2.51	2.26
32. . .	...	...	...	...	4.54	4.03	3.58	3.23	2.91	2.59	2.34
33. . .	...	...	...	...	4.6	4.16	3.7	3.33	3.	2.67	2.41
34. . .	...	...	...	...	4.8	4.28	3.81	3.43	3.09	2.75	2.48
35. . .	...	...	...	...	4.97	4.41	3.92	3.54	3.19	2.84	2.56
36. . .	...	...	...	...	...	4.54	4.03	3.64	3.28	2.92	2.63
37. . .	...	...	...	...	...	4.66	4.14	3.74	3.37	3.	2.7
38. . .	...	...	...	...	...	4.79	4.26	3.84	3.46	3.08	2.77
39. . .	...	...	...	...	...	4.91	4.37	3.94	3.55	3.16	2.85
40. . .	...	...	...	...	...	5.04	4.48	4.04	3.64	3.24	2.92
41. . .	...	...	...	...	...	...	4.59	4.14	3.73	3.32	2.99
42. . .	...	...	...	...	...	...	4.7	4.24	3.82	3.4	3.07
43. . .	...	...	...	...	...	...	4.82	4.34	3.91	3.48	3.14
44. . .	...	...	...	...	...	...	4.93	4.44	4.	3.56	3.21
45. . .	...	...	...	...	...	...	5.04	4.55	4.1	3.65	3.29
46. . .	...	...	...	...	...	...	...	4.65	4.19	3.73	3.36
47. . .	...	...	...	...	...	...	...	4.75	4.28	3.81	3.43
48. . .	...	...	...	...	...	...	...	4.85	4.37	3.89	3.5
49. . .	...	...	...	...	...	...	...	...	4.46	3.97	3.58
50. . .	...	...	...	...	...	...	...	...	4.55	4.05	3.65
52. . .	...	...	...	...	...	...	...	...	4.73	4.21	3.82
54. . .	...	...	...	...	...	...	...	...	4.91	4.37	3.94
56. . .	...	...	...	...	...	...	...	...	...	4.54	4.09
58. . .	...	...	...	...	...	...	...	...	...	4.7	4.23
60. . .	...	...	...	...	...	...	...	...	...	4.86	4.38
62. . .	...	...	...	...	...	...	...	...	...	..	4.53

Table IVe.—Linear Space occupied by Double Cotton-Covered Wires.

Turns or Layers.	Wire Numbers, B. and S. Gauge:									
	15	16	17	18	19	20	21	22	23	24
7	0.46	0.42	0.38	0.35	0.32	0.29	0.26	0.24	0.22	0.2
8	0.53	0.48	0.43	0.4	0.36	0.33	0.3	0.27	0.25	0.23
9	0.59	0.54	0.49	0.45	0.4	0.37	0.34	0.31	0.28	0.26
10	0.66	0.6	0.54	0.5	0.45	0.41	0.37	0.34	0.31	0.28
11	0.73	0.66	0.59	0.55	0.5	0.45	0.41	0.38	0.34	0.31
12	0.79	0.72	0.65	0.59	0.54	0.49	0.45	0.41	0.37	0.34
13	0.86	0.78	0.71	0.65	0.59	0.53	0.49	0.44	0.41	0.37
14	0.92	0.84	0.76	0.69	0.63	0.58	0.53	0.48	0.43	0.39
15	0.99	0.9	0.81	0.74	0.68	0.62	0.56	0.51	0.47	0.42
16	1.06	0.96	0.86	0.79	0.72	0.66	0.6	0.54	0.5	0.45
17	1.12	1.02	0.92	0.84	0.77	0.7	0.64	0.58	0.53	0.48
18	1.19	1.08	0.97	0.89	0.81	0.74	0.86	0.61	0.56	0.51
19	1.25	1.14	1.03	0.94	0.86	0.78	0.71	0.65	0.59	0.53
20	1.32	1.2	1.08	0.99	0.9	0.82	0.75	0.68	0.62	0.56
21	1.39	1.26	1.13	1.04	0.95	0.86	0.79	0.72	0.65	0.59
22	1.45	1.32	1.19	1.09	0.99	0.9	0.83	0.75	0.68	0.62
23	1.52	1.38	1.24	1.14	1.04	0.94	0.86	0.78	0.72	0.65
24	1.58	1.44	1.3	1.19	1.08	0.98	0.9	0.82	0.75	0.67
25	1.65	1.5	1.35	1.24	1.13	1.03	0.94	0.85	0.78	0.7
26	1.72	1.56	1.4	1.29	1.17	1.07	0.98	0.88	0.81	0.73
27	1.78	1.62	1.46	1.34	1.22	1.11	1.01	0.92	0.84	0.76
28	1.85	1.68	1.51	1.39	1.26	1.15	1.05	0.95	0.87	0.79
29	1.91	1.74	1.57	1.44	1.31	1.19	1.09	0.99	0.9	0.81
30	1.98	1.8	1.62	1.49	1.35	1.23	1.13	1.02	0.93	0.84
31	2.05	1.86	1.68	1.54	1.4	1.27	1.16	1.06	0.96	0.87
32	2.11	1.92	1.73	1.58	1.44	1.31	1.2	1.09	0.99	0.9
33	2.18	1.98	1.78	1.63	1.49	1.35	1.24	1.12	1.02	0.92
34	2.25	2.04	1.84	1.68	1.53	1.4	1.28	1.16	1.05	0.95
35	2.31	2.1	1.89	1.73	1.58	1.44	1.31	1.19	1.09	0.98
36	2.38	2.16	1.95	1.78	1.62	1.48	1.35	1.23	1.12	1.01
37	2.44	2.22	2.	1.83	1.67	1.52	1.39	1.26	1.15	1.04
38	2.51	2.28	2.05	1.88	1.71	1.56	1.43	1.29	1.18	1.07
39	2.58	2.34	2.11	1.93	1.76	1.6	1.46	1.33	1.21	1.09
40	2.64	2.4	2.16	1.98	1.8	1.64	1.5	1.36	1.24	1.12
41	2.71	2.46	2.22	2.03	1.85	1.68	1.54	1.4	1.27	1.15
42	2.77	2.52	2.27	2.08	1.89	1.72	1.58	1.43	1.3	1.18
43	2.84	2.58	2.32	2.13	1.94	1.76	1.61	1.46	1.33	1.21
44	2.91	2.64	2.38	2.18	1.98	1.81	1.65	1.5	1.37	1.23
45	2.97	2.7	2.43	2.23	2.03	1.85	1.69	1.53	1.4	1.26
46	3.04	2.76	2.49	2.28	2.07	1.89	1.73	1.57	1.43	1.29
47	3.1	2.82	2.54	2.33	2.12	1.93	1.76	1.6	1.46	1.32
48	3.17	2.88	2.59	2.38	2.16	1.97	1.8	1.63	1.49	1.34
49	3.23	2.94	2.65	2.43	2.21	2.01	1.84	1.67	1.52	1.37
50	3.3	3.	2.7	2.47	2.25	2.05	1.87	1.7	1.55	1.4
52	3.43	3.12	2.81	2.57	2.34	2.13	1.95	1.77	1.61	1.46

Table IVe. — Linear Space occupied by Double Cotton-Covered Wires. — *Continued.*

Turns or Layers.	Wire numbers, B. and S. Gauge.									
	15	16	17	18	19	20	21	22	23	24
54 . . .	3.56	3.24	2.92	2.67	2.43	2.22	2.03	1.84	1.67	1.51
56 . . .	3.7	3.36	3.03	2.77	2.52	2.3	2.1	1.9	1.74	1.57
58 . . .	3.83	3.48	3.13	2.87	2.61	2.38	2.18	1.97	1.8	1.63
60 . . .	3.96	3.6	3.24	2.97	2.7	2.46	2.25	2.04	1.86	1.68
62 . . .	4.09	3.72	3.35	3.07	2.79	2.54	2.33	2.11	1.92	1.74
64 . . .	4.23	3.84	3.46	3.17	2.88	2.63	2.4	2.18	1.99	1.79
66 . . .	4.36	3.96	3.57	3.27	2.97	2.71	2.48	2.25	2.05	1.85
68 . . .	4.49	4.08	3.67	3.37	3.06	2.79	2.55	2.31	2.11	1.91
70 . . .	4.62	4.2	3.78	3.47	3.15	2.87	2.63	2.38	2.17	1.96
72 . . .	4.75	4.32	3.89	3.57	3.24	2.95	2.7	2.45	2.23	2.02
74. . . .	....	....	4.	3.67	3.33	3.04	2.78	2.52	2.3	2.07
76. . . .	....	....	4.11	3.76	3.42	3.12	2.85	2.59	2.36	2.13
78. . . .	....	....	4.21	3.86	3.51	3.2	2.93	2.65	2.42	2.19
80. . . .	....	....	4.32	3.96	3.6	3.28	3.	2.72	2.48	2.24
82. . . .	....	....	4.43	4.06	3.60	3.36	3.08	2.79	2.54	2.3
84. . . .	....	....	4.54	4.16	3.78	3.45	3.15	2.86	2.61	2.35
86. . . .	....	....	4.65	4.26	3.87	3.53	3.23	2.93	2.67	2.41
88. . . .	....	....	4.75	4.36	3.96	3.61	3.3	2.99	2.73	2.47
90. . . .	....	....	....	4.46	4.05	3.69	3.38	3.06	2.79	2.52
92. . . .	....	....	....	4.56	4.14	3.77	3.45	3.13	2.85	2.58
94. . . .	....	....	....	4.66	4.23	3.86	3.53	3.2	2.92	2.63
96. . . .	....	....	....	4.75	4.32	3.94	3.6	3.27	2.98	2.69
98. . . .	....	....	....	....	4.41	4.02	3.68	3.33	3.04	2.75
100. . . .	....	....	....	....	4.5	4.1	3.75	3.4	3.1	2.8
102. . . .	....	....	....	....	4.59	4.18	3.83	3.47	3.16	2.86
104. . . .	....	....	....	....	4.68	4.27	3.9	3.54	3.23	2.91
106. . . .	....	....	....	....	....	4.35	3.98	3.61	3.29	2.97
108. . . .	....	....	....	....	....	4.43	4.05	3.67	3.35	3.03
110. . . .	....	....	....	....	....	4.51	4.13	3.74	3.41	3.08
112. . . .	....	....	....	....	....	4.59	4.2	3.81	3.47	3.14
114. . . .	....	....	....	....	....	....	4.28	3.88	3.54	3.19
116. . . .	....	....	....	....	....	....	4.35	3.95	3.6	3.25
118. . . .	....	....	....	....	....	....	4.43	4.01	3.66	3.31
120. . . .	....	....	....	....	....	....	4.5	4.08	3.72	3.36
122. . . .	....	....	....	....	....	....	....	4.15	3.78	3.42

Note. — Because of the compression of the insulation on wires wound in layers, and the tendency of the wires of each layer to "bed" between those of the preceding layer, a given number of layers will occupy from 2% to 8% less space than the same number of turns side by side, according to the size of wire and thickness of the insulation. Most of the difference is due to the compression of insulation, the "bedding" effect being almost negligible. For wires of medium size with single cotton insulation, an allowance of 4% will usually be ample to cover the increase in number of layers within a given space.

Alternating-Current Electromagnets.

The cores of electromagnets to be used with alternating currents must be laminated, and the laminations must run at right angles to the direction in which eddy currents would be set up. Eddy currents tend to circulate parallel to the coils of the wire, and the laminations must, therefore, be longitudinal to or parallel with the axis of the cores.

The coils of an alternating-current electromagnet offer more resistance to the passage of the alternating current than the mere resistance of the conductor in ohms. This extra resistance is called *inductance*, and this combined with the resistance of the conductor in ohms produces the quality called *impedance*. (See Index for Impedance, etc.)

If L = coefficient of self-induction,
N = cycles per second,
R = resistance,

$$\text{Impedance} = \sqrt{R^2 + 4\pi^2 N^2 L^2};$$

and,

$$\text{Maximum current} = \frac{\text{Maximum E.M.F.}}{\text{Impedance}}.$$

$$\text{Mean current} = \frac{\text{Mean E.M.F.}}{\text{Impedance.}}$$

Heating of Magnet Coils.

PROFESSOR FORBES.

I = current permissible.
r_1 = resistance of coil at permissible temperature.
Permissible temperature = cold $r \times 1.2$.
t = rise in temperature C°.
s = sq. cms. surface of coil exposed to air.

$$I = \sqrt{\frac{.0003 \times t \times s}{.24 \times r_1}}.$$

Law of the Plunger Electromagnet.

Charles R. Underhill gives the following formula as having been found by practise the most accurate and complete for the design of plunger electromagnets.

Let P = pull in pounds.
B = flux density in the working air-gap.
l = length of the air-gap.
IN = ampere-turns in the winding.
A = cross section of plunger in sq. in.
P_c = pull at 10,000 ampere-turns and 1 sq. in. of plunger.
n = ampere-turn factor.
L = length of the winding in inches.

Then, the pull due to an iron-clad solenoid is

$$P = \frac{AP_c(IN - n)}{10,000 - n},$$

and, at points along the uniform range of solenoids, the pull for the plunger electromagnet will be

$$P = A\left(\frac{IN^2}{7,075,600\, l^2} + \frac{P_c(IN - n)}{10,000 - n}\right).$$

Here l must include the extra length assumed due to the reluctance outside of the working air-gap.

Pull in Pounds, and Ampere-turn Factor at Different Points along an Electromagnet.

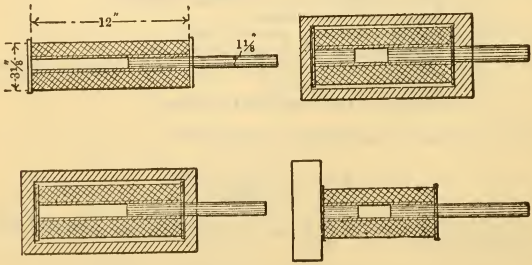
L	P_c	n
1	33.0	3600
2	28.3	3150
3	23.4	2800
4	19.2	2500
5	16.0	2200
6	13.8	1970
7	12.2	1750
8	11.0	1580
9	10.0	1400
10	9.2	1230
11	8.4	1100
12	7.8	960
13	7.2	840
14	6.8	725
15	6.4	625
16	6.0	525
17	5.7	430
18	5.3	350
19	5.0	270
20	4.7	210

To approximate the curve of a plunger electromagnet at points between the center of the winding, and the end of the winding where the plunger enters, assume that the curve is a straight line for the last .4 of the distance; then the pull at any point, *la* as measured in inches, back from the end of the winding, will be

$$P = A\left(\frac{IN^2}{7{,}075{,}600\, l^2} + \frac{laP_c\,(IN - n)}{.4\, L\,(10{,}000 - n)}\right) \quad . \; . \; . \; . \; . \quad (8)$$

where L equals length of the winding. In this it is assumed that the winding is approximately as long as the inside of the frame.

In cases where a low density in the core is used, the curve for the iron-clad solenoid effect cannot be calculated with so high a degree of accuracy.



FIGS. 2, 3, 4 and 5. Shapes of Electromagnets.

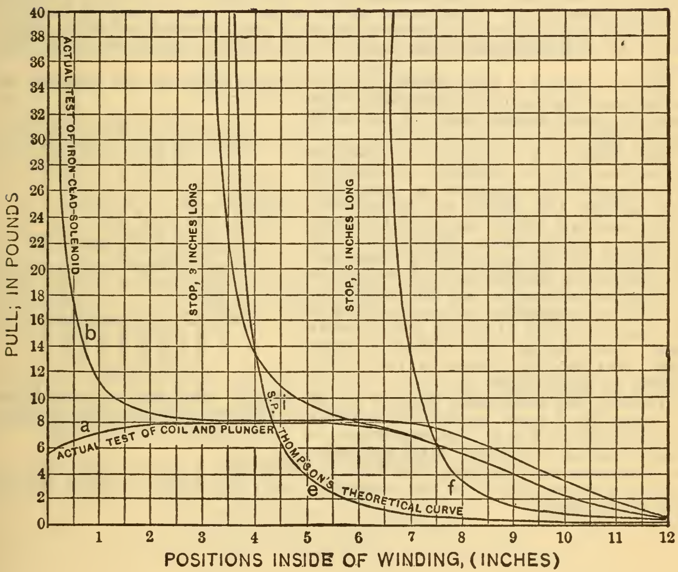


Fig. 6. Characteristics of Electromagnets.

Fig. 2 shows a simple coil and plunger and Fig. 4 the same magnet, but with an iron jacket or return circuit about the outside of the winding. This is usually referred to as an iron-clad solenoid.

By placing a "stop" inside the winding at the rear end of the frame we have the plunger electromagnet in Fig. 3.

It is to be observed that the same coil and the same plunger are used in each case. The cross section, A, of the plunger is just 1 square inch.

Referring to Fig. 6, curve "*a*" is due to the simple coil and plunger in Fig. 2, and curve "*b*" is due to the iron-clad solenoid in Fig. 4, the ampere-turns in the winding being 10,000 in all cases. It will be noticed that the only difference between curves "*a*" and "*b*" is that curve "*b*" is slightly higher at distances greater than 6 in., owing to the confinement of the field, and also that it bends upward for short distances instead of falling off like curve "*a*." This latter effect is due to the attraction between the end of the plunger and the iron frame of the iron-clad solenoid. However, the pull throughout the center of the winding is the same in both cases.

Where there is a high density of the lines of force in the plunger, an additional reluctance is in evidence, which must be added to the length of the working air-gap.

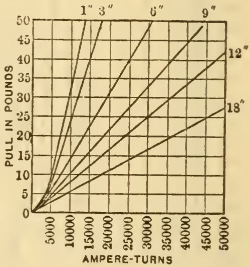


FIG. 7. Pull due to Solenoids of Different Lengths with Plunger 1 sq. in. in Cross-Section.

The range of a solenoid is the distance through which its plunger will perform work when the winding is energized. The greater the length of the solenoid, the greater will be the range, as the range varies in nearly direct proportion with the length of the solenoid. The range of the solenoid is nearly constant regardless of the ampere-turns, but the attraction or pull on the plunger varies directly with the ampere-turns after the core is saturated, there being some variation below this point due to change in the permeability of the plunger.

In designing a solenoid, the pull should be taken at a point on the curve which is considerably below the maximum, as this will allow for enough extra attraction to overcome any friction, and also to keep the load moving, and by assuming a low point for the necessary pull, the effective range will be greatly increased.

PROPERTIES OF WIRES AND CABLES.

REVISED BY HAROLD PENDER, PH.D.

GENERAL.

Units of Resistance.

THE unit of resistance now universally used is the International Ohm. The following multiples of this unit are sometimes employed.

Megohm = 1,000,000 ohms.
Microhm = 0.000,001 ohm.

The following table gives the value of the principal practical units of resistance which existed previous to the establishment of the International Units.

Unit.	International Ohm.	B.A. Ohm.	Legal Ohm 1884.	Siemens's Ohm.
International ohm. .	1.	1.0136	1.0028	1.0630
B. A. ohm	0.9866	1.	0.9894	1.0488
Legal ohm	0.9972	1.0107	1.	1.0600
Siemens's ohm . . .	0.9407	0.9535	0.9434	1.

Thus to reduce British Association ohms to international ohms we divide by 1.0136, or multiply by 0.9866; and to reduce legal ohms to international ohms we divide by 1.0028, or multiply by 0.9972, etc.

Specific Resistance.

Let l = length of the conductor.
A = cross section of the conductor.
R = resistance of the conductor.
ρ = specific resistance of the conductor.

Then
$$R = \rho \frac{l}{A},$$
or
$$\rho = R \frac{A}{l}.$$

If l is measured in centimeters and A in square centimeters, ρ is the resistance of a centimeter cube of the conductor. If l is measured in inches and A in square inches, ρ is the resistance of an inch cube of the conductor.

In telegraph and telephone practice, specific resistance is sometimes expressed as the *weight per mile-ohm*, which is the weight in pounds of a conductor one mile long having a resistance of one ohm.

Another common way of expressing specific resistance is in terms of *ohms per mil-foot*, i.e., the resistance of a round wire one foot long and 0.001 inch in diameter; l is then measured in feet and A in circular mils.

Microhms per inch cube = 0.3937 × microhms per centimeter cube.
Pounds per mile-ohm = 57.07 × microhms per centimeter cube × specific gravity.
Ohms per mil-foot = 6.015 × microhms per centimeter cube.

Specific Conductivity is the reciprocal of specific resistance. If c = specific conductivity

$$R = \frac{l}{cA},$$

$$c = \frac{l}{RA},$$

$$c = \frac{1}{\rho}.$$

By **Relative or Percentage Conductivity** of a sample is meant 100 times the ratio of the conductivity of the sample at standard temperature to the conductivity of a conductor of the same dimensions made of the standard material and at standard temperature. If ρ_0 is the specific resistance of the sample at standard temperature and ρ_s is the specific resistance of the standard at standard temperature, then

$$\text{Percentage conductivity} = 100 \frac{\rho_s}{\rho_0}.$$

In comparing different materials, the specific resistance should always be determined at the standard temperature, which is usually taken as 0° Centigrade. If it is inconvenient to measure the resistance of the sample at the standard temperature, this may be readily calculated if the temperature coefficient a of the sample is known, i.e.,

$$\rho_0 = \frac{\rho_t}{1 + at}.$$

where ρ_t is the specific resistance at temperature t.

Matthiessen's Standard of Conductivity, which is the commercial standard, is a copper wire having the following properties at the standard temperature of 0° C.

Specific gravity	8.89.
Length	1 meter.
Weight	1 gram.
Resistance	.141729 ohms.
Specific Resistance	1.594 microhms per cubic centimeter.
Relative Conductivity	100%.

Specific Resistance, Relative Resistance, and Relative Conductivity of Conductors.

Referred to Matthiessen's Standard.

Metals:	Resistance in Microhms at 0° C.		Relative Resistance. %	Relative Conductivity. %
	Centimeter Cube.	Inch Cube.		
Silver, annealed . . .	1.47	.579	92.5	108.2
Copper "	1.55	.610	97.5	102.6
Copper (Matthiessen's Standard).	1.594	.6276	100	100.0
Gold (99.9% pure) .	2.20	.865	138	72.5
Aluminum (99% pure)	2.56	1.01	161	62.1
Zinc	5.75	2.26	362	27.6
Platinum, annealed . .	8.98	3.53	565	17.7
Iron	9.07	3.57	570	17.6
Nickel	12.3	4.85	778	12.9
Tin	13.1	5.16	828	12.1
Lead	20.4	8.04	1,280	7.82
Antimony	35.2	13.9	2,210	4.53
Mercury	94.3	37.1	5,930	1.69
Bismuth	130.	51.2	8,220	1.22
Carbon (graphitic) . .	2,400–42,000	950–16,700		
Carbon (arc light) . .	about 4,000	about 1,590		
Selenium	6×10^{10}	2.38×10^{10}		

Liquids at 18° C.	Ohms per Centimeter Cube.	Ohms per Inch Cube.
Pure water	2650	1050
Sea water	30	11.8
Sulphuric acid, 5%	4.86	1.93
Sulphuric acid, 30%	1.37	.544
Sulphuric acid, 80%	9.18	3.64
Nitric acid, 30%	1.29	.512
Zinc sulphate, 24%	21.4	8.54

Temperature Coefficient.

The resistance of a conductor varies with the temperature of the conductor.

Let R_0 = Resistance at 0°.
R = Resistance at t°.
Then $R = R_0(1 + a\,t)$.

a is called the *temperature coefficient* of the conductor. 100 a is the percentage change in resistance per degree change in temperature.

The following values of the temperature coefficient have been found for temperatures measured in degrees Centigrade and in degrees Fahrenheit. It is to be noted that the coefficients vary considerably with the purity of the conductor.

Pure Metals.	Centigrade a	Fahrenheit a
Silver, annealed	0.00400	0.00222
Copper, annealed	0.00428	0.00242
Gold (99.9%)	0.00377	0.00210
Aluminium (99%)	0.00423	0.00235
Zinc	0.00406	0.00226
Platinum, annealed	0.00247	0.00137
Iron	0.00625	0.00347
Nickel	0.0062	0.00345
Tin	0.00440	0.00245
Lead	0.00411	0.00228
Antimony	0.00389	0.00216
Mercury	0.00072	0.00044
Bismuth	0.00354	0.00197

Matthiessen's formula for soft copper wire

$$R = R_0\,(1 + .00387t + .00000597t^2).$$

The wire used by Matthiessen was as pure as could be obtained at the time (1860), but in reality contained considerable impurities; the above formula, therefore, is not generally applicable. Later experiments have shown that for all practical work the above equation for copper wire may be written

$$R = R_0\,(1 + .0042t) \text{ for } t \text{ in } ^\circ\text{C}.$$

Physical and Electrical Properties of Various Metals and Alloys.

By H. F. Parshall, M. Inst. C.E., and H. M. Hobart, S.B.

The following Table gives some physical and electrical properties of various metals and alloys. In nearly every case the name of the observer is stated. No attempt has been made to reconcile divergent measurements, it being left to the reader to follow whichever guide he prefers. The merit of the Table is that it presents in compact form recent information previously scattered through a large number of publications and technical journals.

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms, at 0° C.	Per cent Increase or Resistance per Degree C.	Melting Point, Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Aluminium (Neuhausen), 99 per cent Al. Dewar and Fleming	2.56	1.01	15.4	.423	600	.21	....	2.6	.094
Aluminium (Commercial), 97.5 per cent Al. Dewar and Fleming	2.67	1.05	16.0	.435	600	.21	....	2.6	.094
Aluminium (annealed). Matthiessen	2.89	1.14	17.4	.139	600	.21	....	2.6	.094
Aluminium, 94 per cent; copper, 6 per cent. Dewar and Fleming	2.90	1.14	17.4	.381	....	....	....	.....	....
Aluminium, 94 per cent; copper, 6 per cent (annealed). Charpentier	3.11	1.23	18.7	....	....	....	....	2.95	.107
Aluminium, 94 per cent; copper, 6 per cent (hard). Charpentier	3.33	1.31	20.0	....	....	....	....	2.95	.107
Aluminium, 94 per cent; silver, 6 per cent. Dewar and Fleming	4.64	1.83	27.8	.238	....	....	....	.....	....
Aluminium Bronze, Cu (90 per cent); Al (10 per cent). C. Limb	12.6	4.96	75.5	.105	....	....	....	7.7	.278

Physical and Electrical Properties of Various Metals and Alloys. — *Continued.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase or Resistance per Degrees C.	Melting Point, Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Antimony (compressed). Matthiessen	35.2	13.9	211	.389	440	.049	....	6.7	.242
Bessemer soft steel, C (.045); Mn (.200), S (.030); Sl (0); P (.040). Hopkinson	10.5	4.14	63.0	....	....	.117	....	7.8	.282
Bismuth (compressed). Matthiessen	130	51.2	780	.354	260	.030	....	9.8	.354
Cadmium (pure). Dewar and Fleming	10.0	3.93	60.0	.419	....	....	....	8.60	.310
Chrome bronze, copper, tin, and chromium. Hospitalier	1.64	.645	9.84	....	....	....	64,000	8.9	.321
Chrome bronze, copper, tin, and chromium	4.71	1.85	28.3	....	....	....	107,000	.....	....
Chrome bronze, copper, tin, and chromium. Hospitalier	7.80	3.07	46.8	....	....	....	150,000	8.9	.321
Chrome steel (annealed) C, 687; Mn, .28; S, .02; Sl, .134; P, .043; Cr, 1.195. Hopkinson	17.9	7.05	108	....	....	....	....	.....	....
Chrome steel (annealed) C, .532; Mn, .393; S, .02; .Sl, .22; P, .04; Cr, .621. Hopkinson	19.4	7.65	117	....	....	....	....	.....	....
Electrolytic copper (annealed). Lagarde	1.54	.605	9.25	.445	1050	.093	....	9.05	.327
Electrolytic copper (annealed). Dewar and Fleming	1.56	.614	9.35	.428	1050	.093	....	8.91	.322
Copper (annealed). Matthiessen	1.59	.625	9.54	.388	1050	.093	....	8.9	.321
Copper, 50 per cent; silver, 50 per cent. Abbott	1.84	.725	11.1	....	....	....	....	.....	....
Copper, 96 per cent; silicon, 4 per cent. Abbott	2.11	.830	12.7	....	....	....	....	.....	....
Copper, 88 per cent; silicon, 12 per cent. Abbott	2.94	1.16	17.7	....	....	....	....	.....	....
Copper, 99.29 per cent; zinc, 71 per cent. R. Haas	1.83	.720	11.0	.373	....	....	....	.....	....

Physical and Electrical Properties of Various Metals and Alloys. — *Continued.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase or Resistance per Degrees C.	Melting Point, Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Copper, 90.9 per cent; zinc, 9.1 per cent. R. Haas	3.64	1.43	21.8	.204	....	....	....	.....	....
Zinc, 99.5 per cent; copper, 5 per cent. R. Haas	5.88	2.31	35.3	.385	....	.095	....	7.1	.256
Copper, 65.8 per cent; zinc, 34.2 per cent. R. Haas	6.30	2.48	37.8	.158	....	....	....	.....	....
Cast copper	4.65	1.83	27.9	....	....	....	....	.....	....
Copper, 90 per cent; lead, 10 per cent. Abbott	5.28	2.08	31.7	....	....	....	....	.....	....
Copper, 97 per cent; aluminium, 3 per cent. Dewar and Fleming	8.81	3.48	53.0	.090	....	....	....	.....	....
Copper, 87 per cent; Ni, 6.5 per cent; Al, 6.5 per cent. Dewar and Fleming	14.9	5.87	89.5	.0645	....	....	....	.....	....
Copper, 90 per cent; arsenic, 10 per cent. Abbott	17.6	6.94	106	....	....	....	....	.....	....
Copper, 75 per cent; nickel, 25 per cent. Feussner and Lindeck	34.2	13.5	205	.019	....	....	....	.....	....
German silver, Cu (60); Zn (25); Ni (15). Feussner and Lindeck	30.0	11.8	180	.036	....	....	....	.....	....
Gold (annealed). Matthiessen	2.04	.803	12.3	.365	1100	.032	....	19.3	.695
Gold, 99.9 per cent (pure). Dewar and Fleming	2.20	.865	13.2	.377	1200	.032	....	19.3	.695
Gold, 90 per cent; silver, 10 per cent. Dewar and Fleming	6.28	2.47	37.7	.124	....	....	....	.....	....
Gold, 67 per cent; silver, 33 per cent (alloy). Matthiessen	10.8	4.25	64.8	.065	....	....	....	.....	....

Physical and Electrical Properties of Various Metals and Alloys. — *Continued.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase of Resistance per Degree C.	Melting Point. Degrees C.	Specific Heat, Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Iron (very pure). Dewar and Fleming	9.07	3.57	54.5	.625	....	.113	....	7.8	.282
Iron with .25 per cent Mn and .01 per cent S. Dewar and Fleming	10.5	4.14	63.0	.544	....	.113	....	7.8	.282
White cast iron, C, 2.04; graphite, O, Mn, .386; S, .467; Sl, .764; P, .458. Hopkinson	56.6	22.3	340	....	1130	....	....	7.20	.260
Spiegeleisen — C, 4.5 per cent; Mn, 7.97 per cent; S, traces; Sl, .5?2 per cent; P, .128 per cent. Hopkinson	105	41.4	630	....	....	....	....	.....	....
Grey cast iron — C, 3.46; graphite, 2.06; Mn, .173; S, .042; Sl, 2.04; P, .151. Hopkinson	114	44.9	684	....	1220	....	....	7.20	.260
Wrought iron (annealed). Hopkinson	13.8	5.44	82.8	....	....	....	....	7.8	.282
Lead (compressed). Matthiessen	19.5	7.68	117	.387	330	.032	....	11.4	.410
Lead (pure). Dewar and Fleming	20.4	8.04	123	.411	330	.032	....	11.4	.410
Magnesium. Dewar and Fleming	4.36	1.72	26.2	.381	....	.25	....	1.74	.063
Manganese steel (annealed), C, .674; Mn, 4.73; S, .023; Sl, .608; P, .078. Hopkinson	39.3	15.5	236	....	1260	....	....	7.8	.282
Copper, 84 per cent; manganese, 12 per cent; Nl, 4 per cent (manganine). Dewar and Fleming	46.7	18.4	28	.00	....	....	....	8.9	.321
Copper, 73 per cent; manganese, 24 per cent; nickel, 3 per cent. Feussner and Lindeck	47.7	18.8	287	.003	....	....	....	8.9	.321
Copper, 80.5 per cent; manganese, 16.5 per cent; nickel, 3 per cent (manganine). Tests by G. E. Co.	49.0	19.3	294	.0	....	....	....	8.9	.321

Physical and Electrical Properties of Various Metals and Alloys. — *Continued.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase of Resistance per Degree C.	Melting Point. Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Copper, 83.4 per cent; Mn, 15.2 per cent; Fe, 1.4 per cent. Tests by G. E. Co.	50.0	19.7	300	.0	....	....	....	8.9	.321
Copper, 79.5 per cent; Mn, 19.7 per cent; Fe, .8 per cent. Tests by G. E. Co.	65.5	25.8	393	.0	....	....	....	.....	....
Manganese steel (annealed), C, 1.298; Mn, 8.74; S, .024; Sl, .094; P, .072. Hopkinson	63.2	24.9	380	....	1260	....	....	7.8	.282
Manganese steel (Hadfield), C, 1.005; Mn, 12.36; S, .038; Sl, .204; P, .070. Hopkinson	65.5	25.8	393	....	1260	....	....	7.8	.282
Manganese steel (Hadfield), 12 per cent Mn. Dewar and Fleming	67.1	26.4	401	.127	1260	....	....	7.8	.282
Manganese steel (Hadfield's Hecla Foundry), C, 1.001; Mn, 11.40; P, .059. Tests by G. E. Co.	69.0	27.1	414	.135	1260	....	....	7.8	.282
Manganese steel. Hospitalier	75.0	29.5	450	.136	1260	....	230,000	7.8	.282
Copper, 70 per cent; manganese, 30 per cent. Feussner and Lindeck	101.0	39.8	605	.004	....	....	....	.....	....
Mercury. Matthiessen	94.3	37.1	566	.072	....	.032	....	13.6	.490
Nickel. Dewar and Fleming	12.3	4.85	73.7	.62	1500	.109	....	8.9	.321
Nickel (annealed). Matthiessen	12.4	4.89	74.4	.50	1500	.109	....	8.9	.321
Nickel steel (Hadfield), 4.35 per cent; nickel. Dewar and Fleming	29.5	11.6	177	.201	....	....	....	.....	....
Nickeline. Lange and Co., Berlin	40.0	15.8	240	....	....	....	....	.....	....
Palladium (pure). Dewar and Fleming	10.2	4.02	61.1	.354	....	....	....	.....	....
Platinum, 67 per cent; Silver, 33 per cent (alloy). Matthiessen	24.2	9.54	145	.133	....	....	....	.....	....

Physical and Electrical Properties of Various Metals and Alloys. — *Continued.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase of Resistance per Degree C.	Melting Point. Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Platinum, 80 per cent; Iridium, 20 per cent. Dewar and Fleming	30.9	12.2	186	.082	....	....	....	.....	....
Platinoid. Dewer and Fleming	41.7	16.4	251	.031	....	....	....	8.8	.318
Platinoid-martino. Dewar and Fleming	43.6	17.2	262	....	....	....	....	8.8	.318
Platinoid-martino	33.0	13.0	198	.024	....	....	....	.....	....
Platinum (soft annealed, pure)	8.25	3.24	49.5	....	1775	.032	....	21.2	.765
Platinum (annealed). Matthiessen	8.98	3.53	53.9	.247	1775	.032	....	21.2	.765
Platinum (pure) wire .0259 cm. in diam. Dewar and Fleming	11.0	4.34	66.0	.35	1775	.032	....	21.2	.765
Platinum 90 per cent; Rodium, 10 per cent. Dewar and Fleming	21.1	8.30	127	.143	....	....	.....	.....	....
Platinum, 90 per cent; Iridium, 10 per cent (alloy). Matthiessen	21.6	8.50	130	.133	....	....	....	.....	....
Phosphor-bronze, with 9 per cent phosphorus. Abbott	32.5	12.8	195	....	....	....	....	.....	....
Phosphor-bronze (copper, tin, and phosphorus). Hospitalier	1.6	.630	9.6	.394	....	....	64,000	8.9	.321
Phosphor-bronze (copper, tin, and phosphorus). Hosptalier	5.6	2.20	33.6	.394	....	....	117,000	8.9	.321
Phosphor-bronze, with 10 per cent of tin. Abbott	24.6	9.69	148	....	....	....	....	.....	....
Pure electrolytic (annealed) silver. Dewar and Fleming	1.47	.579	8.82	.400	950	.056	....	10.5	.379
Silver (annealed). Matthiessen	1.49	.586	8.94	.377	950	.056	....	10.5	.379
Silverine, Cu (77); Ni (17); Fe (2); Zn (2); CO (2). Dewar and Fleming	2.06	.810	12.4	.285	....	....	....	.....	....

Physical and Electrical Properties of Various Metals and Alloys. — *Concluded.*

	Specific Resistance at 0° C. Microhms per Centimeter Cube.	Microhms per Inch Cube.	Resistance per Mil-foot Ohms at 0° C.	Per Cent Increase of Resistance per Degree C.	Melting Point. Degrees C.	Specific Heat. Mean.	Ultimate Tensile Strength, Pounds per Square Inch.	Specific Gravity.	Weight of 1 Cubic Inch. Pounds.
Silver, 80 per cent; palladium, 20 per cent. Dewar and Fleming	15.0	5.90	90.0	....	....	....	....	.....	....
Silver, 66 per cent; platinum, 33 per cent. Dewar and Fleming	31.6	12.4	190	.0243	....	....	....	.....	....
Silicon-bronze (copper, tin, and silicon). Hospitalier	1.67	.657	10.0	.152	....	....	64,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	2.69	1.06	16.2	....	....	....	93,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	5.76	2.27	34.6	....	....	....	107,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	7.80	3.07	46.8	....	....	....	143,000	8.9	.321
Silicon steel (annealed) C, .685; Mn, .694; S, .024; Sl, 3.44; P, .133. Hopkinson	61.9	24.3	372	....	....	....	....	.....	....
Thallium (pure). Dewar and Fleming	17.6	6.94	106	.398	....	....	....	.....	....
Tin (pure). Dewar and Fleming	13.1	5.16	78.5	.440	230	.056	....	7.3	.264
Tin (compressed). Matthiessen	13.1	5.16	78.5	.365	230	.056	....	7.3	.264
Tungsten steel (annealed) C. 1.36; Mn, .36; S, 0; Sl, .043; P, .047; tungsten, 4.65. Hopkinson	22.5	8.86	135.0	....	....	....	....	.....	....
Whitworth soft steel (annealed) C .090; Mn, .153; S, .016; Sl .0; P .042. Hopkinson	10.8	4.25	64.8	....	....	.117	....	7.8	.282
Zinc (very pure). Dewar and Fleming	5.75	2.26	34.5	.406	415	.095	....	7.1	.256
Zinc (compressed). Matthiessen	5.80	2.28	34.8	.365	415	.095	....	7.1	.256

WIRE GAUGES.

The sizes of wires are ordinarily expressed by an arbitrary series of numbers. Unfortunately there are several independent numbering methods, so that it is always necessary to specify the method or wire gauge used. The following table gives the numbers and diameters in decimal parts of an inch for the various wire gauges used in this country and England.

In Decimal Parts of an Inch.

Number of Wire Gauge.	Roebling or Washburn & Moens.	Brown & Sharpe.	Birmingham, or Stubs.	English Legal Standard.	Old English, or London.
6–0	.460	......	....	.464	......
5–0	.430	......	....	.432	......
4–0	.393	.4600	.454	.400	.4540
3–0	.362	.4096	.425	.372	.4250
2–0	.331	.3648	.380	.348	.3800
0	.307	.3249	.340	.324	.3400
1	.283	.2893	.300	.300	.3000
2	.263	.2576	.284	.276	.2840
3	.244	.2294	.259	.252	.2590
4	.225	.2043	.238	.232	.2380
5	.207	.1819	.220	.212	.2200
6	.192	.1620	.203	.192	.2030
7	.177	.1443	.180	.176	.1800
8	.162	.1285	.165	.160	.1650
9	.148	.1144	.148	.144	.1480
10	.135	.1019	.134	.128	.1340
11	.120	.09074	.120	.116	.1200
12	.105	.08081	.109	.104	.1090
13	.092	.07196	.095	.092	.0950
14	.080	.06408	.083	.080	.0830
15	.072	.05706	.072	.072	.0720
16	.063	.05082	.065	.064	.0650
17	.054	.04525	.058	.056	.0580
18	.047	.04030	.049	.048	.0490
19	.041	.03589	.042	.040	.0400
20	.035	.03196	.035	.036	.0350
21	.032	.02846	.032	.032	.0315
22	.028	.02534	.028	.028	.0295
23	.025	.02257	.025	.024	.0270
24	.023	.02010	.022	.022	.0250
25	.020	.01790	.020	.020	.0230
26	.018	.01594	.018	.018	.0205
27	.017	.01419	.016	.0164	.01875
28	.016	.01264	.014	.0148	.01650
29	.015	.01125	.013	.0136	.01550
30	.014	.01002	.012	.0124	.01375
31	.0135	.00893	.010	.0116	.01225
32	.0130	.00795	.009	.0108	.01125
33	.0110	.00708	.008	.0100	.01025
34	.0100	.00630	.007	.0092	.0095
35	.0095	.00561	.005	.0084	.0090
36	.0090	.00500	.004	.0076	.0075
37	.0085	.00445	....	.0068	.0065
38	.0080	.00397	....	.0060	.0057
39	.0075	.00353	....	.0052	.0050
40	.0070	.00314	....	.0048	.0045

Roebling Gauge. — Used almost universally in this country for iron and steel wire.

Brown & Sharpe Gauge. — The American standard for wires for electrical purposes.

Birmingham Gauge. — Used largely in England and also in this country for wires other than those made especially for electrical purposes, excepting iron wire.

Law of the Brown & Sharpe Gauge.

The diameters of wires on the B. and S. gauge are obtained from the geometric series in which No. 0000 = 0.4600 inch and No. 36 = .005 in., the nearest fourth significant figure being retained in the areas and diameters so deduced.

Let n = gauge number (0000 = − 3; 000 = − 2; 00 = − 1).
d = diameter of wire in inches.

Then $$d = \frac{0.3249}{1.123^n}.$$

WIRE STRANDS.

Wires larger than No. 0000 B. and S. are seldom made solid but are built up of a number of small wires into a strand. The group of wires is called a "strand;" the term "wire" being reserved for the individual wires of the strand. Strands are usually built up of wires of such a size that the cross section of the metal in the strand is the same as the cross section of a solid wire having the same gauge number.

If n = number of concentric layers around one central strand,

then $$\frac{3\,(n^2+n)+1}{(2\,n+1)^2} = \text{ratio of } \frac{\text{metal area}}{\text{available area}}.$$

The number of wires that will strand will be $3\,n\,(n+1)+1$.

Number of Strands.	$\frac{\text{metal area}}{\text{available area}}$.
1	1.000
7	.778
19	.760
37	.755
61	.753
91	.752

Sheathing Core. — The number, N, of sheathing wires having a diameter, d, which will cover a core having a diameter, D, is

$$N = \pi\,\frac{D+d}{d}.$$

COPPER WIRE.

Physical Constants of Commercial Wire. — Average Values.

	Annealed.	Hard.
Per Cent Conductivity (Matthiessen's Standard 100)	100	98
Specific Gravity	8.9	8.94
Pounds in 1 cubic foot	555	558
Pounds in 1 cubic inch	.321	.323
Pounds per mile per circular mil	.0160	.0161
Ultimate Strength $\frac{\text{lbs.}}{\text{sq. in.}}$	23,000	55,000
Modulus of Elasticity $\frac{\text{lb.} \times \text{in.}}{\text{in.} \times \text{sq. in.}}$	....	16,000,000
Coefficient of Linear Expansion per ° C.	.0000171	.0000171
Coefficient of Linear Expansion per ° F.	.0000095	.0000095
Melting Point in ° C.	1050	1050
Melting Point in ° F.	1920	1920
Specific Heat (watt-seconds to heat 1 lb. 1° C.)	176	176
Thermal Conductivity (watts through cu. in., temperature gradient 1° C.)	8.7	8.7
Resistance:		
Microhms per centimeter cube 0° C.	1.594	1.626
Microhms per inch cube 0° C.	.6276	.6401
Ohms per mil-foot 0° C.	9.59	9.78
Ohms per mil-foot 20° C.	10.36	10.57
Resistance per mile 0° C.	$\frac{50,600}{\text{cir. mils.}}$	$\frac{51,600}{\text{cir. mils.}}$
Resistance per mile 20° C.	$\frac{54,600}{\text{cir. mils.}}$	$\frac{55,700}{\text{cir. mils.}}$
Pounds per mile ohm 0° C.	810	830
Pounds per mile ohm 20° C.	875	896
Temperature Coefficient per ° C.	.0042	.0042
Temperature Coefficient per ° F.	.00233	.00233

Table showing the Effect of Admixture of Copper with Specific Quantities of Various Substances.

MATTHIESSEN.

Substances alloyed with Pure Copper.	Conducting Power of Hard-drawn Alloy, Pure Soft Copper being 100.	Temperature Centigrade. Degrees.
Carbon:		
Copper with .05 per cent of carbon . .	77.87	18.3
Sulphur:		
Copper, with .18 per cent of sulphur . .	92.08	19.4
Phosphorus:		
Copper, with .13 per cent of phosphorus .	70.34	20.0
Copper, with .95 per cent of phosphorus .	24.16	22.1
Copper, with 2.5 per cent of phosphorus .	7.52	17.5
Arsenic:		
Copper, with traces of arsenic	60.08	19.7
Copper, with 2.8 per cent of arsenic . . .	13.66	19.3
Copper, with 5.4 per cent of arsenic . . .	6.42	16.8
Zinc:		
Copper, with traces of zinc	88.41	19.0
Copper, with 1.6 per cent of zinc	79.37	16.8
Copper, with 3.2 per cent of zinc	59.23	10.3
Iron:		
Copper, with .48 per cent of iron	35.92	11.2
Copper, with 1.06 per cent of iron. . . .	28.01	13.1
Tin:		
Copper, with 1.33 per cent of tin	50.44	16.8
Copper, with 2.52 per cent of tin	33.93	17.1
Copper, with 4.9 per cent of tin.	20.24	14.4
Silver:		
Copper, with 1.22 per cent of silver . . .	90.34	20.7
Copper, with 2.45 per cent of silver . . .	82.52	19.7
Gold:		
Copper, with 3.5 per cent of gold	67.94	18.1
Aluminum:		
Copper, with 10 per cent of aluminum. . .	12.68	14.0

COPPER WIRE TABLES.

Below are given the Copper Wire Tables of the American Institute of Electrical Engineers. The table for the Brown and Sharpe gauge is derived from the following formulæ:

Let n = wire gauge number.

d = diameter of wire in inches.

C.M. = area in circular mils.

r = resistance in ohms per 1000 feet at 20° C.

ω = weight in pounds per 1000 feet.

Then $$d = \frac{0.3249}{1.123^n}$$

$$\text{C.M.} = \frac{105{,}500}{1.261^n}$$

$$r = 0.09811 \times 1.261^n$$

$$\omega = \frac{319.5}{1.261^n}.$$

A useful approximate formula for resistance per 1000 feet at about 20° C. is $r = 0.1 \times 2^{\frac{n}{3}}$. $\left(2^{\frac{1}{3}} = 1.26;\ 2^{\frac{2}{3}} = 1.59\right)$.

From this it is seen that an increase of 3 in the wire number corresponds to doubling the resistance and halving the cross section and weight. Also, that an increase of 10 in the wire number increases the resistance 10 times and diminishes the cross section and weight to $\frac{1}{10}$th their original values.

The data in the following table has been computed as follows: Matthiessen's standard resistivity, Matthiessen's temperature coefficient, specific gravity of copper = 8.89. Resistance in terms of the international ohm.

Matthiessen's standard 1 meter gramme of hard drawn copper = 0.1469 B.A.U. @ 0° C. Ratio of resistivity hard to soft copper 1.0226.

Matthiessen's standard 1 meter gramme of soft drawn copper = 0.14365 B.A.U. @ 0° C. One B.A.U. = 0.9866 international ohm.

Matthiessen's standard 1 meter gramme of soft drawn copper = 0.141729 international ohm at 0° C.

Temperature coefficients of resistance for 20° C., 50° C., and 80° C., 1.07968, 1.20625 and 1.33681 respectively. 1 foot = 0.3048028 meter, 1 pound = 453.59256 grammes.

Although the entries in the table are carried to the fourth significant digit, the computations have been carried to at least five figures. The last digit is therefore correct to within half a unit, representing an arithmetical degree of accuracy of at least one part in two thousand. The diameters of the B. & S. or A. W. G. wires are obtained from the geometrical series in which No. 0000 = 0.4600 inch and No. 36 = 0.005 inch, the nearest fourth significant digit being retained in the areas and diameters so reduced.

It is to be observed that while Matthiessen's standard of resistivity may be permanently recognized, the temperature coefficient of its variation which he introduced, and which is here used, may in future undergo slight revision.

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving **Weights** and **Lengths** of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

Brown & Sharpe Gauge.

B. & S. or A. W. G.	Dia-meter.	Area.		Lbs. per foot.	Lbs. per ohm.			Feet per lb.	Feet per ohm.		
	Inches.	Circular mils.	Sq. in. Sq. mils.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
0000	0.460	211,600	166,190	0.6405	13,090	11,720	10,570	1.561	20,440	18,290	16,510
000	0.4096	167,800	131,790	0.5080	8,232	7,369	6,647	1.969	16,210	14,510	13,090
00	0.3648	133,100	104,518	0.4028	5,177	4,634	4,182	2.482	12,850	11,500	10,380
0	0.3249	105,500	82,887	0.3195	3,256	2,914	2,630	3.130	10,190	9,123	8,232
1	0.2893	83,690	65,732	0.2533	2,048	1,833	1,654	3.947	8,083	7,235	6,528
2	0.2576	66,370	52,128	0.2009	1,288	1,153	1,040	4.977	6,410	5,738	5,177
3	0.2294	52,630	41,339	0.1593	810.0	725.0	654.2	6.276	5,084	4,550	4,106
4	0.2043	41,740	32,784	0.1264	509.4	455.9	411.4	7.914	4,031	3,608	3,256
5	0.1819	33,100	25,999	0.1002	320.4	286.7	258.7	9.980	3,197	2,862	2,582
6	0.1620	26,250	20,618	0.07946	201.5	180.3	162.7	12.58	2,535	2,269	2,048
7	0.1443	20,820	16,351	0.06302	126.7	113.4	102.3	15.87	2,011	1,800	1,624
8	0.1285	16,510	12,967	0.04998	79.69	71.33	64.36	20.01	1,595	1,427	1,288
9	0.1144	13,090	10,283	0.03963	50.12	44.86	40.48	25.23	1,265	1,132	1,021
10	0.1019	10,380	8,155	0.03143	31.52	28.21	25.46	31.82	1,003	897.6	809.9
11	0.09074	8,234	6,467	0.02493	19.82	17.74	16.01	40.12	795.3	711.8	642.3
12	0.08081	6,530	5,129	0.01977	12.47	11.16	10.07	50.59	630.7	564.5	509.4
13	0.07196	5,178	4,067	0.01568	7.840	7.017	6.332	63.79	500.1	447.7	404.0
14	0.06408	4,107	3,225	0.01243	4.931	4.413	3.982	80.44	396.6	355.0	320.3
15	0.05707	3,257	2,558	0.009858	3.101	2.776	2.504	101.4	314.5	281.5	254.0
16	0.05082	2,583	2,029	0.007818	1.950	1.746	1.575	127.9	249.4	223.3	201.5
17	0.04526	2,048	1,609	0.006200	1.226	1.098	0.9906	161.3	197.8	177.1	159.8
18	0.04030	1,624	1,276	0.004917	0.7713	0.6904	0.6230	203.4	156.9	140.4	126.7
19	0.03589	1,288	1,012	0.003899	0.4851	0.4342	0.3918	256.5	124.4	111.4	100.5
20	0.03196	1,022	802	0.003092	0.3051	0.2731	0.2464	323.4	98.66	88.31	79.68
21	0.02846	810.1	636.3	0.002452	0.1919	0.1717	0.1550	407.8	78.24	70.03	63.19

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving **Weights** and **Lengths** of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

Brown & Sharpe Gauge.

B. & S. or A. W. G.	Diameter.	Area.		Lbs. per foot.	Lbs. per ohm.			Feet per lb.	Feet per ohm.		
	Inches.	Circular mils.	Sq. in. Sq. mils.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
22	0.02535	642.4	504.6	0.001945	0.1207	0.1080	0.09746	514.2	62.05	55.54	50.11
23	0.02257	509.5	400.2	0.001542	0.07589	0.06793	0.06129	648.4	49.21	44.04	39.74
24	0.02010	404.0	317.3	0.001223	0.04773	0.04272	0.03855	817.6	39.02	34.93	31.52
25	0.01790	320.4	251.7	0.0009699	0.03002	0.02687	0.02424	1,031	30.95	27.70	24.99
26	0.01594	254.1	199.6	0.0007692	0.01888	0.01690	0.01525	1,300	24.54	21.97	19.82
27	0.0142	201.5	158.3	0.0006100	0.01187	0.01063	0.009588	1,639	19.46	17.42	15.72
28	0.01264	159.8	125.5	0.0004837	0.007466	0.006683	0.006030	2,067	15.43	13.82	12.47
29	0.01126	126.7	99.53	0.0003836	0.004696	0.004203	0.003792	2,607	12.24	10.96	9.886
30	0.01003	100.5	78.94	0.0003042	0.002953	0.002643	0.002385	3,287	9.707	8.688	7.840
31	0.008928	79.70	62.60	0.0002413	0.001857	0.001662	0.001500	4,145	7.698	6.890	6.217
32	0.007950	63.21	49.64	0.0001913	0.001168	0.001045	0.0009436	5,227	6.105	5.464	4.930
33	0.007080	50.13	39.37	0.0001517	0.0007346	0.0006575	0.0005933	6,591	4.841	4.333	3.910
34	0.006305	39.75	31.22	0.0001203	0.0004620	0.0004135	0.0003731	8,311	3.839	3.436	3.101
35	0.005615	31.52	24.76	0.00009543	0.0002905	0.0002601	0.0002347	10,480	3.045	2.725	2.459
36	0.0050	25.0	19.64	0.00007568	0.0001827	0.0001636	0.0001476	13,210	2.414	2.161	1.950
37	0.004453	19.83	15.57	0.00006001	0.0001149	0.0001029	0.00009281	16,660	1.915	1.714	1.547
38	0.003965	15.72	12.35	0.00004759	0.00007210	0.00006454	0.00005824	21,010	1.519	1.359	1.226
39	0.003531	12.47	9.79	0.00003774	0.00004545	0.00004068	0.00003671	26,500	1.204	1.078	0.9726
40	0.003145	9.888	7.77	0.00002993	0.00002858	0.00002559	0.00002309	33,410	0.9550	0.8548	0.7713

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving **Resistances** of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

Brown & Sharpe Gauge.

GAUGES.	RESISTANCE.					
B. & S. or A. W. G.	Ohms per lb.			Ohms per foot.		
	68° F. 20° C.	122° F. 50° C.	176° F. 80° C.	68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
0000	0.00007639	0.00008535	0.00009459	0.00004893	0.00005467	0.00006058
000	0.0001215	0.0001357	0.0001504	0.00006170	0.00006893	0.00007640
00	0.0001931	0.0002158	0.0002391	0.00007780	0.00008692	0.00009633
0	0.0003071	0.0003431	0.0003803	0.00009811	0.0001096	0.0001215
1	0.0004883	0.0005456	0.0006046	0.0001237	0.0001382	0.0001532
2	0.0007765	0.0008675	0.0009614	0.0001560	0.0001743	0.0001932
3	0.001235	0.001379	0.001529	0.0001967	0.0002198	0.0002435
4	0.001963	0.002193	0.002431	0.0002480	0.0002771	0.0003071
5	0.003122	0.003487	0.003865	0.0003128	0.0003495	0.0003873
6	0.004963	0.005545	0.006145	0.0003944	0.0004406	0.0004883
7	0.007892	0.008817	0.009772	0.0004973	0.0005556	0.0006158
8	0.01255	0.01402	0.01554	0.0006271	0.0007007	0.0007765
9	0.01995	0.02229	0.02471	0.0007908	0.0008835	0.0009791

10	0.03173	0.03545	0.03928	0.0009972	0.001114	0.001235
11	0.05045	0.05636	0.06246	0.001257	0.001405	0.001557
12	0.08022	0.08962	0.09932	0.001586	0.001771	0.001963
13	0.1276	0.1425	0.1579	0.001999	0.002234	0.002476
14	0.2028	0.2266	0.2511	0.002521	0.002817	0.003122
15	0.3225	0.3603	9.3993	0.003179	0.003552	0.003936
16	0.5128	0.5729	0.6349	0.004009	0.004479	0.004964
17	0.8153	0.9109	1.010	0.005055	0.005648	0.006259
18	1.296	1.448	1.605	0.006374	0.007122	0.007892
19	2.061	2.303	2.552	0.008038	0.008980	0.009952
20	3.278	3.662	4.058	0.01014	0.01132	0.01255
21	5.212	5.823	6.453	0.01278	0.01428	0.01583
22	8.287	9.259	10.26	0.01612	0.01801	0.01996
23	13.18	14.72	16.32	0.02032	0.02271	0.02516
24	20.95	23.41	25.94	0.02563	0.02863	0.03173
25	33.32	37.22	41.25	0.03231	0.03610	0.04001
26	52.97	59.18	65.59	0.04075	0.04552	0.05045
27	84.23	94.11	104.3	0.05138	0.05740	0.06362
28	133.9	149.6	165.8	0.06479	0.07239	0.08022
29	213.0	237.9	263.7	0.08170	0.09128	0.1012
30	338.6	378.3	419.3	0.1030	0.1151	0.1276
31	538.4	601.6	666.7	0.1299	0.1451	0.1608
32	856.2	956.5	1,060	0.1638	0.1830	0.2028
33	1,361	1,521	1,685	0.2066	0.2308	0.2558
34	2,165	2,418	2,680	0.2605	0.2910	0.3225
35	3,441	3,845	4,262	0.3284	0.3669	0.4067
36	5,473	6,114	6,776	0.4142	0.4627	0.5129
37	8,702	9,722	10,770	0.5222	0.5835	0.6466
38	13,870	15,490	17,170	0.6585	0.7357	0.8154
39	22,000	24,580	27,240	0.8304	0.9277	1.028
40	34,980	39,080	43,320	1.047	1.170	1.296

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving **Weights** and **Lengths** of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

Birmingham Wire Gauge.

Gauges. To the nearest fourth significant digit.				Weight.				Length.			
Stub's or B.W.G.	Diameter.	Area.		Lbs. per. foot	Lbs. per ohm.			Feet per lb.	Feet per ohm.		
	Inches.	Circular mils.	Sq. in. Sq. mils.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
0000	0.454	206,100	161,883	0.6239	12,420	11,120	10,030	1.603	19,910	17,820	16,080
000	0.425	180,600	141,863	0.5468	9,538	8,537	7,704	1.829	17,450	15,620	14,090
00	0.380	144,400	113,411	0.4371	6,096	5,456	4,924	2.288	13,950	12,480	11,260
0	0.340	115,600	90,792	0.3499	3,907	3,497	3,155	2.858	11,160	9,993	9,017
1	0.3000	90,000	70,686	0.2724	2,368	2,120	1,913	3.671	8,692	7,780	7,020
2	0.2840	80,660	63,347	0.2441	1,902	1,702	1,536	4.096	7,790	6,973	6,292
3	0.2590	67,080	52,685	0.2031	1,316	1,178	1,063	4.925	6,479	5,799	5,233
4	0.2380	56,640	44,488	0.1715	938.0	839.6	757.6	5.832	5,471	4,897	4,419
5	0.2200	48,400	38,013	0.1465	684.9	613.0	553.1	6.826	4,675	4,184	3,775
6	0.2030	41,210	32,365	0.1247	496.5	444.4	401.0	8.017	3,980	3,562	3,215

7	0.1800	32,400	25,447	0.09808	306.9	274.7	247.9	10.20	3,129	2,801	2,527
8	0.1650	27,230	21,382	0.08241	216.7	194.0	175.0	12.13	2,629	2,354	2,124
9	0.1480	21,900	17,203	0.06630	140.3	125.6	113.3	15.08	2,116	1,894	1,709
10	0.1340	17,960	14,103	0.05435	94.26	84.37	76.13	18.40	1,734	1,552	1,401
11	0.1200	14,400	11,310	0.04359	60.62	54.26	48.96	22.94	1,391	1,245	1,123
12	0.1090	11,880	9,331	0.03596	41.27	36.94	33.33	27.81	1,147	1,027	926.9
13	0.0950	9,025	7,088	0.02732	23.81	21.31	19.23	36.60	871.7	780.2	704.0
14	0.08300	6,889	5,411	0.02085	13.87	12.42	11.21	47.95	665.4	595.5	537.4
15	0.07200	5,184	4,072	0.01569	7.857	7.032	6.346	63.73	500.7	448.1	404.4
16	0.06500	4,225	3,318	0.01279	5.219	4.671	4.215	78.19	408.1	365.2	329.6
17	0.0580	3,364	2,642	0.01018	3.308	2.961	2.672	98.23	324.9	290.8	262.4
18	0.04900	2,401	1,886	0.007268	1.685	1.509	1.361	137.6	231.9	207.6	187.3
19	0.04200	1,764	1,385	0.005340	0.9097	0.8143	0.7347	187.3	170.4	152.5	137.6
20	0.03500	1,225	962	0.003708	0.4387	0.3927	0.3543	269.7	118.3	105.9	95.56
21	0.03200	1,024	804.2	0.003100	0.3066	0.2744	0.2476	322.6	98.90	88.52	79.88
22	0.02800	784.0	615.8	0.002373	0.1797	0.1608	0.1451	421.4	75.72	67.78	61.16
23	0.0250	625.0	490.9	0.001892	0.1142	0.1022	0.09224	528.6	60.36	54.03	48.75
24	0.0220	484.0	380.1	0.001465	0.06849	0.06130	0.05531	682.6	46.75	41.84	37.75
25	0.0200	400.0	314.2	0.001211	0.04678	0.04187	0.03778	825.9	38.63	34.58	31.20
26	0.0180	324.0	254.5	0.0009808	0.03069	0.02747	0.02479	1,020	31.29	28.01	25.27
27	0.0160	256.0	201.1	0.0007749	0.01916	0.01715	0.01548	1,290	24.73	22.13	19.97
28	0.0140	196.0	153.9	0.0005933	0.01123	0.01005	0.009071	1,685	18.93	16.94	15.29
29	0.0130	169.0	132.7	0.0005116	0.008350	0.007474	0.006744	1,955	16.32	14.61	13.18
30	0.0120	144.0	113.1	0.0004359	0.006062	0.005426	0.004896	2,294	13.91	12.45	11.23
31	0.0100	100.0	78.54	0.0003027	0.002924	0.002617	0.002361	3,304	9.658	8.645	7.800
32	0.0090	81.0	63.62	0.0002452	0.001918	0.001717	0.001549	4,078	7.823	7.002	6.318
33	0.0080	64.0	50.27	0.0001937	0.001197	0.001072	0.0009672	5,162	6.181	5.533	4.992
34	0.0070	49.0	38.48	0.0001483	0.0007019	0.0006283	0.0005669	6,742	4.733	4.236	3.822
35	0.0050	25.0	19.64	0.00007568	0.0001827	0.0001636	0.0001476	13,210	2.414	2.161	1.950
36	0.0040	16.	12.57	0.00004843	0.00007484	0.00006699	0.00006045	20,650	1.545	1.383	1.248

COPPER WIRE TABLE OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Giving **Resistances** of cool, warm, and hot wires, of Matthiessen's standard of conductivity.

Birmingham Wire Gauge.

GAUGES.	RESISTANCE.					
B. W. G. or Stub's.	Ohms per pound.			Ohms per foot.		
	68° F. 20° C.	122° F. 50° C.	176° F. 80° C	68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
0000	0.00008051	0.00008996	0.00009969	0.00005023	0.00005612	0.00006220
000	0.0001048	0.0001171	0.0001298	0.00005732	0.00006404	0.00007097
00	0.0001640	0.0001833	0.0002031	0.00007170	0.00008011	0.00008878
0	0.0002560	0.0002860	0.0003169	0.00008957	0.0001001	0.0001109
1	0.0004223	0.0004718	0.0005228	0.0001150	0.0001285	0.0001424
2	0.0005258	0.0005874	0.0006510	0.0001284	0.0001434	0.0001589
3	0.0007601	0.0008492	0.0009412	0.0001543	0.0001724	0.0001911
4	0.001066	0.001191	0.001320	0.0001828	0.0002042	0.0002263
5	0.001460	0.001631	0.001808	0.0002139	0.0002390	0.0002649
6	0.002014	0.002250	0.002494	0.0002513	0.0002807	0.0003111
7	0.003258	0.003640	0.004034	0.0003196	0.0003570	0.0003957
8	0.004615	0.005156	0.005714	0.0003803	0.0004249	0.0004709
9	0.007129	0.007965	0.008827	0.0004727	0.0005281	0.0005853

10	0.01061	0.01185	0.01314	0.0005766	0.0006442	0.0007140
11	0.01650	0.01843	0.02042	0.0007190	0.0008033	0.0008903
12	0.02423	0.02707	0.03000	0.0008715	0.0009736	0.001079
13	0.04199	0.04692	0.05200	0.001147	0.001282	0.001420
14	0.07207	0.08052	0.08924	0.001503	0.001679	0.001861
15	0.1273	0.1422	0.1576	0.001997	0.002231	0.002473
16	0.1916	0.2141	0.2373	0.002451	0.002738	0.003034
17	0.3023	0.3377	0.3742	0.003078	0.003439	0.003811
18	0.5933	0.6629	0.7346	0.004312	0.004818	0.005339
19	1.099	1.228	1.361	0.005870	0.006558	0.007267
20	2.279	2.547	2.822	0.008452	0.009443	0.01047
21	3.262	3.644	4.039	0.01011	0.01130	0.01252
22	5.565	6.217	6.890	0.01321	0.01475	0.01635
23	8.756	9.783	10.84	0.01657	0.01851	0.02051
24	14.60	16.31	18.08	0.02139	0.02390	0.02649
25	21.38	23.88	26.47	0.02588	0.02892	0.03205
26	32.58	36.40	40.34	0.03196	0.03570	0.03957
27	52.19	58.31	64.62	0.04045	0.04519	0.05008
28	89.04	99.48	110.2	0.05283	0.05902	0.06541
29	119.08	133.8	148.3	0.06127	0.06845	0.07586
30	165.0	184.3	204.2	0.07190	0.08033	0.08903
31	342.0	382.1	423.5	0.1035	0.1157	0.1282
32	521.3	582.5	645.5	0.1278	0.1428	0.1583
33	835.1	933.0	1,034	0.1618	0.1807	0.2003
34	1,425	1,592	1,764	0.2113	0.2361	0.2616
35	5,473	6,114	6,776	0.4142	0.4627	0.5129
36	13,360	14,930	16,540	0.6471	0.7230	0.8011

The following condensed copper wire tables for both solid and stranded conductors are more convenient for ordinary calculations.

Solid Copper Wire—100% Matthiessen's Standard.

No. B.&S.	Diam. Mils.	Area. Cir. Mils.	Weight. Pounds.			Resistance, 20° C. 68° F.	
	Bare.		1000′.	Mile.	Feet per Pound.	1000′.	Mile.
0000	460	211,600	640.5	3,381	1.561	.04893	.2583
000	409.6	167,800	508	2,682	1.969	.06170	.3258
00	364.8	133,100	402.8	2,127	2.482	.07780	.4108
0	324.9	105,500	319.5	1,687	3.130	.09811	.5180
1	289.3	83,690	253.3	1,337	3.947	.12370	.6531
2	257.6	66,370	200.9	1,062	4.977	.1560	.8237
3	229.4	52,630	159.3	841.1	6.276	.1967	1.0386
4	204.3	41,740	126.4	667.4	7.914	.2480	1.3094
5	181.9	33,100	100.2	529.0	9.980	.3128	1.6516
6	162.0	26,250	79.46	419.5	12.580	.3944	2.0824
7	144.3	20,820	63.02	332.7	15.87	.4973	2.6257
8	128.5	16,510	49.98	263.9	20.01	.6271	3.3111
9	114.4	13,090	39.63	209.2	25.23	.7908	4.1754
10	101.9	10,380	31.43	166.0	31.82	.9972	5.2652
11	90.74	8,234	24.93	131.6	40.12	1.257	6.6370
12	80.81	6,530	19.77	104.4	50.59	1.586	8.374
13	71.96	5,178	15.68	82.79	63.79	2.000	10.560
14	64.08	4,107	12.43	65.63	80.44	2.521	13.311
15	57.07	3,257	9.858	52.05	101.4	3.179	16.785
16	50.82	2,583	7.818	41.28	127.9	4.009	21.168
17	45.26	2,048	6.200	32.74	161.3	5.055	26.690
18	40.30	1,624	4.917	25.96	203.4	6.374	33.655
19	35.89	1,288	3.899	20.59	256.5	8.038	42.440
20	31.96	1,022	3.092	16.33	323.4	10.14	53.540

Stranded Copper Wire—100% Matthiessen's Standard.

No. B.&S.	Diam. Mils. Bare.	Area Cir. Mils.	Weight Pounds. 1,000′.	Weight Pounds. Per Mile.	Weight Pounds. Feet per lb.	Resistance 20° C. 68° F. 1,000′.	Resistance 20° C. 68° F. Mile.
		2,000,000	6,100	32,208	.164	.005177	.02733
		1,500,000	4,575	24,156	.219	.006902	.03644
		1,250,000	3,813	20,132	.262	.008282	.04373
	1,152	1,000,000	3,050	16,104	.328	.010353	.05466
	1,125	950,000	2,898	15,299	.345	.010900	.05755
	1,092	900,000	2,745	14,494	.364	.01150	.06072
	1,062	850,000	2,593	13,688	.385	.01218	.06431
	1,035	800,000	2,440	12,883	.409	.01294	.06832
	999	750,000	2,288	12,078	.437	.01380	.07286
	963	700,000	2,135	11,273	.468	.01479	.07809
	927	650,000	1,983	10,468	.504	.01593	.08411
	891	600,000	1,830	9,662	.546	.01725	.09108
	855	550,000	1,678	8,857	.596	.01882	.09937
	819	500,000	1,525	8,052	.655	.02070	.10930
	770	450,000	1,373	7,247	.728	.02300	.12144
	728	400,000	1,220	6,442	.819	.02588	.13664
	679	350,000	1,068	5,636	.936	.02958	.15618
	630	300,000	915	4,831	1.093	.03451	.18221
	590	250,000	762	4,026	1.312	.04141	.21864
0000	530	211,600	645	3,405	1.550	.04893	.2583
000	470	167,800	513	2,709	1.949	.06170	.3258
00	420	133,100	406	2,144	2.463	.07780	.4108
0	375	105,500	322	1,700	3.106	.09811	.5180
1	330	83,690	255	1,347	3.941	.12370	.6531
2	291	66,370	203	1,072	4.926	.15600	.8237
3	261	52,630	160	845	6.250	.19670	1.0386
4	231	41,740	127	671	7.874	.2480	1.3094

This table is calculated for untwisted strands; if the strand is twisted the cross section of the copper at right angles to the length of the strand, the weight per unit length and the resistance per unit length will each increase from 1 to 3 per cent, and the length per unit weight will decrease from 1 to 3 per cent, depending on the number of twists per unit length and the number of wires in the strand.

Tensile Strength of Copper Wire.

ROEBLING.

Numbers, B. & S. Gauge.	Breaking Weight, Lbs. Hard-drawn.	Breaking Weight, Lbs. Annealed.	Numbers, B. & S. Gauge.	Breaking Weight, Lbs. Hard-drawn.	Breaking Weight, Lbs. Annealed.
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

The strength of soft copper wire varies from 32,000 to 36,000 pounds per square inch, and of hard copper wire from 45,000 to 68,000 pounds per square inch, according to the degree of hardness.

The above table is calculated for 34,000 pounds for soft wire and 60,000 pounds for hard wire, except for some of the larger sizes, where the breaking weight per square inch is taken at 50,000 pounds for 0000, 000, and 00, 55,000 for 0, and 57,000 pounds for 1.

Hard-Drawn Copper Telegraph Wire.

ROEBLING.

Size B. & S. Gauge.	Resistance in Ohms per Mile.	Breaking Strength, Pounds.	Weight per Mile.	Furnished in Coils as follows, Miles.	Approx. Size E.B.B. Iron Wire Equal to Copper.
9	4.30	625	209	1	2
10	5.40	525	166	1.2	3 Iron-Wire Gauge.
11	6.90	420	131	.52	4 Iron-Wire Gauge.
12	8.70	330	104	.65	6 Iron-Wire Gauge.
13	10.90	270	83	1.20	6½ Iron-Wire Gauge.
14	13.70	213	66	1.50	8 Iron-Wire Gauge.
15	17.40	170	52	2.00	9 Iron-Wire Gauge.
16	22.10	130	41	1.20	10

In handling this wire the greatest care should be observed to avoid kinks, bends, scratches, or cuts. Joints should be made only with McIntire Connectors.

On account of its conductivity being about five times that of Ex. B. B. Iron Wire, and its breaking strength over three times its weight per mile, copper may be used of which the section is smaller and the weight less than an equivalent iron wire, allowing a greater number of wires to be strung on the poles.

Besides this advantage, the reduction of section materially decreases the electrostatic capacity, while its non-magnetic character lessens the self-induction of the line, both of which features tend to increase the possible speed of signalling in telegraphing, and to give greater clearness of enunciation over telephone lines, especially those of great length.

Weight of Copper Wire.

ENGLISH SYSTEM, PER 1,000 FEET AND PER MILE, IN POUNDS.

Number.	English Legal Standard. Diameter in Mils.	Weight. 1000 Feet.	Weight. Mile.	Birmingham. Diameter in Mils.	Weight. 1000 Feet.	Weight. Mile.	Brown & Sharpe. Diameter in Mils.	Weight. 1000 Feet.	Weight. Mile.
6-0	464	652	3,441	....	....	....	....	....	....
5-0	432	565	2,983	....	....	....	....	....	....
4-0	400	484	2,557	454	624	3,294	460	641	3,382
3-0	372	419	2,212	425	547	2,887	410	509	2,687
2-0	348	367	1,935	380	437	2,308	365	403	2,129
0	324	318	1,678	340	350	1,847	325	320	1,688
1	300	272	1,438	300	272	1,438	289	253	1,335
2	276	231	1,217	284	244	1,289	258	202	1,064
3	252	192	1,015	259	203	1,072	229	159	838
4	232	163	860	238	171	905	204	126	665
5	212	136	718	220	146	773	182	100	529
6	192	112	589	203	125	659	162	79	419
7	176	94	495	180	98	518	144	63	331
8	160	77	409	165	82	435	128	50	262
9	144	63	331	148	66	350	114	39	208
10	128	50	262	134	54	287	102	32	166
11	116	41	215	120	44	230	91	25	132
12	104	33	173	109	36	190	81	20	105
13	92	25.6	135	95	27.3	144	72	15.7	83
14	80	19.4	102	83	20.8	110	64	12.4	65
15	72	15.7	83	72	15.7	83	57	9.8	52
16	64	12.4	65	65	12.8	68	51	7.9	42
17	56	9.5	50	58	10.2	54	45	6.1	32
18	48	7.0	36.8	49	7.3	38.4	40	4.8	25.6
19	40	4.8	25.6	42	5.3	28.2	36	3.9	20.7
20	36	3.9	20.7	35	3.7	19.6	32	3.1	16.4
21	32	3.1	16.4	32	3.1	16.4	28.5	2.5	13.0
22	28	2.4	12.5	28	2.4	12.5	25.3	1.9	10.2
23	24	1.7	9.2	25	1.9	10.0	22.6	1.5	8.2
24	22	1.5	7.7	22	1.5	7.7	20.1	1.2	6.5
25	20	1.2	6.4	20	1.2	6.4	17.9	.97	5.1
26	18	.98	5.2	18	.98	5.2	15.9	.77	4.0
27	16.4	.81	4.3	16	.77	4.1	14.2	.61	3.2
28	14.8	.66	3.5	14	.59	3.1	12.6	.48	2.5
29	13.6	.56	3.0	13	.51	2.7	11.3	.39	2.0
30	12.4	.47	2.5	12	.44	2.3	10.0	.30	1.6
31	11.6	.41	2.15	10	.30	1.6	8.9	.24	1.27
32	10.8	.35	1.86	9	.25	1.3	8.0	.19	1.02
33	10.0	.30	1.60	8	.19	1.02	7.1	.15	.81
34	9.2	.26	1.35	7	.15	.78	6.3	.12	.63
35	8.4	.21	1.13	5	.075	.40	5.6	.095	.50
36	7.6	.17	.92	4	.048	.256	5.0	.076	.40

The diameters given for the various sizes are those to which the wire is actually drawn.

Weight of Copper Wire.

METRIC SYSTEM — PER KILOMETER, IN KILOGRAMS.

Number of Wire Gauge.	Roebling.	Brown & Sharpe.	Birmingham or Stubs.	English Legal Standard.
6–0	954.3	.....	....	970.9
5–0	833.9	.....	.....	841.6
4–0	696.5	954.3	929.4	721.5
3–0	591.0	756.8	814.5	624.0
2–0	494.1	600.2	651.3	546.2
0	425.1	480.4	521.3	473.4
1	361.2	377.4	405.8	405.8
2	311.9	299.3	363.3	343.5
3	268.5	237.4	302.6	286.3
4	228.3	188.3	255.3	242.7
5	193.2	149.3	218.3	202.7
6	166.2	118.4	185.9	166.2
7	141.3	93.9	146.1	139.7
8	118.3	74.5	122.8	115.4
9	98.8	59.0	98.8	93.5
10	82.2	46.8	81.0	73.9
11	64.9	37.1	64.9	60.7
12	49.9	29.5	53.6	48.8
13	38.2	23.4	39.8	38.2
14	28.9	18.5	31.1	28.9
15	23.4	14.7	23.4	23.4
16	17.9	11.7	19.1	18.5
17	13.2	9.23	15.2	14.1
18	9.96	7.32	10.8	10.4
19	7.58	5.80	7.95	7.22
20	5.52	4.61	5.52	5.85
21	4.61	3.65	4.62	4.61
22	3.54	2.89	3.54	3.54
23	2.81	2.16	2.81	2.59
24	2.38	1.82	2.19	2.19
25	1.80	1.44	1.80	1.80
26	1.46	1.15	1.46	1.46
27	1.30	.908	1.16	1.21
28	1.15	.720	.884	.988
29	1.02	.572	.762	.833
30	.884	.452	.649	.694
31	.822	.359	.451	.607
32	.762	.284	.365	.525
33	.544	.226	.289	.451
34	.451	.179	.220	.381
35	.406	.141	.113	.319
36	.365	.113	.071	.260

Standard Copper Strands.

ROEBLING.

C.M.	Wires.		Outside Diam.	Weight lbs. per 1000 ft.
	No.	Size.		
2,000,000	127	.1255	1.632	6100
1,950,000	127	.1239	1.611	5948
1,900,000	127	.1223	1.590	5795
1,850,000	127	.1207	1.569	5643
1,800,000	127	.1191	1.548	5490
1,750,000	127	.1174	1.526	5338
1,700,000	91	.1367	1.504	5185
1,650,000	91	.1347	1.482	5033
1,600,000	91	.1326	1.459	4880
1,550,000	91	.1305	1.436	4728
1,500,000	91	.1284	1.412	4575
1,450,000	91	.1262	1.388	4423
1,400,000	91	.1240	1.364	4270
1,350,000	91	.1218	1.340	4118
1,300,000	91	.1195	1.315	3965
1,250,000	91	.1172	1.289	3813
1,200,000	61	.1403	1.263	3660
1,150,000	61	.1373	1.236	3508
1,100,000	61	.1343	1.209	3355
1,050,000	61	.1312	1.181	3203
1,000,000	61	.1280	1.152	3050
950,000	61	.1247	1.122	2898
900,000	61	.1214	1.093	2745
850,000	61	.1180	1.062	2593
800,000	61	.1145	1.031	2440
750,000	61	.1108	.997	2288
700,000	61	.1071	.964	2135
650,000	61	.1032	.929	1983
600,000	61	.0991	.892	1830
550,000	61	.0949	.854	1678
500,000	61	.0905	.815	1525
450,000	37	.1103	.772	1373
400,000	37	.1039	.727	1220
350,000	37	.0972	.680	1068
300,000	37	.0900	.630	915
250,000	37	.0821	.575	763

Standard Copper Strands. — (*Continued*).

ROEBLING.

Size. B. &. S.	Wires. No.	Wires. Size.	Outside Diameter.	Weight. Lbs. per 1000 ft.
0000	19	.1055	.528	645
000	19	.0941	.471	513
00	19	.0837	.419	406
0	19	.0746	.373	322
1	19	.0663	.332	255
2	7	.0975	.293	203
3	7	.0866	.260	160
4	7	.0771	.231	127
5	7	.0688	.206	101
6	7	.0612	.184	80
8	7	.0484	.145	50
10	7	.0386	.116	32
12	7	.0306	.092	20
14	7	.0242	.073	12
16	7	.0193	.058	8
18	7	.0151	.045	5

INSULATED COPPER WIRES AND CABLES.

Weather-proof Line and House Wire. Solid Conductor.

STANDARD UNDERGROUND CABLE CO.

B. & S. Gauge.	Double Covered.			Triple Covered.		
	Lbs. per Mile.	Lbs. per 1000 ft.	Diam. in Mils.	Lbs. per Mile.	Lbs. per 1000 ft.	Diam. in Mils.
0000	3690	699	725	3910	741	780
000	2970	562	655	3160	598	700
00	2390	452	585	2560	485	635
0	1860	352	545	2020	382	590
1	1500	284	505	1650	312	550
2	1225	232	470	1340	254	515
3	980	186	385	1050	199	450
4	800	151	360	860	163	430
5	640	121	335	700	132	400
6	520	98	300	575	109	360
7	420	79	270	465	88	335
8	345	65	245	390	74	265
9	275	52	225	320	60	255
10	235	45	195	265	50	220
11	190	36	180	225	42	205
12	145	27	165	180	34	185
14	105	20	140	130	24	160
16	80	15	130	100	19	150
18	55	10	125	80	15	145
20	42	8	122	68	12	135

The following tables of weights of weatherproof wire are in *general* use by the manufacturers and are guaranteed to be correct within 3%.

WEATHER-PROOF WIRE.

Approximate Weights. — Solid.

Size. B. & S. Gauge.	Double Braid.		Triple Braid.	
	Lbs. per 1000 ft.	Lbs. per Mile.	Lbs. per 1000 ft.	Lbs. per Mile.
0000	723	3,817	767	4,050
000	587	3,098	629	3,320
00	467	2,467	502	2,650
0	377	1,989	407	2,150
1	294	1,553	316	1,670
2	239	1,264	260	1,370
3	185	977	199	1,050
4	151	795	164	865
5	122	646	135	710
6	100	529	112	590
8	66	349	75	395
9	54	283	62	325
10	46	241	53	280
12	30	158	35	185
14	20	107	25	130
16	16	83	20	105
18	12	64	16	85
20	9	48	12	65

Approximate Weights. — Stranded.

Capacity. Circular Mills.				
2,000,000	6,690	35,323	7,008	37,000
1,750,000	5,894	31,119	6,193	32,700
1,500,000	5,098	26,915	5,380	28,400
1,250,000	4,264	22,516	4,508	23,800
1,000,000	3,456	18,246	3,674	19,400
900,000	3,127	16,513	3,332	17,600
800,000	2,799	14,779	2,992	15,800
750,000	2,635	13,913	2,822	14,900
700,000	2,471	13,045	2,650	14,000
600,000	2,093	11,052	2,235	11,800
500,000	1,765	9,318	1,894	10,000
450,000	1,601	8,452	1,724	9,100
400,000	1,436	7,584	1,553	8,200
350,000	1,248	6,589	1,345	7,100
300,000	1,083	5,721	1,174	6,200
250,000	907	4,788	985	5,200
Size–B. & S. Gauge.				
0000	745	3,935	800	4,220
000	604	3,190	653	3,450
00	482	2,544	522	2,760
0	388	2,051	424	2,240
1	303	1,599	328	1,735
2	246	1,301	270	1,425
3	190	1,004	206	1,090
4	155	820	170	900
5	126	668	140	740
6	103	544	115	610
8	68	359	78	410

SLOW BURNING WEATHER-PROOF WIRE.

TRIPLE BRAID — BLACK OUTSIDE.

Capacity. Circular Mills.	Stranded. Lbs. per 1000 ft.	Stranded. Lbs. per Mile.	Solid. Lbs. per 1000 ft.	Solid. Lbs. per Mile.	Capacity. Circular Mills. Size—B. & S. Gauge.	Stranded. Lbs. per 1000 ft.	Stranded. Lbs. per Mile.	Solid. Lbs. per 1000 ft.	Solid. Lbs. per Mile.
1000000	3860	20400	......	......	0000	900	4750	862	4550
900000	3520	18600	......	......	000	735	3880	710	3750
800000	3180	16800	......	......	00	583	3080	562	2970
700000	2820	14900	......	......	0	480	2530	462	2440
600000	2350	12400	......	......	1	355	1870	340	1800
500000	1990	10500	......	......	2	290	1540	280	1480
450000	1820	9600	......	......	3	240	1270	230	1220
400000	1650	8700	......	......	4	195	1030	190	1000
350000	1440	7600	......	......	5	160	845	155	820
300000	1270	6700	......	......	6	132	695	127	670
250000	1060	5600	......	......	8	87	460	85	450
					10	......	......	60	315
					12	......	......	42	220
					14	......	......	30	160
					16	......	......	24	130
					18	......	......	19	100

WEATHER-PROOF IRON WIRE.

APPROXIMATE WEIGHTS PER MILE.

Iron Wire Gauge.	Double Braid.	Triple Braid.	Iron Wire Gauge.	Double Braid.	Triple Braid.
No. 4	860	940	No. 10	350	400
6	665	740	12	225	260
8	470	525	14	145	175
9	400	450			

SLOW BURNING WIRE.

APPROXIMATE WEIGHTS — TRIPLE BRAID.

Capacity. Circular Mills.	Stranded. Lbs. per 1000 ft.	Stranded. Lbs. per Mile.	Solid. Lbs. per 1000 ft.	Solid. Lbs. per Mile.	Capacity. Circular Mills. Size—B. & S. Gauge.	Stranded. Lbs. per 1000 ft.	Stranded. Lbs. per Mile.	Solid. Lbs. per 1000 ft.	Solid. Lbs. per Mile.
1000000	3980	21000	......	......	0000	960	5070	925	4890
900000	3640	19200	......	......	000	785	4150	760	4020
800000	3280	17300	......	......	00	625	3300	600	3170
700000	2920	15400	......	......	0	510	2700	495	2610
600000	2460	13000	......	......	1	380	2000	365	1930
500000	2080	11000	......	......	2	335	1770	320	1690
450000	1900	10000	......	......	3	280	1480	270	1425
400000	1700	9000	......	......	4	230	1220	220	1160
350000	1500	7900	......	......	5	195	1030	190	1000
300000	1310	6900	......	......	6	165	870	160	845
250000	1120	5900	......	......	8	105	555	100	530
					10	......	......	80	420
					12	......	......	55	290
					14	......	......	40	210
					16	......	......	30	160
					18	......	......	24	130

Underwriters' Test of Rubber Covered Wire.

Adopted Dec. 6, 1904.

The Electrical Committee of the Underwriters National Association recommended the following, which was adopted.

Each foot of the completed covering must show a dielectric strength sufficient to resist throughout five minutes the application of an electromotive force proportionate to the thickness of insulation in accordance with the following table:

Thickness in 64ths inches.	Breakdown Test on 1 Foot.
1	3,000 Volts A. C.
2	6,000 " "
3	9,000 " "
4	11,000 " "
5	13,000 " "
6	15,000 " "
7	16,500 " "
8	18,000 " "
10	21,000 " "
12	23,500 " "
14	26,000 " "
16	28,000 " "

Standard Rubber Covered Wires and Cables.

(Made by General Electric Company.)

Rubber covered wires and cables are insulated with two or more coats of rubber, the inner coat in all cases being free from sulphur or other substance liable to corrode the copper, the best grade of fine Para being employed. All conductors are heavily and evenly tinned.

Five distinct finishes can be furnished as follows: — White or black braid, plain lead jacket, lead jacket protected by a double wrap of asphalted jute, lead jacket armored with a special steel tape, white armored, for submarine use.

For use in conduits the plain lead covering is recommended, or if corrosion is especially to be feared, the lead and asphalt. For use where no conduit is available, the band steel armored cable is best, as it combines moderate flexibility with great mechanical strength, enabling it to resist treatment which would destroy an unarmored cable.

In addition to the ordinary galvanometer tests, wires and cables are tested with an alternating current (as specified in table) before shipping.

Special rubber covered wire and cable with lead jackets will be covered with the following thicknesses of lead unless otherwise specified:

Outside diameter of cable (inside diameter of lead pipe).

Up to and including .500″	$\frac{3}{64}$″
.501″ to .750″, inclusive	$\frac{1}{16}$″
.751″ to 1.250″, inclusive	$\frac{5}{64}$″
1.251″ to 1.5″, inclusive	$\frac{3}{32}$″
Larger than 1.501″	$\frac{1}{8}$″

Standard Conductor. National Electric Code, General Electric Company.

I. Solid.

Size. B. & S.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 Feet, Leaded.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Thickness of Rubber, Inches.	Test Pressure for 30 min.	
		Single Braid.	Double Braid.					Red Core.	White Core.
18	.159	20	33	170	.253	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
16	.190	25	40	203	.284	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
14	.203	33	47	220	.297	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
12	.220	43	58	243	.314	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
10	.241	58	74	273	.335	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
8	.268	81	99	316	.362	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
6	.352	130	150	389	.411	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
5	.372	159	180	433	.431	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
4	.394	187	210	476	.453	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
3	.419	230	254	538	.478	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
2	.448	273	298	599	.507	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
1	.540	362	390	722	.570	$\frac{3}{64}$	$\frac{5}{64}$	2500	3500
0	.576	438	467	981	.636	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
00	.616	533	562	1116	.675	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
000	.661	648	678	1279	.721	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
0000	.711	794	827	1473	.771	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500

NOTE. — Wire and cable No. 1 B. & S and larger have tape over rubber in addition to braid. Add $\frac{1}{16}''$ to single braid for diameter of double braid.

Standard Conductor. — National Electric Code, General Electric Company.— *Cont.*

II. Stranded.

Size. B. & S. and C. M.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 Feet, Leaded.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Thickness of Rubber, Inches.	Test Pressure for 30 min.	
		Single Braid.	Double Braid.					Red Core.	White Core.
16	.196	28	43	210	.290	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
14	.212	35	50	228	.306	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
12	.231	46	63	253	.325	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
10	.255	63	81	288	.349	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
8	.285	86	107	335	.379	$\frac{3}{64}$	$\frac{3}{64}$	1000	1500
6	.374	139	162	410	.433	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
5	.396	165	189	455	.455	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
4	.422	197	221	507	.481	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
3	.450	240	265	567	.509	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
2	.512	289	316	639	.541	$\frac{3}{64}$	$\frac{1}{16}$	2000	2500
1	.587	381	410	935	.647	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
100000	.616	447	476	1030	.676	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
0	.626	464	493	1055	.686	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
125000	.656	513	544	1128	.716	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
00	.669	563	595	1202	.730	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
150000	.690	617	650	1275	.750	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
000	.721	683	716	1372	.781	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
200000	.763	800	834	1532	.823	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
0000	.779	835	869	1583	.839	$\frac{1}{16}$	$\frac{5}{64}$	2500	3500
250000	.873	1032	1095	2047	.948	$\frac{1}{16}$	$\frac{3}{32}$	4000	5000
300000	.932	1218	1283	2303	1.008	$\frac{5}{64}$	$\frac{3}{32}$	4000	5000
350000	.976	1381	1449	2527	1.056	$\frac{5}{64}$	$\frac{3}{32}$	4000	5000
400000	1.027	1548	1617	2753	1.102	$\frac{5}{64}$	$\frac{3}{32}$	4000	5000
500000	1.113	1888	1958	3202	1.189	$\frac{5}{64}$	$\frac{3}{32}$	4000	5000
600000	1.222	2275	2354	3725	1.298	$\frac{5}{64}$	$\frac{7}{64}$	5000	6000
700000	1.294	2619	2707	4148	1.370	$\frac{5}{64}$	$\frac{7}{64}$	5000	6000
750000	1.328	2791	2880	4355	1.404	$\frac{5}{64}$	$\frac{7}{64}$	5000	6000
800000	1.360	2959	3051	4912	1.436	$\frac{3}{32}$	$\frac{7}{64}$	5000	6000
900000	1.423	3295	3390	5340	1.531	$\frac{3}{32}$	$\frac{7}{64}$	5000	6000
1000000	1.482	3624	3721	5752	1.590	$\frac{3}{32}$	$\frac{7}{64}$	5000	6000
1250000	1.650	4496	4600	7704	1.820	$\frac{1}{8}$	$\frac{1}{8}$	5000	6000
1500000	1.772	5319	5432	8754	1.942	$\frac{1}{8}$	$\frac{1}{8}$	5000	6000
2000000	1.992	6958	7075	10821	2.162	$\frac{1}{8}$	$\frac{1}{8}$	5000	6000

NOTE. — Wire and cable No. 1 B. & S. and larger have tape over rubber in addition to braid. Add $\frac{1}{16}''$ to single braid for diameter of double braid.

Diameters and Weights of Small Sizes of Cotton Covered Wire.

Size B. & S.	Diameters.				Weight in Pounds per 1000 Feet.			
	S.C.C.	D.C.C.	S.S.C.	D.S.C.	S.C.C.	D.C.C.	S.S.C.	D.S.C.
14	.0700	.0740	....	....	12.684	12.918	....	....
15	.0630	.0670	....	....	10.082	10.274	....	....
16	.0560	.0590	....	....	8.012	8.176	....	....
17	.0500	.0530	....	....	6.375	6.510	....	....
18	.0450	.0480	....	....	5.081	5.188	....	....
19	.0400	.0440	....	....	4.043	4.130	....	....
20	.0360	.0400	....	....	3.218	3.289	....	....
21	.0325	.0365	....	....	2.569	2.628	....	....
22	.0294	.0334	....	....	2.055	2.106	....	....
23	.0265	.0305	.0260	.0290	1.630	1.676	1.573	1.604
24	.0241	.0280	.0230	.0260	1.297	1.344	1.241	1.298
25	.0220	.0260	.0210	.0240	1.036	1.082	.991	1.040
26	.0200	.0240	.0190	.0220	.828	.873	.791	.833
27	.0180	.0220	.0170	.0200	.661	.703	.631	.666
28	.0166	.0206	.0156	.0186	.524	.562	.499	.521
29	.0153	.0193	.0140	.0170	.421	.457	.397	.416
30	.0140	.0180	.0125	.0159	.336	.372	.315	.332
31	.0130	.0170	.0114	.0139	.271	.307	.254	.267
32	.0119	.0159	.0105	.0130	.215	.248	.203	.214
33	.0110	.0150	.0095	.0120	.174	.201	.161	.172
34	.0103	.0143	.0088	.0113	.141	.161	.130	.140
35	.0096	.0136	.0076	.0096	.120	.137	.110	.119
36	.0085	.0120	.0070	.0090	.099	.112	.089	.096
38	....	....	.0060	.0080	....	....	.058	.065
40	....	....	.0050	.0070	....	....	.037	.040

General Electric Company Rubber Insulated Wire and Cable ($\frac{1}{16}''$ Rubber).

TEST PRESSURE. — RED CORE, 2500 VOLTS; WHITE CORE, 3000 VOLTS, FOR 30 MINUTES.

Wire.

Size. B. & S.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in Lbs.		Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	
		Single Braid.	Double Braid.				Red Core.	White Core.
16	.221	33	48	233	.315	$\frac{3}{64}$	350	600
14	.234	40	56	249	.328	$\frac{3}{64}$	350	600
12	.251	51	67	273	.345	$\frac{3}{64}$	350	600
10	.272	67	85	305	.366	$\frac{3}{64}$	350	600
8	.299	91	109	348	.393	$\frac{3}{64}$	350	600

Cable.

16	.227	39	56	242	.326	$\frac{3}{64}$	350	600
14	.243	43	61	260	.337	$\frac{3}{64}$	350	600
12	.262	60	80	285	.356	$\frac{3}{64}$	350	600
10	.286	78	99	316	.380	$\frac{3}{64}$	350	600
8	.316	105	127	360	.395	$\frac{3}{64}$	350	600

NOTE. — Add $\frac{1}{16}''$ to single braid for diameter of double braid.

General Electric Company Rubber Insulated Wire and Cable ($\frac{3}{32}''$ Rubber).

TEST PRESSURE. — RED CORE, 5000 VOLTS; WHITE CORE, 6000 VOLTS, FOR 30 MINUTES.

Wire.

Size. B. & S. and C. M.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	
		Single Braid.	Double Braid.				Red Core.	White Core.
14	.296	61	80	293	.376	$\frac{3}{64}$	400	700
12	.313	73	93	318	.393	$\frac{3}{64}$	400	700
10	.354	90	111	351	.414	$\frac{3}{64}$	400	700
8	.381	115	138	395	.441	$\frac{3}{64}$	400	700
6	.414	153	177	457	.474	$\frac{3}{64}$	400	700
5	.434	181	205	498	.494	$\frac{3}{64}$	350	600
4	.456	211	236	545	.516	$\frac{3}{64}$	350	600
3	.481	253	280	603	.541	$\frac{3}{64}$	350	600
2	.540	313	340	674	.569	$\frac{3}{64}$	350	600
1	.571	374	402	913	.632	$\frac{1}{16}$	350	600
0	.607	449	478	1025	.667	$\frac{1}{16}$	350	600
00	.647	543	574	1160	.707	$\frac{1}{16}$	300	500
000	.692	661	694	1323	.752	$\frac{1}{16}$	300	500
0000	.742	806	841	1519	.802	$\frac{1}{16}$	300	500
Cable.								
14	.305	69	91	304	.385	$\frac{3}{64}$	400	700
12	.324	83	105	332	.403	$\frac{3}{64}$	400	700
10	.368	103	126	367	.427	$\frac{3}{64}$	400	700
8	.398	131	155	416	.457	$\frac{3}{64}$	400	700
6	.436	176	201	485	.495	$\frac{3}{64}$	400	700
5	.458	203	229	528	.518	$\frac{3}{64}$	350	600
4	.484	239	266	583	.523	$\frac{3}{64}$	350	600
3	.542	285	313	647	.571	$\frac{3}{64}$	350	600
2	.574	336	365	878	.634	$\frac{1}{16}$	350	600
1	.618	409	438	996	.678	$\frac{1}{16}$	350	600
100000	.647	467	498	1084	.707	$\frac{1}{16}$	350	600
0	.657	485	515	1108	.717	$\frac{1}{16}$	350	600
125000	.687	562	566	1182	.747	$\frac{1}{16}$	300	500
00	.701	585	618	1255	.761	$\frac{1}{16}$	300	500
150000	.721	638	672	1329	.781	$\frac{1}{16}$	300	500
000	.752	709	743	1430	.812	$\frac{1}{16}$	300	500
200000	.794	826	861	1590	.854	$\frac{1}{16}$	300	500
0000	.810	864	900	1643	.870	$\frac{1}{16}$	300	500

NOTE. — Add $\frac{1}{16}''$ to single braid for diameter of double braid.

General Electric Company Rubber Insulated Wire ($\frac{4}{32}''$ Rubber).

TEST PRESSURE. — RED CORE, 7500 VOLTS; WHITE CORE, 9000 VOLTS, FOR 30 MINUTES.

I. Wire.

Size. B. & S.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	
		Single Braid.	Double Braid.				Red Core.	White Core.
14	.379	84	106	372	.438	$\frac{3}{64}$	600	1000
12	.396	98	121	398	.455	$\frac{3}{64}$	600	1000
10	.417	117	141	432	.476	$\frac{3}{64}$	600	1000
8	.444	144	169	479	.503	$\frac{3}{64}$	600	1000
6	.477	186	213	547	.536	$\frac{3}{64}$	550	900
5	.527	224	252	583	.556	$\frac{3}{64}$	550	900
4	.549	259	287	635	.578	$\frac{3}{64}$	550	900
3	.572	300	329	852	.633	$\frac{1}{16}$	550	900
2	.603	351	380	933	.663	$\frac{1}{16}$	550	900
1	.634	414	445	1028	.694	$\frac{1}{16}$	550	900
0	.670	493	525	1142	.730	$\frac{1}{16}$	500	800
00	.710	591	625	1282	.770	$\frac{1}{16}$	300	800
000	.755	712	746	1450	.815	$\frac{1}{16}$	300	800
0000	.805	859	895	1649	.865	$\frac{1}{16}$	300	800

General Electric Company Rubber Insulated Cable ($\frac{4}{32}$″ Rubber).

Test Pressure. — Red Core, 7500 Volts; White Core, 9000 Volts, for 30 Minutes.

II. Cable.

Size. B. & S. and C. M.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs. Single Braid.	Weight per 1000 ft. in lbs. Double Braid.	Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile. Red Core.	Insulation Resistance in Megohms per Mile. White Core.
14	.388	89	113	373	.447	$\frac{3}{64}$	600	1000
12	.407	103	127	401	.466	$\frac{3}{64}$	600	1000
10	.431	125	150	439	.490	$\frac{3}{64}$	600	1000
8	.461	156	182	491	.520	$\frac{3}{64}$	600	1000
6	.529	210	237	563	.558	$\frac{3}{64}$	550	900
5	.551	240	268	608	.580	$\frac{3}{64}$	550	900
4	.577	277	306	821	.636	$\frac{1}{16}$	550	900
3	.605	322	351	895	.665	$\frac{1}{16}$	550	900
2	.637	376	407	981	.697	$\frac{1}{16}$	550	900
1	.681	454	486	1104	.741	$\frac{1}{16}$	550	900
100000	.710	514	547	1192	.770	$\frac{1}{16}$	550	900
0	.720	530	564	1216	.780	$\frac{1}{16}$	500	800
125000	.750	582	616	1290	.810	$\frac{1}{16}$	500	800
00	.764	635	669	1364	.824	$\frac{1}{16}$	500	800
150000	.784	689	723	1443	.844	$\frac{1}{16}$	500	800
000	.815	760	796	1545	.875	$\frac{1}{16}$	500	800
200000	.872	914	977	1929	.948	$\frac{5}{64}$	500	800
0000	.888	953	1018	1987	.964	$\frac{5}{64}$	500	800
250000	.955	1084	1149	2178	1.031	$\frac{5}{64}$	400	700
300000	.994	1278	1346	2444	1.070	$\frac{5}{64}$	400	700
350000	1.042	1445	1514	2672	1.118	$\frac{5}{64}$	400	700
400000	1.088	1617	1686	2901	1.164	$\frac{5}{64}$	400	700
500000	1.175	1958	2034	3350	1.251	$\frac{5}{64}$	350	600
600000	1.253	2308	2391	3790	1.329	$\frac{5}{64}$	350	600
700000	1.325	2657	2747	4222	1.401	$\frac{5}{64}$	350	600
750000	1.359	2831	2923	4781	1.466	$\frac{3}{32}$	300	500
800000	1.391	3031	3126	5012	1.498	$\frac{3}{32}$	300	500
900000	1.454	3343	3438	5432	1.561	$\frac{3}{32}$	300	500
1000000	1.513	3675	3773	5852	1.620	$\frac{3}{32}$	300	500

Note. — Add $\frac{1}{16}$″ to single braid for diameter of double braid.

General Electric Company Rubber Insulated Wire and Cable ($\frac{6}{32}''$ Rubber).

TEST PRESSURE.— RED CORE, 12,000 VOLTS; WHITE CORE, 15,000 VOLTS, FOR 30 MINUTES.

I. Solid.

Size. B. & S.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	
		Single Braid.	Double Braid.				Red Core.	White Core.
14	.534	156	184	512	.562	$\frac{3}{64}$	700	1200
12	.551	173	201	540	.580	$\frac{3}{64}$	700	1200
10	.572	196	224	735	.601	$\frac{3}{64}$	700	1200
8	.598	226	255	792	.658	$\frac{1}{16}$	700	1200
6	.632	272	303	872	.692	$\frac{1}{16}$	700	1200
5	.652	302	333	924	.712	$\frac{1}{16}$	600	1100
4	.674	340	372	982	.734	$\frac{1}{16}$	600	1100
3	.699	386	419	1053	.759	$\frac{1}{16}$	600	1100
2	.728	441	474	1137	.788	$\frac{1}{16}$	600	1100
1	.759	509	543	1235	.819	$\frac{1}{16}$	600	1100
0	.795	592	638	1356	.855	$\frac{1}{16}$	550	1000
00	.850	696	732	1708	.926	$\frac{5}{64}$	550	1000
000	.895	851	926	1898	.971	$\frac{5}{64}$	550	1000
0000	.945	1011	1084	2109	1.021	$\frac{5}{64}$	550	1000

General Electric Company Rubber Insulated Wire and Cable ($\frac{6}{32}''$ Rubber) — *Continued.*

II. Stranded.

Size. B. & S. and C. M.	Diameter, Single Braid, Inches.	Weight per 1000 ft. in lbs.		Weight per 1000 ft., Leaded, lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	
		Single Braid.	Double Braid.				Red Core.	White Core.
14	.543	162	190	524	.572	$\frac{3}{64}$	700	1200
12	.562	181	209	566	.591	$\frac{3}{64}$	700	1200
10	.586	205	233	758	.646	$\frac{1}{16}$	700	1200
8	.616	239	268	822	.676	$\frac{1}{16}$	700	1200
6	.654	290	320	912	.714	$\frac{1}{16}$	600	1100
5	.676	323	354	968	.736	$\frac{1}{16}$	600	1100
4	.702	365	397	1034	.762	$\frac{1}{16}$	600	1100
3	.730	413	447	1112	.790	$\frac{1}{16}$	600	1100
2	.762	472	506	1201	.822	$\frac{1}{16}$	600	1100
1	.806	555	591	1332	.866	$\frac{1}{16}$	550	1000
100000	.850	619	656	1638	.926	$\frac{5}{64}$	550	1000
0	.860	637	675	1666	.936	$\frac{5}{64}$	550	1000
125000	.890	708	759	1750	.966	$\frac{3}{64}$	550	1000
00	.904	780	844	1834	.980	$\frac{3}{64}$	550	1000
150000	.924	838	903	1917	1.000	$\frac{3}{64}$	550	1000
000	.955	915	981	2032	1.031	$\frac{3}{64}$	550	1000
200000	.997	1042	1110	2212	1.073	$\frac{3}{64}$	500	900
0000	1.013	1083	1151	2271	1.089	$\frac{3}{64}$	500	900
250000	1.060	1225	1294	2473	1.136	$\frac{3}{64}$	500	900
300000	1.119	1424	1494	2745	1.195	$\frac{3}{64}$	500	900
350000	1.167	1600	1675	2980	1.243	$\frac{3}{64}$	450	800
400000	1.213	1781	1860	3218	1.289	$\frac{3}{64}$	450	800
500000	1.300	2138	2226	3679	1.376	$\frac{3}{64}$	450	800
600000	1.378	2497	2589	4474	1.485	$\frac{3}{32}$	400	700
700000	1.450	2854	2950	4938	1.557	$\frac{3}{32}$	400	700
750000	1.484	3030	3127	5161	1.591	$\frac{3}{32}$	350	600
800000	1.516	3205	3304	5384	1.623	$\frac{3}{32}$	350	600
900000	1.579	3557	3658	5829	1.687	$\frac{3}{32}$	350	600
1000000	1.638	3900	4004	7085	1.808	$\frac{1}{8}$	350	600

Note. — Add $\frac{1}{16}''$ to single braid for diameter of double braid.

For $\frac{5}{32}''$ insulation the insulation resistance will be in proportion with $\frac{4}{32}''$ and $\frac{6}{32}''$ insulation.

Test pressure for $\frac{5}{32}''$ Red Core, 10,000 volts; White Core, 12,000 volts for 30 minutes.

General Electric Company Three Conductor Cable, White Core Insulation.

TEST PRESSURE.—3000 VOLTS FOR 30 MINUTES.

Size. B. & S. and C. M.	Leaded.				Braided.		Insulation Resistance in Megohms per Mile.
	Weight, lbs. per 1000 ft.	Thickness of Rubber in Inches.	Diameter, Leaded, in Inches.	Thickness of Lead in Inches.	Diameter in Inches.	Weight, lbs. per 1000 ft.	
8	1192	$\frac{1}{16}$	.805	$\frac{1}{16}$	.740	449	600
6	1567	$\frac{1}{16}$	.918	$\frac{5}{64}$	.852	551	500
5	1728	$\frac{1}{16}$	.966	$\frac{5}{64}$	.900	653	500
4	1889	$\frac{1}{16}$	1.022	$\frac{5}{64}$	.956	756	500
3	2123	$\frac{1}{16}$	1.082	$\frac{5}{64}$	1.016	909	500
2	2358	$\frac{1}{16}$	1.152	$\frac{5}{64}$	1.077	1062	500
1	2847	$\frac{5}{64}$	1.314	$\frac{5}{64}$	1.239	1352	500
100000	3032	$\frac{5}{64}$	1.376	$\frac{5}{64}$	1.301	1492	500
0	3217	$\frac{5}{64}$	1.398	$\frac{5}{64}$	1.327	1632	500
125000	3631	$\frac{5}{64}$	1.494	$\frac{5}{64}$	1.386	1800	500
00	4045	$\frac{5}{64}$	1.524	$\frac{5}{64}$	1.427	1967	500
150000	4332	$\frac{5}{64}$	1.567	$\frac{5}{64}$	1.470	2175	500
000	4619	$\frac{5}{64}$	1.635	$\frac{5}{64}$	1.537	2381	500
200000	4968	$\frac{5}{64}$	1.724	$\frac{5}{64}$	1.626	2638	500
0000	5318	$\frac{5}{64}$	1.759	$\frac{5}{64}$	1.662	2895	500

TEST PRESSURE.—8000 VOLTS FOR 30 MINUTES.

Size. B. & S. and C. M.	Leaded.			Braided.		Insulation Resistance in Megohms per Mile.
	Weight, lbs. per 1000 ft.	Diameter in Inches.	Thickness of Lead in Inches.	Diameter in Inches.	Weight, lbs. per 1000 ft.	
8	1892	1.106	$\frac{5}{64}$	1.040	641	1000
6	2144	1.188	$\frac{5}{64}$	1.122	796	900
5	2322	1.236	$\frac{5}{64}$	1.170	912	900
4	2499	1.292	$\frac{5}{64}$	1.226	1029	900
3	2926	1.353	$\frac{5}{64}$	1.287	1204	900
2	3354	1.453	$\frac{3}{32}$	1.356	1378	900
1	3760	1.548	$\frac{3}{32}$	1.451	1647	900
100000	3947	1.611	$\frac{3}{32}$	1.514	1775	900
0	4134	1.633	$\frac{3}{32}$	1.530	1904	800
125000	4385	1.697	$\frac{3}{32}$	1.594	2083	800
00	4636	1.727	$\frac{3}{32}$	1.630	2261	800
150000	5372	1.770	$\frac{3}{32}$	1.673	2478	800
000	6108	1.900	$\frac{1}{8}$	1.740	2696	800
200000	6500	1.991	$\frac{1}{8}$	1.831	2967	800
0000	6893	2.026	$\frac{1}{8}$	1.865	3238	800

General Electric Company Three Conductor Cable, White Core Insulation.

TEST PRESSURE.—15,000 VOLTS FOR 30 MINUTES.

Size. B. & S. and C. M.	Leaded.			Braided.		Insulation Resistance in Megohms per Mile.
	Weight, lbs. per 1000 ft.	Diameter in Inches.	Thickness of Lead in Inches.	Diameter in Inches.	Weight, lbs. per 1000 ft.	
8	2452	1.376	5/64	1.310	913	1300
6	3077	1.490	3/32	1.392	1097	1200
5	3282	1.538	3/32	1.440	1224	1200
4	3488	1.594	3/32	1.496	1352	1200
3	3767	1.654	3/32	1.556	1536	1200
2	4046	1.723	3/32	1.626	1721	1200
1	4471	1.818	3/32	1.721	2020	1100
100000	5120	1.943	1/8	1.783	2160	1100
0	5769	1.965	1/8	1.800	2301	1100
125000	6055	2.030	1/8	1.865	2490	1100
00	6342	2.060	1/8	1.900	2679	1100
150000	6677	2.103	1/8	1.943	2907	1100
000	7013	2.170	1/8	2.010	3135	1100
200000	7418	2.261	1/8	2.101	3421	1100
0000	7823	2.295	1/8	2.135	3707	1100

TEST PRESSURE.—26,000 VOLTS FOR 30 MINUTES.

Size. B. & S. and C. M.	Leaded.			Braided.		Insulation Resistance in Megohms per Mile.
	Weight, lbs. per 1000 ft.	Diameter in Inches.	Thickness of Lead in Inches.	Diameter in Inches.	Weight, lbs. per 1000 ft.	
8	4103	1.878	3/32	1.781	1558	1600
6	4437	1.960	3/32	1.863	1770	1500
5	4661	2.008	3/32	1.911	1919	1500
4	4885	2.064	3/32	1.967	2068	1500
3	5710	2.124	3/32	2.027	2281	1500
2	6535	2.256	1/8	2.096	2495	1500
1	6995	2.351	1/8	2.183	2792	1500
100000	7259	2.414	1/8	2.246	2968	1400
0	7523	2.436	1/8	2.271	3145	1400
125000	7828	2.500	1/8	2.335	3354	1400
00	8133	2.530	1/8	2.371	3563	1400
150000	8490	2.576	1/8	2.417	3813	1400
000	8848	2.641	1/8	2.481	4064	1400
200000	9292	2.731	1/8	2.571	4378	1300
0000	9736	2.766	1/8	2.606	4693	1300

General Electric Company Extra Flexible Dynamo Cable.

This is adapted for use as brush-holder leads, or to any use where great flexibility is required. The finish is black glazed linen braid. Each wire of the strand is No. 25 B. & S.

Number Wires in Strand.	Circular Mils.	Dimensions in Inches.		
		Diameter Bare.	Thickness Rubber.	Diameter Over All.
25	8,000	.108	.047	.275
50	16,000	.150	.047	.320
75	24,000	.205	.047	.375
100	32,000	.235	.047	.450
150	48,000	.285	.047	.500
200	64,000	.325	.047	.540
250	80,000	.350	.047	.600
300	96,000	.385	.065	.665
350	112,000	.425	.065	.705
400	128,000	.460	.065	.740
450	144,000	.485	.065	.765
500	160,000	.570	.065	.810
550	176,000	.530	.065	.830
600	192,000	.570	.065	.870
650	208,000	.605	.065	.935
700	224,000	.625	.065	.955
750	240,000	.640	.065	.970
800	256,000	.680	.065	1.010
900	288,000	.700	.065	1.030
1000	320,000	.725	.065	1.055
1250	400,000	.825	.065	1.165
1500	480,000	.880	.065	1.213
1750	560,000	.960	.093	1.360
2000	640,000	1.060	.093	1.410
2250	720,000	1.100	.093	1.500
2500	800,000	1.200	.093	1.600
2750	880,000	1.250	.093	1.650
3125	1,000,000	1.430	.093	1.830

Rubber Insulated Cable for Car Wiring.

Single Conductor, Weatherproof Finish.

This class of cable is made with separator, standard code thickness of insulation tape and single-braid weatherproof finish.

Standard Strands.

Size B. & S.	Stranding.	Finished Weight in Pounds per M Feet.	Diameter in Inches.
14	7/.0243	37	.23
12	7/.0306	48	.25
10	7/.0386	64	.27
8	7/.0485	90	.31
6	7/.0613	139	.38
4	7/.0773	197	.42
2	7/.0974	289	.51
1	19/.0664	381	.59
1/0	19/.0746	464	.63
2/0	19/.0838	563	.67
3/0	19/.0940	683	.72
4/0	19/.1056	835	.78
250,000	37/.0823	1032	.87

For each additional braid, add approximately $\frac{1}{16}$ inch to diameter.

Single Conductor, Flameproof Finish.

National Electric Code Standard.

This class of cable is made with separator, standard code thickness of insulation and double braid finish — the first braid is cotton, well compounded, the second or finishing braid is filled asbestos.

Standard Strands.

Size B. & S.	Stranding.	Finished Weight in Pounds per M Feet.	Diameter in Inches.
14	7/.0243	65	.31
12	7/.0306	78	.33
10	7/.0386	99	.36
8	7/.0485	128	.39
6	7/.0613	189	.47
4	7/.0773	255	.52
2	7/.0974	353	.58
1	19/.0664	461	.68
1/0	19/.0746	545	.72
2/0	19/.0838	650	.77
3/0	19/.0940	778	.82
4/0	19/.1056	937	.88
250,000	37/.0823	1138	.99
300,000	37/.0906	1330	1.05
350,000	37/.0974	1497	1.10
500,000	61/.0906	2024	1.23
750,000	61/.1110	2945	1.45
1,000,000	61/.1281	3801	1.62

Rubber Insulated Cable for Type M Control.

For connecting contactors and controllers, 19/25 B. & S. single conductor $\frac{3}{64}$-inch rubber insulation is used; double braid weatherproof finish. The nearest equivalent size is number 12 B. & S.

The weight per 1000 feet is 52 pounds, and diameter .25 inches.

Train Cables.

Multiple conductors, each single conductor being composed of 19/25 B. & S. wires, rubber covered, single braid and a tape and braid finish overall.

Number of Conductors.	Diameter Overall.	Weight per 1000 Ft.
5	.7	255
6	.75	343
7	.75	373
9	.85	479
10	.93	503
12	1.03	613
20	1.28	893

Jumper Cables.

Are similar in construction to train cables with the exception that the group of conductors is surrounded by a rubber jacket and a double braid finish.

Number of Conductors.	Diameter Overall.	Weight per 1000 Feet.
5	.88	371
6	.94	461
7	.94	491
9	1.00	632
10	1.07	687
12	1.30	846
20	1.54	1246

Both train and jumper cables have distinctive marking threads woven in the braid of each conductor.

NAVY STANDARD WIRES.

In the following table are given sizes of Navy Standard Wires as per specifications issued by the Navy Department in March, 1897.

Actual C. M.	No. Wires in Strand.	Size of Wire B. & S.	Diameter Inches.		Diameter in 32ds of an inch.			Approx. Weight per 1000 feet.
			Over copper.	Over Para rubber.	Over vulc. rubber.	Over tape.	Over braid.	
4,107	1	14	.06408	.0953	7	9	11	56.9
9,016	7	19	.10767	.1389	10	12	14	103
11,368	7	18	.12090	.1522	10	12	14	108.5
14,336	7	17	.13578	.1670	10	12	14	115.5
18,081	7	16	.15225	.1837	11	13	15	140
22,799	7	15	.17121	.2025	12	14	16	165¼
30,856	19	18	.20150	.2328	12	14	16	184
38,912	19	17	.22630	.2576	13	15	17	218
49,077	19	16	.25410	.2854	14	16	18	260¼
60,088	37	18	.28210	.3134	15	17	19	314
75,776	37	17	.31682	.3481	16	18	20	371
99,064	61	18	.36270	.3940	18	20	22	463
124,928	61	17	.40734	.4386	19	21	23	557
157,563	61	16	.45738	.4885	20	22	24	647
198,677	61	15	.51363	.5449	22	24	26	794
250,527	61	14	.57672	.6080	24	26	28	970
296,387	91	15	.62777	.6590	26	28	30	1,138
373,737	91	14	.70488	.7361	29	31	33	1,420
413,639	127	15	.74191	.7732	30	32	34	1,553

Double Conductor, Plain, 2–7–22 B. & S.	181.5
Double Conductor, Silk, 2–7–25 B. & S..	28
Double Conductor, Diving Lamp, 2–7–20 B. & S.	218.3
Bell Cord, 1–16 B. & S.	29.7

PAPER INSULATED AND LEADED WIRES AND CABLES.

GENERAL ELECTRIC CO.

There will be found on the following pages data of a full line of paper insulated and lead covered wires and cables. All cables insulated with fibrous covering depend for their successful operation and maintenance upon the exclusion of moisture by the lead sheath; and this fact should be borne in mind constantly in handling this class of cables, consequently the lead on them is extra heavy. The use of jute and asphalt covering over the lead is strongly recommended on all this class of cables, inasmuch as their life is absolutely dependent upon that of the lead. Paper insulated cables cannot be furnished without the lead covering.

General Electric Company Paper Insulated and Lead Covered Cable.

I. Solid.

Size. B. & S. and C. M.	3/32" Insulation Test Pressure, 4000 Volts for 30 Minutes.			4/32" Insulation Test Pressure, 6000 Volts for 30 Minutes.			Insulation Resistance in Megohms per Mile Either 3/32" or 4/32".
	Weight per 1000 ft. in lbs.	Diameter in Inches.	Thickness of Lead in in.	Weight per 1000 ft. in lbs.	Diameter in Inches.	Thickness of Lead in in.	
10	413	.414	1/16	493	.477	1/16	300
8	461	.441	1/16	542	.503	1/16	300
6	530	.474	1/16	613	.537	1/16	300
5	574	.494	1/16	660	.557	1/16	300
4	626	.517	1/16	715	.579	1/16	300

II. Stranded.

6	558	.496	1/16	645	.559	1/16	250
5	605	.518	1/16	694	.581	1/16	250
4	662	.544	1/16	754	.607	1/16	250
2	814	.604	1/16	1,068	.698	5/64	250
1	1,072	.679	5/64	1,184	.742	5/64	250
100000	1,176	.708	5/64	1,289	.771	5/64	250
0	1,199	.718	5/64	1,315	.781	5/64	250
125000	1,276	.748	5/64	1,393	.811	5/64	200
00	1,354	.762	5/64	1,470	.825	5/64	200
150000	1,431	.782	5/64	1,547	.845	5/64	200
000	1,536	.813	5/64	1,655	.876	5/64	200
200000	1,703	.855	5/64	2,046	.949	3/32	150
0000	1,758	.871	5/64	2,106	.965	3/32	150
250000	2,165	.950	3/32	2,304	1.012	3/32	150
300000	2,435	1.009	3/32	2,574	1.071	3/32	150
350000	2,660	1.057	3/32	2,804	1.119	3/32	125
400000	2,890	1.103	3/32	3,041	1.165	3/32	125
500000	3,929	1.252	1/8	4,106	1.315	1/8	125
600000	4,409	1.330	1/8	4,598	1.393	1/8	125
700000	4,876	1.402	1/8	5,067	1.465	1/8	100
750000	5,106	1.436	1/8	5,298	1.499	1/8	100
800000	5,337	1.468	1/8	5,523	1.531	1/8	100
900000	5,782	1.531	1/8	5,976	1.594	1/8	100
1000000	6,213	1.590	1/8	6,416	1.653	1/8	100
1250000	7,293	1.727	1/8	7,500	1.790	1/8	100
1500000	8,329	1.849	1/8	8,542	1.912	1/8	75
2000000	10,355	2.069	1/8	10,586	2.132	1/8	50

General Electric Company Paper Insulated and Lead Covered Cable.

I. Solid.

Size. B. & S. and C. M.	$\frac{5}{32}''$ Insulation Test Pressure, 8000 Volts for 30 Minutes.			$\frac{6}{32}''$ Insulation Test Pressure, 10,000 Volts for 30 Minutes.			Insulation Resistance in Megohms per Mile Either $\frac{5}{32}''$ or $\frac{6}{32}''$.
	Weight per 1000 ft. in lbs.	Diameter in Inches.	Thickness of Lead in in.	Weight per 1000 ft. in lbs.	Diameter in Inches.	Thickness of Lead in in.	
10	576	.539	$\frac{1}{16}$	669	.602	$\frac{1}{16}$	400
8	632	.565	$\frac{1}{16}$	875	.659	$\frac{5}{64}$	400
6	707	.599	$\frac{1}{16}$	960	.693	$\frac{5}{64}$	400
5	753	.619	$\frac{1}{16}$	1,011	.713	$\frac{5}{64}$	400
4	963	.672	$\frac{5}{64}$	1,075	.735	$\frac{5}{64}$	400

II. Stranded.

6	737	.621	$\frac{1}{16}$	999	.715	$\frac{5}{64}$	400
5	943	.674	$\frac{5}{64}$	1,056	.737	$\frac{5}{64}$	400
4	1,012	.700	$\frac{5}{64}$	1,124	.763	$\frac{5}{64}$	400
2	1,182	.760	$\frac{5}{64}$	1,300	.823	$\frac{5}{64}$	350
1	1,300	.804	$\frac{5}{64}$	1,420	.867	$\frac{5}{64}$	350
100000	1,407	.833	$\frac{5}{64}$	1,529	.896	$\frac{5}{64}$	350
0	1,433	.843	$\frac{5}{64}$	1,555	.906	$\frac{5}{64}$	350
125000	1,513	.873	$\frac{5}{64}$	1,752	.967	$\frac{3}{32}$	350
00	1,593	.887	$\frac{5}{64}$	1,949	.981	$\frac{3}{32}$	300
150000	1,892	.939	$\frac{3}{32}$	2,029	1.001	$\frac{3}{32}$	300
000	2,006	.970	$\frac{3}{32}$	2,147	1.032	$\frac{3}{32}$	300
200000	2,187	1.012	$\frac{3}{32}$	2,330	1.074	$\frac{3}{32}$	250
0000	2,246	1.028	$\frac{3}{32}$	2,390	1.090	$\frac{3}{32}$	250
250000	2,451	1.075	$\frac{3}{32}$	2,597	1.137	$\frac{3}{32}$	250
300000	2,724	1.134	$\frac{3}{32}$	3,470	1.259	$\frac{1}{8}$	250
350000	2,958	1.182	$\frac{3}{32}$	3,715	1.307	$\frac{1}{8}$	200
400000	3,795	1.290	$\frac{3}{32}$	3,980	1.353	$\frac{1}{8}$	200
500000	4,298	1.377	$\frac{1}{8}$	4,488	1.440	$\frac{1}{8}$	200
600000	4,793	1.455	$\frac{1}{8}$	4,983	1.518	$\frac{1}{8}$	200
700000	5,269	1.527	$\frac{1}{8}$	5,463	1.590	$\frac{1}{8}$	150
750000	5,500	1.561	$\frac{1}{8}$	5,702	1.624	$\frac{1}{8}$	150
800000	5,721	1.539	$\frac{1}{8}$	5,931	1.656	$\frac{1}{8}$	150
900000	6,189	1.656	$\frac{1}{8}$	6,390	1.719	$\frac{1}{8}$	150
1000000	6,631	1.715	$\frac{1}{8}$	6,838	1.778	$\frac{1}{8}$	125
1250000	7,715	1.852	$\frac{1}{8}$	7,943	1.915	$\frac{1}{8}$	100
1500000	8,776	1.974	$\frac{1}{8}$	9,001	2.037	$\frac{1}{8}$	100
2000000	10,834	2.194	$\frac{1}{8}$	11,066	2.257	$\frac{1}{8}$	100

General Electric Company Paper Insulated and Lead Covered Cable.

I. Solid.

Size. B. &. S and C. M.	$\frac{9}{32}''$ Insulation. Test Pressure, 16,000 Volts for 30 Minutes.			$\frac{12}{32}''$ Insulation. Test Pressure, 22,000 Volts for 30 Minutes.			Insulation Resistance in Megohms per Mile Either $\frac{9}{32}''$ or $\frac{12}{32}''$.
	Weight per 1000 ft. in lbs.	Diameter, Leaded, Inches.	Thickness of Lead in in.	Weight per 1000 ft. in lbs.	Diameter, Leaded, Inches.	Thickness of Lead in in.	
10	1,157	.820	$\frac{3}{32}$	1,770	1.039	$\frac{3}{32}$	600
8	1,223	.846	$\frac{3}{32}$	1,846	1.065	$\frac{3}{32}$	600
6	1,313	.880	$\frac{3}{32}$	1,949	1.099	$\frac{3}{32}$	600
5	1,369	.899	$\frac{3}{32}$	2,013	1.119	$\frac{3}{32}$	550
4	1,659	.953	$\frac{3}{32}$	2,086	1.141	$\frac{3}{32}$	550

II. Stranded.

6	1,357	.902	$\frac{3}{32}$	2,001	1.121	$\frac{3}{32}$	500
5	1,639	.955	$\frac{3}{32}$	2,068	1.143	$\frac{3}{32}$	500
4	1,717	.981	$\frac{3}{32}$	2,155	1.169	$\frac{3}{32}$	500
2	1,917	1.041	$\frac{3}{32}$	2,959	1.292	$\frac{1}{8}$	500
1	2,052	1.085	$\frac{3}{32}$	3,121	1.336	$\frac{1}{8}$	500
100000	2,175	1.114	$\frac{3}{32}$	3,267	1.365	$\frac{1}{8}$	450
0	2,204	1.124	$\frac{3}{32}$	3,300	1.375	$\frac{1}{8}$	450
125000	2,293	1.154	$\frac{3}{32}$	3,404	1.405	$\frac{1}{8}$	450
00	2,382	1.168	$\frac{1}{8}$	3,508	1.419	$\frac{1}{8}$	450
150000	3,053	1.251	$\frac{1}{8}$	3,610	1.439	$\frac{1}{8}$	450
000	3,215	1.282	$\frac{1}{8}$	3,755	1.470	$\frac{1}{8}$	450
200000	3,400	1.323	$\frac{1}{8}$	3,970	1.512	$\frac{1}{8}$	400
0000	3,473	1.340	$\frac{1}{8}$	4,046	1.528	$\frac{1}{8}$	400
250000	3,706	1.387	$\frac{1}{8}$	4,293	1.575	$\frac{1}{8}$	400
300000	4,023	1.446	$\frac{1}{8}$	4,611	1.634	$\frac{1}{8}$	400
350000	4,293	1.494	$\frac{1}{8}$	4,888	1.682	$\frac{1}{8}$	350
400000	4,559	1.540	$\frac{1}{8}$	5,168	1.728	$\frac{1}{8}$	350
500000	5,088	1.627	$\frac{1}{8}$	5,707	1.815	$\frac{1}{8}$	300
600000	5,594	1.705	$\frac{1}{8}$	6,228	1.893	$\frac{1}{8}$	300
700000	6,087	1.777	$\frac{1}{8}$	6,740	1.965	$\frac{1}{8}$	300
750000	6,331	1.811	$\frac{1}{8}$	6,983	1.999	$\frac{1}{8}$	300
800000	6,555	1.843	$\frac{1}{8}$	7,224	2.031	$\frac{1}{8}$	300
900000	7,040	1.908	$\frac{1}{8}$	7,706	2.094	$\frac{1}{8}$	250
1000000	7,495	1.965	$\frac{1}{8}$	8,171	2.153	$\frac{1}{8}$	250
1250000	8,608	2.102	$\frac{1}{8}$	9,324	2.290	$\frac{1}{8}$	200
1500000	9,702	2.224	$\frac{1}{8}$	10,424	2.412	$\frac{1}{8}$	150
2000000	11,810	2.443	$\frac{1}{8}$	12,579	2.631	$\frac{1}{8}$	150

General Electric Company Three Conductor Paper Insulated Cables.

Size. B. & S. and C. M.	Test Pressure, 3000 Volts for 30 Minutes.				Test Pressure, 8000 Volts for 30 Minutes.			
	Weight per 1000 Feet in Lbs.	Diameter, Leaded, Inches	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile.	Weight per 1000 Feet in Lbs.	Diameter, Leaded, Inches.	Thickness of Lead, Inches.	Insulation Resistance in Megohms per Mile,
8	1388	.864	$\frac{5}{64}$	150	1,892	1.029	$\frac{3}{32}$	200
6	1874	.979	$\frac{3}{32}$	125	2,190	1.114	$\frac{3}{32}$	175
5	2072	1.027	$\frac{3}{32}$	125	2,393	1.162	$\frac{3}{32}$	175
4	2270	1.083	$\frac{3}{32}$	125	2,597	1.218	$\frac{3}{32}$	175
2	2837	1.213	$\frac{3}{32}$	100	3,188	1.345	$\frac{3}{32}$	150
1	3405	1.314	$\frac{3}{32}$	100	3,583	1.441	$\frac{3}{32}$	150
100000	3635	1.437	$\frac{3}{32}$	100	3,814	1.504	$\frac{3}{32}$	150
0	3864	1.459	$\frac{3}{32}$	100	4,045	1.525	$\frac{3}{32}$	150
125000	4142	1.524	$\frac{3}{32}$	100	4,327	1.591	$\frac{3}{32}$	150
00	4420	1.553	$\frac{3}{32}$	100	4,610	1.622	$\frac{3}{32}$	125
150000	4750	1.595	$\frac{3}{32}$	100	5,358	1.663	$\frac{3}{32}$	125
000	5081	1.663	$\frac{3}{32}$	100	6,106	1.795	$\frac{1}{8}$	125
200000	6300	1.815	$\frac{1}{8}$	100	6,546	1.876	$\frac{1}{8}$	125
0000	6700	1.852	$\frac{1}{8}$	100	6,978	1.919	$\frac{1}{8}$	125
	Test Pressure, 15,000 Volts for 30 Minutes.				Test Pressure, 26,000 Volts for 30 Minutes.			
8	2874	1.424	$\frac{3}{32}$	300	5,342	2.017	$\frac{1}{8}$	400
6	3199	1.508	$\frac{3}{32}$	300	5,742	2.100	$\frac{1}{8}$	400
5	3422	1.557	$\frac{3}{32}$	275	6,020	2.150	$\frac{1}{8}$	400
4	3646	1.608	$\frac{3}{32}$	275	6,299	2.206	$\frac{1}{8}$	400
2	4274	1.740	$\frac{3}{32}$	275	7,052	2.335	$\frac{1}{8}$	400
1	4705	1.837	$\frac{3}{32}$	275	7,561	2.433	$\frac{1}{8}$	350
100000	5407	1.962	$\frac{1}{8}$	275	7,883	2.495	$\frac{1}{8}$	350
0	6110	1.984	$\frac{1}{8}$	275	8,144	2.515	$\frac{1}{8}$	350
125000	6433	2.049	$\frac{1}{8}$	275	8,492	2.580	$\frac{1}{8}$	350
00	6755	2.080	$\frac{1}{8}$	250	8,841	2.608	$\frac{1}{8}$	350
150000	7134	2.122	$\frac{1}{8}$	250	9,249	2.653	$\frac{1}{8}$	350
000	7513	2.190	$\frac{1}{8}$	250	9,657	2.720	$\frac{1}{8}$	350
200000	7980	2.298	$\frac{1}{8}$	250	10,160	2.809	$\frac{1}{8}$	300
0000	8446	2.315	$\frac{1}{8}$	250	10,663	2.845	$\frac{1}{8}$	300

Thickness of insulation for 3000 volt class, sizes No. 2 and smaller, $\frac{1}{16}$″ paper on each conductor, $\frac{1}{16}$″ paper over all; sizes 0000 to No. 1 inclusive, $\frac{5}{64}$″ paper on each conductor, $\frac{1}{16}$″ paper over all.

Thickness of insulation for 8000 volt class, all sizes, $\frac{3}{32}$″ paper on each conductor, $\frac{1}{16}$″ paper over all.

Thickness of insulation for 15,000 volt class, all sizes, $\frac{5}{32}$″ paper on each conductor, $\frac{4}{32}$″ paper over all.

Thickness of insulation for 26,000 volt class, all sizes, $\frac{8}{32}$″ paper on each conductor, $\frac{6}{32}$″ paper over all.

Varnished Cambric Cables.

Special Finishes.

The standard braided finish of varnished cambric cables is a weatherproof cotton braid.

The following special finishes may be applied if desired:

Asbestos Braid. — Generally applied over the regular cotton braid is filled with flameproof paint. It is especially recommended for interior wiring as a protection against the arcing of one cable affecting another.

Asbestos braid adds about $\frac{1}{10}$ to diameter of cable.

Cotton Braid, Flameproof. — The standard braid may be treated with flameproof paint instead of being weatherproofed, or one or more cotton braids may be applied, all being treated with flameproof paint.

This style of finish is slightly more expensive than standard weatherproof but not as expensive as asbestos braided.

Varnish Cambric cables leaded may have any of the special finishes described applied over the lead.

Working and Test Pressures of Paper Insulated Lead Covered Cables.

Factors by which to multiply working pressure to obtain proper test pressure for paper insulated lead covered cables.

Test at Factory.

For 5 mins., pressure = 2.5 × working pressure.
For 30 mins., pressure = 2.0 × working pressure.
For 60 mins., pressure = 1.6 × working pressure.

Test After Installation by Manufacturer.

For 5 mins., pressure = 2.0 × working pressure.
For 30 mins., pressure = 1.6 × working pressure.
For 60 mins., pressure = 1.3 × working pressure.

Varnished Cambric Cables. Single Stranded Conductor—Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 1000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	1/16	3/64	.40	Approximately same as Leaded.	386	151
4	1/16	3/64	.45		490	202
2	1/16	1/16	.54		725	279
1	5/64	1/16	.61		880	362
0	5/64	1/16	.66		1015	448
00	5/64	1/16	.70		1120	534
000	5/64	1/16	.75		1301	642
0,000	5/64	5/64	.84		1690	778
250,000	3/32	3/32	.95		2267	1034
300,000	3/32	3/32	1.01		2520	1220
350,000	3/32	3/32	1.06		2780	1409
400,000	3/32	3/32	1.11		2994	1556
500,000	3/32	3/32	1.19		3473	1893
600,000	7/64	3/32	1.30		3999	2281
700,000	7/64	3/32	1.37		4388	2562
750,000	7/64	3/32	1.41		4589	2731
800,000	7/64	3/32	1.44		4794	2901
900,000	7/64	3/32	1.50		5241	3245
1,000,000	7/64	3/32	1.56		5656	3589
1,250,000	See 2000 volt class					
1,500,000						
1,750,000						
2,000,000						

FOR WORKING PRESSURES NOT EXCEEDING 2000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter Leaded.	Diameter Braided.	Weight Leaded.	Weight Braided.
6	3/32	3/64	.47	Approximately same as Leaded	468	180
4	3/32	3/64	.52		570	248
2	3/32	1/16	.61		870	352
1	3/32	1/16	.65		963	426
0	3/32	1/16	.69		1082	496
00	3/32	1/16	.74		1,239	605
000	3/32	5/64	.82		1,502	739
0,000	3/32	5/64	.87		1,846	905
250,000	7/64	3/32	.98		2,329	1063
300,000	7/64	3/32	1.04		2,590	1252
350,000	7/64	3/32	1.09		2,845	1440
400.000	7/64	3/32	1.14		3,045	1569
500,000	7/64	3/32	1.22		3,539	1924
600,000	1/8	3/32	1.33		4,068	2315
700,000	1/8	3/32	1.41		4,455	2597
750,000	1/8	3/32	1.44		4,658	2765
800,000	1/8	3/32	1.47		4,903	2938
900,000	1/8	3/32	1.53		5,311	3280
1,000,000	1/8	3/32	1.59		5,766	3632
1,250,000	1/8	7/64	1.76		7,185	4453
1,500,000	1/8	1/8	1.92		8,700	5297
1,750,000	1/8	1/8	2.03		9,793	6157
2,000.000	1/8	1/8	2.14		10,835	7010

Specifications, diameters and weights for solid conductors same as above.

Varnished Cambric Cables. Single Stranded Conductor —Leaded and Braided.

For Working Pressures not Exceeding 3,000 Volts.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	9/64	3/64	.56	Approximately same as Leaded.	565	228
4	9/64	1/16	.64		837	301
2	9/64	1/16	.70		961	416
1	9/64	1/16	.74		1,128	495
0	9/64	1/16	.78		1,417	570
00	9/64	5/64	.86		1,597	676
000	9/64	5/64	.91		1,786	818
0,000	9/64	3/32	1.00		2,293	994
250,000	9/64	3/32	1.05		2,495	1124
300,000	9/64	3/32	1.11		2,757	1319
350,000	9/64	3/32	1.15		3,019	1510
400,000	9/64	3/32	1.20		3,176	1639
500,000	9/64	3/32	1.29		3,677	1996
600,000	9/64	3/32	1.36		4,145	2359
700,000	9/64	3/32	1.44		4,532	2639
750,000	9/64	3/32	1.47		4,776	2811
800,000	9/64	3/32	1.50		4,982	2986
900,000	9/64	7/64	1.60		5,772	3330
1,000,000	9/64	7/64	1.65		6,237	3678
1,250,000	9/64	1/8	1.82		7,717	4509
1,500,000	9/64	1/8	1.95		8,802	5354
1,750,000	9/64	1/8	2.06		9,904	6222
2,000,000	9/64	1/8	2.16		10,944	7072

For Working Pressures not Exceeding 5,000 Volts.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter Leaded.	Diameter Braided.	Weight Leaded.	Weight Braided.
6	3/16	1/16	.69	Approximately same as Leaded.	871	285
4	3/16	1/16	.74		999	365
2	3/16	5/64	.83		1,171	483
1	3/16	5/64	.87		1,509	568
0	3/16	5/64	.91		1,608	638
00	3/16	5/64	.95		2,023	757
000	3/16	3/32	1.04		2,242	1004
0,000	3/16	3/32	1.09		2,525	1087
250,000	3/16	3/32	1.14		2,695	1219
300,000	3/16	3/32	1.20		3,004	1442
350,000	3/16	3/32	1.25		3,266	1619
400,000	3/16	3/32	1.29		3,427	1749
500,000	3/16	3/32	1.38		3,942	2116
600,000	3/16	3/32	1.46		4,415	2485
700,000	3/16	3/32	1.53		4,802	2771
750,000	3/16	7/64	1.60		5,388	2946
800,000	3/16	7/64	1.63		5,647	3123
900,000	3/16	1/8	1.72		6,499	3473
1,000,000	3/16	1/8	1.78		7,010	3823
1,250,000	3/16	1/8	1.92		8,067	4664
1,500,000	3/16	1/8	2.04		9,168	5532
1,750,000	3/16	1/8	2.15		10,282	6410
2,000,000	3/16	1/8	2.26		11,318	7259

Specifications, diameters and weights for solid conductor approximately same as above.

Varnished Cambric Cables. Single Stranded Conductor —Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 7,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	1/4	1/16	.81	Approximately same as Leaded	1,112	405
4	1/4	5/64	.89		1,252	497
2	1/4	5/64	.95		1,653	622
1	1/4	5/64	.99		1,802	714
0	1/4	3/32	1.06		2,183	812
00	1/4	3/32	1.11		2,364	926
000	1/4	3/32	1.16		2,594	1085
0,000	1/4	3/32	1.22		2,898	1283
250,000	1/4	3/32	1.27		3,144	1397
300,000	1/4	3/32	1.32		3,363	1610
350,000	1/4	3/32	1.37		3,642	1816
400,000	1/4	3/32	1.42		3,888	1996
500,000	1/4	3/32	1.51		4,327	2331
600,000	1/4	3/32	1.58		4,816	2714
700,000	1/4	7/64	1.69		5,633	3022
750,000	1/4	1/8	1.75		5,848	3197
800,000	1/4	1/8	1.78		6,546	3379
900,000	1/4	1/8	1.85		7,004	3746
1,000,000	1/4	1/8	1.90		7,514	4111
1,250,000	1/4	1/8	2.04		8,574	4938
1,500,000	1/4	1/8	2.17		9,692	5820
1,750,000	1/4	1/8	2.28		10,828	6719
2,000,000	1/4	1/8	2.38		11,890	7599

FOR WORKING PRESSURES NOT EXCEEDING 10,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter Leaded.	Diameter Braided.	Weight Leaded.	Weight Braided.
6	5/16	5/64	.97	Approximately same as Leaded	1583	523
4	5/16	5/64	1.02		1710	624
2	5/16	5/64	1.08		1923	750
1	5/16	3/32	1.15		2360	851
0	5/16	3/32	1.19		2472	930
00	5/16	3/32	1.23		2683	1068
000	5/16	3/32	1.29		2915	1233
0,000	5/16	3/32	1.34		3227	1439
250,000	5/16	3/32	1.39		3380	1554
300,000	5/16	3/32	1.45		3705	1775
350,000	5/16	3/32	1.50		3985	1989
400,000	5/16	3/32	1.54		4557	2115
500,000	5/16	3/32	1.63		5083	2514
600,000	5/16	7/64	1.74		5598	2911
700,000	5/16	1/8	1.84		6471	3213
750,000	5/16	1/8	1.88		6756	3401
800,000	5/16	1/8	1.91		6984	3581
900,000	5/16	1/8	1.97		7460	3966
1,000,000	5/16	1/8	2.03		7967	4331

Specifications, diameters and weights for solid conductor approximately same as above.

Varnished Cambric Cables. Single Stranded Conductor —Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 13,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	$\frac{3}{8}$	$\frac{5}{64}$	1.09	Approximately same as Leaded	1724	636
4	$\frac{3}{8}$	$\frac{5}{64}$	1.14		1978	749
2	$\frac{3}{8}$	$\frac{3}{32}$	1.23		2493	878
1	$\frac{3}{8}$	$\frac{3}{32}$	1.27		2668	986
0	$\frac{3}{8}$	$\frac{3}{32}$	1.31		2766	1048
00	$\frac{3}{8}$	$\frac{3}{32}$	1.36		2997	1211
000	$\frac{3}{8}$	$\frac{3}{32}$	1.41		3241	1383
0,000	$\frac{3}{8}$	$\frac{3}{32}$	1.47		3661	1596
250,000	$\frac{3}{8}$	$\frac{3}{32}$	1.52		3711	1715
300,000	$\frac{3}{8}$	$\frac{3}{32}$	1.57		4042	1940
350,000	$\frac{3}{8}$	$\frac{3}{32}$	1.62		4333	2159
400,000	$\frac{3}{8}$	$\frac{7}{64}$	1.70		4981	2330
500,000	$\frac{3}{8}$	$\frac{7}{64}$	1.79		5469	2701

FOR WORKING PRESSURES NOT EXCEEDING 17,000 VOLTS.

6	$\frac{7}{16}$	$\frac{3}{32}$	1.25	Approximately same as Leaded	2193	755
4	$\frac{7}{16}$	$\frac{3}{32}$	1.30		2488	873
2	$\frac{7}{16}$	$\frac{3}{32}$	1.36		2803	1017
1	$\frac{7}{16}$	$\frac{3}{32}$	1.40		2981	1123
0	$\frac{7}{16}$	$\frac{3}{32}$	1.44		3054	1161
00	$\frac{7}{16}$	$\frac{3}{32}$	1.48		3316	1351
000	$\frac{7}{16}$	$\frac{3}{32}$	1.53		3561	1530
0,000	$\frac{7}{16}$	$\frac{3}{32}$	1.59		3891	1757
250,000	$\frac{7}{16}$	$\frac{3}{32}$	1.64		4046	1872
300,000	$\frac{7}{16}$	$\frac{7}{64}$	1.73		4793	2106
350,000	$\frac{7}{16}$	$\frac{7}{64}$	1.78		5102	2334
400,000	$\frac{7}{16}$	$\frac{1}{8}$	1.86		5806	2548
500,000	$\frac{7}{16}$	$\frac{1}{8}$	1.94		6332	2884

Specifications, diameters and weights for solid conductor approximately same as above.

Varnished Cambric Insulated Cables. — Single Conductor.

WORKING PRESSURE, 10,000 VOLTS OR LESS.

TEST PRESSURE, 25,000 VOLTS.

Size. B. & S. and C. M.	Thick. Ins. in Inches.	Thick. Lead in Inches.	Dia. in Inches.	Braided. Weight in Lbs. per 1000 ft.	Leaded. Weight in Lbs. per 1000 ft.
6 Sol.	$\frac{1}{4}$	$\frac{1}{16}$	.80	424	1063
4 Sol.	$\frac{1}{4}$	$\frac{1}{16}$	.84	498	1176
6 St.	$\frac{1}{4}$	$\frac{1}{16}$	.82	441	1102
4 St.	$\frac{1}{4}$	$\frac{1}{16}$	.87	521	1227
2 St.	$\frac{1}{4}$	$\frac{5}{64}$	.96	712	1651
1 St.	$\frac{1}{4}$	$\frac{3}{32}$	1.04	793	1925
1/0 St.	$\frac{1}{4}$	$\frac{3}{32}$	1.08	891	2182
2/0 St.	$\frac{1}{4}$	$\frac{3}{32}$	1.12	1009	2365
3/0 St.	$\frac{1}{4}$	$\frac{3}{32}$	1.17	1150	2580
4/0 St.	$\frac{1}{4}$	$\frac{3}{32}$	1.23	1327	2839
250,000	$\frac{1}{4}$	$\frac{3}{32}$	1.28	1483	3058
300,000	$\frac{1}{4}$	$\frac{3}{32}$	1.38	1707	3353
400,000	$\frac{1}{4}$	$\frac{3}{32}$	1.48	2087	4031
500,000	$\frac{1}{4}$	$\frac{7}{64}$	1.57	2467	4709
750,000	$\frac{17}{64}$	$\frac{7}{64}$	1.80	3458	6470
1,000,000	$\frac{17}{64}$	$\frac{1}{8}$	1.96	4386	7688

Duplex cables larger than 250,000 Cm. are difficult to handle and therefore are not recommended.

The fourth column — Dia. in Inches — is the over-all diameter of the finished cable and is approximately the same for either braided or leaded.

Varnished Cambric Insulated Cables. — Single Conductor.

WORKING PRESSURE, 15,000 VOLTS OR LESS.

TEST PRESSURE, 33,000 VOLTS.

Size. B. &. S. and C. M.	Thick. Ins. in Inches.	Thick. Lead in Inches.	Dia. in Inches.	Braided. Weight in Lbs. per 1000 ft.	Leaded. Weight in Lbs. per 1000 ft.
6 Sol.	$\frac{11}{32}$	$\frac{3}{32}$	1.05	660	1939
4 Sol.	$\frac{11}{32}$	$\frac{3}{32}$	1.10	767	2084
6 St.	$\frac{11}{32}$	$\frac{3}{32}$	1.08	705	1994
4 St.	$\frac{11}{32}$	$\frac{3}{32}$	1.12	797	2153
2 St.	$\frac{11}{32}$	$\frac{3}{32}$	1.18	927	2373
1 St.	$\frac{3}{8}$	$\frac{3}{32}$	1.29	1110	2693
1/0 St.	$\frac{3}{8}$	$\frac{3}{32}$	1.33	1225	2860
2/0 St.	$\frac{3}{8}$	$\frac{3}{32}$	1.37	1360	3051
3/0 St.	$\frac{3}{8}$	$\frac{3}{32}$	1.42	1533	3288
4/0 St.	$\frac{3}{8}$	$\frac{3}{32}$	1.48	1732	3562
250,000	$\frac{3}{8}$	$\frac{3}{32}$	1.53	1901	3795
300,000	$\frac{3}{8}$	$\frac{7}{64}$	1.63	2130	4487
400,000	$\frac{3}{8}$	$\frac{1}{8}$	1.73	2530	5246
500,000	$\frac{3}{8}$	$\frac{1}{8}$	1.82	2930	6006
750,000	$\frac{25}{64}$	$\frac{1}{8}$	2.05	3998	7468
1,000,000	$\frac{13}{32}$	$\frac{1}{8}$	2.23	5005	8835

Duplex cables larger than 250,000 Cm. are difficult to handle and therefore are not recommended.

The fourth column — Dia. in Inches — is the over-all diameter of the finished cable and is approximately the same for either braided or leaded.

Varnished Cambric Cables. Triple Stranded Conductor —Leaded and Braided.

For Working Pressures not Exceeding 1,000 Volts.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 100 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	1/16—1/64	1/16	.824	Approximately same as Leaded.	1,245	538
4	1/16—1/64	5/64	.959		1,820	760
2	1/16—1/64	5/64	1.085		2,290	1089
1	5/64—1/64	3/32	1.279		3,066	1384
0	5/64—1/64	3/32	1.357		3,446	1660
00	5/64—1/64	3/32	1.456		3,933	2003
000	5/64—1/64	3/32	1.566		4,528	2416
0,000	5/64—1/64	7/64	1.723		5,642	2955
250,000	3/32—1/64	7/64	1.891		6,470	3537
300,000	3/32—1/64	7/64	2.023		7,296	4155
350,000	3/32—1/64	1/8	2.150		8,595	4770
400,000	3/32—1/64	1/8	2.253		9,347	5288
500,000	3/32—1/64	1/8	2.438		10,870	6483

For Working Pressures not Exceeding 3,000 Volts.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 100 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	5/64—1/16	5/64	1.016	Approximately same as Leaded	1,803	692
4	5/64—1/16	5/64	1.120		2,159	930
2	5/64—1/16	3/32	1.277		2,955	1273
1	5/64—1/16	3/32	1.363		3,290	1505
0	5/64—1/16	3/32	1.451		3,725	1795
00	5/64—1/16	3/32	1.550		4,206	2139
000	5/64—1/16	7/64	1.691		5,184	2573
0,000	5/64—1/16	7/64	1.815		5,928	3115
250,000	3/32—1/16	7/64	1.984		6,805	3704
300,000	3/32—1/16	1/8	2.134		8,169	4344
350,000	3/32—1/16	1/8	2.243		8,986	4973
400,000	3/32—1/16	1/8	2.346		9,692	5492
500,000	3/32—1/16	1/8	2.531		11,288	6713

Note.—Under Thickness Insulation: The first fraction is thickness of insulation on each conductor; the second fraction is thickness of insulation over all.

Varnished Cambric Cables. Triple Stranded Conductor — Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 5,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	$\frac{3}{32}-\frac{3}{32}$	$\frac{5}{64}$	1.15	Approximately same as Leaded	2,092	835
4	$\frac{3}{32}-\frac{3}{32}$	$\frac{3}{32}$	1.28		2,765	1083
2	$\frac{3}{32}-\frac{3}{32}$	$\frac{3}{32}$	1.41		3,302	1444
1	$\frac{3}{32}-\frac{3}{32}$	$\frac{3}{32}$	1.50		3,682	1686
0	$\frac{3}{32}-\frac{3}{32}$	$\frac{3}{32}$	1.58		4,084	1982
00	$\frac{3}{32}-\frac{3}{32}$	$\frac{7}{64}$	1.71		4,989	2338
000	$\frac{3}{32}-\frac{3}{32}$	$\frac{7}{64}$	1.82		5,640	2790
0,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{7}{64}$	1.95		6,356	3342
250,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{1}{8}$	2.08		7,517	3835
300,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{1}{8}$	2.20		8,398	4476
350,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{1}{8}$	2.31		9,267	5113
400,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{1}{8}$	2.41		9,978	5641
500,000	$\frac{3}{32}-\frac{3}{32}$	$\frac{1}{8}$	2.60		11,533	6866

FOR WORKING PRESSURES NOT EXCEEDING 7,000 VOLTS.

6	$\frac{1}{8}-\frac{1}{8}$	$\frac{3}{32}$	1.38	Approximately same as Leaded	2,909	1083
4	$\frac{1}{8}-\frac{1}{8}$	$\frac{3}{32}$	1.48		3,317	1352
2	$\frac{1}{8}-\frac{1}{8}$	$\frac{3}{32}$	1.61		3,867	1733
1	$\frac{1}{8}-\frac{1}{8}$	$\frac{3}{32}$	1.69		4,268	1991
0	$\frac{1}{8}-\frac{1}{8}$	$\frac{7}{64}$	1.81		5,115	2302
00	$\frac{1}{8}-\frac{1}{8}$	$\frac{7}{64}$	1.91		5,651	2673
000	$\frac{1}{8}-\frac{1}{8}$	$\frac{7}{64}$	2.02		6,280	3139
0,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.18		7,585	3713
250,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.28		8,259	4200
300,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.39		9,183	4892
350,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.50		10,075	5550
400,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.61		10,800	6086
500,000	$\frac{1}{8}-\frac{1}{8}$	$\frac{1}{8}$	2.79		12,392	7348

NOTE. — Under Thickness Insulation: The first fraction is thickness of insulation on each conductor; the second fraction is thickness of insulation over all.

Varnished Cambric Cables. Triple Stranded Conductor —Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 10,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	$\frac{5}{32}-\frac{5}{32}$	$\frac{3}{32}$	1.57	Approximately same as Leaded.	3,480	1378
4	$\frac{5}{32}-\frac{5}{32}$	$\frac{3}{32}$	1.68		3,992	1661
2	$\frac{5}{32}-\frac{5}{32}$	$\frac{3}{32}$	1.80		4,480	2065
1	$\frac{5}{32}-\frac{5}{32}$	$\frac{7}{64}$	1.92		5,309	2331
0	$\frac{5}{32}-\frac{5}{32}$	$\frac{7}{64}$	2.01		5,797	2656
00	$\frac{5}{32}-\frac{5}{32}$	$\frac{7}{64}$	2.11		6,336	3031
000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.25		7,539	3526
0,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.37		8,373	4127
250,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.47		9,083	4654
300,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.59		10,010	5343
350,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.70		10,883	6023
400,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.81		11,660	6569
500,000	$\frac{5}{32}-\frac{5}{32}$	$\frac{1}{8}$	2.99		13,290	7868

Varnished Cambric Cables. Triple Stranded Conductor — Leaded and Braided.

FOR WORKING PRESSURES NOT EXCEEDING 13,000 VOLTS.

Size.	Thick. Insulation in Inches.	Thick. Lead in Inches.	Diameter.		Weight in Lbs. per 1000 Feet.	
			Leaded.	Braided.	Leaded.	Braided.
6	$\frac{3}{16}-\frac{3}{16}$	$\frac{3}{32}$	1.77	Approximately same as Leaded.	4,103	1720
4	$\frac{3}{16}-\frac{3}{16}$	$\frac{3}{32}$	1.87		4,542	2019
2	$\frac{3}{16}-\frac{3}{16}$	$\frac{7}{64}$	2.03		5,623	2441
1	$\frac{3}{16}-\frac{3}{16}$	$\frac{7}{64}$	2.12		6,019	2714
0	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.23		7,070	3057
00	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.33		7,660	3460
000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.44		8,350	3963
0,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.57		9,199	4582
250,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.67		9,933	5128
300,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.79		10,884	5840
350,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	2.90		11,779	6541
400,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	3.00		12,511	7089
500,000	$\frac{3}{16}-\frac{3}{16}$	$\frac{1}{8}$	3.18		14,202	8402
FOR WORKING PRESSURES NOT EXCEEDING 17,000 VOLTS.						
6	$\frac{7}{32}-\frac{7}{32}$	$\frac{3}{32}$	1.97	Approximately same as Leaded.	4,784	2123
4	$\frac{7}{32}-\frac{7}{32}$	$\frac{7}{64}$	2.10		5,724	2419
2	$\frac{7}{32}-\frac{7}{32}$	$\frac{7}{64}$	2.23		6,381	2877
1	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.34		7,364	3164
0	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.43		7,906	3519
00	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.53		8,459	3884
000	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.64		9,218	4454
0,000	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.77		10,091	5092
250,000	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.88		10,847	5664
300,000	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	2.99		11,802	6380
350,000	$\frac{7}{32}-\frac{7}{32}$	$\frac{1}{8}$	3.10		12,697	7086

NOTE. — Under Thickness Insulation: The first fraction is thickness of insulation on each conductor; the second fraction is thickness of insulation over all.

Enameled Wire.

Size B. & S.	Diameter in Inches.		Comparative Weight per 1000 Feet in Pounds.	
	Bare.	Over Enamel.	Single Cotton-Covered.	Enamel.
14	.0640	.0670	12.684	12.684
15	.0570	.0600	10.082	10.053
16	.0510	.0535	8.012	7.973
17	.0450	.0475	6.375	6.322
18	.0400	.0425	5.081	5.009
19	.0360	.0380	4.043	3.966
20	.0320	.0340	3.218	3.136
21	.0280	.0305	2.569	2.475
22	.0250	.0275	2.055	1.970
23	.0230	.0250	1.630	1.555
24	.0200	.0220	1.297	1.232
25	.0180	.0200	1.036	.980
26	.0160	.0175	.828	.777
27	.0140	.0155	.661	.616
28	.0126	.0140	.524	.485
29	.0110	.0123	.421	.384
30	.0100	.0113	.336	.303
31	.0090	.0102	.271	.242
32	.0080	.0092	.215	.192
33	.0070	.0082	.174	.152
34	.0063	.0075	.141	.121
35	.0056	.0063	.120	.101
36	.0050	.0056	.099	.081
37	.0045	.0051	.090	.061
38	.0040	.0046	.080	.0507
40	.0031	.0037	.060	.0304

TELEPHONE CABLES.

Lead Sheathed for Underground or Aërial Use.

The insulation of these cables is dry paper. The following specifications have been adopted by the larger telephone companies and, therefore, may be considered standard.

Cable Conductor. No. 19 B. and S. G., 98% conductivity, insulated with one or two paper tapes; conductor twisted in pairs; one of the pairs to have a distinctive colored paper for marker; length of twist not to exceed 3″. Pairs to be laid up in reverse layers; insulation to be unsaturated except two feet from each end to prevent moisture from entering. The lead sheath to have an alloy of $2\frac{1}{2}$ to $3\frac{1}{2}$% of tin; thickness of sheath $\frac{1}{12}$″ for fifty pair of cables, $\frac{3}{32}$″ for one hundred pair of cables, and $\frac{1}{8}$″ for larger sizes. Insulation resistance to be at least 100 megohms per mile after the cable is laid and spliced. Electrostatic capacity no greater than .054 with a maximum of .060 microfarads per mile.

The aërial cables for telephone companies usually follow the same specifications as those for underground use, being purchased with the ultimate intention of being put underground. Cables that are to remain overhead indefinitely are usually made with a lighter sheathing of lead than that specified for underground work.

Number Pairs.	Outside Diameters. Inches.	Weights 1000 feet. Pounds.
1	$\frac{5}{16}$	214
2	$\frac{3}{8}$	302
3	$\frac{1}{2}$	515
4	$\frac{9}{16}$	629
5	$\frac{5}{8}$	747
6	$\frac{21}{32}$	877
7	$\frac{11}{16}$	912
10	$\frac{13}{16}$	1,214
12	$\frac{15}{16}$	1,375
15	1	1,566
18	$1\frac{1}{16}$	1,758
20	$1\frac{1}{8}$	1,940
25	$1\frac{5}{16}$	2,332
30	$1\frac{7}{16}$	2,748
35	$1\frac{1}{2}$	2,985
40	$1\frac{9}{16}$	3,176
45	$1\frac{5}{8}$	3,365
50	$1\frac{3}{4}$	3,678
55	$1\frac{13}{16}$	3,867
60	$1\frac{7}{8}$	4,055
65	$1\frac{15}{16}$	4,241
70	2	4,430
80	$2\frac{1}{8}$	4,804
90	$2\frac{1}{4}$	5,180
100	$\frac{3}{8}$	5,505

TELEGRAPH CABLES.

Lead Sheathed for Underground or Taped and Braided for Aërial Use.

The insulation of these cables is made of a compound containing not less than thirty per cent pure Para rubber. These specifications may be considered standard, being used by the principal telegraph companies.

Rubber Insulated Aërial Telegraph Cable.

Gauge B. & S.	No. of Conductors.	Outside Diameter.	Weight per 1,000 ft.
14	7	$\frac{3}{4}''$	425 lbs.
14	10	1″	500 lbs.
14	19	$1\frac{1}{4}''$	890 lbs.

Conductors No. 14 B. and S. insulated to diameter of 6–32″, cabled together and covered with a rubber tape, one layer of tarred jute, a rubber tape, and a heavy cotton braid saturated with waterproof compound.

SUBMARINE CABLES.

These cables are insulated with a rubber compound containing not less than thirty per cent (30%) of pure Para rubber.

These specifications have been adopted by the various telegraph companies and the United States Government for general use.

No. of Conductors.	Gauge of Conductors.	No. of Armor Wires.	Gauge of Armor Wires.	Outside Diameter.	Weight per 1,000 feet.
1	14 B. & S.	12	8 B. W. G.	$\frac{7}{8}''$	1150
2	14 B. & S.	16	8 B. W. G.	$1\frac{3}{32}''$	1675
3	14 B. & S.	14	6 B. W. G.	$1\frac{1}{4}''$	2400
4	14 B. & S.	16	6 B. W. G.	$1\frac{5}{16}''$	2750
5	14 B. & S.	19	6 B. W. G.	$1\frac{3}{8}''$	3100
6	14 B. & S.	21	6 B. W. G.	$1\frac{1}{2}''$	3500
7	14 B. & S.	21	6 B. W. G.	$1\frac{1}{2}''$	3600
10	14 B. & S.	22	4 B. W. G.	$1\frac{7}{8}''$	4600

Conductors built up of 7 No. 21 B. & S. copper wires, heavily tinned. Each conductor insulated with $\frac{8}{32}''$ Rubber and Taped.

The above specifications refer only to river and harbor cables. Ocean cables are of an entirely different character, and consist of Shore End, Intermediate and Deep Sea Types.

Joints in Rubber Insulated Cables.

Preparation of Ends. — Remove the outside protecting braid or tape, and bare the conductor of its rubber insulation for two or three inches back from the end. Clean the metal carefully by scraping with a knife or with sandpaper.

Metal Joint. — If solid conductor, scarf the ends with a file so as to give a good long contact surface for soldering. If conductor is stranded, carefully spread apart the strands, cutting out the centers so conductors can be butted together, the loose ends interlacing as in Fig. 1, and bind wires down tight as in Fig. 2, with gas or other pliers. Solder carefully,

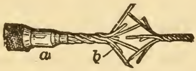


FIG. 1.

FIG. 2.

using no acid; resin is the best, although jointers often use a spermaceti candle as being handy to use and easy to procure. Large cables are easiest soldered by dipping the joint into a pot of molten solder, or by pouring the molten metal over the joint.

The insulation of all kinds of joints is done in the same manner, the only difference in the joint being the manner in which the conductors are joined together. Following are some of the styles of joining conductors, which are afterward insulated with rubber, and covered with lead when necessary.

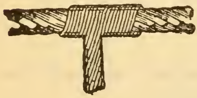
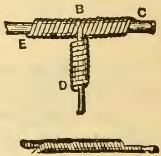


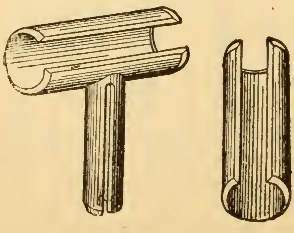
FIG. 3.

FIG. 4.



FIGS. 5, 6.

Seeley's Cable Connectors. — The cuts below show a style of copper connectors very handy in joining cables. They are copper tinned over, and after putting in place can be "sweated" on with solder; when dry can be insulated as previously described.



FIGS. 7, 8.

Insulating the Joint.—Jointers must have absolutely dry and clean hands, and all tools must be kept in the best possible condition of cleanliness. Clean the joint carefully of all flux and solder ; scarf back the rubber insulation like a lead-pencil for an inch or more with a sharp knife.

Carefully wind the joint with three layers of pure unvulcanized rubber, taking care not to touch the strip with the hands any more than necessary ; over this wind red rubber strip ready for vulcanizing. Lap the tape upon the taper ends of the insulation, and make the covering of the same diameter as the rubber insulation on the conductor, winding even and round. Cover the rubber strip with two or three layers of rubber-saturated tape.

Lead covering. — If the insulation is covered and protected by lead, a loose sleeve is slipped over one end before jointing, and slipped back over the joint when the insulation is finished, a plumber's wiped joint being made at the ends.

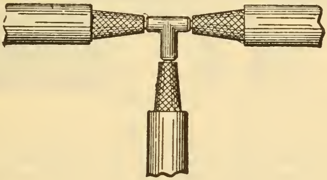


FIG. 9.

Joints in Waring Cables.—This cable is covered with cotton, thoroughly impregnated with a composition of hydro-carbon oils applied at high temperature, the whole being covered with lead to protect the insulation. The insulating properties of this covering are very high if the lead is kept intact.

Metal joints are made as usual, and a textile tape may be used for covering the bare copper. A large lead-sleeve is then drawn over the joint, and wiped onto the lead covering at either end ; then the interior space is filled with a compound similar to that with which the insulation is impregnated.

Joints in Paper Insulated Cables.—This cable is covered or insulated with narrow strips of thin manila paper wound on spirally, after which the whole is put into an oven and thoroughly dried, then plunged into a hot bath of resin oil, which thoroughly impregnates the paper. This insulation is not the highest in measurement, but the electrostatic capacity is low and the breakdown properties high. When used for telephone purposes the paper is left dry, and is wound on the conductor very loosely, thus leaving large air spaces and giving very low electrostatic capacity.

Joints are made as in the Waring cable by covering the conductor with paper tape of the same kind as the insulation, then pulling over the lead sleeve, which is finally filled with paraffine wax.

Dossert Joint.—Dossert & Company, New York City, make a mechanical joint for solid or stranded conductor which has great mechanical strength and an electrical conductance in excess of that of the cable. The joint illustrated in Fig. 10 consists of a nipple (*A*), two compression sleeves or bushings (*B*) and two compression nuts (*C*).

As shown in Fig. 11, the compression sleeves are split lengthwise and tapered at both ends. The tapered ends of the sleeve fit into correspondingly tapered parts of the nipple and nut. When the nut is screwed upon the nipple the action of the taper causes the compression sleeve to decrease in diameter and grip the strands tightly together, thereby getting good electrical contact.

To make a splice with this connector cut the insulation from the cables to a distance equal to half the length of the connector, slip the cable into the connector and screw the nuts up tightly on the nipple.

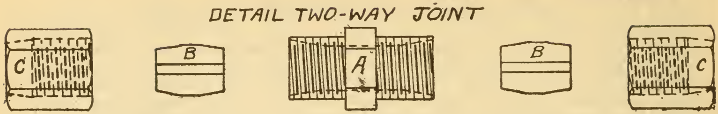


FIG. 10.

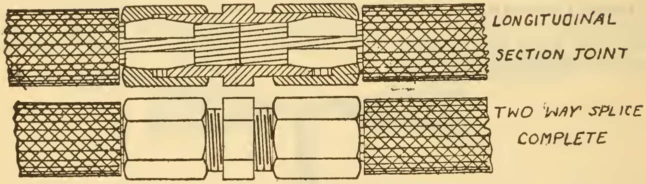
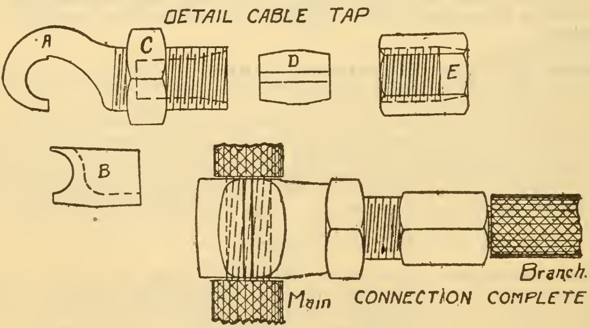


FIG. 11.

Lugs, 3-Ways, Y's, Reducers, Elbows and many other types of connectors are made with this principle for making the electrical connections and can be used for connections on switchboards, bus bars, transformers, meters, oil switches, storage batteries, electric smelting furnaces and the like.

A special application of this joint is the cable tap as shown in Figs. 12 and 13. It consists of a hook (*A*), cover (*B*), jam nut *C*), compression sleeve (*D*) and compression nut (*E*). The hook is machined to fit the main cable while its shank is drilled and threaded to form the nipple of a standard Dossert joint for size of branch required. The branch is secured to the



FIGS. 12 AND 13.

connector by inserting it in the sleeve (*D*) and screwing nut (*E*) up tight. Connection is made to main by placing the hook part of the connector over the main cable, inserting the cover (*B*) and screwing up the jam nut (*C*).

For overhead work where the cables are subjected to considerable tensile strain the Company makes another type of joint.

Jointing Gutta-Percha Covered Wire.

First remove the gutta-percha for about two inches from the ends of the wires which are to be jointed. Fig. 14.

FIG. 14.

Next cross the wires midway from the gutta-percha, and grasp with the pliers. Fig. 15.

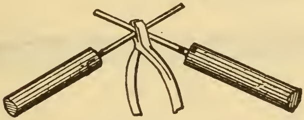


FIG. 15.

Then twist the wires, the overlapping right-hand wire first, and then, reversing the grip of the pliers, twist the left-hand wire over the right. Cut off the superfluous ends of the wires and solder the twist, leaving it as shown in Fig. 16.

FIG. 16.

Next warm up the gutta-percha for about two inches on each side of the twist. Then, first draw down the insulation from one side, half way over

FIG. 17.

the twisted wires, Fig. 17, and then from the other side in the same way, Fig. 18.

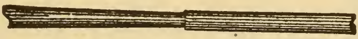


FIG. 18.

Then tool the raised end down evenly over the under half with a heated iron. Then warm up the whole and work the "drawdown" with the thumb and forefinger until it resembles Fig. 19. Now allow the joint to cool and set.

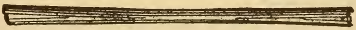


FIG. 19.

Next roughen the drawdown with a knife, and place over it a thin coating of Chatterton's compound for one inch, in the center of the drawdown, which is also allowed to set.

Next cut a thick strip of gutta-percha, about an inch wide and six inches long, and wrap this, after it has been well warmed by the lamp, evenly over the center of the drawdown. Fig. 20.

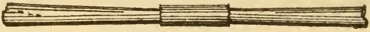


FIG. 20.

The strip is then worked in each direction by the thumb and forefinger over the drawdown until it extends about 2 inches from center of drawdown. Then tool over carefully where the new insulation joins the old, after which the joint should be again warmed up and worked with the forefinger and thumb as before. Then wet and soap the hand, and smooth and round out the joint as shown in Fig. 21.

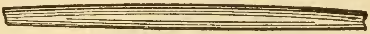


FIG. 21.

Between, and at every operation, the utmost care must be exercised to remove every particle of foreign matter, resin, etc.

NOTE. Chatterton's compound consists of 1 part by weight Stockholm tar; 1 part resin; 3 parts Gutta-percha.

ALUMINUM WIRE.

Physical Constants of Commercially (99%) Pure Aluminum.

Per cent Conductivity (Copper 100)	62
Specific Gravity	2.68
Pounds in 1 cubic foot	167
Pounds in 1 cubic inch	.0967
Pounds per mile per circular mil	.00481
Ultimate strength, $\frac{\text{lb.}}{\text{sq. in.}}$	26.000
Modulus of Elasticity, $\frac{\text{lb.} \times \text{in.}}{\text{in.} \times \text{sq. in.}}$	9,000,000
Coefficient of Linear Expansion per ° C.	.0000231
Coefficient of Linear Expansion per ° F.	.0000128
Melting Point in °C.	625
Melting Point in °F.	1157
Specific Heat (watt-seconds to heat 1 lb. 1° C.)	402
Thermal Conductivity (watts through cu. in. temperature gradient 1° C.)	36.5
Resistance	
Microhms of centimeter cube at 0° C.	2.571
Microhms of inch cube at 0° C.	1.012
Ohms per mile-foot at 0° C.	15.47
Ohms per mil-foot at 20° C.	16.70
Ohms per mile at 0° C.	$\frac{81{,}700}{\text{cir. mils}}$
Ohms per mile at 20° C.	$\frac{88{,}200}{\text{cir. mils}}$
Pounds per mile-ohm at 0° C.	393
Pounds per mile-ohm at 20° C.	424
Temperature coefficient per ° C.	.004
Temperature coefficient per ° F.	.0022

Aluminum and Copper Compared.

Aluminum wire of 62% conductivity is the generally accepted standard. Aluminum of 62% conductivity, bought at 2.13 times the price of copper per pound, will give the same length and conductivity for the same expenditure.

Comparative Cost of Aluminum of 62% Conductivity and Copper for Equal Length and Conductivity.

Cost per Pound of Copper of 100 % Conductivity.	Cost per Pound of Aluminum of 62% Conductivity.
14 cents	28.8 cents
15 "	32.0 "
16 "	34.1 "
17 "	36.2 "
18 "	38.4 "
19 "	40.5 "
20 "	42.6 "
21 "	44.7 "
22 "	46.8 "
23 "	49.0 "
24 "	51.1 "
25 "	53.2 "

Comparison of Copper and Aluminum of Various Conductivities for Equal Length and Conductivity.

Metal.	Conductivity.	Cross Section.	Weight.	Breaking Weight.*	Price per lb.
Copper	100	100	100.0	100	100
Aluminum . .	54	180	54.0	85.1	185
" . . .	55	176	53.0	83.5	189
" . . .	56	173	52.0	82.0	192
" . . .	57	170	51.1	80.6	196
" . . .	58	167	50.2	79.2	199
" . . .	59	164	49.4	77.9	203
" . . .	60	162	48.6	76.6	206
" . . .	61	159	47.8	75.3	210
" . . .	62	157	47.0	74.1	213
" . . .	63	154	46.3	72.9	216

* Breaking weights (pounds to break wire of equal conductivity) are calculated on the assumption of an ultimate strength of 55,000 pounds per square inch for copper and 26,000 pounds per square inch for aluminum.

Table of Resistances of Solid Aluminum Wire 62% Conductivity.*

PITTSBURG REDUCTION CO.

Conductivity 62 in., the Matthiessen Standard Scale. Pure aluminum weighs 167.111 pounds per cubic foot.

Am. Gauge B. & S. No.	Resistances at 70° F.				Log d^2.	Log R.
	R Ohms per 1000 Feet.	Ohms per Mile.	Feet per Ohm.	Ohms per lb.		
0000	.07904	.41730	12652.	.00040985	5.325516	$\bar{2}$.897847
000	.09966	.52623	10034.	.00065102	5.224808	$\bar{2}$.998521
00	.12569	.66362	7956.	.0010364	5.124102	$\bar{1}$.099301
0	.15849	.83684	6310.	.0016479	5.023394	$\bar{1}$.200002
1	.19982	1.0552	5005.	.0026194	4.922688	$\bar{1}$.300639
2	.25200	1.3305	3968.	.0041656	4.821980	$\bar{1}$.401401
3	.31778	1.6779	3147.	.0066250	4.721274	$\bar{1}$.502127
4	.40067	2.1156	2496.	.010531	4.620566	$\bar{1}$.602787
5	.50526	2.6679	1975.	.016749	4.519860	$\bar{1}$.703515
6	.63720	3.3687	1569.	.026628	4.419152	$\bar{1}$.804276
7	.80350	4.2425	1245.	.042335	4.318446	$\bar{1}$.904986
8	1.0131	5.3498	987.0	.067318	4.217738	0.005652
9	1.2773	6.7442	783.0	.10710	4.117030	0.106293
10	1.6111	8.5065	620.8	.17028	4.016324	0.207122
11	2.0312	10.723	492.4	.27061	3.915616	0.307753
12	2.5615	13.525	390.5	.43040	3.814910	0.408494
13	3.2300	17.055	309.6	.68437	3.714202	0.509203
14	4.0724	21.502	245.6	1.0877	3.613496	0.609850
15	5.1354	27.114	194.8	1.7308	3.513788	0.710574
16	6.4755	34.190	154.4	2.7505	3.412082	0.811273
17	8.1670	43.124	122.50	4.3746	3.311374	0.912063
18	10.300	54.388	97.15	6.9590	3.210668	1.012837
19	12.985	68.564	77.06	11.070	3.109960	1.113442
20	16.381	86.500	61.03	17.595	3.009254	1.214340
21	20.649	109.02	48.44	27.971	2.908546	1.314899
22	26.025	137.42	38.4	44.450	2.807838	1.415391
23	32.830	173.35	30.45	70.700	2.707132	1.516271
24	41.400	218.60	24.16	112.43	2.606424	1.617000
25	52.200	275.61	19.16	178.78	2.505718	1.717671
26	65.856	347.70	15.19	284.36	2.405010	1.818595
27	83.010	438.32	12.05	452.62	2.304304	1.919130
28	104.67	552.64	9.55	718.95	2.203596	2.019822
29	132.00	697.01	7.58	1142.9	2.102890	2.120574
30	166.43	878.80	6.01	1817.2	2.002182	2.221232
31	209.85	1108.0	4.77	2888.0	1.901476	2.321909
32	264.68	1397.6	3.78	4595.5	1.800768	2.422721
33	333.68	1760.2	3.00	7302.0	1.700060	2.523330
34	420.87	2222.2	2.38	11627.	1.599354	2.624148
35	530.60	2801.8	1.88	18440.	1.498646	2.724767
36	669.00	3532.5	1.50	29352.	1.397940	2.825426
37	843.46	4453.0	1.19	46600.	1.297234	2.926064
38	1064.0	5618.0	.95	74240.	1.196526	3.026942
39	1341.2	7082.0	.75	118070.	1.095820	3.127494
40	1691.1	8930.0	.59	187700.	0.995112	3.228169

* Calculated on the basis of Dr. Matthiessen's standard, viz.: The resistance of a pure soft copper wire 1 meter long, having a weight of 1 gram = .141729 International Ohm at 0° C. The purest aluminum obtainable has a conductivity of over 63 per cent, but this gain in conductivity is at a greatly increased cost.

Stranded Weatherproof Aluminum Wire.

(Triple Braid.)

Circular Mils and B. & S. Gauge.	Diameter in Mils.	Lbs. per 1000 ft.	Circular Mils and B. & S. Gauge.	Diameter in Mils.	Lbs. per 1000 ft.
1,000,000	1.152	1408	400,000	.728	567
950,000	1.125	1340	350,000	.679	502
900,000	1.092	1270	300,000	.630	436
850,000	1.062	1202	250,000	.590	375
800,000	1.035	1135	0000	.530	280
750,000	.999	1067	000	.470	232
700,000	.963	1001	00	.420	192
650,000	.927	938	0	.375	155
600,000	.891	878	1	.330	132
550 000	.855	806	2	.291	108
500,000	.819	740	3	.261	88
450,000	.770	665	4	.231	72

Dimensions and Resistances of Stranded Aluminum Wire.

H. W. BUCK.

Relative Conductivity	62%.
Resistance per Mil-foot.	16.95 ohms.
Temperature	75° F.
Elastic Limit	14,000 lbs. per square inch.
Ultimate Strength	26,000 lbs. per square inch.

Size C. M. and B. & S.	Diam. Stranded, Inches.	Area Sq. Inch.	Pounds per		Feet per Lb.	Ohms per		Elastic Limit, Lbs.	Ultimate Strength, Lbs.
			1000 Feet.	Mile.		1000 Feet.	Mil.		
1,000,000	1.15	.7870	920	4,858	1.087	.01695	.08950	10,995	20,420
950,000	1.12	.7470	874	4,617	1.144	.01784	.09420	10,440	19,400
900,000	1.09	.7075	828	4,374	1.208	.01883	.09942	9,900	18,380
850,000	1.06	.6680	782	4,131	1.279	.01994	.10529	9,350	17,360
800,000	1.03	.6290	736	3,888	1.359	.02119	.11188	8,800	16,340
750,000	1.00	.5890	690	3,645	1.449	.02260	.11933	8,230	15,320
700,000	.96	.5500	644	3,402	1.553	.02421	.12782	7,700	14,300
650,000	.93	.5120	598	3,159	1.672	.02608	.13770	7,150	13,270
600,000	.89	.4720	552	2,916	1.812	.02825	.14917	6,600	12,250
550,000	.85	.4330	506	2,673	1.977	.03082	.16275	6,050	11,230
500,000	.81	.3930	460	2,430	2.041	.03300	.17900	5,500	10,210
450,000	.77	.3540	414	2,187	2.415	.03766	.19884	4,950	9,190
400,000	.73	.3141	368	1,944	2.718	.04237	.22370	4,400	8,170
350,000	.68	.2750	322	1,701	3.106	.04843	.25570	3,850	7,150
300,000	.63	.2360	276	1,458	3.623	.05652	.29830	3,300	6,130
250,000	.58	.1965	230	1,215	4.348	.06780	.35800	2,750	5,110
0000	.54	.1661	194.7	1,028	5.733	.08010	.42290	2,330	4,320
000	.47	.1317	154.4	816	6.477	.10100	.53315	1,850	3,430
00	.42	.1045	122.4	647	8.165	.12740	.67270	1,460	2,720
0	.37	.0829	97.1	513	10.300	.16050	.84740	960	2,150
1	.33	.0657	77.0	407	12.990	.20250	1.0692	920	1,710
2	.30	.0521	61.0	323	16.400	.25540	1.3486	730	1,355
3	.26	.0413	48.5	256	20.620	.32200	1.7002	579	1,075
4	.23	.0327	38.5	203	25.970	.40600	2.1438	450	852

Dimensions and Resistances of Stranded Aluminum Wire.

EQUIVALENT IN RESISTANCES TO STANDARD COPPER SIZES.

H. W. BUCK.

Relative Conductivity of Copper . . . . . . 98%.
Relative Conductivity of Aluminum . . . . . 62%.
Resistance of Aluminum per Mil-Foot . . . . 16.95 ohms.
Temperature . . . . 75° F.
Elastic Limit Aluminum . . . 14,000 lbs per sq. in.
Ultimate Strength Aluminum. 26,000 lbs. per sq. in.

Equivalent Copper. Size C. M. and B. & S.	Aluminum.									
	Cir. Mils.	Diam. Inches.	Area Sq. In.	Pounds per 1000 Ft.	Pounds per Mile.	Feet Per Pound.	Ohms per 1000 Feet.	Ohms per Mile.	Elastic Limit.	Ultimate Strength.
1,000,000	1,580,700	1.45	1.2415	1454	7678	.6878	.01072	.05660	17,380	32,280
950,000	1,501,700	1.41	1.1794	1381	7291	.7242	.01129	.05961	16,510	30,660
900,000	1,422,600	1.38	1.1172	1309	6912	.7640	.01191	.06288	15,640	29,050
850,000	1,343,500	1.34	1.0552	1236	6526	.8085	.01261	.06658	14,770	27,430
800 000	1,264,400	1.29	.9924	1163	6141	.8600	.01340	.07075	13,900	25,820
750,000	1,185,500	1.25	.9310	1091	5761	.9166	.01430	.07550	13,030	24,210
700,000	1,106,300	1.21	.8690	1018	5375	.9824	.01533	.08094	12,160	22,590
650,000	1,027,300	1.17	.8076	9450	4989	1.0582	.01650	.08712	11,300	20,980
600,000	948,400	1.12	.7448	872.5	4554	1.1460	.01787	.09435	10,430	19,370
550,000	869,400	1.07	.6828	799.8	4223	1.2551	.01884	.09947	9,560	17,750
500,000	790,400	1.02	.6208	727.2	3839	1.3733	.02144	.1132	8,690	16,140
450,000	711,150	.97	.5586	654.4	3457	1.5282	.02383	.1258	7,820	14,520
400,000	632,300	.92	.4966	581.7	3071	1.7192	.02680	.1415	6,950	12,910
350,000	553,150	.86	.4345	509.0	2687	1.9648	.03064	.1618	6,080	11,300
300,000	474,200	.79	.3724	436.2	2303	2.2927	.03574	.1887	5,210	9,680
250,000	395,150	.72	.3103	363.5	1919	2.7511	.04289	.2265	4,340	8,070
0000	334,450	.66	.2627	307.7	1625	3.2500	.05068	.2676	3,680	6,830
000	265,250	.59	.2083	244.0	1288	4.0985	.0639	.3374	2,920	5,420
00	210,300	.53	.1652	193.5	1022	5.1680	.0806	.4255	2,310	4,290
0	166,850	.47	.1310	153.5	810.5	6.5150	.1017	.5370	1,830	3,410
1	132,300	.42	.1039	121.7	642.6	8.2170	.1281	.6764	1,450	2,700
2	104,900	.37	.0824	96.5	509.5	10.363	.1616	.8532	1,150	2,143
3	83,190	.33	.0653	76.5	403.9	13.073	.2037	1.0760	914	1,700
4	65,980	.30	.0518	60.7	320.5	16.477	.2569	1.3563	726	1,350
5	52,320	.26	.0411	48.2	254.5	20.750	.3239	1.7103	575	1,070
6	41,490	.23	.0326	38.2	201.7	26.180	.4085	2.1570	456	850

Aluminum for High Tension Transmission Lines.

1. Stranded wire should always be used, even in the smaller sizes, as the action of the wind causes solid aluminum wire to "crystallize," thereby decreasing its strength; also, there is less liability of flaws in the metal causing breakage.
2. Aluminum gathers much less sleet than copper.
3. It costs less to string aluminum than copper, due to the less weight.
4. Care must be taken in stringing aluminum to prevent denting and abrasion, as the wire is very soft.
5. Mechanical and splice joints made without the use of solder are entirely satisfactory.
6. Wires should be strung far enough apart to prevent trouble from burning-off of the wire in case of a short circuit.
7. Due to its high coefficient of linear expansion and low tensile strength, the minimum allowable sag for aluminum wire is considerably greater than for copper. This is one great objection to aluminum for telephone and telegraph lines. For long spans the difference in deflection between aluminum and copper wires may be so great as to require a considerably higher pole in case aluminum is used, although the pole need not be as strong as would be required for copper, as the weight of aluminum for equal conductivity is but 47 per cent of the weight of copper.

IRON AND STEEL WIRE.

Physical Constants of Best Galvanized Telegraph Wire.

	Iron.	Steel.
Per cent Conductivity (copper 100)	16.8	12.2
Per cent Conductivity (pure iron 100)	95.5	69.2
Specific Gravity	7.8	7.85
Pounds in 1 cubic foot	487	490
Pounds in 1 cubic inch	.282	.284
Pounds per mile per circular mil.	.014	.0141
Ultimate strength, $\frac{\text{lb.}}{\text{sq. in.}}$	55,000	68,000
Modulus of elasticity, $\frac{\text{lb.} \times \text{in.}}{\text{in.} \times \text{sq. in.}}$	26,000,000	30,000,000
Coefficient of Linear Expansion per ° C.	.000012	.000012
Coefficient of Linear Expansion per ° F.	.0000067	.0000067
Melting Point in ° C.	1600	1475
Melting Point in ° F.	2910	2685
Specific Heat (watt-seconds to heat 1 lb. 1° C.).	209	209
Thermal Conductivity (watts through cu. in., temperature gradient 1° C.)	1.39	1.39
Resistance		
Microhms per centimeter cube at 0° C.	9.5	13.1
Microhms per inch cube at 0° C.	3.74	5.17
Ohms per mil foot at 0° C.	57.2	78.9
Ohms per mil foot at 20° C.	62.9	86.8
Ohms per mile at ° C.	$\frac{302{,}000}{\text{cir. mils}}$	$\frac{417{,}000}{\text{cir. mils}}$
Ohms per mile at 20° C.	$\frac{332{,}000}{\text{cir. mils}}$	$\frac{458{,}000}{\text{cir. mils}}$
Pounds per mile-ohm ° C.	4230	5850
Pounds per mile-ohm 20° C.	4700	6500
Temperature Coefficient per ° C.	.005	.005
Temperature Coefficient per ° F.	.0028	.0028

Double Galvanized Telegraph and Telephone Wire of the Highest Electrical Qualities.

ROEBLING.

Number, Roebling Gauge.	Diameter in Inches.	Weight in Pounds per Mile.	Put up in bundles of	Approximate Breaking Strain in Pounds.			Average Resistance in Ohms at 68° F.		
				E.B.B.	B.B.	Steel.	E.B.B.	B.B.	Steel.
4	.225	730	¼ mile.	2,190	2,409	2,701	6.44	7.53	8.90
6	.192	540	⅓ mile.	1,620	1,782	1,998	8.70	10.19	12.04
8	.162	380	½ mile.	1,140	1,254	1,406	12.37	14.47	17.10
9	.148	320	½ mile.	960	1,056	1,184	14.69	17.19	20.31
10	.135	260	½ mile.	780	858	962	18.08	21.15	25.00
11	.120	214	½ mile.	642	706	792	21.96	25.70	30.37
12	.105	165	½ mile.	495	545	611	28.48	33.33	39.39
14	.080	96	½ mile.	288	317	355	48.96	57.29	67.71

The values given in this table are averages of a large number of tests. They are within the limits of the specifications of the Western Union Telegraph Company.

The average value of the mile-ohm is 4,700 for E. B. B. wire.
The average value of the mile-ohm is 5,500 for B. B. wire.
The average value of the mile-ohm is 6,500 for Steel wire.
The average breaking strain is 3 times the weight per mile for E. B. B. wire.
The average breaking strain is 3.3 times the weight per mile for B. B. wire.
The average breaking strain is 3.7 times the weight per mile for Steel wire.
The mile-ohm = weight per mile × resistance per mile.

Galvanized Signal Strand. Seven Wires.

Diameter, Inches.	Weight per 1000′.			Estimated Breaking Weight.
	Bare Strand.	Double Braid W. P.	Triple Braid W. P.	
1–2	520	616	677	8,320
15–32	420	510	561	6,720
7–16	360	444	488	5,720
3–8	290	362	398	4,640
5–16	210	270	297	3,360
9–32	160	214	235	2,560
17–64	120	171	188	1,920
1–4	100	148	163	1,600
7–32	80	122	134	1,280
3–16	60	96	105	960
11–64	43	76	84	688
9–64	33	60	66	528
1–8	24	48	53	384
3–32	20	38	42	320

Properties of Steel Wire.

ROEBLING.

NOTE.—The breaking weights given for *steel* wire are not those of *Steel Telegraph wire.* They apply to wire with a tensile strength of 100,000 pounds per square inch. This strength is higher than that of telegraph wire.

No., Roebling G.	Diameter in Inches.	Area in Square Inches.	Breaking Strain 100,000 lbs. sq. inch.	Weight in Pounds. Per 1,000 ft.	Weight in Pounds. Per Mile.	Feet in 2,000 lbs.
6–0	.460	.166191	16,619	558.4	2,948	3,582
5–0	.430	.145221	14,522	487.9	2,576	4,099
4–0	.393	.121304	12,130	407.6	2,152	4,907
3–0	.362	.102922	10,292	345.8	1,826	5,783
2–0	.331	.086049	8,605	289.1	1,527	6,917
0	.307	.074023	7,402	248.7	1,313	8,041
1	.283	.062902	6,290	211.4	1,116	9,463
2	.263	.054325	5,433	182.5	964	10,957
3	.244	.046760	4,676	157.1	830	12,730
4	.225	.039761	3,976	133.6	705	14,970
5	.207	.033654	3,365	113.1	597	17,687
6	.192	.028953	2,895	97.3	514	20,559
7	.177	.024606	2,461	82.7	437	24,191
8	.162	.020612	2,061	69.3	366	28,878
9	.148	.017203	1,720	57.8	305	34,600
10	.135	.014314	1,431	48.1	254	41,584
11	.120	.011310	1,131	38.0	201	52,631
12	.105	.008659	866	29.1	154	68,752
13	.092	.006648	665	22.3	118	89,525
14	.080	.005027	503	16.9	89.2	118,413
15	.072	.004071	407	13 7	72.2	146,198
16	.063	.003117	312	10.5	55.3	191,022
17	.054	.002290	229	7.70	40.6	259,909
18	.047	.001735	174	5.83	30.8	343,112
19	.041	.001320	132	4.44	23.4	450,856
20	.035	.000962	96	3.23	17.1	618,620
21	.032	.000804	80	2.70	14.3	740,193
22	.028	.000616	62	2.07	10.9	966,651
23	.025	.000491	49	1.65	8.71	....
24	.023	.000415	42	1.40	7.37	....
25	.020	.000314	31	1.06	5.58	....
26	.018	.000254	25	.855	4.51	....
27	.017	.000227	23	.763	4.03	....
28	.016	.000201	20	.676	3.57	....
29	.015	.000177	18	.594	3.14	....
30	.014	.000154	15	.517	2.73	....
31	.0135	.000143	14	.481	2.54	....
32	.013	.000133	13	.446	2.36	....
33	.011	.000095	9.5	.319	1.69	....
34	.010	.000079	7.9	.264	1.39	....
35	.0095	.000071	7.1	.238	1.26	....
36	.009	.000064	6.4	.214	1.13	....

This table was calculated on a basis of 483.84 pounds per cubic foot for steel wire. Iron wire is a trifle lighter.

The breaking strains are calculated for 100,000 pounds per square inch throughout, simply for convenience, so that the breaking strains of wires of any strength per square inch may be quickly determined by multiplying the values given in the tables by the ratio between the strength per square inch and 100,000. Thus, a No. 15 wire, with a strength per square inch of 150,000 pounds, has a breaking strain of $407 \times \frac{150,000}{100,000} = 610.5$ pounds.

The "Roebling" or "Market wire Gauge" is now used as standard for steel wires in America.

RESISTANCE WIRES.

SPECIFIC RESISTANCE AND TEMPERATURE COEFFICIENT.

Substance.	Microhms per Cubic Centimeter about 20° F.	Temperature Coefficient per ° C.
Platinum silver (Pt 66, Ag 33)	31.726	.000243
Patent-Nickel (Cu 74.41, Zn 0.23, Ni 25.10, Fe 0.42, Mn 0.13)	34.2	.00019
Platinoid (Cu 59 Zn 25.5, Ni 14, W 55)	32.5	....
German Silver (Cu, Zn, Ni in various proportions)	19 to 46	.00025 to .00044
Manganin (Cu, Ni, and Fe-Mn in various proportions)	42 to 74	.000011 to .00014
Boker & Co.'s IaIa, hard	50.2	—.000011
Boker & Co.'s IaIa, soft	47.1	+.000005
Krupp's metal	85.13	.0007007
Driver-Harris Co.'s "S. B."	55.8	Small
Driver-Harris Co.'s "Advance"	48.8	Very small
Driver-Harris Co.'s "Ferro-Nickel"	28.3	.00207
Constantin	50 to 52	....

German Silver.

German silver is an alloy of copper, nickel, and zinc. The electrical properties of the alloy naturally vary considerably with the proportions of the constituent metals. The proportion of nickel present is ordinarily used to distinguish the various alloys, as the amount of this metal present in the alloy fixes the proportions of the other constituents in order that the resulting material may be easily worked. As made in the United States, commercial German silver is made with approximately the following proportions.

(DR. F. A. C. PERRINE.)

Designation. Per Cent. Alloy.	Constituents.			Resistance at ° C.	
	Nickel.	Copper.	Zinc.	Microhms Per Centimeter.	Ohms Per Mil Foot.
8	8	60	32	19	114
12.5	12.5	57	30.5	25	150
20	20	56	24	32	193
30	30	50	20	46	277

Specific gravity, 8.5.
Temperature coefficient per ° C., .00025 to .00044.

Resistances of German Silver Wire at 70° F.

AMERICAN GAUGE.—(American Electrical Works).

	18% ALLOY. Resistance varies .03 of one per cent for one degree Centigrade.		30% ALLOY. Resistance varies .022 of one per cent for one degree Centigrade.	
Size.	Ohms per 1000 ft.	Ohms per pound.	Ohms per 1000 ft.	Ohms per pound.
No. 8	11.772	.24702	17.658	.37054
" 9	14.83	.39249	22.22	.58873
" 10	18.72	.62443	28.08	.93666
" 11	23.598	.99281	35.397	1.4927
" 12	29.754	1.5785	44.631	2.3676
" 13	37.512	2.5101	56.268	3.7650
" 14	47.304	3.9911	70.956	5.9862
" 15	59.652	6.3462	89.478	9.5192
" 16	75.222	10.090	112.833	15.135
" 17	94.842	16.045	142.263	24.066
" 18	119.61	25.511	179.41	38.266
" 19	155.106	42.909	232.659	64.362
" 20	190.188	64.498	285.282	96.524
" 21	239.814	102.56	359.721	153.84
" 22	302.382	163.06	453.573	244.60
" 23	381.33	259.33	571.99	388.99
" 24	480.834	412.37	721.251	618.55
" 25	606.312	655.61	909.468	983.43
" 26	764.586	1042.7	1146.879	1563.8
" 27	964.134	1657.7	1446.201	2486.6
" 28	1215.756	2636.0	1823.634	3953.9
" 29	1533.06	4191.5	2299.59	6287.2
" 30	1933.038	6666.5	2899.557	9999.6
" 31	2437.236	10594.	3655.854	15890.
" 32	3073.77	16850.	4610.65	25275.
" 33	3875.616	26788.	5813.424	40181.
" 34	4888.494	42618.	7332.741	63927.
" 35	6163.974	67759.	9245.961	101640.
" 36	7770.816	107700.	11656.224	161540.
" 37	9797.166	171170.	14695.749	256770.
" 38	12357.198	269820.	18535.797	404740.
" 39	15570.828	428720.	23356.242	643070.
" 40	19653.57	682540.	29480.35	1023800.

Specific Gravity 8.5 approx.

Manganin.

DR. F. A. C. PERRINE.

Perhaps the most remarkable resistance alloy which has been produced is manganin, invented by Edward Weston in 1889. It is composed of copper, nickel, and ferro-manganese in varying proportions.

Prof. Nichols of Cornell, has shown that coils made of this material are apt to change their resistance when successively heated to 100° Cent. and cooled to 0° Cent., but Dr. Lindeck, working for the Reichsanstalt, states that when a completed coil is annealed at a temperature of 140° Cent. for five hours, no further difficulty is experienced from any aging change, whether produced by time or repeated heatings and coolings.

A further advantage of manganin which has been noticed by Dr. Lindeck, when used for resistance coils, is its very feeble thermo-electric power when soldered to copper, as is almost always the case in standard coils. While for german silver the thermo-electric power is between 20 and 30 micro-volts per degree Centigrade, and for constantin, an alloy of copper 50 parts with nickel 50 parts, having a temperature coefficient between .00003 and .00004, a thermo-electric power of 40 micro-volts per degree Centigrade is found, the thermo-electric power of manganin is not above one or two micro-volts per degree.

Electrical Properties and Constitution of Manganin.

Dr. F. A. C. Perrine.

Authority.	Composition.			Ohms per Mil-Foot.	Microhms per Cubic Centimeter.	Temperature Coefficient.
	Cu.	Fe. Mn.	Ni.			
Nichols	78.28	14.07	7.65	...	.....	0.000011
Nichols	51.52	31.27	16.22	...	.....	0.000039
Perrine	70.	25.	5. } mixture	392	65.15	....
Perrine	65.	30.	5. } mixture	404	67.2	....
Perrine	65.	30.	5. } mixture	443	73.6	....
Feussner and Lindeck	73.	24.	3.	287	47.7	0.00003
Lindeck	84.	12.	4.	253	42.0	0.00014
Dewar and Fleming	84.	12.	4.	287	47.64	0.0000

Dimensions, Resistance, and Weights of Resistance Wires.

Boker & Co.'s IaIa.

Specific gravity	8.4
Microhms per centimeter cube, 0° C., hard	50.2
Microhms per centimeter cube, 0° C., soft	47.1
Microhms per mil-foot, 0° C., hard	310.
Microhms per mil-foot, 0° C., soft.	284.
Temperature coefficient per 0° C., hard	−.000011
Temperature coefficient per 0° C., soft	+.000005

B. & S. Gauge No.	Diameter, Inch.	Area, Circular, Mils.	Ohms per 1000 Feet.	Feet per Lb. Approximately.	Carrying Capacity with Free Radiation Amperes.
14	.0641	4107.	73.5	85.	....
16	.0508	2583.	116.9	135.3	....
17	.0453	2048.	147.4	170.6	....
18	.0403	1624.	185.9	215.5	15.8
19	.0359	1289.	234.3	271.0	13.6
20	.0320	1024.	295.6	342.3	11.5
21	.0285	812.3	374.4	433.	9.7
22	.0253	640.1	470.1	543.5	8.0
23	.0225	506.25	596.6	689.6	6.8
24	.0201	404.	747.6	870.	5.8
25	.0179	320.4	945.6	1098.	4.9
26	.0159	252.8	1192.9	1370.	4.1
27	.0142	201.6	1497.8	1724.	3.6
28	.0126	158.8	1890.1	2174.	3.1
29	.0113	127.7	2407.8	2777.	2.9
30	.0100	100.	3005.3	3448.	2.7
31	.0089	79.2	3789.2	4347.	....
32	.0080	64.	4779.1	5555.	2.5
33	.0071	50.4	6025.1	7142.	....
34	.0063	39.69	7600.4	9090.	2.2
35	.0056	31.56	9582.7	11100.	....
36	.005	25.	12081.	14286.	2.0
37	.0044	19.83	15229.	17543.	....
38	.004	16.	19213.	22220.	....
39	.0035	12.25	24218.	27700.	....
40	.0031	9.61	30570.	35714.	....

Supplied by Boker Co., 101–103 Duane St., New York.

Resistance Ribbon. Ia Ia Quality.

B. & S. Gauge No.	Thickness, Inch.	Ohms per 1000 feet.							
		$\frac{1}{8}$ in.	$\frac{1}{4}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	$\frac{7}{8}$ in.	1 in.
8	.128	14.81	7.40	4.93	3.70	2.96	2.46	2.11	1.85
9	.114	16.69	8.34	5.56	4.17	3.34	2.78	2.38	2.08
10	.101	18.80	9.40	6.26	4.70	3.76	3.13	2.70	2.35
11	.0907	20.97	10.48	6.99	5.24	4.19	3.49	2.99	2.62
12	.0808	23.46	11.73	7.82	5.86	4.69	3.91	3.35	2.93
13	.0719	26.63	13.31	8.87	6.65	5.32	4.43	3.80	3.32
14	.0641	29.62	14.81	9.87	7.40	5.92	4.93	4.22	3.70
15	.0571	33.38	16.69	11.12	8.34	6.68	5.56	4.77	4.17
16	.0508	37.60	18.80	12.53	9.40	7.52	6.26	5.37	4.70
17	.0452	41.94	20.97	13.98	10.48	8.38	6.99	5.99	5.24
18	.0403	46.92	23.46	15.64	11.73	9.38	7.82	6.70	5.86
19	.0359	53.26	26.63	17.78	13.31	10.64	8.87	7.60	6.65
20	.0320	59.24	29.62	19.75	14.81	11.84	9.87	8.46	7.40
21	.0284	66.76	33.38	22.25	16.69	13.35	11.12	9.53	8.34
22	.0253	75.20	37.60	25.07	18.80	15.04	12.53	10.74	9.40
23	.0225	83.88	41.94	27.96	20.97	16.77	13.98	11.98	10.48
24	.0201	93.84	46.92	31.28	23.46	18.77	15.64	13.40	11.73
25	.0179	106.52	53.26	35.50	26.63	21.30	17.78	15.21	13.31
26	.0159	118.48	59.24	39.49	29.62	23.69	19.75	16.91	14.81
27	.0142	133.52	66.76	44.50	33.38	26.70	22.25	19.07	16.69
28	.0126	150.40	75.20	50.13	37.60	30.08	25.07	21.50	18.80
29	.0112	167.76	83.88	55.92	41.94	33.55	27.96	23.96	20.97
30	.0100	187.68	93.84	62.56	46.92	37.53	31.28	26.81	23.46
31	.0089	213.04	106.52	71.01	53.26	42.60	35.50	30.43	26.63
32	.0079	236.96	118.48	78.98	59.24	47.40	39.49	33.82	29.62
33	.0071	267.04	133.52	89.01	66.76	53.40	44.50	38.15	33.38
34	.0063	300.80	150.40	100.26	75.20	60.16	50.13	42.97	37.60
35	.0056	335.52	167.76	111.84	83.88	67.10	55.92	47.93	41.94
36	.005	375.36	187.68	125.12	93.84	75.07	62.56	53.62	46.92
37	.0044	426.08	213.04	142.02	106.52	85.21	71.01	60.87	53.26
38	.004	473.92	236.96	157.97	118.48	94.78	78.98	67.64	59.24

Krupp's Resistance Wires.

Specific gravity . . . . 8.102.
Specific resistance at 20° C. mean . . . . . . 85.13 microhms.
Temperature coefficient, mean . . . . .0007007.
Resistance per circular mil-foot . . . . 314. ohms.
Resistance per 1000′, 1 square inch area . . . .8513 ohms.

This metal can be permanently loaded with current sufficient to raise its temperature to 600° C. (1112° F.) without undergoing any structural change. It should never be put in contact with asbestos, however, as this material causes it to deteriorate rapidly.

Diam. in m.m.	Diam. in inches.	Nearest B. & S. Gauge No.	Feet per lb.	Resistance in ohms per foot.			
				at 68° F.	at 176° F.	at 284° F.	at 428° F.
5	.1968	4	9	.0132	.0138	.0143	.0150
4½	.1772	5	12	.0163	.0170	.0176	.0184
4	.1575	6	15	.0206	.0215	.0224	.0235
3½	.1378	7	19	.0269	.0280	.0291	.0307
3	.1181	9+	26	.0368	.0382	.0396	.0417
2¾	.1083	9−	31	.0437	.0455	.0472	.0497
2½	.0984	10	37	.0528	.0550	.0570	.0601
2¼	.0885	11	46	.0653	.0679	.0705	.0742
2	.0787	12	58	.0825	.0860	.0892	.0940
1¾	.0689	13	76	.1078	.112	.116	.123
1½	.0590	15	104	.1468	.153	.159	.167
1¼	.0492	16	150	.2115	.220	.229	.241
1	.0393	18	234	.3305	.344	.356	.376
¾	.0295	21	415	.5870	.610	.633	.667
½	.0196	24	937	1.324	1.38	1.43	1.51

American Agent, Thomas Prosser & Son, 15 Gold St., New York City.

Resistance Wires Made by Driver-Harris Wire Co., Harrison, N. J.

"S. B." — Resistance per mil-foot at 75° F. 336 ohms
Low temperature coefficient and low thermo-electric effect against copper. Will not rust.

"Advance." — Resistance per mil-foot at 75° F. 294 ohms
A copper-nickel alloy containing no zinc. Temperature coefficient practically nil.

"Ferro-Nickel." — Resistance per mil-foot at 75° F. 170 ohms
Temperature coefficient per ° F. .00115
About the same resistance as German Silver, but weighs about ten per cent less and is cheaper.

Resistances of Driver-Harris Resistance Wires.

No. B. & S.	"S. B." Ohms per 1,000 ft.	"Advance." Ohms per 1,000 ft.	"Ferro-Nickel." Ohms per 1,000 ft.
10	32	28.	2.0
11	40	35.5	2.5
12	51	44.8	3.2
13	64	56.7	4.1
14	82	71.7	5.1
15	103	90.4	6.5
16	130	113	8.2
17	168	145	10.4
18	210	184	13.1
19	260	226	16.3
20	328	287	20.5
21	415	362	25.9
22	525	460	32.7
23	660	575	41.5
24	831	725	52.3
25	1,050	919	65.4
26	1,328	1,162	85
27	1,667	1,455	106
28	2,112	1,850	131
29	2,625	2,300	166
30	3,360	2,940	209
31	4,250	3,680	266
32	5,250	4,600	333
33	6,660	5,830	425
34	8,400	7,400	531
35	10,700	9,360	672
36	13,440	11,760	850
37	16,640	14,550	1,070
38	21,000	18,375	1,330
39	27,540	24,100	1,700
40	37,300	32,660	2,120
. .	. . .	. . .	. . .

CURRENT CARRYING CAPACITY OF WIRES AND CABLES.

Let D = diameter of wire or cable core in inches.
T = temperature elevation of wire or cable core in ° Centigrade.
I = current in wire in amperes.
r = specific resistance of wire in ohms per mil-foot at final temperature.

The following approximate formulæ give results sufficiently accurate for practical purposes.

Bare Overhead Wires Out of Doors.

Stranded:

$$I = 1100\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 1250\sqrt{\frac{TD^3}{r}}.$$

Bare Wires In Doors, Exposed.

Stranded:

$$I = 610\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 660\sqrt{\frac{TD^3}{r}}.$$

Single Conductor Rubber Covered Cable in Still Air.

Stranded:

$$I = 490\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 530\sqrt{\frac{TD^3}{r}}.$$

Single Conductor Rubber Covered Lead Sheathed Cable in Underground Single Duct Conduit.

Stranded:

$$I = 490\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 530\sqrt{\frac{TD^3}{r}}.$$

Single Conductor Paper Covered Lead Sheathed Cable in Underground Single Duct Conduit.

Stranded:

$$I = 430\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 470\sqrt{\frac{TD^3}{r}}.$$

* Three-Conductor Rubber Covered Lead Sheathed Cable in Underground Single Duct Conduit.

Stranded:

$$I = 370\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 400\sqrt{\frac{TD^3}{r}}.$$

* Three-Conductor Paper Covered Lead Sheathed Cable in Underground Single Duct Conduit.

Stranded:

$$I = 320\sqrt{\frac{TD^3}{r}}.$$

Solid:

$$I = 350\sqrt{\frac{TD^3}{r}}.$$

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* I is here current per wire.

Carrying Capacity of Insulated Copper Wires for Interior Wiring.

NATIONAL ELECTRICAL CODE.

B. & S. Co.	Circular Mils.	Rubber Covered Wires. Amperes.	Weather proof Wires. Amperes.	Circular Mils.	Rubber Covered Wires. Amperes.	Weather-proof Wires. Amperes.
18	1,624	3	5	200,000	200	300
16	2,583	6	8	300,000	270	400
14	4,107	12	16	400,000	330	500
12	6,530	17	23	500,000	390	590
10	10,380	24	32	600,000	450	680
8	16,510	33	46	700,000	500	760
6	26,250	46	65	800,000	550	840
5	33,100	54	77	900,000	600	920
4	41,740	65	92	1,000,000	650	1,000
3	52,630	76	110	1,100,000	690	1,080
2	66,370	90	131	1,200,000	730	1,150
1	83,690	107	156	1,300,000	770	1,220
0	105,500	127	185	1,400,000	810	1 290
00	133,100	150	220	1,500,000	850	1,360
000	167,800	177	262	1,600,000	890	1,430
0000	211,600	210	312	1,700,000	930	1,490
				1,800,000	970	1,550
				1,900,000	1,010	1,610
				2,000,000	1,050	1,670

Carrying Capacity of Stranded Copper Conductors for Interior Wiring.

NATIONAL ELECTRICAL CODE.

B. & S. G.	Area Actual C. M.	No. of Strands.	Size of Strand B. & S. G.	Amperes.
19	1,288	..	..	..
18	1,624	..	..	..
17	2,048	..	..	..
16	2,583	..	..	6
15	3,257	..	..	..
14	4,107	..	..	12
12	6,530	..	..	17
..	9,016	7	19	21
..	11,368	7	18	25
..	14,336	7	17	30
..	18,081	7	16	35
..	22,799	7	15	40
..	30,856	19	18	50
..	38,912	19	17	60
..	49,077	19	16	70
..	60,088	37	18	85
..	75,776	37	17	100
..	99,064	61	18	120
..	124,928	61	17	145
..	157,563	61	16	170
..	198,677	61	15	200
..	250,527	61	14	235
..	296,387	91	15	270
..	373,737	91	14	320
..	413,639	127	15	340

For aluminum wire the carrying capacity of any given size is to be taken as 84 per cent of the value given in the above table.

Carrying Capacity of Rubber Insulated Cables.

(*From technical letter of General Electric Company.*)

The following table of carrying capacity is based on tests of cables in still air. Insulation alone $\frac{5}{32}''$ thick; lead $\frac{1}{16}''$ to $\frac{1}{8}''$ thick; jute and asphalt jacket $\frac{7}{64}''$ thick. Paper insulated cables heat 8% to 10% more than rubber insulated cables with same current and thickness of coverings. Cables require about four hours to reach final temperature.

60% of total increase in temperature in 1st hour.
30% of total increase in temperature in 2d hour.
8% of total increase in temperature in 3d hour.

Cables immersed in water will carry 50% more current with same increase of temperature, and cables *buried* in *moist* earth about 15% more. Rubber cables should not be run above 70° C. Paper cables should not be run above 90° C.

Size.	Diameter Copper Core. Inches.	Amperes at 30° C. Rise.		Amperes at 50° C. Rise.	
		Braided.	Leaded and Jute Covered.	Braided.	Leaded and Jute Covered.
6 B. & S. Solid	.162	61	56	76	68
4 B. & S. Solid	.204	85	78	104	94
2 B. & S. Stranded	.300	133	121	162	146
1 B. & S. Stranded	.325	155	141	189	170
0 B. & S. Stranded	.390	191	174	231	210
00 B. & S. Stranded	.420	218	199	268	241
000 B. & S. Stranded	.475	266	242	325	293
0000 B. & S. Stranded	.543	320	291	391	352
250000 C.M.	.570	355	324	435	392
300000 C.M.	.640	414	377	506	456
350000 C.M.	.680	460	419	563	507
400000 C.M.	.735	512	466	626	564
450000 C.M.	.787	562	511	687	618
500000 C.M.	.820	606	551	742	668
600000 C.M.	.900	694	631	848	763
750000 C.M.	1.020	825	750	1016	915
900000 C.M.	1.096	940	855	1149	1034
1000000 C.M.	1.157	1017	925	1333	1200
1250000 C.M.	1.298	1204	1095	1481	1328
1500000 C.M.	1.413	1376	1251	1644	1480
2000000 C.M.	1.760	1766	1606	2178	1960

Heating of Cables in Multiple Duct Conduit.

The mutual heating of cables in multiple duct conduit has been investigated experimentally by H. W. Fisher. The following diagram and table shows the arrangement of the conduit system used by him and the size and kind of cable in each duct. Means were provided for connecting any or all the cables in series and observing the temperature of the conductor in each duct.

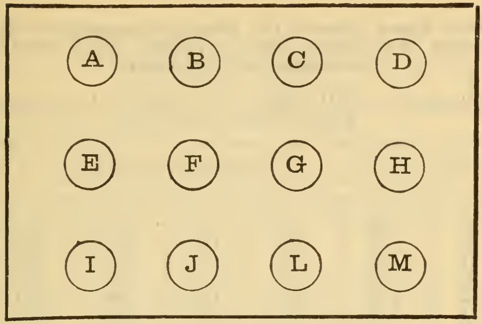

FIG. 22.

Cable.	Number of Conductors.	Size B. & S. and C. M.	Insulation.
A*		000	$\frac{7}{32}$″ and $\frac{7}{32}$″ Paper
B	1	500,000	$\frac{7}{32}$″ Paper
C*		000	$\frac{7}{32}$″ and $\frac{7}{32}$″ Paper
D	1	500,000	$\frac{7}{32}$″ Paper
E	1	1,250,000	$\frac{7}{32}$″ Paper
F.	1	1,250,000	$\frac{7}{32}$″ Paper
G.	1	000	$\frac{7}{32}$″ Paper
H	1	000	Rubber
I.	1	1,250,000	$\frac{7}{32}$″ Paper
J	1	1,250,000	$\frac{7}{32}$″ Paper
K	1	000	Rubber
L.	1	000	$\frac{7}{32}$″ Paper

* The three conductors of *A* and *C* in multiple.

Fisher's results are summarized in the following table :

Conductors Carrying Current.	30° C. Rise.		50° C. Rise.	
	Conductor.	Amperes.	Conductor.	Amperes.
All	A. & C.	130	A. & C.	180
G, H, K, L..	G	155	G	190
	L	180	L	260
E, F, I, J..	I	600	I	765
	E	590	E	750
	J	560	J	725
	F	535	F	690
A, B, C, D, E, F, I, J. . . .	B	355	B	425
	D	400	D	550

An inspection of this table will show that the current corresponding to a given temperature elevation is in each case less than that given by the formulæ on page 208, the difference being from 4 to 25 per cent, depending on the number of conductors in service and the location of the cable in question. It is to be noted that corner ducts radiate heat the best, and all outside ducts radiate heat much better than do the inside ducts.

Watts per Foot Lost in Single-Conductor Cables at Different Maximum Temperature with Different Amounts of Currents.

(From Handbook No. XVII, 1906. Copyrighted by Standard Underground Cable Company.)

Size B. & S.	Current in Amperes.					
6	66	81	93	104	114	123
5	74	91	105	117	128	138
4	84	102	117	131	144	153
3	93	114	132	148	161	175
2	**105**	**128**	**148**	**166**	**181**	**196**
1	118	148	166	186	203	220
0	132	162	187	209	228	247
00	149	181	210	235	256	277
000	166	204	235	263	288	311
0000	**186**	**229**	**264**	**295**	**323**	**350**
Area in 1000 C. M.						
300	222	273	315	352	385	416
400	248	315	363	406	445	480
500	288	352	406	455	498	537
600	315	385	445	497	545	587
700	**341**	**416**	**480**	**538**	**588**	**635**
800	364	446	514	575	628	679
900	386	473	545	610	666	720
1000	407	498	575	642	703	758
1100	426	522	602	674	736	796
1200	**446**	**546**	**630**	**705**	**772**	**833**
1300	462	568	655	732	802	866
1400	480	590	681	761	834	900
1500	496	610	704	788	862	931
1600	512	629	726	812	889	960
1700	**529**	**649**	**750**	**837**	**916**	**990**
1800	543	667	770	862	943	1018
1900	557	686	792	886	970	1048
2000	573	705	813	910	995	1075
	Watts lost per ft.					
Temp. of cond. in °F. 100	1.81	2.71	3.62	4.52	5.43	6.33
125	**1.91**	**2.87**	**3.82**	**4.78**	**5.73**	**6.69**
150	2.00	3.00	4.00	5.00	6.00	7.00

The watts lost per foot means the amount of electric energy lost in heating the conductor and is equal to the product of the resistance per foot of cable times the square of the current in amperes.

The above table is useful in showing the watts lost in heating effect per foot of cable with different currents, and also in finding the size of conductor that must be used for a given current and watts per foot loss.

For Two-Conductor Cables the watts corresponding to the different currents must be multiplied by two, and to obtain the currents corresponding to the watts in the table multiply the currents given in the table by .707.

For Three-Conductor Cables the watts corresponding to the currents in the table, must be multiplied by 3, and to obtain the currents corresponding to the watts in the table multiply the currents given in the table by .577.

Current Carrying Capacity of Lead Covered Cables.

(From Handbook No. XVII, 1906. Copyrighted by Standard Underground Cable Company.)

The current carrying capacity of insulated copper cables sheathed with lead depends primarily upon

(*a*) The size and number of conductors and their relative position.

(*b*) The ability of the insulating material to withstand high temperatures and to conduct heat away from the copper conductor, — this latter being in turn dependent upon kind of insulation and its thickness.

(*c*) The initial temperature of the medium surrounding the cable.

(*d*) The ability of the medium surrounding the cable to dissipate heat with small temperature rise.

(*e*) The number of operating cables in close proximity and their relative positions.

Where a number of insulated conductors are under the same sheath, they are subject to an interchange of heat somewhat similar to that which takes place when a number of separate cables are laid closely together, and for that reason each conductor of a multi-conductor cable will have a smaller current carrying capacity than a single-conductor cable. If the various conductors are separately insulated and laid together in the form of flat or round duplex or triplex, their carrying capacity will be greater than if they are laid up in the form of two-conductor concentric or three-conductor concentric, since the enveloping conductors in the latter formation seriously retard the dissipation of heat from the inner conductors. Assuming that unity (1.00) represents the carrying capacity of single-conductor cables, the capacity of multi-conductor cables would be given by the following:

2 cond. flat or round form,	.87;	concentric form,	.79
3 cond. triplex form	.75;	concentric form,	.60

The following experiment on duplex concentric cable of 525,000 C. M. indicates clearly the danger in subjecting this type of cable to heavy overloads of even short duration. The cable was first heated up by a current of 440 amperes for 5 hours. An overload of 50 per cent was then applied, the results in degrees Fahrenheit above the surrounding air being as follows:

Time from Start.	0 Min.	15 Min.	30 Min.	45 Min.	60 Min.	90 Min.
Inner Conductor .	70°	84°	98°	111°	123°	142°
Outer Conductor .	55	65	76	85	94	108
Lead Cover . . .	31	35	40	45	49	57

In any cable the area over which dissipation of heat must take place is proportional to the circumference of the conductor or (since the circumference varies as the diameter), upon the diameter of the conductor, while the cross section of the conductor varies as the square of the diameter. Hence the size of conductor varies much more rapidly than its heat radiating surface, and in consequence the amperage per square inch, or circular mil of copper section, must be less for large size conductors than for small, in order to have the same rise of temperature under the same conditions. The usual formula for carrying capacity,

$$\text{Current} = \frac{(\text{diam. of Cond.})^{\frac{3}{2}}}{\text{A constant}}$$

takes account of this fact but not to a sufficient degree, and we find that for cables as ordinarily used in underground work, a more correct expression is the following:

$$\text{Current} = \frac{(\text{diam. of Cond.})^{\frac{5}{4}}}{\text{A constant}}$$

Rubber insulation is a somewhat better heat conductor than dry or saturated paper, and therefore, when applied to the same size conductor in equal thickness, will permit of a larger current flowing in the conductor for the same rise of temperature above the surrounding air. On the other hand, rubber deteriorates much more rapidly at high temperatures than saturated paper, and while this disadvantage is apparently compensated for up to about 150° Fahrenheit by its superior heat dissipating qualities, at higher temperatures deterioration takes place and becomes so serious that its value as an insulating medium disappears in a comparatively short time.

As the thickness of insulation is increased, the temperature of the conductor, with any given current flowing gradually, increases and therefore the current carrying capacity becomes reduced. The reduction in capacity however, is not very great, being in the ratio of about 93 for $\frac{14}{32}$ insulation to 100 for $\frac{7}{32}$ insulation, so that the values in the table given below should be slightly decreased when greater thicknesses than $\frac{7}{32}$ are used.

As it is the final temperature reached which really affects the carrying capacity, the initial temperature of surrounding medium must be taken into account. If, for instance, the conduit system parallels steam or hot water mains, the temperature of 150° F. (which we have assumed in the table on page 215 to be the maximum for safe continuous work on cables) will be reached with lower values of current than would otherwise be the case; and as 70° is the actual temperature we have assumed to exist in the surrounding medium prior to loading the cables, any increase over 70° must be compensated for by reducing the current carried.

For rough calculations it will be safe to use the following multipliers to reduce the current carrying capacity given in the table on page 215 to the proper value for the corresponding initial temperatures:

Initial Temp. .	70	80	90	100	110	120	130	140	150
Multipliers . .	1.00	.93	.86	.78	.70	.60	.48	.34	.00

The ability of the surrounding medium to dissipate heat, directly affects the carrying capacity of the cables, as with the same current the cable might be comparatively cool if laid in good heat conducting material such as water, and dangerously hot if laid in poor heat conducting material such as dry sand. Ordinary conduit systems of clay or terra cotta ducts laid in cement, dissipate heat fairly well, the outside ducts, however, being much more efficient in this function than the inner ones, so that an ideal system, from this point of view, would consist of a single horizontal layer of ducts. As this would require an enormous width of trench and considerable inconvenience in handling the cables in manholes when many cables are to be installed, we would suggest the form shown in Fig. 23 as being more practicable.

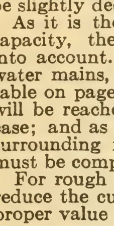

Fig. 23.

Where more ducts are required, the vertical section shown could be easily duplicated, a considerable space, however, being left between them. With this arrangement, the carrying capacities given in the table on p. 215 could be somewhat increased.

When a number of loaded cables are operating in close proximity to one another, the heat from one radiates, or is carried by conduction, to each of the others, and all raised in temperature beyond what would have resulted had only a single cable been in operation; and if the cables occupy adjacent ducts in a conduit system of approximately square cross section laid in the usual way, the centrally located cable or the one just above the center in large installations (*A* in Fig. 24) will reach the highest temperature. This is equivalent to saying that its carrying capacity is reduced, and while this reduction does not amount to more than about 12 per cent (as compared with the cable most favorably located, — as at *D*, Fig. 24) in the duct arrangement given, it may easily assume much greater proportions where large numbers of cables are massed together.

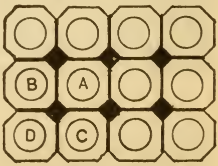

Fig. 24.

Assuming that not more than twelve cables, arranged as shown in Fig. 24, can be used, the average carrying capacity may be taken as the criterion for proper size of conductor; and for cables of a given type and size the carrying capacities of all cables, even though placed in adjacent ducts, will be represented by the following figures, taking unity as the average carrying capacity of four cables:

No. Cables	2	4	6	8	10	12
Multiplier	1.16	1.00	.88	.79	.71	.63

Recommended Current Carrying Capacities for Cables and Watts Lost per foot.

For each of four equally loaded single conductor paper insulated lead covered cables, installed in adjacent ducts in the usual type of conduit system where the initial temperature does not exceed 70° F., the maximum safe temperature for continuous operation being taken at 150° F.

(From Handbook No. XVII, 1906. Copyrighted by Standard Underground Cable Company.)

Size B. & S. G.	Safe Current in Amperes.	Watts * lost per ft. at 150° F.	Size C. M.	Safe Current in Amperes.	Watts * lost per ft. at 150° F.
14	18	.97	300,000	323	4.22
13	21	1.03	400,000	390	4.61
12	24	1.09	500,000	450	4.91
11	29	1.15	600,000	505	5.16
10	**33**	**1.25**	**700,000**	**558**	**5.36**
9	38	1.39	800,000	607	5.56
8	45	1.53	900,000	650	5.71
7	53	1.67	1,000,000	695	5.86
6	64	1.85	1,100,000	740	6.01
5	**76**	**2.08**	**1,200,000**	**780**	**6.13**
4	91	2.31	1,300,000	820	6.25
3	108	2.54	1,400,000	857	6.37
2	125	2.77	1,500,000	895	6.49
1	146	3.00	1,600,000	933	6.61
0	**168**	**3.23**	**1,700,000**	**970**	**6.73**
00	195	3.46	1,800,000	1010	6.85
000	225	3.69	1,900,000	1045	6.97
0000	260	3.92	2,000,000	1085	7.09

* This column represents the amount of energy which is transformed into heat and which must be dissipated. It is what is usually called the I^2R loss and it is figured by using for I the current values given; and for R the resistance of the respective conductor at a temperature of 150° F.

NOTE. — The table is compiled from a long series of tests made by us in conjunction with the Niagara Falls Power Company, the conduit system being of the type shown in Fig. 24. The ducts were of terra cotta with 3-inch openings.

Recommended Power Carrying Capacity in Kilowatts of Delivered Energy, Three-Conductor, Three-Phase Cables.

(From Handbook No. XVII, 1906. Copyrighted by Standard Underground Cable Company.)

Size in B. & S. G.	Volts.							
	1100	2200	3300	4000	6600	11000	13200	22000
	Kilowatts.							
6	92	183	275	333	549	915	1098	1831
5	109	217	326	395	652	1087	1304	2174
4	130	260	390	473	781	1301	1562	2603
3	154	309	463	562	927	1544	1854	3089
2	**179**	**358**	**536**	**650**	**1073**	**1788**	**2145**	**3575**
1	209	418	626	759	1253	2088	2506	4176
0	240	481	721	874	1442	2402	2884	4805
00	279	558	836	1014	1674	2788	3347	5577
000	322	644	965	1172	1931	3217	3862	6435
0000	**372**	**744**	**1115**	**1352**	**2231**	**3717**	**4462**	**7435**
250000	413	827	1240	1503	2480	4132	4960	8264

Single Conductor Cables, A. C. or D. C.

Size in B. & S. G.	Volts.							
	125	250	500	1100	2200	3300	6600	11000
	Kilowatts.							
6	8.0	16.0	32	70	141	211	422	704
5	9.5	19.0	38	84	167	251	502	836
4	11.4	22.8	45	100	200	300	601	1001
3	**13.5**	**27.0**	**54**	**119**	**238**	**356**	**713**	**1188**
2	15.6	31.2	62	138	275	413	825	1375
1	18.3	36.5	73	161	321	482	964	1606
0	21.0	42.0	84	185	370	554	1109	1848
00	24.4	48.8	97	215	429	644	1287	2145
000	**28.1**	**56.3**	**113**	**248**	**495**	**743**	**1485**	**2475**
0000	32.5	65.0	130	286	572	858	1716	2860
300000	40.4	80.8	162	355	711	1066	2132	3553
400000	48.8	97.5	195	429	858	1287	2574	4290
500000	56.3	112.5	225	495	990	1485	2970	4950
600000	**63.1**	**126.3**	**253**	**556**	**1111**	**1667**	**3333**	**5555**
700000	69.8	139.5	279	614	1228	1841	3683	6138
800000	75.9	151.8	304	668	1335	2003	4006	6677
900000	81.3	162.5	325	715	1430	2145	4290	7150
1000000	86.9	173.8	348	764	1529	2294	4587	7645
1100000	**92.5**	**185.0**	**370**	**814**	**1628**	**2442**	**4884**	**8140**
1200000	97.5	195.0	390	858	1716	2574	5148	8580
1400000	107.1	214.3	429	943	1885	2828	5656	9427
1500000	111.9	223.8	448	985	1969	2954	5907	9845
1600000	**116.6**	**233.3**	**467**	**1026**	**2053**	**3079**	**6158**	**10263**
1700000	121.3	242.5	485	1067	2134	3201	6402	10670
1800000	126.3	252.5	505	1111	2222	3333	6666	11110
2000000	135.6	271.3	543	1194	2387	3581	7161	11935

These tables are based on the recommended current carrying capacity of cables given on page 215. A power factor = 1, was used in the calculation and hence the values found in the last table are correct for direct currents. For alternating currents the kilowatts given in both tables must be multiplied by the power factor of the delivered load.

FUSING EFFECTS OF ELECTRIC CURRENTS.

By W. H. Preece, F. R. S. See "Proc. Roy. Soc.," vol. xliv., March 15, 1888.

The Law — $I = ad^{\frac{3}{2}}$, where I, current; a, constant; and d, diameter — is strictly followed; and the following are the final values of the constant "a," for the different metals as determined by Mr. Preece: —

	Inches.	Centimeters.	Millimeters.
Copper	10,244	2,530	80.0
Aluminum	7,585	1,873	59.2
Platinum	5,172	1,277	40.4
German Silver. . . .	5,230	1,292	40.8
Platinoid	4,750	1,173	37.1
Iron	3,148	777.4	24.6
Tin	1,642	405.5	12.8
Alloy (lead and tin 2 to 1)	1,318	325.5	10.3
Lead	1,379	340.6	10.8

Table Giving the Diameters of Wires of Various Materials Which Will Be Fused by a Current of Given Strength. — W. H. Preece, F. R. S. $d = \left(\frac{I}{a}\right)^{2/3}$

Current in Amperes.	Diameter in Inches.								
	Copper. $a = 10,244$.	Aluminum. $a = 7585$.	Platinum. $a = 5172$.	Ger. Silver. $a = 5230$.	Platinoid. $a = 4750$.	Iron. $a = 3148$.	Tin. $a = 1642$.	Tin-lead alloy. $a = 1318$.	Lead. $a = 1379$.
1	0.0021	0.0026	0.0033	0.0033	0.0035	0.0047	0.0072	0.0083	0.0081
2	0.0034	0.0041	0.0053	0.0053	0.0056	0.0074	0.0113	0.0132	0.0128
3	0.0044	0.0054	0.0070	0.0069	0.0074	0.0097	0.0149	0.0173	0.0168
4	0.0053	0.0065	0.0084	0.0084	0.0089	0.0117	0.0181	0.0210	0.0203
5	0.0062	0.0076	0·0098	0.0097	0.0104	0.0136	0.0210	0.0243	0.0236
10	0.0098	0.0120	0.0155	0.0154	0.0164	0.0216	0.0334	0.0386	0.0375
15	0.0129	0.0158	0.0203	0.0202	0.0215	0.0283	0.0437	0.0506	0.0491
20	0.0156	0.0191	0.0246	0.0245	0.0261	0.0343	0.0529	0.0613	0.0595
25	0.0181	0.0222	0.0286	0.0284	0.0303	0.0398	0.0614	0.0711	0.0690
30	0.0205	0.0250	0.0323	0.0320	0.0342	0.0450	0.0694	0.0803	0.0779
35	0.0227	0.0277	0.0358	0.0356	0.0379	0.0498	0.0769	0.0890	0.0864
40	0.0248	0.0303	0.0391	0.0388	0.0414	0.0545	0.0840	0.0973	0.0944
45	0.0268	0.0328	0.0423	0.0420	0.0448	0.0589	0.0909	0.1052	0.1021
50	0.0288	0.0352	0.0454	0.0450	0.0480	0.0632	0.0975	0.1129	0.1095
60	0.0325	0.0397	0.0513	0.0509	0.0542	0.0714	0.1101	0.1275	0.1237
70	0.0360	0.0440	0.0568	0.0564	0.0601	0.0791	0.1220	0.1413	0.1371
80	0.0394	0.0481	0.0621	0.0616	0.0657	0.0864	0.1334	0.1544	0.1499
90	0.0426	0.0520	0.0672	0.0667	0.0711	0.0935	0.1443	0.1671	0.1621
100	0.0457	0.0558	0.0720	0.0715	0.0762	0.1003	0.1548	0.1792	0.1739
120	0.0516	0.0630	0.0814	0.0808	0.0861	0.1133	0.1748	0.2024	0.1964
140	0.0572	0.0698	0.0902	0.0895	0.0954	0.1255	0.1937	0.2243	0.2176
160	0.0625	0.0763	0.0986	0.0978	0.1043	0.1372	0.2118	0.2452	0.2379
180	0.0676	0.0826	0.1066	0.1058	0.1128	0.1484	0.2291	0.2652	0.2573
200	0.0725	0.0886	0.1144	0.1135	0.1210	0.1592	0.2457	0.2845	0.2760
225	0.0784	0.0958	0.1237	0.1228	0.1309	0.1722	0.2658	0.3077	0.2986
250	0.0841	0.1028	0.1327	0.1317	0.1404	0.1848	0.2851	0.3301	0.3203
275	0.0897	0.1095	0.1414	0.1404	0.1497	0.1969	0.3038	0.3518	0.3413
300	0.0950	0.1161	0.1498	0.1487	0.1586	0.2086	0.3220	0.3728	0.3617

TENSION AND SAG IN WIRE SPANS.

By Harold Pender, Ph.D.

The accompanying charts* (No. 1 for long spans, No. 2 for short spans) enable one to determine without arithmetical computation the variation of the tension and sag in copper wire spans with the temperature and resultant load on the wire. Similar charts can be readily prepared for wires of any material.

The symbols used in the discussion below are as follows:

m = weight of wire per cubic inch in pounds.
α = coefficient of linear expansion of wire per degree Fahr.
M = modulus of elasticity of wire (pounds — square inch).
ρ = ratio of resultant of the weight of wire, the weight of sleet and the wind pressure to the weight of wire.
l = length of span in feet.
t = rise in temperature in degrees Fahr.
T = tension in thousands of pounds per square inch.
D = deflection at center of span in feet in direction of resultant force when points of suspension are on the same level.
S = vertical sag at center of span in feet when points of support are on the same level.

The lines on the charts are plotted as follows:

The hyperbolic curves on the right have the equation $y = \left(\frac{\rho}{T}\right)^2$ where y is the ordinate and T the abscissa. A curve is plotted for $\rho = 1.0, 1.2, 1.4 \ldots 4.0$. The value of ρ for each curve is indicated at the top of the chart. It is to be noted that the horizontal distance between these curves at any level is directly proportional to the increment in the value of ρ. These curves are independent of the material of the wire.

The inclined straight lines have the equation $y = \frac{10^9}{6\,M\,m^2 l^2}\,T$. For a given material the equation of these lines depends only on the length of the span. The lines on the charts are drawn for copper wire for which $m = 0.321$ and $M = 12 \times 10^6$. The corresponding length of span is indicated on the right-hand margin of the charts. For any other material, the line for a given length of span will have a different slope.

The temperature scale on the X axis to the right of the origin is laid off so that $x = M\alpha t$. The scale given on the chart is for copper, for which $M = 12 \times 10^6$ and $\alpha = 9.6 \times 10^{-6}$. This scale will be different for any other material.

The parabolic curves on the left of the chart have the equation $D = 0.0015\, m\, l^2 \sqrt{y}$, where D is measured off from the left of the origin. For a given material these curves are fixed by the length of the span. The curves given on the chart are for copper, for which $m = 0.321$. The corresponding lengths of span are indicated on the curves. These curves will be different for any other material.

Rules for the Use of the Charts.

Given: A span of length l and the points of support on the same level, tension T_1; ratio of resultant force to weight of wire, ρ_1; to find the tension T when the temperature rises t degrees and the ratio of resultant force to weight of wire changes to ρ (for example, sleet melts off).

At the point 1 (Fig. 27) on the curve corresponding to ρ_1 and having the abscissa T_1, lay off 12 = the ordinate of the point 3 on the line corresponding to l having the abscissa t on the temperature scale.

* These charts were devised to obtain a graphical solution of the equations deduced by the author in an article in the *Electrical World* for Jan. 12, 1907, Vol. 49, p. 99. The present article also appeared in the *Electrical World* for Sept. 28, 1907.

Through 2 draw a line parallel to the line l: the abscissa of the point 4 where this line cuts the curve corresponding to ρ is the tension T at the temperature t when the ratio of resultant force to weight of wire is ρ. The abscissa of the point 5 where the horizontal line through 4 cuts the parabolic curve corresponding to l gives the corresponding deflection D at the center of the span in feet. Instead of actually drawing the straight line 24, a pair of compasses may be used; *i.e.*, lay off the distance 12, then open the compasses until the lower point touches the straight line l; then keeping the compasses vertical, slide the lower point along l until the upper point intersects the curve corresponding to ρ. If t is negative, *i.e.*, if the temperature decreases, lay off 12 in the opposite direction. To determine D with greater accuracy use the formula

$$D = .0015\, m\, l^2 \frac{\rho}{T}\cdot$$

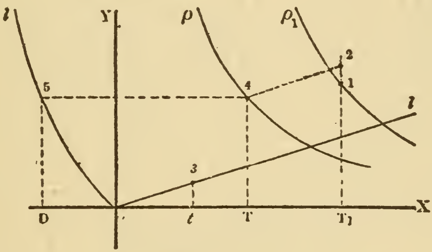

Fig. 25.

Calculation of ρ.

Let w = weight of wire in pounds per foot.

The weight of sleet (and hemp core, if any) in pounds per foot of wire is

$$w_1 = 0.314\,(d_1^2 - d^2) + 0.25\, d_0^2,$$

where d is the diameter of the wire, d_1 the diameter over sleet and d_0 the diameter of the core, all in inches.

The wind pressure in pounds per foot of wire is *

$$w_2 = 0.00021\, V^2\, d_1,$$

where V is the actual wind velocity in miles per hour; $d_1 = d$ in case of no sleet. The relation between indicated wind velocity (as given by U. S. Weather Reports) and actual velocity is as follows:

Indicated Velocity.	Actual Velocity.	$0.00021\ V^2$.
10	9.6	0.0194
20	17.8	0.0667
30	25.7	0.139
40	33.3	0.233
50	40.8	0.350
60	48.0	0.485
70	55.2	0.640
80	62.2	0.812
90	69.2	1.01
100	76.2	1.22

The ratio ρ is then

$$\rho = \sqrt{\left(1 + \frac{\omega_1}{\omega}\right)^2 + \left(\frac{\omega_2}{\omega}\right)^2}.$$

* H. W. Buck in Transactions International Electrical Congress, 1904.

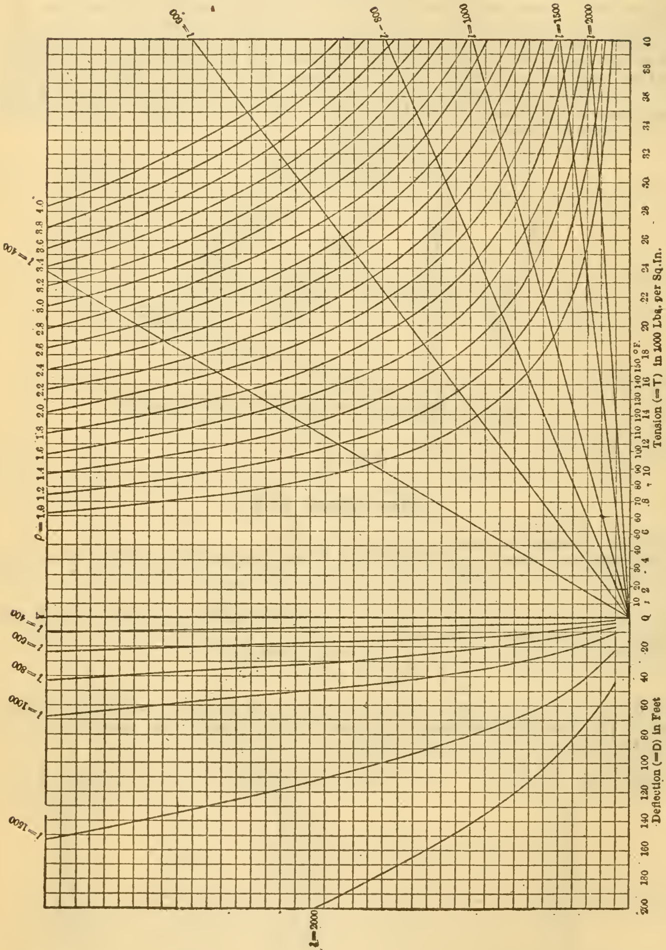

FIG. 26. Chart for Long Spans.

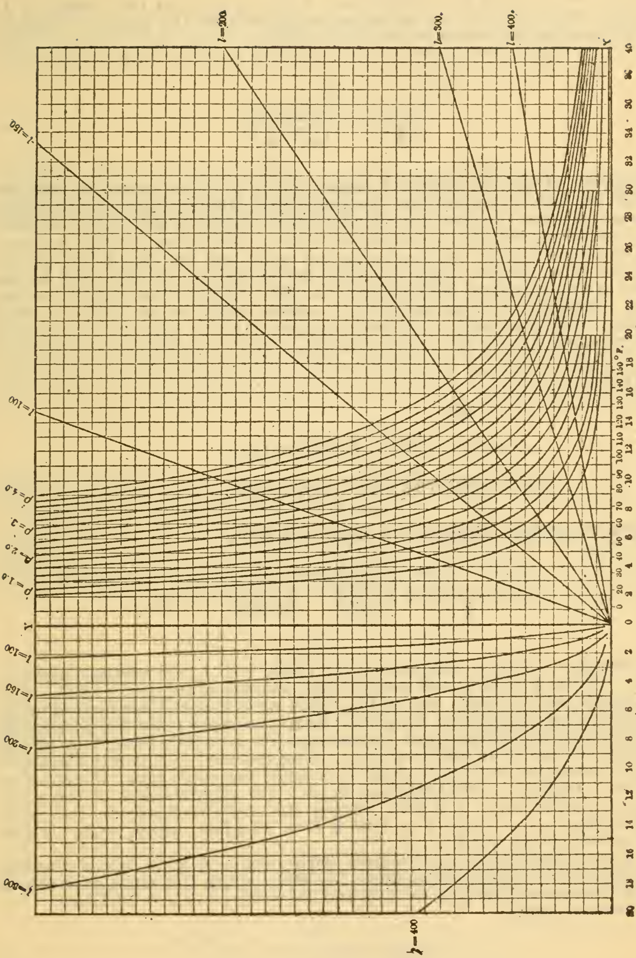

FIG. 27. Chart for Short Spans.

Calculation of Vertical Sag.

In case of no wind the vertical sag S is the same as the deflection D. The wind pressure gives a horizontal component to the resultant force so that the vertical sag when wind is blowing is,

$$S = \frac{D}{\sqrt{1 + \left(\frac{w_2}{w + w_1}\right)^2}}.$$

Example: A No. 00 stranded copper cable is to be strung in still air at 70° F. between two points on the same level 800 feet apart, so that at a temperature of zero degrees Fahrenheit, with a coating of sleet 0.41 inch thick all around and wind blowing perpendicularly to the cable at 69.5 miles an hour (actual velocity) the tension in the cable will be 30,000 lbs. per sq. in.; (1) at what tension must the cable be strung and (2) what will be the vertical sag at stringing temperature, *i.e.*, 70°, also (3) what will be the sag at zero temperature when the cable is coated with ½-in. of sleet and wind is blowing with a velocity of 65 miles an hour, and (4) what will be the sag at the temperature of 150°, in the still air?

We have

$$w = 0.406$$

$$w^1 = 0.314\ (\overline{1.238^2} - \overline{0.418^2}) = 0.425$$

$$w_2 = .00021 + \overline{69.5^2} + 1.238 = 1.26.$$

Therefore, at zero degrees with wind and sleet,

$$\rho_0 = \sqrt{\left(1 + \frac{0.425}{0.406}\right)^2 + \left(\frac{1.26}{0.406}\right)^2} = 3.72.$$

(1) Measure off with compasses, on chart No. 1, the vertical distance from $t = 70$ on X axis to the straight line corresponding to $l = 800$. Lay this distance off vertically above the point on the curve corresponding to $\rho = 3.72$ having the abscissa $T = 30$. Keep the upper point fixed, open the compasses until the lower point touches the line $l = 800$; then, keeping the compasses vertical, slide the lower point along the line $l = 800$ until the upper point intersects the curve $\rho = 1$ at $T = 8.95$; the cable must therefore be strung at a tension of 8950 lbs. per sq. in. (2) The abscissa of the point on the parabolic curve $l = 800$, having the same ordinate as the point corresponding to $\rho = 1$ and $T = 8.95$ is $D = 34.4$ feet, which is the vertical sag S, in still air at 70° F.

(3) The deflection at zero degrees with sleet and wind is the abscissa of the point on the parabolic curve $l = 800$ having the same ordinate as the point corresponding to $\rho_0 = 3.72$ and $T_0 = 30$, *i.e.*, $D_0 = 38.2$ feet.

The vertical sag is

$$S = \frac{38.2}{\sqrt{1 + \left(\frac{1.26}{.831}\right)^2}} = 21.0 \text{ feet.}$$

(4) To find the sag at 150° proceed as under (1) and (2) taking $t = 150$. The sag will be found to be $S = 36.8$ feet.

Wire Suspended from Points not on the Same Level.

The charts also apply directly to the determination of the change in tension in spans when the points of support are at different heights. In this case, however, the vertical sag S_1 (= deflection in case of no wind) below the highest point of support is given by the formula

$$S_1 = S\left(1 + \frac{h}{4\,S}\right)^2$$

where h is the difference in height of the two points of support, and S is the vertical sag for a span of *equal* length, but points of support on the *same* level; S is calculated by the formula given above, *i.e.*,

$$S = \frac{D}{\sqrt{1 + \left(\frac{w_2}{w + w_1}\right)^2}},$$

D being the deflection, taken directly from the chart, for a span of *equal* length but points of support on the *same* level; in case of no wind $S = D$. The distance of the point of maximum sag from the highest point of support is

$$\frac{l}{2}\left(1 + \frac{h}{4\,S}\right).$$

When h is greater than $4\,S$ the lowest point of support is the point of maximum sag, *i.e.*, the lowest point in the span.

Example: In the example given above, suppose the difference in height of the points of support is 20 feet: Then (1) the tension at 70° will still be 8950 lbs. per sq. in. (2) The corresponding vertical sag at 70° in still air for points of support at same level is 34.4 ft., therefore, for the span under consideration the vertical sag from the highest point of support is

$$34.4\left(1 + \frac{20}{4 \times 34.4}\right)^2 = 45.1 \text{ ft.}$$

(3) The vertical sag at zero degrees with sleet and wind for points of support on the same level is 21 ft.; therefore, for a 20-ft. difference in the height of points of support the vertical sag from the highest point of support is

$$21\left(1 + \frac{20}{4 \times 21}\right)^2 = 32.1 \text{ ft.}$$

(4) The vertical sag at a temperature of 150°, for points of support on the same level is 36.8 ft.; therefore, for a 20-ft. difference in height of the points of support the vertical sag from the highest point of support is

$$36.8\left(1 + \frac{20}{4 \times 36.8}\right)^2 = 47.5 \text{ ft.}$$

The accompanying table, giving the value of T and ρ for various values of $y = \left(\frac{\rho}{T}\right)^2$ will be found useful in plotting the hyperbolic curves in case one wishes to make charts on a larger scale than those given herein, or similar charts for wires having different constants. The other lines are readily plotted from the equations given above.

Table Giving the Value of T for Various Values of ρ and $y = \left(\frac{\rho}{T}\right)^2$

Values of $y = \left(\frac{\rho}{T}\right)^2$	Values of ρ. 1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
.2	2.24	2.68	3.13	3.58	4.02	4.47	4.92	5.37	5.81	6.26	6.71	7.16	7.60	8.05	8.50	8.94
.17	2.43	2.91	3.40	3.88	4.37	4.85	5.34	5.82	6.31	6.79	7.28	7.76	8.25	8.73	9.22	9.70
.13	2.77	3.33	3.88	4.44	4.99	5.55	6.10	6.66	7.21	7.77	8.32	8.87	9.43	9.98	10.54	11.09
.10	3.16	3.79	4.43	5.06	5.69	6.32	6.96	7.59	8.22	8.85	9.49	10.12	10.75	11.38	12.02	12.65
.07	3.78	4.54	5.29	6.05	6.80	7.56	8.32	9.07	9.83	10.58	11.34	12.10	12.85	13.61	14.36	15.12
.04	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.0
.03	5.77	6.92	8.08	9.24	10.39	11.55	12.70	13.86	15.01	16.16	17.32	18.47	19.63	20.8	21.9	23.1
.02	7.07	8.49	9.90	11.31	12.73	14.14	15.56	16.97	18.38	19.80	21.21	22.63	24.0	25.5	26.9	28.3
.017	7.67	9.20	10.74	12.27	13.81	15.34	16.87	18.41	19.94	21.5	23.0	24.5	26.1	27.6	29.1	30.7
.014	8.45	10.14	11.83	13.52	15.21	16.90	18.59	20.3	22.0	23.7	25.4	27.0	28.7	30.4	32.1	33.8
.012	9.13	10.95	12.78	14.61	16.43	18.26	20.1	21.9	23.7	25.6	27.4	29.2	31.0	32.9	34.7	36.5
.010	10.00	12.00	14.00	16.00	18.00	20.00	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0
.008	11.18	13.42	15.65	17.89	20.1	22.4	24.6	26.8	29.1	31.3	33.5	35.8	38.0	40.2	42.5	44.7
.006	12.91	15.49	18.07	20.7	23.2	25.8	28.4	31.0	33.6	36.1	38.7	41.3	43.9	46.5	49.1	51.6
.005	14.14	16.97	19.80	22.6	25.5	28.3	31.1	33.9	36.8	39.6	42.4	45.2	48.1	50.9	53.7	56.6
.004	15.81	18.97	22.1	25.3	28.5	31.6	34.8	37.9	41.1	44.3	47.4	50.6	53.8	56.9	60.1	63.2
.0035	16.90	20.3	23.7	27.0	30.4	33.8	37.2	40.6	43.9	47.3	50.7	54.1	57.5	60.8	64.2	67.6
.0030	18.26	21.9	25.0	29.2	32.9	36.5	40.2	43.8	47.5	51.1	54.8	58.4	62.1	65.7	69.4	73.0
.0025	20.00	24.0	28.0	32.0	36.0	40.0	44.0	48.0	52.0	56.0	60.0	64.0	68.0	72.0	76.0	80.0
.0020	22.4	26.8	31.3	35.8	40.2	44.7	49.2	53.7	58.1	62.6	67.1	71.6	76.0	80.5	85.0	89.4
.0015	25.8	31.0	36.1	41.3	46.5	51.6	56.8	61.9	67.1	72.4	77.4	82.6	87.8	92.9	89.1	103.2
.0010	31.6	37.9	44.3	50.6	56.9	63.2	69.6	75.9	82.2	88.5	94.9	101.2	107.5	113.8	120.2	126.5
.0005	44.7	53.7	62.6	71.6	80.5	89.4	98.4	107.3	116.3	125.0	134.2	143.1	152.0	161.0	170.0	178.9

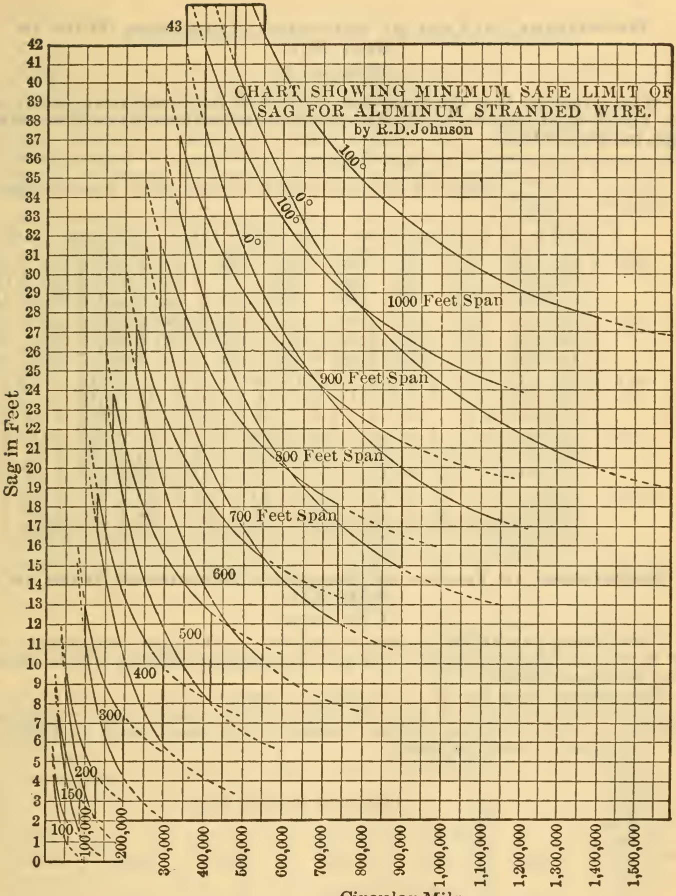

FIG. 28.—The top boundary of each span diagram is drawn for conditions at 100° Fahr.; the bottom boundary line for 0°. For other temperatures, interpolate or exterpolate proportionately. For mechanical reasons it is not recommended to string larger sizes of wire than appear in any closed span diagram, with any less sag than the minimum shown therein. The values of constants and assumptions of weather conditions are open to criticism. No responsibility is assumed beyond the correctness of the arithmetic.

Assumptions.—Maximum stress at −20° = 14,000 lbs. Ice coating one-half inch thick. Wind pressure 10 lbs. per sq. ft. proj. Diam. Diam. stranded conductor = 1.15 that of a solid wire of same section, Modulus of Elasticity = 7,500,000.

Deflections in Feet of Stranded Aluminum Wire in Still Air.

H. W. Buck.

Wire strung so that the maximum tension at minimum temperature of 0° F with wind blowing at 65 miles per hour (actual velocity) will be 14,000 lbs. per square inch.

Span in Feet.	Area of Wire in Cir. Mils.	Degrees Fahrenheit Rise above Minimum Temperature.								
		0°	20°	40°	60°	80°	100°	120°	140°	150°
200	553,150	.42	.51	.65	.83	1.07	1.57	2.20	2.75	2.97
	265,400	.45	.52	.65	.85	1.13	1.65	2.27	2.80	3.03
	132,300	.46	.55	.69	.92	1.30	1.82	2.45	2.95	3.10
400	553,150	1.80	2.20	2.70	3.35	4.15	5.05	6.00	6.90	7.20
	265,400	1.95	2.42	2.90	3.70	4.50	5.45	6.40	7.35	7.78
	132,300	2.20	2.75	3.40	4.20	5.10	6.00	7.00	7.85	8.50
600	553,150	4.3	5.1	6.0	7.0	8.2	9.5	10.8	11.9	12.5
	265,400	5.1	6.1	7.1	8.2	9.5	10.8	12.0	13.1	13.6
	132,300	6.2	7.2	8.4	9.7	11.0	12.2	13.3	14.4	15.7
800	553,150	8.4	9.5	10.8	12.3	13.8	15.4	16.9	18.3	19.0
	265,400	10.3	11.7	13.2	14.7	16.4	17.7	19.1	20.4	21.5
	132,300	14.0	15.4	16.9	18.3	19.6	29.0	22.2	23.4	25.5
1000	553,150	13.9	15.6	17.3	19.1	20.8	22.5	24.2	25.9	26.7
	265,400	18.6	20.3	22.0	23.8	25.5	27.1	28.6	30.0	31.5
	132,300	26.0	27.6	29.0	30.5	31.8	33.1	34.4	35.8	37.5

Deflections in Inches of Stranded Aluminum Wire in Still Air.

H. W. Buck.

Wire strung so that the maximum tension at minimum temperature of **0° F with wind blowing at 65 miles per hour (actual velocity) will be 14,000 lbs. per square inch.**

Calculations made for No. 2 B. and S. stranded conductor, but it is safe to follow this table for all sizes of cable, for the larger sizes will have slightly smaller deflections without exceeding their elastic limit on account of their greater relative strength.

Degrees Fahrenheit Rise above Minimum Temp.	Length of Span in Feet.					
	200	180	160	140	120	100
0	6.3	5.3	4.2	3.1	2.2	1.7
10	7.0	5.7	4.5	3.4	2.4	1.8
20	7.8	6.4	5.1	3.8	2.8	1.9
30	8.8	7.3	5.8	4.5	3.2	2.2
40	10.2	8.4	6.7	5.2	3.8	2.7
50	12.0	9.8	7.8	6.4	4.6	3.3
60	14.0	11.5	9.4	7.5	5.6	4.0
70	16.5	14.0	11.5	9.2	7.0	5.2
80	19.8	17.0	14.3	11.4	8.9	6.8
90	23.1	20.0	16.8	13.8	10.3	8.8
100	26.6	23.3	20.0	16.6	13.1	10.8
110	29.8	26.6	23.0	19.5	16.5	13.1
120	33.5	29.8	25.8	22.2	18.7	15.2
130	36.8	32.8	28.7	24.5	20.8	17.2
140	40.0	35.8	31.5	26.8	22.8	18.8
150	43.0	38.4	33.6	29.1	24.8	20.3

PROPERTIES OF DIELECTRICS.

Approximate Values of Specific Inductive Capacity of Various Dielectrics.

Non-conducting materials or insulators are called dielectrics. The dielectric constant or specific inductive capacity of a dielectric is the ratio of the capacity of a condenser having the space between its plates filled with this substance to the capacity of the same condenser with this space filled with air.

All gases and vacuum	1.00
Glass	3 to 8
Treated paper used in manufacture of power cables	2 to 4
Porcelain	4.4
Ebonite	2.5
Gutta-percha	2.5
Pure Para Rubber	2.2
Vulcanized Rubber	2.5
Paraffin	2.3
Rosin	1.8
Pitch	1.8
Wax	1.6
Mica	6
Water	80
Turpentine oil	2.2
Petroleum	2

Specific Resistance of Dielectrics at about 20° C.

These are approximate values; the resistance of dielectrics varies greatly with their purity and method of preparation.

Material.	Resistance in Millions of Megohms per Cubic Centimeter.	Resistance in Millions of Megohms per Cubic Inch.
Benzine	14	5.22
Ebonite	28,000	11,000
Glass, flint	20,000	8,000
Glass, ordinary	90	36
Gutta-percha	450	180
Mica	80	30
Micanite	2,500	900
Micanite cloth	300	120
Micanite paper	1,200	500
Oil asbestos	850	315
Olive oil	1	0.4
Ozokerite (crude)	450	180
Paper, parchment	0.03	0.01
Paper, ordinary	0.05	0.02
Treated paper used in manufacture of power cables	10 to 20	4 to 8
Paraffin	24,000	13,000
Paraffin oil	8	3
Shellac	9,000	3,500
Vulcanized fiber, black	68	27
Vulcanized fiber, red	10	4
Vulcanized fiber, white	14	6
Wood, ordinary	600	250
Wood, paraffined	3,700	1,500
Wood, tar	1,700	670
Wood, walnut	50	20

Variation of Resistance with Temperature.

The variations in resistance of dielectrics with temperature is much more rapid than in the case of metals. The variation can be expressed by an exponential equation.

$$R_0 = R_t a^t.$$

Where R_0 = resistance at standard temperature.
R_t = resistance at temperature differing t degrees from standard temperature.
t = temperature.
a = constant depending on the material.

For gutta-percha, t in ° C. . . . . $a = 0.88$
For pure rubber, t in ° C. . . . . $a = 0.95$

For other substances, the processes of manufacture vary too widely to permit the establishment of temperature coefficients.

Dielectric Strength of Insulating Materials.

C. Kinzbrunner.

Let V = Voltage required to puncture a given thickness of material.
v = Volts required to puncture a sheet of material .001 inch thick.
t = Thickness of the material in thousandths of an inch.

For all the materials given in table below, except pure para,

$$V = v\sqrt{t}.$$

For pure para,

$$V = vt.$$

For all the materials given below, except ordinary paper and impregnated paper, the puncturing voltage is the same for a solid sheet of material as for a sheet built up of thin layers. In the case of ordinary paper and impregnated paper the puncturing voltage is proportional to the number of layers; *i.e.*, $V = nv\sqrt{t'}$, where n is the number of layers and t' the thickness of each layer.

Puncturing Voltages for Sheet .001 in. thick (v.)

Presspahn	117
Manila paper	56
Ordinary paper	37
Fiber	57
Varnished paper	267
Red Rope paper	239
Impregnated paper	107
Varnished linen	256
Empire cloth	201
Leatheroid	73
Ebonite	682
Rubber	502
Gutta-percha	454
Para	370

The values in the preceding table are for tests made under the following conditions:

1. Electrodes, flat disks with round edges 1.5 inches in diameter.
2. Pressure on electrodes 0.5 pounds per square inch.
3. Voltage curve sinusoidal.
4. Frequency of the alternating current between 20 and 75 cycles per second.
5. Temperature 17° C., humidity of the air about 70 per cent.
6. Pressure applied for 15 minutes.

Rubber.

Pure rubber is a liquid gum having a specific gravity of .915. The rubber of commerce is obtained by coagulating this gum by various means, the most approved method being by the hot vapor rising from a smudge made from oily nuts. Rubbers prepared in this way are called "Para" rubbers; Para is the name of a province of Brazil which supplies a large quantity of this kind of rubber. Vulcanized rubber is a mixture of this coagulated gum, thoroughly cleaned and dried, with sulphur. Pure rubber deteriorates rapidly, whereas vulcanized rubber is comparatively stable, and at the same time retains the properties which make it valuable as an insulating material. The amount of sulphur present varies from five to twenty per cent of the entire mass, the amount determining the hardness of the product. Rubber with a large admixture of sulphur is called variously "hard rubber," "vulcanite" or "ebonite." Vulcanized rubber is used largely for insulating cables of all kinds.

Specifications for 30% Rubber Insulating Compound.

Adopted 1906, by the following wire manufacturers:

American Steel & Wire Co.
American Electrical Works.
Bishop Gutta Percha Co.
Canadian Gen. Electric Co.
Crescent Ins. Wire & Cable Co.
General Electric Co.
Hazard Mfg. Co.
India Rubber & Gutta Percha Ins. Co.
Indiana Rubber & Ins. Wire Co.
National India Rubber Co.
New York Ins. Wire Co.
John A. Roebling's Sons Co.
Safety Ins. Wire & Cable Co.
Simplex Electrical Co.
Standard Underground Cable Co.

The compound shall contain not less than 30% by weight of fine dry Para rubber which has not previously been used in rubber compounds. The composition of the remaining 70% shall be left to the discretion of the manufacturer.

Chemical. — The vulcanized rubber compound shall contain not more than 6% by weight of Acetone Extract. For this determination, the Acetone extraction shall be carried on for five hours in a Soxhlet extractor, as improved by Dr. C. O. Weber.

Mechanical. — The rubber insulation shall be homogeneous in character, shall be placed concentrically about the conductor, and shall have a tensile strength of not less than 800 pounds per square inch.

A sample of vulcanized rubber compound, not less than four inches in length shall be cut from the wire, with a sharp knife held tangent to the copper. Marks should be placed on the sample two inches apart. The sample shall be stretched until the marks are six inches apart and then immediately released; one minute after such release, the marks shall not be over 2⅜ inches apart. The samples shall then be stretched until the marks are 9 inches apart before breaking.

For the purpose of these tests, care must be used in cutting to obtain a proper sample, and the manufacturer shall not be responsible for results obtained from samples imperfectly cut.

Electrical. — Each and every length of conductor shall comply with the requirements given in the following table. The tests shall be made at the Works of the Manufacturer when the conductor is covered with vulcanized rubber, and before the application of other coverings than tape or braid.

Tests shall be made after at least twelve hours' submersion in water and while still immersed. The voltage specified shall be applied for five minutes. The insulation test shall follow the voltage test, shall be made with a battery of not less than 100 nor more than 500 volts, and the reading shall be taken after one minute's electrification. Where tests for acceptance are made by the purchaser on his own premises, such tests shall be made within ten days of receipt of wire of cable by purchaser.

Inspection. — The purchaser may send to the works of the manufacturer a representative, who shall be afforded all necessary facilities to make the above specified electrical and mechanical tests, and, also, to assure himself that the 30% of rubber above specified is actually put into the compound, but he shall not be privileged to inquire what ingredients are used to make up the remaining 70% of the compound.

30% Rubber Compound Voltage Test for 5 Minutes.

For 30 Minutes Test, Take 80% of These Figures.

I.

Size.	Thickness of Insulation in Inches.					
	$\frac{3}{64}$	$\frac{2}{32}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{4}{32}$
1,000,000 to 550,000 .	....	....	....	....	4,000	6,000
500,000 to 250,000 .	....	....	....	4,000	6,000	8,000
4/0 to 1	....	....	4,000	6,000	8,000	10,000
2 to 7	....	4,000	6,000	8,000	10,000	12,000
8 to 14	3,000	5,000	7,000	9,000	11,000	13,000

II.

Size.	Thickness of Insulation in Inches.					
	$\frac{5}{32}$	$\frac{6}{32}$	$\frac{7}{32}$	$\frac{8}{32}$	$\frac{9}{32}$	$\frac{10}{32}$
1,000,000 to 550,000 .	10,000	14,000	18,000	22,000	26,000	30,000
500,000 to 250,000 .	12,000	16,000	20 000	24,000	28,000	32,000
4/0 to 1	14,000	18,000	22,000	26 000	30,000	34,000
2 to 7	16,000	20,000	24,000	28,000	32,000	36 000
8 to 14	17,000	21,000	25,000	....	....	....

Megohms per Mile 60 Degrees F.

ONE MINUTE ELECTRIFICATION.

	3/64	2/32	5/64	3/32	7/64	4/32	5/32	6/32	7/32
1000000 C. M.	...	...	...	...	200	210	235	265	300
900000 C. M.	...	...	...	...	235	250	280	315	360
800000 C. M.	...	...	...	...	270	290	325	370	420
700000 C. M.	...	...	...	...	305	325	370	420	480
600000 C M.	...	...	...	...	340	365	420	470	540
500000 C. M.	...	...	...	350	375	405	465	525	600
400000 C. M.	...	...	...	390	420	450	530	600	670
300000 C. M.	...	...	...	430	470	505	590	680	750
250000 C. M.	...	...	...	455	500	540	630	720	810
4/0 Strd.	...	...	440	480	520	565	660	750	840
3/0 Strd.	...	...	450	490	535	580	675	770	860
2/0 Strd.	...	...	460	500	545	590	690	790	880
1/0 Strd.	...	...	490	540	590	650	760	860	950
1 Solid	...	...	520	580	635	700	830	950	1060
2 Solid	...	500	550	615	680	750	900	1040	1160
3 Solid	...	530	585	650	715	795	940	1080	1210
4 Solid	...	560	620	690	750	830	990	1130	1260
5 Solid	...	590	655	720	790	870	1040	1180	1300
6 Solid	...	620	690	760	840	920	1100	1230	1350
8 Solid	610	710	800	880	985	1060	1240	1370	1490
9 Solid	650	750	850	940	1050	1130	1310	1440	1560
10 Solid	690	795	905	1000	1120	1200	1380	1510	1620
12 Solid	750	870	990	1110	1250	1370	1540	1680	1790
14 Solid	800	930	1060	1200	1340	1470	1640	1780	1890

Gutta-Percha.

A higher grade of insulating material is another gum, gutta-percha, which is used in its pure state. The use of this gum is confined almost entirely to the construction of the insulated core of submarine cables.

Specific gravity, 0.9693 to 0.981.

Weight per cubic foot, 60.56 to 61.32 pounds.

Weight per cubic inch, 0.560 to 0.567 oz.

Softens at 115 degrees F.

Becomes plastic at 120 degrees F.

Melts at 212 degrees F.

Oxidizes and becomes brittle, shrinks and cracks when exposed to the air, especially at temperatures between 70 and 90 degrees F.

Oxidation is hastened by exposure to light.

Oxidation may be delayed by covering the gutta-percha insulation with a tape which has been soaked in prepared Stockholm tar.

Where gutta-percha is kept continually under water there is no noticeable deterioration, and the same applies where gutta-percha leads are covered with lead tubing.

Stretched gutta-percha, such as is used for insulating cables, will stand a strain of 1,000 pounds per square inch before any elongation.

The breaking strain is about 3,500 pounds per square inch.

The tenacity of gutta-percha is increased by stretching it.

Resistance of Gutta-Percha under Pressure. — The resistance of gutta-percha under pressure increases according to the following formula, when R = the resistance at the pressure of the atmosphere, and r the resistance at p pounds per square inch.

$$r = R\ (1 + 0.00023\ p).$$

Let D = diameter in mils of over gutta-percha insulation.
d = diameter of cable core.
W = weight in pounds of gutta-percha per knot.
w = weight in pounds of copper.

Then for *Solid Cable*

$$D = \sqrt{55\,w + 491\,W}.$$

$$\frac{D}{d} = \sqrt{1 + 8.93\,\frac{W}{w}}.$$

For *Stranded Cables.*

$$D = \sqrt{70.4\,w + 491\,W}$$

$$\frac{D}{d} = \sqrt{1 + 6.97\,\frac{W}{w}}.$$

Approximate Electrostatic Capacity of a gutta-percha cable per knot is

$$\frac{0.19}{\log D - \log d}\text{ microfarads.}$$

The *electrostatic capacity* of a gutta-percha insulated cable compared with one of the same size insulated with india rubber is about as 120 is to 100.

Dividing Coefficients for Correcting the observed Resistance of Gutta-Percha at any Temperature to 75° F.

K. Winnertz — 1907.

Degree F.	Coefficient.	Degree F.	Coefficient.	Degree F.	Coefficient.
95	0.1415	74	1.089	53	6.015
94	0.1561	73	1.187	52	6.373
93	0.1721	72	1.293	51	6.722
92	0.1898	71	1.409	50	7.057
91	0.2105	70	1.535	49	7.377
90	0.2332	69	1.672	48	7.670
89	0.2574	68	1.821	47	7.943
88	0.2836	67	1.984	46	8.178
87	0.3125	66	2.161	45	8.383
86	0.3442	65	2.353	44	8.499
85	0.3833	64	2.562	43	8.585
84	0.4304	63	2.790	42	8.637
83	0.4801	62	3.035	41	8.678
82	0.5251	61	3.302	40	8.719
81	0.5848	60	3.588	39	8.757
80	0.6458	59	3.896	38	8.796
79	0.7066	58	4.223	37	8.834
78	0.7707	57	4.564	36	8.880
77	0.8406	56	4.919	35	8.932
76	0.9168	55	5.282	34	8.990
75	1.0000	54	5.650	33	9.053

Dielectric Strength of Air.

The voltage required to break down the air between two terminals depends on the shape of the terminals, the distance between the terminals, and the constants of the circuit in series with the terminals.

The following curves, published by Mr. S. M. Kintner in the proceedings of the American Institute of Electrical Engineers, give the voltage required to break down air gaps of various lengths under various conditions.

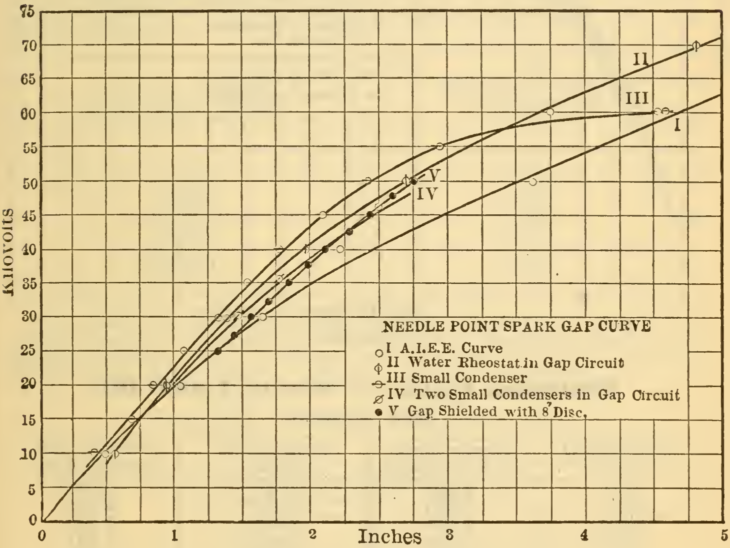

Fig. 29.

With regard to the use of a spark gap for measuring high voltages, Mr. Kintner makes the following recommendations:

"For the measurement of sudden pressure variations, such as those produced on transmission lines by lightning, switching, grounds, short circuits, etc., where the use of an oscillograph or similar device is not feasible, the spark-gap method is very useful. It is, in fact, the only method by which any satisfactory quantitative results can be obtained under such conditions.

"When using a gap the writer prefers 'round nose' (hemispherical shielded terminals); (slightly concave shields placed back of and coaxial with the terminals); the gap should be standardized over the range for which it is to be used just prior to taking measurements, and under as nearly the same surroundings, connections, etc., as possible. This preference is based on the convenience of operation and greater freedom from erratic behavior of this form of gap.

"The spark gap, although apparently a very simple device, requires an expert operator to get results that are at all satisfactory."

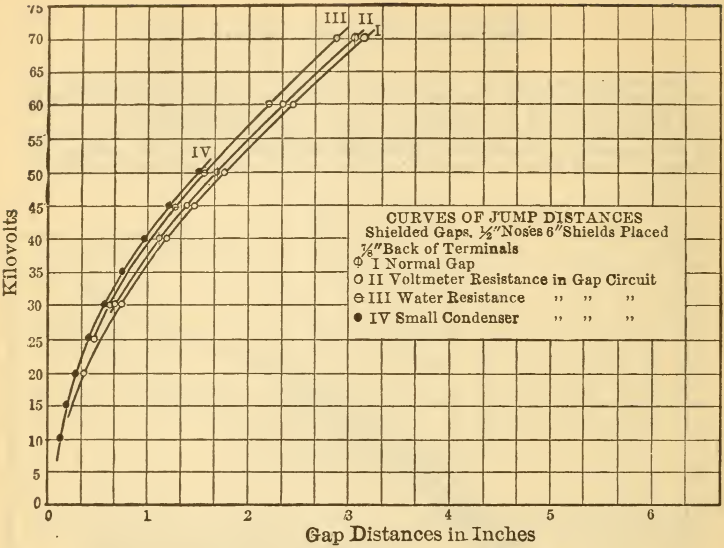

FIG. 30.

Puncturing Voltage of Mica in Transil Oil.

W. S. ANDREWS.

Thickness of Mica.	Average Puncturing Voltage.	Thickness of Mica.	Average Puncturing Voltage.
.001″	3,800	.006″	6,700
.0015″	4,500	.0065″	6,930
.002″	4,600	.007″	7,220
.0025″	4,750	.0075″	7,400
.003″	5,300	.008″	7,700
.004″	5,570	.0085″	8,550
.00475″	5,950	.01″	8,900
.005″	6,050		

Specific Thermal Conductivity of Dielectrics.

WATTS THROUGH **INCH CUBE.** TEMPERATURE GRADIENT 1° C.

Name of Substance.	Specific Conductivity.	Name of Substance.	Specific Conductivity.
Air	.0006	. . . .	. . .
Vulcanized Rubber	.00105	Glass	.0053
Beeswax	.00093	Wood	.032
Felt	.00093	Caoutchouc	.0044
Vulcanite	.00089	Gutta-percha	.0051
Cotton Wool	.00046	Sandy Loam	.085
Sawdust	.00131	Bricks and Cement	.032
Sand	.00140	India Rubber	.0043
Paraffin	.00121	Sand with Air Spaces	.96

Minimum Size of Conductors for High Tension Transmission.

The loss of energy in a high tension transmission line due to the brush discharge from the wires depends on the electric pressure, the size of the conductors and the atmospheric temperature and barometric pressure. For any given size of conductor a certain critical electric pressure exists for which there is a sudden rise in the curve of "loss between wires." Conductors should never be used in practice so small that the operating pressure is greater than this critical pressure. Mr. H. J. Ryan has deduced the following table, giving the minimum size of conductor which should be used for pressures from 50,000 to 250,000 volts for a distance between conductors of 48 inches:

Operating Pressure; 90 per cent of Critical Effective Volts.	Minimum Diameter of Conductor in Inches.
50,000	0.058
75,000	0.106
100,000	0.192
150,000	0.430
200,000	0.710
250,000	0.990

The equation showing the relation between the maximum value of the pressure wave, the atmospheric temperature and barometric pressure, the distance between the line conductors and the radius of the conductors for conductors larger than No. 4 B. and S. gauge is as follows:

$$E = \frac{17.946}{459 + t} \times 350{,}000 \log_{10} \left(\frac{S}{r}\right) (r + .07)$$

where E = critical pressure at which the sudden increase in the brush discharge takes place.
r = radius of conductors in inches.
s = distance between conductors from center to center in inches.
t = atmospheric temperature in degrees Fahrenheit.
b = barometric pressure in inches of mercury.

PROPERTIES OF CONDUCTORS CARRYING ALTERNATING CURRENTS.

REVISED BY HAROLD PENDER, PH.D.

Besides the ohmic resistance of a wire, the following phenomena affect the flow of an alternating current:

Skin effect, a retardation of the current due to the property of alternating currents apparently flowing along the outer surface or shell of the conductor, thus not making use of the full area.

Inductive effects, (*a*) *self induction* of the current due to its alternations, inducing a counter E.M.F. in the conductor; and (*b*) *mutual inductance*, or the effect of other alternating current circuits.

Capacity effects, due to the fact that all lines or conductors act as electrical condensers, which are alternately charged and discharged with the fluctuations of the E.M.F.

EFFECTIVE RESISTANCE — SKIN EFFECT.

The *effective resistance* of a circuit to an alternating current depends on the shape of the circuit, the specific resistance, permeability, cross section and shape of the conductor, and the frequency of the current. The current density over the cross section of the conductor is a minimum at the center, increasing to a maximum at the periphery; in a solid conductor of large cross section the current is confined almost entirely to an outer shell or "skin." The "Skin Effect Factor" is the number by which the resistance of the circuit to a continuous current must be multiplied to give the effective resistance to an alternating current. The following curve, formulæ and table give the "Skin Effect Factor" for a straight wire of circular cross section, the return wire of the circuit being assumed sufficiently remote to be without effect, which is practically the case in an aërial transmission line.

Let R = Resistance of wire in ohms to a continuous current.
R' = Effective resistance of wire in ohms to an alternating current.
f = Cycles per second.
A = Cross section of wire in circular mils.
μ = Permeability of wire in C.G.S. units.
t = Temperature in °C.
a = Temperature coefficient per °C.
C = Percentage conductivity of wire referred to Matthiessen's copper standard at 0° C.

Then $$\frac{R'}{R} = \text{function of } \left(\frac{f\mu CA}{1+at}\right).$$

This function is a complex one, and can be represented best by the accompanying curve; however, for

$$\frac{f\mu CA}{1+at} > 3 \times 10^{10},$$

the approximate formula $$\frac{R'}{R} = 10^{-5}\sqrt{\frac{f\mu CA}{1+at}} + 0.28$$

is sufficiently accurate for all practicable purposes.

Skin Effect Factors at 20° C. for Straight Wires Having Circular Cross Section.

Product of Circular Mils by Cycles per Second. $f \times A$.	Factor * for Iron Wire. $C = 17$ $\mu = 150$.	Product of Circular Mils by Cycles per Second. $f \times A$.	Factor for Copper Wire $C = 100$ $\mu = 1$.	Factor for Aluminum Wire $C = 62$ $\mu = 1$.
500,000	1.000	5,000,000	1.000	1.000
1,000,000	1.015	10,000,000	1.000	1.000
2,000,000	1.068	20,000,000	1.008	1.000
3,000,000	1.144	30,000,000	1.025	1.006
4,000,000	1.234	40,000,000	1.045	1.015
5,000,000	1.332	50,000,000	1.070	1.026
6,000,000	1.435	60,000,000	1.096	1.040
7,000,000	1.535	70,000,000	1.126	1.053
8,000,000	1.628	80,000,000	1.158	1.069
9,000,000	1.714	90,000,000	1.195	1.085
10,000,000	1.795	100,000,000	1.230	1.104
12,500,000	1.974	125,000,000	1.332	1.151
15,000,000	2.14	150,000,000	1.433	1.206
17,500,000	2.29	175,000,000	1.530	1.266
20,000,000	2.42	200,000,000	1.622	1.330
25,000,000	2.68	250,000,000	1.790	1.455
30,000,000	2.90	300,000,000	1.937	1.575
35,000,000	3.11	350,000,000	2.07	1.686
40,000,000	3.31	400,000,000	2.20	1.787
45,000,000	3.49	450,000,000	2.31	1.879
50,000,000	3.67	500,000,000	2.42	1.965
55,000,000	3.83	550,000,000	2.53	2.05
60,000,000	3.99	600,000,000	2.63	2.13

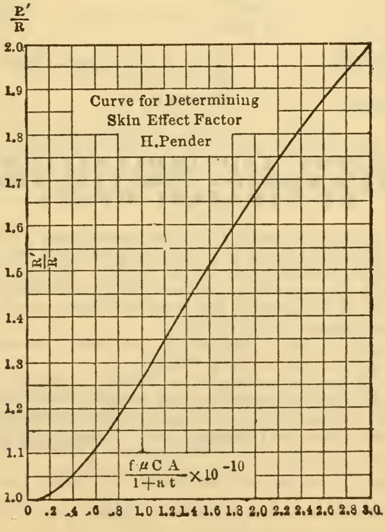

FIG. 1.

* This corresponds to E.B.B. telegraph wire.

The approximate formula

$$\frac{R'}{R} = 10^{-5}\sqrt{\frac{f\mu CA}{1+at}} + 0.28$$

For *Iron* (E.B.B. telegraph wire), reduces to

$$\frac{R'}{R} = 479 \times 10^{-6}\sqrt{fA} + 0.28$$

for $fA > 12.5 \times 10^6$ and $t = 20°\ C$.

For *Copper*, reduces to

$$\frac{R'}{R} = 96 \times 10^{-6}\sqrt{fA} + 0.28$$

for $fA > 300 \times 10^6$ and $t = 20°\ C$.

For *Aluminum*, reduces to

$$\frac{R'}{R} = 76 \times 10^{-6}\sqrt{fA} + 0.28$$

for $fA > 500 \times 10^6$ and $t = 20°\ C$.

Examples: To find the effective resistance of a round-wire .5 inch in diameter, permeability 500, conductivity 10 per cent, at 15 cycles per second and 0° C:

$$\frac{f\mu CA}{1+at} = \frac{15 \times 500 \times 10 \times .25 \times 10^6}{1} = 1.88 \times 10^{10}.$$

From the curve $\frac{R'}{R} = 1.63$

or effective resistance $R' = 1.63\ R.$

To find the effective resistance of the same wire at 60 cycles per second:

$$\frac{f\mu CA}{1+at} = 7.5 \times 10^{-10},$$

therefore, from formula $\frac{R'}{R} = 2.73 + 0.28 = 3.01$

or effective resistance $R' = 3.01\ R.$

SELF INDUCTION AND INDUCTIVE REACTANCE OF TRANSMISSION CIRCUITS FORMED BY PARALLEL WIRES.

The *Coefficient of Self Induction* (L) of an elementary circuit is defined as the ratio of the number of lines of induction produced by a current flowing in the circuit divided by the current in the circuit. When the conductor has a finite cross section the exact definition of the coefficient of self induction is the ratio of twice the energy of the magnetic field produced by the current flowing to the square of the current.

The practical unit of self induction is the henry; sometimes the millihenry is used, which is equal to $\frac{1}{1000}$ of a henry.

The coefficient of self induction of a circuit depends on the size and shape of the circuit, the cross section and shape of the conductor, the permeabilities of the conductor and the surrounding medium, also, when the skin effect is large, upon the frequency of the current and the specific resistance of the conductor. The instantaneous E.M.F. induced in a circuit by any change of the current flowing in the circuit is $e = -\frac{d}{dt}(Li)$, or, if L is constant, which is strictly true when there is no iron in the circuit, and approximately so in any case, $e = -L\frac{di}{dt}$.

When a constant E.M.F. is impressed on a circuit or coil containing inductance, the current does not reach its full value instantly, as it is opposed at first by a counter-electromotive force due to the inductance. This counter-electromotive force gradually grows less until the current reaches its full strength, which theoretically takes an infinite time, and in practice it is usual to determine the time taken for the current to attain 63.2% of its full value and this period is called the *time-constant.*

$$\text{Time-constant in seconds} = \frac{\text{henrys}}{\text{ohms resistance}}$$

or

$$= \frac{\text{henrys} \times \text{final amperes}}{\text{applied volts}}.$$

If the impressed E.M.F. varies according to the sine law and L is constant, the effective value of the counter inductive E.M.F. is

$$E = 2\,\pi f L I$$

where f = cycles per second or frequency and I = the effective value of the current. $2\,\pi f L$ is called the *inductive reactance* or simply the *inductance* of the circuit.

The induced E.M.F. lags 90° behind the current. The E.M.F. required to overcome the induced E.M.F. leads the current by 90°.

Formulæ for Self Induction and Inductive Reactance.

Let r = radius of wire in inches.
n = number of wire on B. and S. gauge.*
D = distance between wires in inches.
l = distance of transmission (length of one wire) in 1000 feet.
L = coefficient of self induction of 1000 feet of wire in millihenrys.
f = frequency of current in cycles per second.
$X = 2\,\pi f L \times 10^{-3}$ = inductive reactance of 1000 feet of wire in ohms.

SINGLE-PHASE CIRCUIT — 2 WIRES.

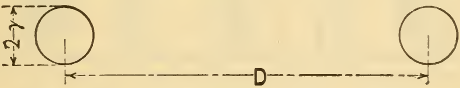

FIG. 2.

Total self induction of circuit = $2\,lL$.
Total inductive reactance of circuit = $2\,lX$.

THREE-PHASE CIRCUIT — 3 WIRES.

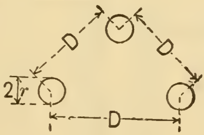

FIG. 3.

Total self induction per phase (circuit formed by any two wires) $= \sqrt{3}\,lL$.
Total inductive reactance per phase $= \sqrt{3}\,lX$.

For **NON-MAGNETIC WIRES,**

$$L = 0.01524 + 0.14 \log_{10}\left(\frac{D}{r}\right)$$
$$= 0.00705\,n + A.$$

where $A = 0.14 \log_{10} + 0.1258.$

* See table on next page for values of n for wires larger than No. 0.

For **IRON WIRE,**

$$L = 0.01524\,\mu + 0.14 \log_{10}\left(\frac{D}{r}\right)$$

where μ = permeability of the iron. μ varies with the quality of the iron and also with the strength of the current. The above formula is true only in case μ is constant over the cross section of the wire, which in any practical case is only approximately true. The tables on p. 248 are calculated for $\mu = 150$, corresponding to good quality telegraph wire, and, therefore,

$$L = 2.286 + 0.14 \log_{10} \frac{D}{r}.$$

Values of A (=0.14 log$_{10}$D + .1258) for Various Interaxial Distances.

D.	*A.*
$\frac{3}{8}$ in.	.0662
$\frac{1}{2}$	.0837
$\frac{3}{4}$	.1083
1	.1258
2	.1679
3	.1925
6	.2347
12	.2768
18	.3015
24	.3190
36	.3436
48	.3611
60	.3747
72	.3857

Values of *n* for Wires Larger than No. 0, B. and S.

Size.	*n.*
00 B. and S.	− 1
000	− 2
0000	− 3
250,000 C. M.	− 3.719
300,000	− 4.505
350,000	− 5.170
400,000	− 5.746
450,000	− 6.254
500,000	− 6.708
550,000	− 7.119
600,000	− 7.495
650,000	− 7.840
700,000	− 8.159
750,000	− 8.457
800,000	− 8.735
850,000	− 8.997
900,000	− 9.243
950,000	− 9.476
1,000,000	− 9.697

$$n = 49.8812 - 9.92978 \log CM.$$

Self Induction in Millihenrys per 1000 Feet of Solid Non-Magnetic Wire.

NOTE. — The self induction of a stranded wire is slightly less than that of a solid wire of the same cross section, and slightly greater than that of a solid wire having the same diameter, but more nearly equal to that of a solid wire with equal cross section. The exact value of the self induction of a strand is a complex expression involving both the size and number of the individual wires. (See *L'Eclairage Electrique*, Vol. III, p. 20.) For all practical purposes the self induction of a strand may be taken equal to that of a solid conductor having the same cross section.

$$L = .00705\, n + A.$$

B. and S. Gauge.	Interaxial Distances.					
	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{3}{4}''$	1″	2″	3″
0000	.....	.....	.0871	.1046	.1467	.1714
000	.....	.....	.0943	.1116	.1538	.1778
00	.....	.....	.1012	.1187	.1608	.1855
0	.....	.....	.1083	.1258	.1679	.1926
1	.....	.....	.1154	.1329	.1750	.1946
2	.....	.0977	.1223	.1398	.1820	.2066
4	.....	.1117	.1364	.1539	.1961	.2207
5	.1013	.1189	.1436	.1610	.2032	.2278
6	.1084	.1259	.1506	.1681	.2102	.2349
8	.1225	.1401	.1647	.1822	.2243	.2490
10	.1367	.1541	.1788	.1963	.2384	.2631
12	.1507	.1682	.1928	.2103	.2525	.2772
14	.1647	.1822	.2068	.2243	.2665	.2911

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.1659	.2080	.2327	.2502	.2748	.2923	.3059	.3169
900,000	.1691	.2112	.2359	.2534	.2780	.2955	.3091	.3201
800 000	.1727	.2148	.2395	.2570	.2816	.2991	.3127	.3237
700 000	.1768	.2189	.2436	.2611	.2857	.3032	.3168	.3278
600,000	.1815	.2236	.2483	.2658	.2904	.3079	.3215	.3325
500 000	.1871	.2292	.2539	.2714	.2960	.3135	.3271	.3381
450,000	.1903	.2324	.2571	.2746	.2992	.3167	.3303	.3413
400,000	.1939	.2360	.2607	.2782	.3028	.3203	.3339	.3449
350,000	.1980	.2401	.2648	.2823	.3069	.3244	.3380	.3490
300,000	.2027	.2448	.2695	.2870	.3116	.3291	.3427	.3537
250,000	.2083	.2504	.2751	.2926	.3172	.3347	.3483	.3593
0000	.2135	.2556	.2803	.2978	.3224	.3399	.3535	.3645
000	.2206	.2627	.2874	.3049	.3295	.3470	.3606	.3716
00	.2276	.2648	.2945	.3120	.3366	.3541	.3677	.3787
0	.2347	.2768	.3015	.3190	.3436	.3611	.3747	.3857
1	.2418	.2839	.3086	.3261	.3507	.3682	.3818	.3928
2	.2488	.2909	.3156	.3331	.3577	.3752	.3888	.3998
4	.2629	.3050	.3297	.3472	.3718	.3893	.4029	.4139
6	.2770	.3191	.3438	.3613	.3859	.4034	.4170	.4280
8	.2911	.3332	.3579	.3754	.4000	.4175	.4311	.4421
10	.3052	.3473	.3720	.3895	.4141	.4316	.4452	.4562

Inductive Reactance in Ohms Per 1000 Feet of Solid Non-Magnetic Wire.

100 Cycles per Second. $X = 0.6283\,L$.

Note. — Inductive reactance at other frequencies proportional to values given in this table.

B. and S. Gauge.	Interaxial Distances.					
	3/8″	1/2″	3/4″	1″	2″	3″
0000	.....	.....	.0547	.0657	.0922	.1076
000	.....	.....	.0592	.0701	.0966	.1116
00	.....	.....	.0635	.0745	.1010	.1165
0	.....	.....	.0680	.0790	.1055	.1209
1	.....	.....	.0725	.0834	.1099	.1254
2	.....	.0613	.0768	.0878	.1143	.1298
4	.....	.0702	.0857	.0966	.1231	.1386
5	.0636	.0747	.0902	.1011	.1276	.1431
6	.0681	.0791	.0946	.1056	.1320	.1475
8	.0770	.0879	.1034	.1144	.1409	.1564
10	.0858	.0968	.1123	.1233	.1497	.1652
12	.0946	.1056	.1211	.1321	.1586	.1741
14	.1034	.1144	.1299	.1409	.1674	.1828

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.1042	.1307	.1462	.1572	.1727	.1837	.1922	.1991
900,000	.1062	.1327	.1481	.1592	.1747	.1857	.1942	.2011
800 000	.1085	.1350	.1505	.1615	.1769	.1879	.1965	.2034
700,000	.1111	.1375	.1531	.1640	.1795	.1905	.1990	.2060
600,000	.1140	.1405	.1560	.1670	.1825	.1954	.2020	.2089
500,000	.1176	.1440	.1595	.1705	.1860	.1970	.2055	.2124
450,000	.1196	.1460	.1615	.1725	.1880	.1990	.2075	.2144
400,000	.1218	.1483	.1638	.1748	.1902	.2012	.2098	.2167
350,000	.1244	.1509	.1664	.1774	.1928	.2038	.2124	.2193
300,000	.1274	.1538	.1693	.1803	.1958	.2068	.2153	.2222
250,000	.1309	.1573	.1728	.1838	.1993	.2103	.2188	.2257
0000	.1341	.1606	.1761	.1871	.2026	.2136	.2221	.2290
000	.1386	.1651	.1806	.1916	.2070	.2180	.2266	.2335
00	.1430	.1695	.1850	.1960	.2115	.2225	.2310	.2379
0	.1475	.1739	.1894	.2004	.2159	.2269	.2354	.2423
1	.1519	.1784	.1939	.2049	.2203	.2313	.2399	.2468
2	.1563	.1828	.1983	.2093	.2247	.2357	.2443	.2512
4	.1652	.1916	.2072	.2181	.2336	.2446	.2531	.2601
6	.1740	.2005	.2160	.2270	.2425	.2535	.2620	.2689
8	.1829	.2093	.2249	.2359	.2513	.2623	.2709	.2778
10	.1918	.2182	.2337	.2447	.2602	.2712	.2797	.2866

Inductive Reactance in Ohms Per 1000 Feet of Solid Non-Magnetic Wire.

25 Cycles Per Second. $X = .1571\,L$.

B. and S. Gauge.	Interaxial Distances.					
	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{3}{4}''$	1″	2″	3″
0000	.....	.....	.0137	.0169	.0230	.0269
000	.....	.....	.0148	.0175	.0242	.0279
00	.....	.....	.0159	.0186	.0253	.0291
0	.....	.....	.0170	.0198	.0264	.0302
1	.....	.....	.0181	.0209	.0275	.0313
2	.....	.0153	.0192	.0220	.0286	.0325
4	.....	.0176	.0214	.0242	.0308	.0347
5	.0159	.0187	.0225	.0253	.0319	.0358
6	.0170	.0198	.0236	.0264	.0330	.0369
8	.0192	.0220	.0259	.0286	.0352	.0391
10	.0215	.0242	.0281	.0308	.0374	.0413
12	.0237	.0264	.0303	.0330	.0396	.0435
14	.0259	.0286	.0325	.0352	.0418	.0457

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.0261	.0327	.0366	.0393	.0432	.0460	.0481	.0498
900,000	.0266	.0332	.0371	.0398	.0437	.0465	.0486	.0503
800,000	.0272	.0338	.0377	.0404	.0443	.0471	.0492	.0509
700,000	.0278	.0344	.0383	.0410	.0449	.0477	.0498	.0515
600,000	.0285	.0351	.0390	.0417	.0456	.0484	.0505	.0522
500,000	.0294	.0360	.0399	.0426	.0465	.0493	.0514	.0531
450,000	.0299	.0365	.0404	.0431	.0470	.0498	.0519	.0536
400,000	.0305	.0371	.0410	.0437	.0476	.0503	.0525	.0542
360,000	.0311	.0377	.0416	.0444	.0482	.0510	.0531	.0548
300,000	.0319	.0385	.0423	.0451	.0490	.0517	.0538	.0556
250,000	.0327	.0393	.0432	.0460	.0498	.0526	.0547	.0564
0000	.0335	.0402	.0440	.0468	.0505	.0534	.0555	.0573
000	.0347	.0413	.0452	.0479	.0518	.0545	.0567	.0584
00	.0358	.0424	.0463	.0490	.0529	.0556	.0578	.0595
0	.0369	.0435	.0474	.0501	.0540	.0567	.0589	.0606
1	.0380	.0446	.0485	.0512	.0551	.0578	.0600	.0617
2	.0391	.0457	.0496	.0523	.0562	.0589	.0611	.0628
4	.0413	.0479	.0518	.0545	.0584	.0612	.0633	.0650
6	.0435	.0501	.0540	.0568	.0606	.0634	.0655	.0672
8	.0457	.0523	.0562	.0590	.0628	.0656	.0677	.0695
10	.0480	.0546	.0584	.0612	.0651	.0678	.0699	.0717

Inductive Reactance in Ohms per 1000 Feet of Solid Non-Magnetic Wire.

60 Cycles Per Second. $X = 0.3770\,L.$

B. and S. Gauge.	Interaxial Distances.					
	3/8″	1/2″	3/4″	1″	2″	3″
0000	.....	.....	.0328	.0394	.0553	.0646
000	.....	.....	.0355	.0421	.0580	.0670
00	.....	.....	.0381	.0447	.0606	.0699
0	.....	.....	.0408	.0474	.0633	.0726
1	.....	.....	.0435	.0501	.0659	.0752
2	.....	.0368	.0461	.0527	.0686	.0779
4	.....	.0421	.0514	.0580	.0739	.0832
5	.0382	.0448	.0541	.0607	.0766	.0859
6	.0409	.0474	.0567	.0633	.0792	.0885
8	.0462	.0528	.0621	.0687	.0845	.0938
10	.0515	.0581	.0674	.0740	.0898	.0991
12	.0568	.0634	.0727	.0793	.0951	.1044
14	.0621	.0687	.0779	.0845	.1004	.1097

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.0626	.0784	.0877	.0943	.1036	.1102	.1153	.1194
900,000	.0638	.0796	.0889	.0955	.1048	.1114	.1165	.1206
800,000	.0652	.0810	.0903	.0969	.1062	.1128	.1179	.1220
700,000	.0667	.0825	.0918	.0984	.1077	.1143	.1194	.1235
600,000	.0685	.0843	.0936	.1002	.1095	.1161	.1212	.1253
500,000	.0706	.0864	.0957	.1023	.1116	.1182	.1233	.1274
450,000	.0718	.0876	.0969	.1035	.1128	.1194	.1245	.1286
400,000	.0731	.0890	.0983	.1049	.1141	.1207	.1259	.1300
350,000	.0746	.0905	.0998	.1064	.1157	.1223	.1274	.1316
300,000	.0764	.0923	.1016	.1082	.1175	.1241	.1292	.1333
250,000	.0785	.0944	.1037	.1103	.1196	.1262	.1313	.1354
0000	.0805	.0964	.1057	.1123	.1216	.1282	.1333	.1374
000	.0832	.0991	.1084	.1150	.1242	.1308	.1360	.1401
00	.0858	.1017	.1110	.1176	.1269	.1335	.1386	.1427
0	.0885	.1043	.1136	.1202	.1295	.1361	.1412	.1454
1	.0911	.1070	.1163	.1229	.1322	.1388	.1439	.1481
2	.0938	.1097	.1190	.1256	.1348	.1414	.1466	.1507
4	.0991	.1150	.1243	.1309	.1402	.1468	.1519	.1561
6	.1044	.1203	.1296	.1362	.1455	.1521	.1572	.1613
8	.1097	.1256	.1349	.1415	.1508	.1574	.1625	.1667
10	.1151	.1309	.1402	.1468	.1561	.1627	.1678	.1720

Inductive Reactance of Loop Formed by Two Wires of a Three-Phase Transmission Line.

OHMS PER 1000 FEET OF LINE* (CONDUCTOR NON-MAGNETIC)
100 CYCLES PER SECOND.

$$X_{\text{loop}} = \sqrt{3}\, X_{\text{for single wire.}}$$

NOTE. — Inductive reactance at other frequencies proportional to values given in this table.

B. and S. Gauge	Interaxial Distances.					
	3/8″	1/2″	3/4″	1″	2″	3″
0000	.....	.....	.0947	.1138	.1596	.1864
000	.....	.....	.1025	.1214	.1673	.1933
00	.....	.....	.1100	.1291	.1749	.2018
0	.....	.....	.1178	.1368	.1827	.2094
1	.....	.....	.1255	.1445	.1903	.2171
2	.....	.1062	.1331	.1521	.1980	.2248
4	.....	.1215	.1484	.1674	.2133	.2401
5	.1102	.1293	.1563	.1758	.2210	.2478
6	.1179	.1369	.1638	.1828	.2286	.2554
8	.1333	.1523	.1791	.1982	.2440	.2708
10	.1487	.1677	.1945	.2135	.2593	.2862
12	.1639	.1830	.2097	.2288	.2746	.3014
14	.1791	.1982	.2250	.2440	.2898	.3167

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.1807	.2265	.2533	.2724	.2992	.3183	.3330	.3450
900,000	.1842	.2300	.2568	.2759	.3027	.3218	.3365	.3485
800,000	.1881	.2339	.2607	.2798	.3066	.3257	.3404	.3524
700,000	.1926	.2384	.2652	.2843	.3111	.3302	.3449	.3569
600,000	.1977	.2435	.2703	.2894	.3162	.3353	.3500	.3620
500,000	.2038	.2496	.2764	.2955	.3223	.3414	.3561	.3681
450,000	.2073	.2530	.2799	.2989	.3258	.3449	.3596	.3716
400,000	.2111	.2570	.2839	.3029	.3296	.3487	.3636	.3755
350,000	.2156	.2615	.2884	.3074	.3341	.3532	.3681	.3800
300,000	.2208	.2665	.2934	.3125	.3393	.3584	.3731	.3851
250,000	.2268	.2726	.2995	.3185	.3454	.3644	.3792	.3911
0000	.2324	.2783	.3052	.3242	.3511	.3702	.3849	.3969
000	.2402	.2861	.3130	.3320	.3587	.3778	.3927	.4047
00	.2478	.2937	.3206	.3397	.3665	.3856	.4003	.4123
0	.2556	.3014	.3282	.3473	.3742	.3932	.4079	.4199
1	.2632	.3092	.3360	.3551	.3818	.4008	.4157	.4277
2	.2709	.3168	.3437	.3627	.3894	.4085	.4234	.4353
4	.2863	.3320	.3591	.3780	.4048	.4239	.4386	.4508
6	.3015	.3475	.3743	.3934	.4203	.4393	.4540	.4660
8	.3170	.3627	.3898	.4088	.4355	.4546	.4695	.4814
10	.3324	.3781	.4050	.4241	.4509	.4700	.4847	.4967

* Length of line equals one half the total length of wire in the loop.

Inductive Reactance of Loop Formed by Two Wires of a Three-Phase Transmission Line.

OHMS PER 1000 FEET OF LINE.* (CONDUCTOR NON-MAGNETIC.)

25 CYCLES PER SECOND.

Xloop = $\sqrt{3}\, X$ for single wire.

B. and S. Gauge.	Interaxial Distances.					
	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{3}{4}''$	1″	2″	3″
0000	.....	.....	.0237	.0285	.0399	.0466
000	.....	.....	.0256	.0304	.0418	.0483
00	.....	.....	.0275	.0323	.0437	.0504
0	.....	.....	.0294	.0342	.0457	.0524
1	.....	.....	.0314	.0361	.0476	.0543
2	.....	.0266	.0333	.0380	.0495	.0562
4	.....	.0304	.0371	.0418	.0533	.0600
5	.0276	.0323	.0391	.0438	.0552	.0620
6	.0295	.0342	.0409	.0457	.0572	.0639
8	.0333	.0381	.0448	.0495	.0610	.0677
10	.0372	.0419	.0486	.0534	.0648	.0715
12	.0410	.0457	.0524	.0572	.0687	.0754
14	.0448	.0495	.0562	.0610	.0725	.0792

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.0452	.0566	.0633	.0681	.0748	.0796	.0832	.0862
900,000	.0461	.0575	.0642	.0690	.0757	.0805	.0841	.0871
800,000	.0471	.0585	.0652	.0700	.0767	.0815	.0851	.0881
700,000	.0482	.0596	.0663	.0711	.0778	.0826	.0862	.0892
600,000	.0495	.0609	.0676	.0724	.0791	.0839	.0875	.0905
500,000	.0510	.0624	.0691	.0739	.0806	.0854	.0890	.0920
450,000	.0518	.0633	.0700	.0747	.0815	.0862	.0899	.0929
400,000	.0528	.0643	.0710	.0757	.0824	.0872	.0909	.0939
350,000	.0539	.0654	.0721	.0769	.0835	.0883	.0920	.0950
300,000	.0552	.0666	.0734	.0781	.0848	.0896	.0933	.0963
250,000	.0567	.0682	.0749	.0796	.0864	.0911	.0948	.0978
0000	.0581	.0696	.0763	.0811	.0878	.0926	.0962	.0992
000	.0601	.0715	.0783	.0830	.0897	.0945	.0982	.1012
00	.0620	.0734	.0802	.0849	.0916	.0964	.1001	.1031
0	.0639	.0754	.0821	.0868	.0936	.0983	.1020	.1050
1	.0658	.0773	.0840	.0888	.0955	.1002	.1039	.1069
2	.0677	.0792	.0859	.0907	.0974	.1021	.1059	.1088
4	.0716	.0830	.0898	.0945	.1012	.1060	.1097	.1127
6	.0754	.0869	.0936	.0984	.1051	.1098	.1135	.1165
8	.0793	.0907	.0975	.1022	.1089	.1137	.1174	.1204
10	.0831	.0945	.1013	.1060	.1127	.1175	.1212	.1242

* Length of line equals half the total length of wire in the loop.

Inductive Reactance of Loop Formed by Two Wires of a Three-Phase Transmission Line.

Ohms Per 1000 Feet of Line.* (Conductor Non-Magnetic.)

60 Cycles per Second.

Xloop = $\sqrt{3}\,X$ for single wire.

B. and S. Gauge.	Interaxial Distances.					
	3/8″	1/2″	3/4″	1″	2″	3″
0000	.....	.....	.0568	.0683	.0958	.1118
000	.....	.....	.0615	.0728	.1004	.1160
00	.....	.....	.0660	.0774	.1049	.1211
0	.....	.....	.0707	.0821	.1096	.1257
1	.....	.....	.0753	.0867	.1142	.1303
2	.....	.0637	.0798	.0912	.1188	.1349
4	.....	.0729	.0890	.1004	.1280	.1440
5	.0661	.0776	.0938	.1051	.1326	.1487
6	.0708	.0821	.0983	.1097	.1372	.1533
8	.0800	.0914	.1075	.1189	.1464	.1625
10	.0892	.1006	.1167	.1281	.1556	.1717
12	.0983	.1098	.1258	.1373	.1648	.1809
14	.1075	.1189	.1350	.1464	.1739	.1900

Cir. Mils and B. and S. Gauge.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.1084	.1359	.1519	.1634	.1795	.1909	.1998	.2070
900,000	.1105	.1380	.1540	.1655	.1816	.1930	.2019	.2091
800,000	.1129	.1404	.1564	.1679	.1840	.1954	.2043	.2115
700,000	.1156	.1431	.1591	.1706	.1867	.1981	.2070	.2142
600,000	.1187	.1462	.1622	.1737	.1898	.2012	.2101	.2173
500,000	.1223	.1498	.1658	.1773	.1934	.2048	.2137	.2209
450,000	.1244	.1518	.1679	.1793	.1955	.2069	.2158	.2230
400,000	.1267	.1542	.1703	.1817	.1978	.2092	.2182	.2253
350 000	.1294	.1569	.1730	.1844	.2005	.2119	.2209	.2280
300,000	.1325	.1599	.1760	.1875	.2036	.2150	.2239	.2311
250,000	.1361	.1636	.1797	.1911	.2072	.2186	.2275	.2347
0000	.1394	.1670	.1831	.1945	.2107	.2221	.2309	.2381
000	.1441	.1717	.1878	.1992	.2152	.2267	.2356	.2428
00	.1487	.1762	.1924	.2038	.2199	.2314	.2402	.2474
0	.1534	.1808	.1969	.2084	.2245	.2359	.2447	.2519
1	.1579	.1855	.2016	.2131	.2291	.2405	.2494	.2566
2	.1625	.1901	.2062	.2176	.2336	.2451	.2540	.2612
4	.1718	.1992	.2155	.2268	.2429	.2543	.2632	.2705
6	.1809	.2085	.2246	.2360	.2522	.2636	.2724	.2796
8	.1902	.2176	.2339	.2453	.2613	.2728	.2817	.2888
10	.1994	.2269	.2430	.2545	.2705	.2820	.2908	.2980

* Length of line equals one half the total length of wire in the loop.

Self Induction in Millihenrys per 1000 Feet of Solid Iron Wire. Permeability 150 C. G. S. Units.

$$L = 2.286 + .14 \log_{10} \left(\frac{D}{r}\right).$$

Roebling Gauge.	Dia. In.	Interaxial Distances.							
		1″	2″	3″	6″	9″	12″	18″	24″
4	.225	2.4189	2.4610	2.4857	2.5278	2.5525	2.5699	2.5946	2.6121
6	.192	2.4285	2.4706	2.4953	2.5374	2.5621	2.5796	2.6042	2.6217
8	.162	2.4389	2.4809	2.5056	2.5478	2.5724	2.5899	2.6146	2.6321
9	.178	2.4443	2.4865	2.5111	2.5533	2.5779	2.5954	2.6201	2.6376
10	.135	2.4499	2.4921	2.5167	2.5589	2.5835	2.6010	2.6257	2.6432
11	.120	2.4571	2.4992	2.5239	2.5660	2.5907	2.6082	2.6328	2.6503
12	.105	2.4652	2.5074	2.5319	2.5742	2.5988	2.6163	2.6409	2.6584
14	.080	2.4817	2.5239	2.5485	2.5907	2.6153	2.6328	2.6575	2.6749

Inductive Reactance in Ohms per 1000 Feet of Solid Iron Wire.

100 Cycles Per Second. $X = 0.6283\ L.$

Note. — Inductive reactance at other frequencies proportional to values given in this table.

Roebling Gauge.	Dia. In.	Interaxial Distances.							
		1″	2″	3″	6″	9″	12″	18″	24″
4	.225	1.5191	1.5455	1.5610	1.5875	1.6029	1.6139	1.6294	1.6404
6	.192	1.5251	1.5516	1.5671	1.5935	1.6090	1.6199	1.6355	1.6465
8	.162	1.5316	1.5581	1.5735	1.6000	1.6155	1.6265	1.6419	1.6529
9	.148	1.5350	1.5615	1.5769	1.6035	1.6189	1.6299	1.6454	1.6564
10	.135	1.5386	1.5650	1.5805	1.6069	1.6225	1.6335	1.6489	1.6599
11	.120	1.5431	1.5695	1.5850	1.6115	1.6269	1.6379	1.6534	1.6644
12	.105	1.5482	1.5746	1.5901	1.6166	1.6320	1.6430	1.6585	1.6695
14	.080	1.5585	1.5850	1.6005	1.6269	1.6424	1.6534	1.6689	1.6799

CAPACITY, CAPACITY REACTANCE, AND CHARGING CURRENT OF TRANSMISSION CIRCUITS FORMED BY PARALLEL WIRES.

Whenever a difference of potential is established between two or more conductors a static charge manifests itself on each conductor. If there are but two conductors present these static charges are equal and opposite. Two conductors thus carrying equal and opposite charges are said to form a condenser. The ratio of the charge (q) on one of the conductors to the difference of potential (e) between the two conductors is called the capacity (C) of the condenser, *i.e.*,

$$C = \frac{q}{e}.$$

If q is expressed in coulombs and e in volts, the unit of capacity as defined by this equation is called the farad. A capacity as large as a farad is a mathematical fiction; the unit employed in practice is the microfarad, which is one millionth of a farad.

The capacity of a condenser depends on the size and shape of the conductors, the specific inductive capacity of the surrounding medium, and its distance from other conductors.

The instantaneous capacity E.M.F. is in practical units,

$$e = \frac{10^6}{C}\int idt,$$

and the effective value of this E.M.F. for a sine wave current is

$$E = \frac{10^6}{2\,\pi f C}.$$

The expression $\frac{10^6}{2\,\pi f C}$ is called the *capacity reactance*, or simply the *capacitance*, of the circuit. The reciprocal of this quantity, namely, $\frac{2\,\pi f C}{10^6}$, is called the *capacity susceptance;* this is the quantity used in the treatment of the capacity of transmission circuits.

The current required to charge and discharge a condenser is called the *charging current*; for a sine wave of impressed E.M.F. the charging current is

$$I_c = 2\,\pi f C E \times 10^{-6}.$$

The capacity E.M.F. leads the current by 90°; the E.M.F. required to overcome the capacity E.M.F. lags 90° behind the current.

Single-Phase Transmission Line. — The capacity effect in a single-phase transmission line is the same as would be produced by shunting across the line at each point an infinitesimal condenser having a capacity equal to that of an infinitesimal length of circuit. The exact calculation of this effect involves the use of hyperbolic functions and complex algebraic quantities. A close approximation is to consider a condenser of half the capacity of the line shunted across the line at each end. A still closer approximation is to divide the line into three equal parts and consider the capacity of each section concentrated in a condenser at the center of that section, but in most practical cases this refinement is not necessary. For the purpose of calculating the charging current a very simple and in general sufficiently accurate method is to determine the current taken by a condenser having a capacity equal to that of the entire line when charged to the pressure on the line at the generating end. For the calculation of the effect of capacity on the efficiency and regulation of transmission lines see page 264.

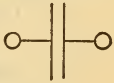

FIG. 4.

Three-Phase Transmission Line. — The capacity effect in a three-phase transmission line is the same as would be produced by shunting the line at each point by three infinitesimal condensers connected in star with the neutral point grounded, the capacity of each condenser being equal to twice that of a condenser of infinitesimal length formed by any two of the wires. The effect of capacity on the regulation and efficiency of the line can be determined with sufficient accuracy in most cases by considering the line shunted at each end by three condensers connected in star, the capacity of each condenser being equal to that formed by any two wires of the line. (See page 264.)

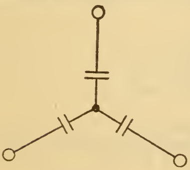

FIG. 5.

An approximate value for the charging current per *wire* is the current required to charge a condenser, equal in capacity to that of any two of the wires, to the pressure at the generating end of the line between any one wire and the neutral point.

Formulæ:

Let r = radius of wire in inches.
n = number of wire on B. and S. gauge.*
H = height of wires above ground.
D = distance between wires in inches.
l = distance of transmission (length of one wire) in 1000 feet.
V = impressed voltage between adjacent wires at generating end.
V_0 = impressed volts between any wire and ground or neutral at generating end.
C_0 = capacity per 1000 feet of a single wire parallel to the earth in microfarads.
C = capacity per 1000 feet of circuit (2000 feet of wire) formed by two parallel wires.
f = frequency of impressed E.M.F. in cycles per second.
$b_0 = \frac{2\pi f C_0}{10^6}$ = capacity susceptance per 1000 feet of a single wire parallel to the earth.
$b = \frac{2\pi f C}{10^6}$ = capacity susceptance per 1000 feet of circuit (2000 feet of wire) formed by two parallel wires.
K = dielectric constant of surrounding medium. For bare or insulated overhead wires, without metallic sheath, $K = 1$.

Single Overhead Wire with Earth Return.

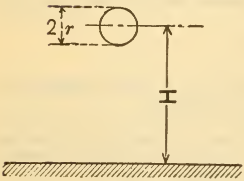

FIG. 6.

$$C_0 = \frac{.007354}{\log_{10}\frac{2H}{r}}.$$

Total capacity of circuit = $l\,C$.
Total capacity susceptance of circuit = $l\,b$.
Total charging current = $l\,b\,V_0$.

Two Overhead Wires, Single-Phase.

$$C = \frac{.003677}{\log_{10}\frac{D}{r}} = \frac{1}{B + 13.7n}\dagger$$

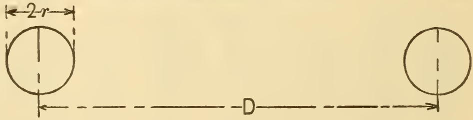

FIG. 7.

Total capacity of circuit = $l\,C$.
Total capacity susceptance of circuit = $l\,b$.
Total charging current = $l\,b\,V$.

Two Wires in Grounded Metallic Sheath, Single-Phase.

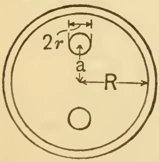

FIG. 8.

$$C = \frac{.003677\,K}{\log_{10}\left[\frac{2a}{r}\;\frac{R^2 - a^2}{R^2 + a^2}\right]}$$

Total capacity of circuit = $l\,C$,
Total capacity susceptance of circuit = $l\,b$.
Total charging current = $l\,b\,V$.

---

* For values of n for wires larger than No. 0 see page 240.

† $B = 272 \log_{10} D + 215$. For values of B see p. 251. For stranded wires neither formula is strictly accurate; the logarithmic formula gives results practically correct; values calculated by the second formula are about 3 per cent too small.

Concentric Cable in Grounded Metallic Sheath, Single-Phase.

Let C' = capacity in microfarads per 1000 feet of condenser formed by the two conductors.

C'' = capacity in microfarads per 1000 feet of condenser formed by outer conductor and sheath.

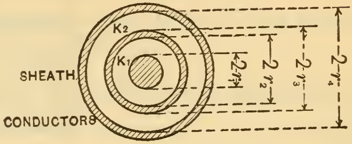

FIG. 9.

Then $$C' = \frac{.007354\,K_1}{\log_{10}\frac{r_2}{r_1}}$$

$$C'' = \frac{.007354\,K_2}{\log_{10}\frac{r_4}{r_3}}$$

Total charging current $= l\,b'\,V + l\,b''\,V_0$.

Three Overhead Wires, Three-Phase.

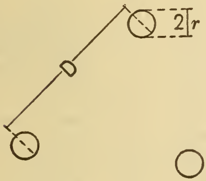

FIG. 10.

$$C = \frac{.003677}{\log_{10}\frac{D}{r}}$$

$$= \frac{1}{B + 13.7\,n}.*$$

Total capacity per wire $= 2\,l\,C$.
Total capacitance per wire $= 2\,l\,b$.
Total charging current per wire $= \frac{2\,l\,b\,V}{\sqrt{3}} = 2\,l\,b\,V_0$.

Three Wires in Metallic Sheath, Three-Phase.

$$C = \frac{.007354\,K}{\log_{10}\left[\frac{3\,a^2}{r^2}\,\frac{(R^2 - a^2)^3}{R^6 - a^6}\right]}.$$

Total capacity per wire $= 2\,l\,C$.
Total capacitance per wire $= 2\,l\,b$.
Total charging current per wire $= \frac{2\,l\,b\,V}{\sqrt{3}} = 2\,l\,b\,V_0$.

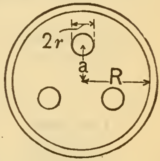

FIG. 11.
Sheath Grounded.

Values of $B = 272 \log_{10} D + 215$.

D.	B.
⅜	99
½	133
¾	181
1	215
2	297
3	344
6	426
12	508
18	556
24	590
36	638
48	672
60	698
72	720

* $B = 272 \log_{10} D + 215$. For values see table. For stranded wires neither formula is strictly accurate; the logarithmic formula gives results practically correct; values calculated by the second formula are about 3 per cent too small.

Capacity in Microfarads per 1000 Feet of Circuit (2000 Feet of Wire) Formed by Two Parallel Aërial Wires.

$$C = \frac{0.003677}{\log_{10}\frac{D}{r}} = \frac{1}{B + 13.7\,n}.^{*}$$

B. & S. G., Solid.	Interaxial Distances.									
	Dia. over Insul.	⅜″	½″	¾″	1″	2″	3″	6″	12″	18″
0000	.00748	......	......	.00716	.00575	.00391	.00329	.00259	.00214	.00194
000	.00723	......	......	.00652	.00534	.00371	.00315	.00250	.00208	.00189
00	.00696	......	......	.00598	.00497	.00353	.00302	.00242	.00202	.00184
0	.00669	......	......	.00553	.00465	.00337	.00290	.00234	.00197	.00180
1	.00643	......	......	.00514	.00437	.00322	.00279	.00227	.00191	.00175
2	.00678	......	.00624	.00480	.00413	.00308	.00269	.00220	.00186	.00171
4	.00626	......	.00533	.00424	.00371	.00284	.00250	.00208	.00177	.00163
5	.00601	.00597	.00496	.00401	.00353	.00274	.00242	.00202	.00173	.00160
6	.00576	.00552	.00465	.00380	.00336	.00264	.00234	.00196	.00169	.00156
8	.00591	.00479	.00412	.00344	.00308	.00246	.00220	.00186	.00162	.00150
10	.00541	.00423	.00370	.00314	.00284	.00230	.00207	.00177	.00155	.00144
12	.00499	.00380	.00336	.00288	.00264	.00217	.00196	.00169	.00148	.00139
14	.00459	.00344	.00308	.00268	.00246	.00205	.00186	.00162	.00143	.00134

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.00361	.00279	.00246	.00227	.00204	.00191	.00182	.00173
900,000	.00353	.00274	.00242	.00223	.00202	.00189	.00180	.00173
800,000	.00345	.00269	.00238	.00220	.00199	.00186	.00178	.00171
750,000	.00340	.00266	.00236	.00218	.00198	.00185	.00177	.00170
700,000	.00335	.00263	.00233	.00216	.00196	.00184	.00175	.00169
600,000	.00325	.00257	.00229	.00212	.00193	.00181	.00172	.00166
500,000	.00314	.00250	.00223	.00207	.00189	.00177	.00169	.00163
450,000	.00308	.00246	.00220	.00205	.00186	.00175	.00168	.00162
400,000	.00302	.00242	.00216	.00202	.00184	.00173	.00166	.00160
350,000	.00295	.00237	.00213	.00199	.00181	.00171	.00163	.00158
300,000	.00287	.00232	.00209	.00195	.00178	.00168	.00161	.00156
250,000	.00278	.00226	.00207	.00191	.00175	.00165	.00158	.00153
0000	.00271	.00222	.00250	.00188	.00172	.00163	.00156	.00151
000	.00261	.00215	.00195	.00183	.00168	.00159	.00153	.00148
00	.00252	.00209	.00190	.00178	.00164	.00156	.00149	.00145
0	.00244	.00203	.00185	.00174	.00161	.00152	.00147	.00142
1	.00235	.00197	.00180	.00170	.00157	.00149	.00143	.00139
2	.00227	.00192	.00175	.00165	.00153	.00146	.00140	.00136
4	.00214	.00182	.00167	.00158	.00147	.00140	.00135	.00131
Solid 6	.00196	.00169	.00156	.00148	.00139	.00132	.00128	.00125
Solid 8	.00186	.00162	.00150	.00143	.00133	.00128	.00124	.00120
Solid 10	.00177	.00155	.00144	.00137	.00129	.00123	.00120	.00117

* For stranded wires the last formula gives values about 3% too small.

Charging Current in Amperes per 1000 Feet of Single-Phase Circuit (2000 Feet of Wire) Formed by Two Parallel Aërial Wires.

PRESSURE, $E = 10{,}000$ VOLTS. FREQUENCY, $f = 100$ CYCLES PER SECOND.

CHARGING CURRENT = 6.283 C.

Note. — Values of charging current at other pressures and frequencies are proportional to those given in this table.

B. & S. G., Solid.	Interaxial Distances.									
	Dia. over Insul.	⅜″	½″	¾″	1″	2″	3″	6″	12″	18″
0000	.04699	.....	.....	.04498	.03613	.02456	.02067	.01627	.01344	.01218
000	.04542	.....	.....	.04096	.03355	.02331	.01979	.01571	.01306	.01187
00	.04373	.....	.....	.03757	.03123	.02218	.01897	.01520	.01269	.01156
0	.04203	.....	.....	.03474	.02921	.02117	.01822	.01470	.01237	.01130
1	.04040	.....	.....	.03229	.02745	.02023	.01753	.01426	.01200	.01099
2	.04260	.....	.03920	.03016	.02595	01935	.01690	.01382	.01168	.01074
4	.03933	.....	.03348	.02664	.02531	.01784	.01571	.01307	.01112	.01024
5	.03776	.03751	.03116	.02519	.02218	.01721	.01520	.01269	.01087	.01005
6	.03619	.03468	.02921	.02387	.02111	.01658	.01470	.01231	.01062	.00980
8	.03513	.03009	.02588	.02161	.01935	.01545	.01382	.01168	.01018	.00942
10	.03399	.02658	.02325	.01973	.01784	.01445	.01300	.01112	.00973	.00905
12	.03135	.02387	.02111	.01809	.01658	.01363	.01231	.01061	.00929	.00873
14	.02884	.02161	.01935	.01684	.01545	.01288	.01168	.01017	.00898	.00842

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.02268	.01753	.01545	.01426	.01281	.01200	.01143	.01099
900,000	.02271	.01721	.01520	.01401	.01269	.01187	.01131	.01087
800,000	.02167	.01690	.01495	.01382	.01250	.01168	.01118	.01074
750,000	.02136	.01671	.01483	.01369	.01244	.01162	.01112	.01068
700,000	.02105	.01654	.01404	.01357	.01231	.01156	.01099	.01062
600,000	.02042	.01615	.01430	.01332	.01213	.01137	.01081	.01043
500,000	.01972	.01571	.01401	.01300	.01187	.01112	.01062	.01024
450,000	.01935	.01545	.01382	.01288	.01168	.01099	.01055	.01018
400,000	.01897	.01520	.01363	.01269	.01156	.01086	.01043	.01005
350,000	.01853	.01489	.01338	.01250	.01137	.01074	.01024	.00993
300,000	.01803	.01457	.01313	.01225	.01118	.01055	.01011	.00980
250,000	.01746	.01426	.01300	.01200	.01099	.01036	.00993	.00961
0000	.01702	.01395	.01256	.01181	.01080	.01024	.00980	.00949
000	.01640	.01351	.01225	.01149	.01055	.00999	.00961	.00930
00	.01583	.01313	.01194	.01118	.01030	.00980	.00936	.00911
0	.01533	.01275	.01162	.01093	.01011	.00955	.00923	.00892
1	.01476	.01238	.01131	.01068	.00986	.00936	.00898	.00873
2	.01426	.01206	.01099	.01043	.00961	.00917	.00879	.00854
4	.01344	.01143	.01049	.00993	.00923	.00879	.00848	.00823
Solid 6	.01231	.01062	.00980	.00936	.00873	.00829	.00804	.00785
Solid 8	.01168	.01011	.00942	.00898	.00835	.00804	.00779	.00754
Solid 10	.01112	.00973	.00905	.00861	.00810	.00773	.00754	.00735

10

Charging Current in Amperes per 1000 Feet of Single-Phase Circuit (2000 Feet of Wire) Formed by Two Parallel Aërial Wires.

PRESSURE, E = 10,000 VOLTS. FREQUENCY, f = 25 CYCLES PER SECOND.

CHARGING CURRENT = 1.571 C.

NOTE. — Values of charging current at other pressures are proportional to those given in this table.

B. & S. G., Solid.	Interaxial Distances.									
	Dia. over Insul.	⅜″	½″	¾″	1″	2″	3″	6″	12″	18″
0000	.01175	....	....	.01124	.00903	.00614	.00517	.00407	.00336	.00305
000	.01135	....	....	.01024	.00839	.00583	.00495	.00393	.00326	.00297
00	.01093	....	....	.00939	.00781	.00554	.00474	.00380	.00317	.00289
0	.01051	....	....	.00868	.00730	.00529	.00455	.00367	.00309	.00282
1	.01010	....	....	.00807	.00686	.00506	.00438	.00356	.00300	.00275
2	.01065	....	.00980	.00754	.00649	.00484	.00422	.00345	.00292	.00268
4	.00983	....	.00837	.00666	.00583	.00446	.00393	.00327	.00278	.00256
5	.00944	.00938	.00779	.00630	.00554	.00430	.00380	.00317	.00272	.00251
6	.00905	.00867	.00730	.00597	.00528	.00414	.00367	.00308	.00265	.00245
8	.00928	.00752	.00647	.00540	.00484	.00386	.00345	.00292	.00254	.00235
10	.00850	.00664	.00581	.00493	.00446	.00361	.00325	.00278	.00243	.00226
12	.00784	.00597	.00528	.00452	.00414	.00341	.00308	.00265	.00232	.00218
14	.00721	.00540	.00484	.00421	.00386	.00322	.00292	.00254	.00224	.00210

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.00567	.00438	.00386	.00356	.00320	.00300	.00286	.00275
900,000	.00554	.00430	.00380	.00350	.00317	.00297	.00283	.00272
800,000	.00542	.00422	.00374	.00345	.00312	.00292	.00279	.00268
750,000	.00534	.00418	.00371	.00342	.00311	.00290	.00278	.00267
700,000	.00526	.00414	.00366	.00339	.00308	.00289	.00275	.00265
600,000	.00510	.00404	.00360	.00333	.00303	.00284	.00270	.00261
500,000	.00493	.00393	.00350	.00325	.00297	.00278	.00265	.00256
450,000	.00484	.00386	.00345	.00322	.00292	.00275	.00264	.00254
400,000	.00474	.00380	.00341	.00317	.00289	.00271	.00261	.00251
350,000	.00463	.00372	.00334	.00312	.00284	.00268	.00256	.00248
300,000	.00451	.00364	.00328	.00306	.00279	.00264	.00253	.00245
250,000	.00436	.00356	.00325	.00300	.00275	.00259	.00248	.00240
0000	.00425	.00349	.00314	.00295	.00270	.00256	.00245	.00237
000	.00410	.00338	.00306	.00287	.00264	.00250	.00240	.00232
00	.00396	.00328	.00298	.00279	.00257	.00245	.00234	.00228
0	.00383	.00319	.00290	.00273	.00253	.00239	.00231	.00223
1	.00369	.00309	.00283	.00267	.00246	.00234	.00224	.00218
2	.00356	.00301	.00275	.00261	.00240	.00229	.00220	.00213
4	.00336	.00286	.00262	.00248	.00231	.00220	.00212	.00206
Solid 6	.00308	.00265	.00245	.00234	.00218	.00207	.00201	.00196
Solid 8	.00292	.00253	.00235	.00224	.00209	.00201	.00195	.00188
Solid 10	.00278	.00243	.00226	.00215	.00202	.00193	.00188	.00184

Charging Current in Amperes per 1000 Feet of Single Phase Circuit (2000 Feet of Wire) Formed by Two Parallel Aërial Wires.

PRESSURE, E = 10,000 VOLTS. FREQUENCY, f = 60 CYCLES PER SECOND.

CHARGING CURRENT = 3.77 C.

NOTE. — Values of charging current at other pressures are proportional to those given in this table.

B. & S. G., Solid.	Dia. over Insul.	Interaxial Distances.								
		3/8″	1/2″	3/4″	1″	2″	3″	6″	12″	18″
0000	.02819	......	......	.02698	.02167	.01473	.01240	.00976	.00806	.00731
000	.02725	......	......	.02457	.02013	.01398	.01187	.00942	.00783	.00712
00	.02623	......	......	.02254	.01873	.01330	.01138	.00912	.00761	.00693
0	.02521	......	......	.02084	.01752	.01270	.01093	.00882	.00742	.00678
1	.02424	......	......	.01937	.01647	.01213	.01051	.00855	.00720	.00659
2	.02556	......	.02352	.01809	.01557	.01161	.01014	.00829	.00700	.00644
4	.02359	......	.02008	.01598	.01398	.01070	.00942	.00784	.00667	.00614
5	.02265	.02251	.01869	.01511	.01331	.01032	.00912	.00761	.00652	.00603
6	.02171	.02080	.01752	.01432	.01266	.00994	.00882	.00738	.00637	.00588
8	.02227	.01805	.01552	.01296	.01161	.00927	.00829	.00700	.00611	.00565
10	.02039	.01595	.01395	.01183	.01070	.00867	.00780	.00667	.00583	.00543
12	.01881	.01432	.01266	.01085	.00995	.00817	.00738	.00636	.00557	.00523
14	.01730	.01296	.01161	.01010	.00927	.00772	.00700	.00610	.00538	.00505

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.01360	.01052	.00927	.00855	.00768	.00720	.00686	.00659
900,000	.01330	.01032	.00912	.00840	.00761	.00712	.00678	.00652
800,000	.01300	.01014	.00897	.00829	.00750	.00700	.00670	.00644
750,000	.01281	.01002	.00889	.00821	.00746	.00697	.00667	.00640
700,000	.01263	.00993	.00878	.00814	.00738	.00693	.00659	.00636
600,000	.01224	.00969	.00863	.00800	.00727	.00682	.00648	.00625
500,000	.01183	.00942	.00840	.00780	.00712	.00667	.00637	.00614
450,000	.01161	.00927	.00829	.00772	.00700	.00659	.00633	.00610
400,000	.01138	.00912	.00817	.00761	.00693	.00651	.00625	.00603
350,000	.01111	.00893	.00802	.00750	.00682	.00644	.00614	.00596
300,000	.01081	.00874	.00787	.00735	.00670	.00633	.00606	.00588
250,000	.01047	.00855	.00780	.00720	.00659	.00621	.00596	.00576
0000	.01021	.00837	.00753	.00708	.00648	.00614	.00588	.00569
000	.00984	.00810	.00735	.00689	.00633	.00599	.00576	.00558
00	.00949	.00787	.00716	.00670	.00618	.00588	.00561	.00546
0	.00919	.00765	.00697	.00655	.00606	.00573	.00553	.00535
1	.00885	.00742	.00678	.00640	.00591	.00561	.00538	.00523
2	.00855	.00723	.00659	.00626	.00576	.00550	.00527	.00512
4	.00806	.00685	.00629	.00595	.00553	.00527	.00508	.00493
Solid 6	.00738	.00636	.00588	.00561	.00523	.00497	.00482	.00471
Solid 8	.00700	.00606	.00565	.00538	.00501	.00482	.00467	.00452
Solid 10	.00667	.00583	.00543	.00516	.00486	.00464	.00452	.00441

Charging Current in Amperes per Wire per 1000 Feet of Three-Phase Circuit Formed by Three Parallel Aërial Wires.

Pressure between Wires, $E = 10{,}000$ Volts. Frequency, $f = 100$ Cycles per Second.

Charging Current per Wire = 7.26 C.

Note. — Values of charging current at other pressures and frequencies are proportional to those given in this table.

B. & S. G., Solid.	Dia. over Insul.	Interaxial Distances. 3/8″	1/2″	3/4″	1″	2″	3″	6″	12″	18″
0000	.05430	......	......	.05198	.04174	.02839	.02388	.01880	.01554	.01408
000	.05249	......	......	.04733	.03877	.02693	.02287	.01815	.01510	.01372
00	.05053	......	......	.04341	.03608	.02563	.02192	.01757	.01466	.01336
0	.04857	......	......	.04015	.03376	.02447	.02105	.01699	.01430	.01307
1	.04668	......	......	.03732	.03173	.02338	.02025	.01648	.01387	.01270
2	.04922	......	.04530	.03485	.02998	.02236	.01953	.01597	.01350	.01241
4	.04545	......	.03869	.03078	.02693	.02062	.01815	.01510	.01285	.01183
5	.04363	.04334	.03601	.02911	.02563	.01989	.01757	.01466	.01256	.01162
6	.04182	.04007	.03376	.02759	.02439	.01917	.01699	.01423	.01227	.01132
8	.04291	.03477	.02991	.02497	.02236	.01786	.01597	.01350	.01176	.01089
10	.03928	.03071	.02686	.02280	.02062	.01670	.01503	.01285	.01125	.01045
12	.03623	.02759	.02439	.02091	.01917	.01575	.01423	.01227	.01074	.01009
14	.03332	.02497	.02236	.01946	.01786	.01488	.01350	.01176	.01038	.00973

Size Cir. Mils Stranded.	Interaxial Distances. 6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.02621	.02025	.01786	.01648	.01481	.01387	.01321	.01270
900,000	.02563	.01989	.01757	.01619	.01466	.01372	.01307	.01256
800,000	.02505	.01953	.01728	.01597	.01445	.01350	.01292	.01241
750,000	.02468	.01931	.01713	.01583	.01437	.01343	.01285	.01234
700,000	.02432	.01911	.01691	.01568	.01423	.01336	.01270	.01227
600,000	.02359	.01866	.01662	.01539	.01401	.01314	.01249	.01205
500,000	.02280	.01815	.01619	.01503	.01372	.01285	.01227	.01183
450,000	.02236	.01786	.01597	.01488	.01350	.01270	.01220	.01176
400,000	.02192	.01757	.01568	.01466	.01336	.01256	.01205	.01161
350,000	.02142	.01721	.01546	.01445	.01314	.01241	.01183	.01147
300,000	.02084	.01684	.01517	.01416	.01292	.01220	.01169	.01132
250,000	.02018	.01641	.01503	.01387	.01270	.01198	.01147	.01111
0000	.01967	.01612	.01452	.01365	.01249	.01183	.01132	.01096
000	.01895	.01561	.01416	.01328	.01220	.01154	.01111	.01074
00	.01829	.01517	.01379	.01292	.01191	.01132	.01082	.01053
0	.01771	.01474	.01343	.01263	.01169	.01103	.01067	.01031
1	.01706	.01430	.01307	.01234	.01140	.01082	.01038	.01009
2	.01648	.01394	.01270	.01198	.01111	.01060	.01016	.00987
4	.01554	.01321	.01212	.01147	.01067	.01016	.00980	.00951
Solid 6	.01423	.01227	.01132	.01074	.01009	.00958	.00929	.00907
Solid 8	.01350	.01176	.01089	.01038	.00965	.00929	.00900	.00871
Solid 10	.01285	.01125	.01045	.00995	.00936	.00893	.00871	.00849

Charging Current in Amperes per Wire per 1000 Feet of Three-Phase Circuit Formed by Three Parallel Aërial Wires.

PRESSURE BETWEEN WIRES, $E = 10{,}000$ VOLTS. FREQUENCY, $f = 25$ CYCLES PER SECOND.

CHARGING CURRENT PER WIRE = 1.815 C.

NOTE. — Values of charging current at other pressures are proportional to those given in this table.

B. & S. G., Solid	Dia. over Insul.	Interaxial Distances.								
		$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{3}{4}''$	1″	2″	3″	6″	12″	18″
0000	.01358	......	......	.01299	.01044	.00710	.00597	.00470	.00388	.00352
000	.01312	......	......	.01183	.00969	.00673	.00572	.00454	.00377	.00343
00	.01263	......	......	.01085	.00902	.00641	.00548	.00439	.00367	.00334
0	.01214	......	......	.01004	.00844	.00612	.00526	.00425	.00357	.00327
1	.01167	......	......	.00933	.00793	.00584	.00506	.00412	.00347	.00318
2	.01230	......	.01132	.00871	.00749	.00559	.00488	.00399	.00337	.00310
4	.01136	......	.00967	.00769	.00673	.00515	.00454	.00377	.00321	.00296
5	.01091	.01083	.00900	.00728	.00641	.00497	.00439	.00367	.00314	.00290
6	.01045	.01002	.00844	.00690	.00610	.00479	.00425	.00356	.00307	.00283
8	.01073	.00869	.00748	.00624	.00559	.00446	.00399	.00337	.00294	.00272
10	.00982	.00768	.00671	.00570	.00515	.00417	.00376	.00321	.00281	.00261
12	.00906	.00690	.00610	.00523	.00479	.00394	.00356	.00307	.00269	.00252
14	.00833	.00624	.00559	.00486	.00446	.00372	.00337	.00294	.00259	.00243

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
1,000,000	.00655	.00506	.00446	.00412	.00370	.00347	.00330	.00318
900,000	.00641	.00497	.00439	.00405	.00367	.00343	.00327	.00314
800,000	.00626	.00488	.00432	.00399	.00361	.00337	.00323	.00310
750,000	.00617	.00483	.00428	.00396	.00359	.00336	.00321	.00308
700,000	.00608	.00478	.00423	.00392	.00356	.00334	.00318	.00307
600,000	.00590	.00466	.00416	.00385	.00350	.00328	.00312	.00301
500,000	.00570	.00454	.00405	.00376	.00343	.00321	.00307	.00296
450,000	.00559	.00446	.00399	.00372	.00337	.00318	.00305	.00294
400,000	.00548	.00439	.00392	.00367	.00334	.00314	.00301	.00290
350,000	.00535	.00430	.00386	.00361	.00328	.00310	.00296	.00287
300,000	.00521	.00421	.00379	.00354	.00323	.00305	.00292	.00283
250,000	.00504	.00410	.00376	.00347	.00318	.00299	.00287	.00278
0000	.00492	.00403	.00363	.00341	.00312	.00296	.00283	.00274
000	.00474	.00390	.00354	.00332	.00305	.00288	.00278	.00269
00	.00457	.00379	.00345	.00323	.00298	.00283	.00270	.00263
0	.00443	.00368	.00336	.00316	.00292	.00276	.00267	.00258
1	.00426	.00357	.00327	.00308	.00285	.00270	.00259	.00252
2	.00412	.00348	.00318	.00299	.00278	.00265	.00254	.00247
4	.00388	.00330	.00303	.00287	.00267	.00254	.00245	.00238
Solid 6	.00356	.00307	.00283	.00269	.00252	.00239	.00232	.00227
Solid 8	.00337	.00294	.00272	.00259	.00241	.00232	.00225	.00218
Solid 10	.00321	.00281	.00261	.00249	.00234	.00223	.00218	.00212

Charging Current in Amperes per Wire per 1000 Feet of Three-Phase Circuit formed by Three Parallel Aërial Wires.

Pressure between Wires, E = 10,000 Volts Frequency, f = 60 Cycles per Second.

Charging Current per Wire = 4.356 C.

Note. — Values of charging current at other pressures are proportional to those given in this table.

B. & S. G., Solid.	Interaxial Distances.									
	Dia. over Insul.	3/8″	1/2″	3/4″	1″	2″	3″	6″	12″	18″
0000	.03258	......	......	.03119	.02505	.01703	.01433	.01128	.00932	.00845
000	.03149	......	......	.02840	.02326	.01616	.01372	.01089	.00906	.00823
00	.03032	......	......	.02605	.02165	.01538	.01315	.01054	.00880	.00801
0	.02914	......	......	.02409	.02025	.01468	.01263	.01019	.00858	.00784
1	.02801	......	......	.02239	.01903	.01403	.01215	.00989	.00832	.00762
2	.02953	......	.02718	.02091	.01799	.01342	.01172	.00958	.00810	.00745
4	.02727	......	.02322	.01847	.01616	.01237	.01089	.00906	.00771	.00710
5	.02618	.02600	.02160	.01747	.01538	.01193	.01054	.00880	.00753	.00697
6	.02509	.02404	.02025	.01655	.01464	.01150	.01019	.00854	.00736	.00679
8	.02574	.02086	.01795	.01498	.01342	.01071	.00958	.00810	.00706	.00653
10	.02356	.01842	.01612	.01368	.01237	.01002	.00902	.00771	.00675	.00627
12	.02174	.01655	.01464	.01254	.01150	.00945	.00854	.00736	.00645	.00605
14	.01999	.01498	.01342	.01167	.01071	.00893	.00810	.00706	.00623	.00584

Size Cir. Mils Stranded.	Interaxial Distances.							
	6″	12″	18″	24″	36″	48″	60″	72″
2,000,000	.01847	.01372	.01189	.01089	.00971	.00906	.00858	.00823
1,500,000	.01721	.01298	.01137	.01045	.00936	.00871	.00828	.00793
1,250,000	.01651	.01259	.01106	.01019	.00915	.00854	.00810	.00780
1,000,000	.01572	.01215	.01071	.00989	.00889	.00832	.00793	.00762
900,000	.01538	.01193	.01054	.00971	.00880	.00823	.00784	.00753
800,000	.01503	.01172	.01037	.00958	.00867	.00810	.00775	.00745
750,000	.01481	.01159	.01028	.00950	.00862	.00806	.00771	.00740
700,000	.01459	.01147	.01015	.00941	.00854	.00801	.00762	.00736
600,000	.01416	.01119	.00997	.00923	.00841	.00788	.00749	.00723
500,000	.01368	.01089	.00971	.00902	.00823	.00771	.00736	.00710
450,000	.01342	.01071	.00958	.00893	.00810	.00762	.00732	.00706
400,000	.01315	.01054	.00941	.00880	.00801	.00753	.00723	.00697
350,000	.01285	.01032	.00928	.00867	.00788	.00745	.00710	.00688
300,000	.01250	.01010	.00910	.00849	.00775	.00732	.00701	.00679
250,000	.01211	.00984	.00902	.00832	.00762	.00719	.00688	.00666
0000	.01180	.00967	.00871	.00819	.00749	.00710	.00679	.00658
000	.01137	.00936	.00849	.00797	.00732	.00693	.00666	.00645
00	.01098	.00910	.00828	.00775	.00714	.00679	.00649	.00632
0	.01063	.00884	.00806	.00758	.00701	.00662	.00640	.00618
1	.01024	.00858	.00784	.00740	.00684	.00649	.00623	.00605
2	.00989	.00836	.00762	.00719	.00666	.00636	.00610	.00592
4	.00932	.00793	.00727	.00688	.00640	.00610	.00588	.00571
Solid 6	.00854	.00736	.00679	.00645	.00605	.00575	.00557	.00544
Solid 8	.00810	.00706	.00653	.00623	.00579	.00557	.00540	.06523
Solid 10	.00771	.00675	.00627	.00597	.00562	.00536	.00523	.00510

SIMPLE ALTERNATING CURRENT CIRCUITS.

The *impedance* (z) of a circuit is defined as the ratio of the difference in pressure (effective) between the two ends of the conductor to the current (effective) flowing through the conductor.

The E.M.F. required to overcome impedance is

$$E = Iz.$$

In the case of direct currents $z = r$.

The following are typical alternating current circuits:

Let R = resistance in ohms.
Z = impedance.
$\omega = 2\pi f$.
L = coefficient of self induction.
C = capacity.

Resistance and Inductance, in Series.

$$Z = \sqrt{R^2 + L^2\omega^2},$$

or diagrammatically

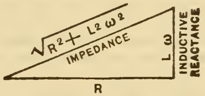

FIG. 12.

Resistance and Capacity in Series.

$$Z = \sqrt{R^2 + \frac{1}{C^2\omega^2}},$$

or diagrammatically,

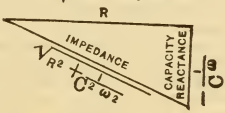

FIG. 13.

Resistance, Inductance, and Capacity in Series.

$$Z = \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2},$$

or diagrammatically,

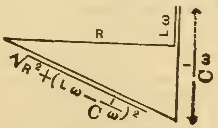

FIG. 14.

NOTE.—In transmission lines the capacity is in parallel with the resistance and inductance; the above formulæ involving capacity do not therefore apply. For the discussion of capacity of transmission lines see p. 264.

THE DIMENSIONS OF CONDUCTORS FOR DISTRIBUTION SYSTEMS.

By Harold Pender, Ph.D.

To proportion properly the size of the conductors for a distribution system, the following data with regard to each circuit is necessary:

1. The maximum power to be transmitted, or the maximum load on the line.
2. The load factor, or the variation of the power delivered with time.
3. The length of the line.
4. The distribution of the load along the line.
5. The pressure at which the power is to be transmitted.
6. The loss of power which may be allowed in the line.

These six conditions will determine a conductor of a definite cross section, but no conductor should ever be used which is not of sufficient size both to insure the proper mechanical strength and also to prevent a dangerous temperature elevation; the first condition is of particular importance in overhead lines, the second in underground and interior wiring.

Assuming that the amount and distribution of the load and the transmission distance are known, the engineer has next to determine what line pressure to employ and what power loss to allow. To do this, he must keep in mind two fundamental facts, namely, that the transmission system is but part of the entire plant, and that the object of the plant as a whole is to gain the maximum net revenue for the least expenditure of money; also, that there is usually a limit to the capital available for the enterprise, which the first cost of the entire plant must not exceed, even though a further increase of the capital outlay might gain a desirable revenue. Consequently, in the selection of the pressure and efficiency for a distribution system, many complex factors enter, such as the nature of the supply of energy, the nature of the load supplied, the probability of increase in the demand for power, etc., as well as the relative costs of the various parts of the plant. Space does not permit of a detailed discussion of all these factors here; it will suffice to state briefly the general American practice under the most common conditions.

LINE PRESSURE. — To transmit a given amount of power a given distance at a fixed efficiency, the amount of copper required will vary inversely as the square of the pressure. High pressure then means decrease in the cost of the conducting material, but an increase in the cost of insulating the line and the rest of the system. As a general rule, especially in long distance transmission, the saving in copper as the pressure is increased more than offsets the increased cost of insulation, up to about 60,000 volts, but in many cases other factors fix a much lower economical limit to the line pressure. Recent improvements in the design of insulators accompanied by a decrease cost of manufacture have raised the economic limit of line pressure to 100,000 volts.

Direct Current Distribution. — On direct current systems supplying directly incandescent lamps and small motors, the maximum pressure allowable is 125 volts for two-wire distribution, 250 volts for three-wire distribution; in certain cases where cheap power may be had, these figures may be increased to 250 and 500 respectively. For large direct current motor systems the corresponding figures are 500 to 600 volts for two-wire and 1000 to 1200 volts for three-wire systems. The limiting transmission pressure is fixed by the maximum pressure which can be employed on the various translating devices, motors, lamps, and the like. Future developments in the latter may set a new limit to the allowable pressure; in fact, the compensating pole direct current motors now being placed on the market will permit the use of pressure as high as 1200 volts for two-wire and 2400 volts for three-wire systems. On circuits supplying direct current series arc lamps, pressures as high as 5000 volts are used.

Alternating Current Distribution.— The line pressure on that part of an alternating current distribution system connected directly to the various translating devices, motors, lamps, and the like, is fixed by the practicable pressure that may be used on these devices. For direct distribution for incandescent lighting, the line pressure between wires should not exceed 125 volts, or possibly 250 volts if power is cheap and 220 to 250 volt incandescent lamps can be advantageously employed.

Distribution in Cities. — In the larger cities the tendency of modern practice (1907) is to generate three-phase alternating current at 11,000 or 13,000 volts (delta), and to transmit the power at this pressure either to static transformer or rotary converter sub-stations. For the distribution of direct current from rotary converter sub-stations see above under "Line Pressure for Direct Current Distribution." At the static transformer sub-stations the pressure is reduced to 2200 volts, and the power transmitted at this pressure to the centers of distribution, where another reduction in pressure to about 125 or 250 volts takes place, and from here the energy is distributed directly to the lamps, motors, or other translating device. In smaller cities, or when it is desired to employ overhead lines entirely (since 11,000 volts overhead in cities is not advisable), the sub-stations may be omitted and generators for 2200 volts be used. Large induction motors may be supplied directly with 2200 volt current, the very largest sometimes with current at 11,000 or 13,000 volts.

POWER LOSS IN THE LINE. — To transmit a given amount of power a given distance at a given pressure, the amount of copper required will vary inversely as the amount of power lost in transmission. Low efficiency, therefore, means decrease in the cost of the conducting material, but an increase in the central station output.

Kelvin's Law. — In general, if two quantities A and B are both functions of the same variable x, then the sum of $A + B$ is a minimum when the rate of change of A with respect to that variable is equal and opposite to the rate of change of B with respect to that variable, *i.e.*, when

$$\frac{dA}{dx} = -\frac{dB}{dx}.$$

Numerous attempts have been made to apply this law to the determination of the most economical efficiency for a transmission line. At first sight it would seem logical to proportion the costs of the central station and transmission line so that the annual cost of delivering an additional kilowatt of power by increasing the central station capacity will equal the annual cost of delivering an additional kilowatt of power by adding more copper to the line. On this basis a very simple law is found to hold, namely, that the most economical current density per million circular mils is *

$$380\sqrt{\frac{K_c}{K_p}},$$

where K_c = increase in annual charges on transmission line, resulting from increasing the weight of copper one ton (2000 lbs.), and K_p = increase in annual operating and capital charges on the central station, resulting from increasing the output one kilowatt.

This law, however, is true only for a given current; when the power supplied by any plant, and therefore the current, varies over wide limits during the year, as is almost invariably the case, the current density as determined by the above law refers to the square root of the mean square current for the year, a quantity which can be determined only to the roughest approximation.

Further, the whole discussion of economical cross section is based on two assumptions, usually unwarranted, namely, that the amount of capital available is unlimited, and that a market can be found for the maximum output of the plant; it will evidently not be economical to install copper to save power which cannot be sold. In short, neither Kelvin's law nor

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* The formula for aluminum is $165\sqrt{\frac{K_a}{K_p}}$.

any modification of it is a safe general guide in determining the proper allowance for loss of power in the line. Each plant has to be considered on its individual merits, and various conditions are likely to determine the pressure and loss in different cases.

Distribution Direct to Translating Devices. — The power loss in a transmission line also fixes the pressure loss or volts drop. In direct current systems the per cent power loss equals the per cent pressure loss; in an alternating current line there is also a fixed relation between the two, see page 264. In that part of a distribution system connected directly to the translating devices, lamps, motors, etc., the regulation of the line, or the percentage pressure loss, must not exceed a certain amount consistent with reasonably efficient operation of these translating devices. For example, the maximum variation in pressure on incandescent lamps should not be more than 2 per cent; distribution lines which supply incandescent lamps and on which the pressure at the sending end is fixed, should therefore be of sufficient size to insure a pressure loss of not over 2 per cent at maximum load. When a line supplies a large number of lamps, all of which are not likely to be burning simultaneously, the per cent drop in pressure for the connected load may be taken considerably greater. For example, if the probable maximum load be figured at one third of the connected load, a drop of 6 per cent for all lamps burning may be allowed.

Distribution in General. — The following discussion of the proper power loss to allow in transmission lines is taken from Bell, "Electric Power Transmission."

"The commonest cases which arise are as follows, arranged in order of their frequency as occurring in American practice. Each case requires a somewhat different treatment in the matter of line loss, and the whole classification is the result not of *a priori* reasoning but of the study of a very large number of concrete cases.

Case I. General distribution of power and light from water-power. This includes something like two thirds of all the power transmission enterprises. The cases which have been investigated by the author have ranged from 100 to 20,000 H.P., to be transmitted all the way from one to one hundred and fifty miles. The market for power and light is usually uncertain, the proposition of power to light unknown within wide limits, and the total amount required only to be determined by future conditions. The average load defies even approximate estimation, and as a rule even when the general character of the market is most carefully investigated little certainty is gained.

For one without the gift of prophecy the attempt to figure the line for such a transmission by following any canonical rules for maximum economy is merely the wildest sort of guesswork. The safest process is as follows: Assume an amount of power to be transmitted which can certainly be disposed of. Figure the line for an assumed loss of energy at full load small enough to insure good and easy regulation, which determines the quality of the service, and hence, in large measure, its growth. Arrange both power station and line with reference to subsequent increase if needed. The exact line loss assumed is more a result of trained judgment than of formal calculation. It will be in general between 5 and 15 per cent, for which losses generators can be conveniently regulated. If raising and lowering transformers are used the losses of energy in them should be included in the estimate for total loss in the line. In this case the loss in the line proper should seldom exceed 10 per cent. A loss of less than 5 per cent is seldom advisable.

It should not be forgotten that in an alternating circuit two small conductors are generally better than one large one, so that the labor of installation often will not be increased by waiting for developments before adding to the line. It frequently happens, too, that it is very necessary to keep down the first cost of installation, to lessen the financial burden during the early stages of a plant's development.

Case II. Delivery of a known amount of power from ample water-power. This condition frequently arises in connection with manufacturing establishments. A water-power is bought or leased *in toto*, and the problem consists of transmitting sufficient power for the comparatively fixed needs of the works. The total amount is generally not large seldom more than a few hundred horse-power. Under these circumstances the plant should be designed for minimum first cost, and any loss in the line is permissible that does not lower the efficiency enough to force the use of larger sizes of dynamos and water-wheels. These sizes almost invariably are near enough together to involve no trouble in regulation if the line be thus designed. The operating expense becomes practically a fixed charge so that the first cost only need be considered.

Such plants are increasingly common. A brief trial calculation will show at once the conditions of economy and the way to meet them.

CASE III. Delivery of a known power from a closely limited source. This case resembles the last, except that there is a definite limit set for the losses in the system. Instead, then, of fixing a loss in the line based on regulation and first cost alone, the first necessity is to deliver the required power. This may call for a line more expensive than would be indicated by any of the formulæ for maximum economy, since it is far more important to avoid a supplementary steam plant entirely than to escape a considerable increase in cost of line. The data to be seriously considered are the cost of maintaining such a supplementary plant properly capitalized, and the price of the additional copper that render it unnecessary. Maximum efficiency is here the governing factor. In cases where the motive-power is rented or derived from steam, formulæ like Kelvin's may sometimes be convenient. Losses in the line will often be as low as 5 per cent, sometimes only 2 or 3.

CASE IV. Distribution of power in known amount and units, with or without long distance transmission, with motive-power which, like steam or rented water-power costs a certain amount per horse-power. Here the desideratum is minimum cost per H.P., and design for this purpose may be carried out with fair accuracy. Small line loss is generally desirable unless the system is complicated by a long transmission. Such problems usually or often appear as distributions only. Where electric motors are in competition with distribution by shafting, rope transmission, and the like, 2 to 5 per cent line loss may advantageously be used in a trial computation.

The problem of power transmisson may arise in still other forms than those just mentioned. Those are, however, the commonest types, and are instanced to show how completely the point of view has to change when designing plants under various circumstances. The controlling element may be minimum first cost, maximum efficiency, minimum cost of transmission, or combinations of any one of these, with locally fixed requirements as to one or more of the others, or as to special conditions quite apart from any of them.

In very many cases it is absolutely necessary to keep down the initial cost, even at a considerable sacrifice in other respects. Or economy in a certain direction must be sought, even at a considerable expense in some other direction. For these reasons no rigid system can be followed, and there is constant necessity for individual skill and judgment. It is no uncommon thing to find two plants for transmitting equal powers over the same distance under very similar conditions, which must, however, be installed on totally different plans in order to best meet the requirements."

CALCULATION OF TRANSMISSION LINES.

HAROLD PENDER, PH.D.

Let

E = pressure between adjacent wires at receiving end in volts.
W = power delivered in kilowatts.
k = power factor of the load expressed as a decimal fraction.
A = cross section of each wire in millions of circular mils.
w = total weight of conductors in pounds.
l = length of circuit (length of each wire) in feet.
R = resistance of each wire in ohms.
t_1 = reactance factor of line = ratio of line reactance to line resistance (Table II).
Q = per cent power loss in terms of delivered power.
P = per cent pressure drop in terms of delivered pressure.

Put

$$F = \frac{lW}{(kE)^2}.$$

In Table I are given formulæ for calculating the cross section, weight, and power loss for any kind of conductor. The per cent pressure drop, P, can be readily calculated when the per cent power loss is known by means of the formula

$$P = MQ + NQ^2.$$

Where M and N are constants depending on the power factor (k) and the ratio t_1 of the line reactance to the line resistance, this ratio is called the "reactance-factor"; Tables III and IV give the values of the constants M and N for various values of k and t_1. To a close approximation, except when the power factor is nearly unity, or the receiver current is leading, the term NQ^2 may be neglected, i.e., in most practical cases $P = MQ$. The complete expression $P = MQ + NQ^2$ is exact in all cases for a 10 per cent power loss; it is in error less than 3 per cent for any value of P less than 30; in any case likely to arise in practice the discrepancy is less than 1 per cent in the value of P. The exact expression for P in terms of Q is

$$P = \sqrt{10^4 + 200\,(1 + tt_1)\,k^2Q + (1 + t_1^2)\,k^2Q^2} - 100$$

where t is the tangent corresponding to the cosine k. (See p. 276.)

Effect of Line Capacity.

The effect of the capacity of the line is to reduce the pressure drop, i.e., improve the regulation, and to decrease or increase the power loss depending on the load and power factor of the receiver. Let

$$b = 2\,\pi fC \times 10^{-6}.$$

Where C is the capacity of the condenser in microfarads formed by any pair of wires of the line, f is the frequency; b is called the capacity susceptance of the line (for a single-phase line, the charging current is bE; for a three-phase line the charging current per wire is 1.155 bE.

Table V gives the values of the capacity susceptance per 1000 feet of circuit for various sizes of wire spaced various distances apart for a frequency of 100 cycles per second; the values for other frequencies are directly proportional. (Continued on p. 270.)

Table I.—Formulæ for Cross Section, Weight and Power Loss.

		Direct Current or Single Phase.			Three Phase.		
		Copper. 100% conductivity. 20° Centigrade or 68° F.	Aluminum. 62 % conductivity. 20° Centigrade or 68° F.	Any material. ρ = microhms per cu. in. δ = lbs. per cu. in.	Copper. 100% conductivity. 20° Centigrade or 68° F.	Aluminum 62% conductivity. 20° Centigrade or 68° F.	Any material. ρ = microhms per cu. in. δ = lbs. per cu. in.
Given E, W, k, l, and Q, then: Cross section in million CM. . .	$A =$	$\frac{2.08\,F}{Q}$	$\frac{3.34\,F}{Q}$	$\frac{3.06\,\rho F}{Q}$	$\frac{1.04\,F}{Q}$	$\frac{1.67\,F}{Q}$	$\frac{1.53\,\rho F}{Q}$
Given E, W, k, l, and Q, then: Total weight of conductors in lbs.	$w =$	$\frac{12.6\,Fl}{Q}$	$\frac{6.11\,Fl}{Q}$	$\frac{57.8\,\rho\delta lF}{Q}$	$\frac{9.45\,Fl}{Q}$	$\frac{4.58\,Fl}{Q}$	$\frac{43.2\,\rho\delta lF}{Q}$
Given A and l, then: Total weight of conductors in lbs.	$w =$	$6.06\,lA$	$1.83\,lA$	$18.9\,\delta lA$	$9.09\,lA$	$2.74\,lA$	$28.3\,\delta lA$
Given E, W, k, l, and A, then: Per cent power loss	$Q =$	$\frac{2.08\,F}{A}$	$\frac{3.34\,F}{A}$	$\frac{3.06\,\rho F}{A}$	$\frac{1.04\,F}{A}$	$\frac{1.67\,F}{A}$	$\frac{1.53\,\rho F}{A}$
Given E, W, k and R, then: Per cent power loss	$Q =$	$2 \times 10^5 \frac{RW}{(kE)^2}$			$10^5 \frac{RW}{(kE)^2}$		

NOTE.—Tables I, II, III, IV and V were first published by Mr. Pender in the *Electrical Age* for Sept., 1907, and are copyrighted by that journal.

Table II. — Cross Section, Resistance and Reactance Factors.

Temperature 20 Degrees Centigrade.

Reactance factors are directly proportional to frequency and to conductivity:

For **Copper Wire** and
25 Cycles divide the reactance factors given below by 4.
60 " multiply " " " " " 0.6

For **Aluminum Wire and**
25 Cycles multiply the reactance factors given below by 0.155
60 " " " " " " " " 0.372

No.	Cross Section. Millions of CM.	Ohms per 1000 ft. at 20° C. or 68° F.		Reactance Factors for 100 per cent Conductivity and 100 Cycles per Second. Distance Apart of Wires in Feet.							
		Copper.	Aluminum.	1	2	3	4	5	6	7	8
	.500	.0207	.0334	6.96	8.24	8.99	9.52	9.93	10.26	10.55	10.80
	.450	.0230	.0371	6.35	7.50	8.17	8.65	9.02	9.32	9.58	9.80
	.400	.0259	.0418	5.73	6.75	7.35	7.77	8.11	8.37	8.61	8.80
	.350	.0296	.0477	5.10	6.00	6.52	6.89	7.18	7.41	7.62	7.79
	.300	.0345	.0556	4.46	5.22	5.67	5.99	6.24	6.44	6.61	6.76
	.250	.0414	.0668	3.80	4.44	4.81	5.08	5.28	5.45	5.60	5.72
0000	.212	.0489	.0790	3.28	3.82	4.14	4.37	4.54	4.68	4.80	4.91
000	.168	.0617	.0995	2.68	3.11	3.35	3.53	3.67	3.78	3.88	3.96
00	.133	.0778	.125	2.18	2.52	2.72	2.86	2.97	3.06	3.13	3.20
0	.106	.0981	.158	1.77	2.04	2.20	2.31	2.40	2.47	2.53	2.58
1	.0837	.124	.200	1.44	1.66	1.78	1.87	1.94	2.00	2.04	2.08
2	.0663	.156	.252	1.17	1.34	1.44	1.51	1.57	1.61	1.65	1.68
3	.0526	.197	.318	.95	1.09	1.16	1.22	1.26	1.30	1.33	1.36
4	.0417	.248	.400	.77	.88	.94	.99	1.02	1.05	1.07	1.09
5	.0331	.313	.505	.63	.71	.76	.80	.82	.85	.87	.88
6	.0263	.394	.636	.51	.58	.61	.64	.66	.68	.70	.71

Note. — The above reactance factors are calculated for solid wire; they are also correct within 1 per cent for stranded cables and cables with hemp cores having the same cross sectional area of conductor.

Table III.—Values of M.

Reactance Factors.	Power Factors of Receiver.									
	Current Leading.			Current Lagging.						
t_1.	90	95	98	100	98	95	90	85	80	70
0.0	.81	.90	.96	1.00	.95	.90	.81	.72	.64	.49
0.1	.77	.87	.94	1.00	.98	.93	.85	.76	.69	.54
0.2	.73	.84	.92	1.00	1.00	.96	.89	.81	.74	.59
0.3	.69	.81	.90	1.00	1.02	.99	.93	.86	.79	.64
0.4	.65	.78	.88	1.00	1.04	1.02	.97	.90	.83	.69
0.5	.61	.75	.86	1.00	1.06	1.05	1.01	.94	.88	.74
0.6	.58	.72	.84	1.00	1.08	1.08	1.05	.99	.93	.79
0.7	.54	.69	.82	1.00	1.10	1.11	1.09	1.03	.98	.84
0.8	.50	.66	.80	1.00	1.12	1.14	1.13	1.08	1.02	.89
0.9	.46	.63	.78	1.00	1.14	1.17	1.17	1.13	1.07	.94
1.0	.42	.61	.77	1.00	1.16	1.20	1.20	1.17	1.12	.99
1.1	.38	.58	.75	1.00	1.18	1.23	1.24	1.21	1.17	1.04
1.2	.34	.55	.73	1.00	1.19	1.26	1.28	1.26	1.22	1.09
1.3	.30	.52	.71	1.00	1.21	1.29	1.32	1.31	1.27	1.14
1.4	.26	.49	.69	1.00	1.23	1.32	1.36	1.35	1.31	1.19
1.5	.22	.46	.67	1.00	1.25	1.35	1.40	1.39	1.36	1.24
1.6	.18	.43	.65	1.00	1.27	1.38	1.44	1.44	1.41	1.29
1.7	.14	.40	.63	1.00	1.29	1.41	1.48	1.48	1.46	1.34
1.8	.10	.37	.61	1.00	1.31	1.44	1.51	1.53	1.50	1.39
1.9	.07	.34	.59	1.00	1.33	1.47	1.55	1.58	1.55	1.44
2.0	.03	.31	.57	1.00	1.35	1.50	1.59	1.62	1.60	1.49
2.1	−.01	.28	.55	1.00	1.37	1.53	1.63	1.66	1.65	1.54
2.2	−.05	.25	.53	1.00	1.39	1.56	1.67	1.70	1.70	1.59
2.3	−.09	.22	.51	1.00	1.41	1.59	1.71	1.75	1.75	1.64
2.4	−.13	.19	.49	1.00	1.43	1.62	1.75	1.80	1.79	1.69
2.5	−.17	.16	.47	1.00	1.45	1.64	1.79	1.84	1.84	1.74
2.6	−.21	.13	.45	1.00	1.47	1.67	1.83	1.88	1.89	1.79
2.7	−.25	.30	.43	1.00	1.49	1.70	1.87	1.93	1.94	1.84
2.8	−.29	.07	.41	1.00	1.51	1.73	1.91	1.98	1.98	1.89
2.9	−.33	.04	.39	1.00	1.53	1.76	1.96	2.02	2.03	1.94
3.0	−.36	−.01	.37	1.00	1.55	1.79	1.99	2.06	2.08	1.99
3.1	−.40	−.02	.36	1.00	1.57	1.82	2.03	2.11	2.13	2.04
3.2	−.44	−.05	.34	1.00	1.58	1.85	2.04	2.15	2.18	2.09
3.3	−.48	−.08	.32	1.00	1.60	1.88	2.10	2.20	2.23	2.14
3.4	−.52	−.11	.30	1.00	1.62	1.91	2.14	2.24	2.27	2.19
3.5	−.56	−.14	.28	1.00	1.64	1.94	2.18	2.29	2.32	2.24

Table IV.—Values of N.

Reactance Factors.	Power Factors of Receiver.									
	Current Leading.			Current Lagging.						
t_1.	90	95	98	100	98	95	90	85	80	70
0.0	.001	.001	.000	.000	.000	.001	.001	.001	.001	.002
0.1	.001	.001	.000	.000	.000	.000	.000	.001	001	.001
0.2	.002	.001	.001	.000	.000	.000	.000	.001	.001	.001
0.3	.002	.002	.001	.000	.000	.000	.000	.000	.000	.001
0.4	.003	.002	.002	.001	.000	.000	.000	.000	.000	.000
0.5	.003	.003	.002	.001	.000	.000	.000	.000	.000	.000
0.6	.003	.003	.003	.002	.000	.000	.000	.000	.000	.000
0.7	.004	.004	.004	.002	.001	.000	.000	.000	.000	.000
0.8	.005	.005	.005	.003	.001	.001	.000	.000	.000	.000
0.9	.006	.006	.006	.004	.002	.001	.001	.000	.000	.000
1.0	.007	.006	.006	.005	.002	.002	.001	.001	.000	.000
1.1	.008	.007	.007	.006	.003	.002	.001	.001	.000	.000
1.2	.009	.008	.008	.007	.004	.003	.002	.001	.000	.000
1.3	.010	.010	.009	.008	.005	.003	.002	.001	.000	.000
1.4	.011	.011	.011	.009	.006	.004	.003	.001	.001	.000
1.5	.013	.013	.012	.010	.007	.005	.003	.002	.001	.000
1.6	.014	.014	.014	.011	.008	.006	.004	.002	.001	.000
1.7	.016	.016	.015	.013	.009	.007	.004	.003	.002	.000
1.8	.017	.018	.017	.015	.011	.008	.005	.003	.002	.000
1.9	.018	.019	.019	.016	.012	.009	.006	.003	.002	.000
2.0	.020	.021	.021	.018	.013	.010	.006	.004	.003	.001
2.1	.022	.023	.023	.020	.015	.011	.007	.005	.003	.001
2.2	.023	.025	.025	.022	.016	.012	.008	.006	.003	.001
2.3	.025	.027	.027	.024	.017	.014	.009	.006	.004	.002
2.4	.027	.029	.030	.026	.019	.015	.010	.007	.005	.002
2.5	.029	.031	.032	.028	.021	.017	.011	.008	.005	.002
2.6	.032	.034	.034	.030	.023	.018	.012	.009	.006	.003
2.7	.034	.036	.037	.033	.024	.020	.013	.010	.006	.003
2.8	.036	.039	.040	.035	.026	.021	.015	.010	.007	.003
2.9	.038	.041	.042	.037	.028	.023	.016	.011	.008	.004
3.0	.040	.044	.045	.040	.030	.024	.018	.012	.009	.004
3.1	.042	.046	.047	.042	.033	.026	.019	.013	.009	.004
3.2	.045	.049	.050	.045	.035	.028	.020	.014	.010	.005
3.3	.048	.052	.053	.048	.038	.030	.021	.015	.011	.005
3.4	.051	.055	.056	.051	.040	.032	.023	.017	.012	.006
3.5	.053	.059	.060	.054	.043	.034	.024	.018	.013	.006

Table V. — Capacity Susceptance per 1000 Feet of Two Parallel Wires.

FREQUENCY 100 CYCLES PER SECOND.

Capacity susceptance is directly proportional to frequency :
For 25 cycles divide numbers given in table by 4.
For 60 cycles multiply numbers given in table by 0.6.

Size Wire Millions of CM. and B. & S.	Diameter in Inches.	Distance Apart of Wires in Feet. 1	2	3	4	5	6	7	8
.500	.707	.00000151	.00000126	.00000115	.00000108	.00000104	.00000100	.00000097	.00000095
.450	.671	.00000149	.00000124	.00000113	.00000107	.00000103	.00000099	.00000096	.00000094
.400	.632	.00000146	.00000123	.00000112	.00000106	.00000102	.00000098	.00000095	.00000093
.350	.592	.00000144	.00000121	.00000110	.00000104	.00000100	.00000097	.00000094	.00000092
.300	.547	.00000141	.00000119	.00000109	.00000103	.00000099	.00000096	.00000093	.00000091
.250	.500	.00000137	.00000116	.00000107	.00000102	.00000097	.00000095	.00000091	.00000090
0000	.460	.00000134	.00000114	.00000105	.00000100	.00000096	.00000093	.00000090	.00000088
000	.410	.00000131	.00000112	.00000103	.00000098	.00000094	.00000091	.00000089	.00000087
00	.365	.00000127	.00000109	.00000100	.00000096	.00000092	.00000089	.00000087	.00000085
0	.325	.00000124	.00000106	.00000099	.00000094	.00000090	.00000087	.00000085	.00000083
1	.289	.00000120	.00000104	.00000097	.00000092	.00000088	.00000086	.00000084	.00000082
2	.258	.00000117	.00000102	.00000095	.00000090	.00000086	.00000084	.00000082	.00000081
3	.229	.00000114	.00000099	.00000093	.00000088	.00000084	.00000083	.00000081	.00000079
4	.204	.00000111	.00000097	.00000091	.00000086	.00000083	.00000081	.00000079	.00000078
5	.184	.00000109	.00000095	.00000089	.00000085	.00000082	.00000080	.00000078	.00000076
6	.162	.00000106	.00000093	.00000087	.00000083	.00000080	.00000079	.00000077	.00000075

NOTE. — The capacity susceptances given in this table are for solid wires; a stranded wire of the same cross section has a capacity susceptance about 3 per cent greater. For special cables having hemp cores use the susceptance corresponding to the actual diameter of the cable; the susceptance is a function of the diameter, not of the cross section.

Using the same notation as given on page 264, putting R for the total resistance and X ($= t_1R$) for the total reactance of each leg of the line,

	Single Phase.	Three Phase.
Decrease in per cent pressure drop $p =$	$50\ bX$	$100\ bX$
Decrease in per cent power loss $q =$	$at - \frac{a^2}{2\,k^2Q}$	$2\,at - \frac{a^2}{k^2Q}$

where $a = 100\,bR$ and t is the tangent corresponding to the cosine k. (See p. 276.) The true regulation of the line is then $P - p$, and the true per cent power loss is $Q - q$, P and Q being calculated by the formulæ given on pages 264 and 265. These formulæ are approximate, being deduced on the assumption that the line capacity can be represented by a condenser of half the capacity of the line shunted across the line at each end, but they are sufficiently accurate for any case likely to arise in practice. It is to be noted that the change in regulation is independent of the load and the power factor, and is independent of the line resistance; the change in the per cent power loss varies with both the load and the power factor.

Direct Current, Three-Wire System. — Figure the weight and cross section of the outer conductors as if the middle or neutral wire was not present, putting E = volts between outside wires. The neutral wire is usually taken from one-third to full size of each outer conductor. The total weight of copper required will therefore be one-sixth to one-half greater than the weight determined by the above formula.

Two-Phase, Four-Wire System. — Treat each phase separately, remembering that half the power is delivered by each phase, and E = volts between diametrically opposite wires.

Two-Phase, Three-Wire System. —

Let
E = pressure between each outer and middle wire at receiving end in volts.
V = pressure between each outer and middle wire at generating end in volts.
Other symbols as above.

Then for equal rise of temperature in the three conductors the following formulæ hold. (The total weight of conductor required for this condition is only a fraction of one per cent greater than for the condition of maximum economy.)

	Copper. 100 % conductivity. 20° Centigrade or 68° F.	Aluminum. 62 % conductivity. 20° Centigrade or 68° F.	Any Material. ρ = microhms per cu. in. δ = lbs. per cu. in.
Cross section of each outer wire in million C.M. $A_1 =$	$\frac{0.93F}{Q}$	$\frac{1.50F}{Q}$	$\frac{1.37\rho F}{Q}$
Cross section of middle wire in million C.M. $A_0 =$	$1.26A_1$	$1.26A_1$	$1.26A_1$
Total weight in pounds $w =$	$9.85lA_1$	$2.97lA_1$	$30.7\delta lA_1$
Total weight in pounds $w =$	$\frac{9.15lF}{Q}$	$\frac{4.45lF}{Q}$	$\frac{42.1\rho\delta lF}{Q}$

On the B. & S. gauge the middle wire is larger than each outer by one number (see p. 145).

Two or more Circuits in Series.

The above formulæ and tables are also applicable to the case of two or more circuits in series, i.e., a transmission line and transformer, if we put

$$R = R_1 + R_2 + \ldots .$$

$$T = \frac{R_1 t_1 + R_2 t_2}{R} + \ldots .$$

where R_1, R_2, etc., are the resistances of the separate circuits and t_1, t_2, etc., are the reactance factors of the separate circuits.

NUMERICAL EXAMPLES OF CALCULATIONS, OF WEIGHT, CROSS SECTION, ETC.

Direct Current, Two-Wire System.

COPPER WIRES.

Given

$$W = 40 \text{ kilowatts.}$$
$$E = 200 \text{ volts.}$$
$$l = 500 \text{ feet.}$$
$$Q = 5 \text{ per cent.}$$

Then $$F = \frac{500 \times 40}{(200)^2} = 0.5.$$

Cross section $$A = \frac{2.08 \times 0.5}{5} = 0.208 \text{ million C.M.}$$

The nearest commercial size is No. 0000 B. & S. (see Table II) which has an area of 0.212 million C.M.

Total weight of copper $$w = 6.06 \times 500 \times 0.212 = 641 \text{ pounds.}$$

Power loss $$Q = \frac{2.08 \times 0.5}{0.212} = 4.92 \text{ per cent.}$$

Pressure drop $$P = Q = 4.92 \text{ per cent.}$$

Pressure at generating end $$= 1.0492 \times 200 = 209.84 \text{ volts.}$$

Direct Current, Three-Wire System.

Take the same constants as in the preceding case, considering $E = 200$ volts as the pressure between outer wires. If the neutral wire is to be half the size of each outer, the total weight of copper required will be

$$641 + \frac{641}{4} = 801 \text{ pounds.}$$

When the system is balanced there will be no current in the neutral wire and the regulation and efficiency will be the same as above. If one side of the system is fully loaded, and the other side not loaded at all, the volts drop in the loaded outer will be the same as if the system was balanced, since the same current flows, and the volts drop in the neutral will be twice the drop in the outer (same current and double resistance); hence total drop will be 14.8 volts in 100 volts or 14.8 per cent. The power loss will also be 14.8 per cent or 2.96 kilowatts.

Alternating Current, Single Phase.

COPPER WIRES SPACED 3 FEET APART.

Given
f = 25 cycles per second.
W = 500 kilowatts.
E = 10,000 volts.
l = 45,000 feet.
k = 0.9, i.e., 90 per cent power factor.
Q = 10 per cent.

Then $F = \dfrac{45{,}000 \times 500}{(0.9 \times 10{,}000)^2} = 0.278.$

Cross section $A = \dfrac{2.08 \times 0.278}{10} = 0.0578$ million C.M.

The nearest commercial size is No. 2 B. & S. (Table II), which has an area of 0.0664 million C.M.

Total weight of copper $w = 6.06 \times 45{,}000 \times 0.0664 = 18{,}100$ lbs.

Exact power loss $Q = \dfrac{2.08 \times 0.278}{0.0664} = 8.71$ per cent.

Reactance factor $t_1 = \dfrac{1.44}{4} = 0.36.$ (Table II).

Therefore $M = 0.95$ (Table III).
$N = 0.000.$ (Table IV).

Then, neglecting the capacity of the line,

Pressure drop $P = 0.95 \times 8.71 = 8.27$ per cent.

Pressure at generating end $= 1.0827 \times 10{,}000 = 10{,}827$ volts.

Two-Phase, Three-Wire System.

COPPER WIRES SPACED 3 FEET APART.

Given
f = 25 cycles per second.
W = 500 kilowatts.
E = 10,000 volts.
l = 45,000 feet.
k = 0.9, i.e., 90 per cent power factor.
Q = 10 per cent.

Then

$$F = \frac{45{,}000 \times 500}{(0.9 \times 10{,}000)^2} = 0.278.$$

Cross section of outers $A_1 = \dfrac{0.93 \times 0.278}{10} = 0.0259$ million C.M.

The nearest commercial size is No. 6 B. & S. (Table II) which has an area of 0.0263 million C.M. The middle wire must therefore be No. 5 B. & S.

Total weight of copper $w = 9.85 \times 45{,}000 \times 0.0263 = 11{,}600$ lbs.

Exact power loss $Q = \dfrac{0.93 \times 0.278}{0.0263} = 9.87$ per cent.

The pressure loss will depend upon how the wires are arranged on the poles. As a first approximation for any ordinary arrangement, the reactance of each phase can be considered the same as in a single phase system with wires of the same cross section as the outer, spaced a distance apart equal to that between each outer and the middle wire.

From Table II the reactance factor of a No. 6 wire corresponding to a three-foot spacing and 25 cycles is

$$t_1 = \frac{0.61}{4} = 0.15.$$

Whence $M = 0.87.$

Then neglecting the capacity of the line, and using the approximate formula $P = MQ$,

Pressure drop $P = 9.87 \times 0.87 = 8.59$ per cent.
Pressure at generating end $= 1.0859 \times 10{,}000 = 10{,}859$ volts.

Alternating Current, Three-Phase.

Copper Wires Spaced 6 Feet Apart.

Given
$f = 60$ cycles per second.
$W = 10{,}000$ kilowatts.
$E = 60{,}000$ volts.
$l = 400{,}000$ feet.
$k = 0.85$, i.e., 85 per cent power factor.
$Q = 12$ per cent.

Then $$F = \frac{400{,}000 \times 10{,}000}{(0.85 \times 60{,}000)^2} = 1.54.$$

Cross section $$A = \frac{1.54 \times 1.04}{12} = 0.133 \text{ million C.M.}$$

The nearest commercial size is No. 00 (see Table II), which has an area of 0.133 million C.M.

Total weight of copper $w = 9.09 \times 400{,}000 \times 0.133 = 484{,}000$ lb.

Neglecting line capacity,

Exact power loss $$Q = \frac{1.54 \times 1.04}{0.133} = 12 \text{ per cent.}$$

Reactance factor $t_1 = 3.06 \times 0.6 = 1.84$.

Therefore $M = 1.55$.
$N = 0.003$.

Pressure drop $P = 1.55 \times 12 + [0.003 \times (12)^2] = 19.0$.

Effect of line capacity (see p. 264).

$b = .00000089 \times 0.6 \times 400 = 0.000214$. (Table V).
$R = 0.0778 \times 400 = 31.1$ (Table II).
$X = 1.84 \times 31.1 = 57.2$.

Then

Decrease in per cent pressure drop $= p = 100 \times 0.000214 \times 57.2 = 1.2$.

$a = 100 \times 0.000214 \times 31.1 = 0.67$.
$t = 0.62$.

Decrease in per cent power loss $$= q = 2 \times 0.67 \times 0.62 - \frac{(0.67)^2}{(0.85)^2 \times 12} = 0.8.$$

Whence

True pressure drop $= 19.0 - 1.2 = 17.8$ per cent.
True power loss $= 12.0 - 0.8 = 11.2$ per cent.
Pressure at generating end $= 1.178 \times 60{,}000 = 70{,}680$ volts.

TRANSMISSION LINE OF KNOWN CONSTANTS.

The following formulæ and tables give an exact method of calculating the efficiency and regulation of a transmission line of known constants, in terms of the pressure between adjacent wires at the generating end of line.

Given: The kind of system, direct or alternating,

n = number of phases, for the "single phase" system $n = 2$.
f = frequency in cycles per second.
V = pressure between adjacent wires at generating end, in volts.
W = power delivered in watts.
$\cos a$ = power factor of load at receiving end.
R = resistance of each wire in ohms.
X = inductive reactance of each wire in ohms.
$Z = \sqrt{R^2 + X^2}$ = impedance of each wire.

Required: E = pressure between adjacent wires at receiving end in volts.
I = current per wire in amperes.
H = total power lost in watts.

The values of E, I, and H are given in the table on p. 275. For approximate calculations J can be taken equal to unity; the exact value of J is given in the table below.

Values of J.

e	000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0001	1.0001
.01	1.0001	1.0001	1.0001	1.0002	1.0002	1.0002	1.0003	1.0003	1.0003	1.0004
.02	1.0004	1.0004	1.0005	1.0005	1.0006	1.0006	1.0007	1.0007	1.0008	1.0008
.03	1.0009	1.0010	1.0010	1.0011	1.0012	1.0012	1.0013	1.0014	1.0014	1.0015
.04	1.0016	1.0017	1.0017	1.0018	1.0019	1.0020	1.0021	1.0022	1.0023	1.0024
.05	1.0025	1.0026	1.0027	1.0028	1.0029	1.0030	1.0031	1.0032	1.0034	1.0035

e	.000	.002	.004	.006	.008	e	.000	.002	.004	.006	.008
.06	1.004	1.004	1.004	1.004	1.005	.29	1.102	1.104	1.106	1.108	1.110
.07	1.005	1.005	1.005	1.006	1.006	.30	1.111	1.113	1.115	1.117	1.119
.08	1.006	1.007	1.007	1.007	1.008	.31	1.121	1.123	1.125	1.127	1.129
.09	1.008	1.008	1.009	1.009	1.010	.32	1.131	1.133	1.135	1.137	1.139
.10	1.010	1.010	1.011	1.011	1.011	.33	1.141	1.143	1.146	1.149	1.151
.11	1.012	1.012	1.013	1.013	1.014	.34	1.154	1.156	1.158	1.161	1.163
.12	1.014	1.015	1.015	1.016	1.017	.35	1.167	1.169	1.171	1.174	1.177
.13	1.018	1.018	1.019	1.019	1.020	.36	1.180	1.183	1.186	1.189	1.192
.14	1.021	1.021	1.022	1.022	1.023	.37	1.195	1.199	1.202	1.206	1.209
.15	1.024	1.024	1.025	1.025	1.026	.38	1.213	1.216	1.220	1.224	1.227
.16	1.027	1.027	1.028	1.029	1.030	.39	1.231	1.234	1.238	1.242	1.246
.17	1.031	1.032	1.032	1.033	1.034	.40	1.250	1.254	1.258	1.263	1.267
.18	1.034	1.035	1.036	1.037	1.038	.41	1.272	1.276	1.280	1.285	1.290
.19	1.039	1.040	1.041	1.042	1.043	.42	1.296	1.301	1.307	1.312	1.318
.20	1.044	1.045	1.046	1.046	1.047	.43	1.324	1.330	1.336	1.342	1.349
.21	1.048	1.049	1.050	1.051	1.052	.44	1.356	1.363	1.370	1.377	1.385
.22	1.053	1.054	1.056	1.057	1.058	.45	1.393	1.401	1.410	1.409	1.428
.23	1.059	1.061	1.062	1.063	1.065	.46	1.437	1.447	1.457	1.468	1.479
.24	1.066	1.067	1.068	1.070	1.071	.47	1.491	1.504	1.518	1.532	1.547
.25	1.072	1.074	1.075	1.076	1.078	.48	1.563	1.580	1.599	1.620	1.643
.26	1.079	1.081	1.082	1.083	1.084	.49	1.668	1.697	1.733	1.778	1.835
.27	1.086	1.087	1.089	1.090	1.092	.50	2.000	.....	.....	.....	.....
.28	1.094	1.096	1.098	1.099	1.100	....	.....	.....	.....	.....	.....

Transmission Line Formulæ.

H. PENDER.

Type of Circuit.	B	e	E	I	H
D.C. 2 Wires . . .	$V^2 - 4\,WR$	$\frac{2\,WR}{B}$	$\sqrt{\frac{B}{J}}$	$\frac{W}{E}$	$2\,R\left(\frac{W}{E}\right)^2$
1 Phase 2 Wires . . .	$V^2 - 4\,W\,(R + X \tan \alpha)$	$\frac{2\,WZ}{B \cos \alpha}$	$\sqrt{\frac{B}{J}}$	$\frac{W}{E \cos \alpha}$	$2\,R\left(\frac{W}{E \cos \alpha}\right)^2$
2 Phase 4 Wires* . .	$V^2 - 2\,W\,(R + X \tan \alpha)$	$\frac{WZ}{B \cos \alpha}$	$\sqrt{\frac{B}{J}}$	$\frac{W}{2\,E \cos \alpha}$	$R\left(\frac{W}{E \cos \alpha}\right)^2$
3 Phase 3 Wires . . .	$V^2 - 2\,W\,(R + X \tan \alpha)$	$\frac{WZ}{B \cos \alpha}$	$\sqrt{\frac{B}{J}}$	$\frac{W}{\sqrt{3}\,E \cos \alpha}$	$R\left(\frac{W}{E \cos \alpha}\right)^2$
4 Phase 4 Wires . . .	$V^2 - W\,(R + X \tan \alpha)$	$\frac{WZ}{2\,B \cos \alpha}$	$\sqrt{\frac{B}{J}}$	$\frac{W}{2\sqrt{2}\,E \cos \alpha}$	$\frac{R}{2}\left(\frac{W}{E \cos \alpha}\right)^2$
n Phase n Wires . . .	$V^2 - \frac{8}{n}\sin^2\frac{\pi}{n}\,W\,(R + X \tan \alpha)$	$\frac{4 \sin^2\frac{\pi}{n} \cdot WZ}{nB \cos \alpha}$	$\sqrt{\frac{B}{J}}$	$\frac{2 \sin \frac{\pi}{n}}{n} \times \frac{W}{E \cos \alpha}$	$\frac{R}{n}\left(\frac{2\,W \sin \frac{\pi}{n}}{E \cos \alpha}\right)^2$

* V is here E.M.F. between diametrically opposite leads.

NOTE: For tan α in terms of cos α see page 276.

K	0.000	0.002	0.004	0.006	0.008	K	0.000	0.002	0.004	0.006	0.008
0.00		500	250	167	125	0.50	1.732	1.723	1.714	1.705	1.696
0.01	100	83.3	71.4	62.5	55.5	0.51	1.687	1.678	1.669	1.660	1.651
0.02	50.0	45.4	41.6	38.4	35.7	0.52	1.643	1.634	1.626	1.617	1.608
0.03	33.3	31.2	29.4	27.7	26.3	0.53	1.600	1.592	1.583	1.575	1.567
0.04	25.0	23.8	22.7	21.7	20.8	0.54	1.559	1.550	1.542	1.534	1.526
0.05	20.0	19.2	18.5	17.8	17.2	0.55	1.519	1.511	1.503	1.495	1.487
0.06	16.6	16.1	15.6	15.1	14.7	0.56	1.479	1.471	1.464	1.457	1.449
0.07	14.3	13.8	13.5	13.1	12.8	0.57	1.442	1.434	1.427	1.419	1.412
0.08	12.5	12.2	11.9	11.6	11.3	0.58	1.404	1.397	1.390	1.383	1.376
0.09	11.1	10.8	10.6	10.4	10.2	0.59	1.368	1.361	1.354	1.347	1.340
0.10	9.95	9.75	9.56	9.38	9.21	0.60	1.333	1.326	1.319	1.313	1.306
0.11	9.03	8.87	8.71	8.56	8.41	0.61	1.299	1.292	1.286	1.279	1.272
0.12	8.27	8.14	8.00	7.87	7.75	0.62	1.265	1.259	1.252	1.246	1.239
0.13	7.63	7.51	7.40	7.28	7.18	0.63	1.233	1.226	1.220	1.213	1.207
0.14	7.07	6.97	6.87	6.78	6.68	0.64	1.201	1.194	1.188	1.181	1.175
0.15	6.59	6.50	6.42	6.33	6.25	0.65	1.169	1.163	1.157	1.151	1.144
0.16	6.17	6.09	6.02	5.94	5.87	0.66	1.138	1.132	1.126	1.120	1.114
0.17	5.80	5.73	5.66	5.59	5.53	0.67	1.108	1.102	1.096	1.090	1.084
0.18	5.47	5.40	5.34	5.28	5.22	0.68	1.078	1.072	1.067	1.061	1.055
0.19	5.17	5.11	5.06	5.00	4.95	0.69	1.049	1.043	1.037	1.032	1.026
0.20	4.90	4.85	4.80	4.75	4.70	0.70	1.020	1.015	1.009	1.003	0.997
0.21	4.66	4.61	4.56	4.52	4.48	0.71	0.992	0.986	0.981	0.975	0.969
0.22	4.43	4.39	4.35	4.31	4.27	0.72	0.964	0.958	0.953	0.947	0.942
0.23	4.23	4.19	4.15	4.12	4.08	0.73	0.936	0.931	0.925	0.920	0.914
0.24	4.05	4.01	3.97	3.94	3.91	0.74	0.909	0.904	0.898	0.893	0.887
0.25	3.87	3.84	3.81	3.78	3.75	0.75	0.882	0.877	0.871	0.866	0.860
0.26	3.71	3.68	3.65	3.62	3.59	0.76	0.855	0.850	0.845	0.839	0.834
0.27	3.57	3.54	3.51	3.48	3.46	0.77	0.829	0.823	0.818	0.813	0.808
0.28	3.43	3.40	3.38	3.35	3.33	0.78	0.802	0.797	0.792	0.787	0.781
0.29	3.30	3.28	3.25	3.23	3.20	0.79	0.776	0.771	0.766	0.760	0.755
0.30	3.18	3.16	3.13	3.11	3.09	0.80	0.750	0.745	0.740	0.734	0.729
0.31	3.07	3.05	3.02	3.00	2.98	0.81	0.724	0.719	0.714	0.708	0.703
0.32	2.96	2.94	2.92	2.90	2.88	0.82	0.698	0.693	0.688	0.682	0.677
0.33	2.86	2.84	2.82	2.80	2.78	0.83	0.672	0.667	0.662	0.656	0.651
0.34	2.77	2.75	2.73	2.71	2.69	0.84	0.646	0.641	0.635	0.630	0.625
0.35	2.68	2.66	2.64	2.63	2.61	0.85	0.620	0.614	0.609	0.604	0.599
0.36	2.59	2.58	2.56	2.54	2.53	0.86	0.593	0.588	0.583	0.577	0.572
0.37	2.51	2.50	2.48	2.46	2.45	0.87	0.567	0.561	0.556	0.551	0.545
0.38	2.43	2.42	2.40	2.39	2.38	0.88	0.540	0.534	0.529	0.523	0.518
0.39	2.36	2.35	2.33	2.32	2.30	0.89	0.512	0.507	0.501	0.496	0.490
0.40	2.29	2.28	2.26	2.25	2.24	0.90	0.489	0.479	0.473	0.467	0.461
0.41	2.22	2.21	2.20	2.19	2.17	0.91	0.456	0.450	0.444	0.438	0.432
0.42	2.16	2.15	2.14	2.12	2.11	0.92	0.426	0.420	0.414	0.408	0.401
0.43	2.10	2.09	2.08	2.06	2.05	0.93	0.395	0.389	0.383	0.376	0.370
0.44	2.04	2.03	2.02	2.01	2.00	0.94	0.363	0.356	0.350	0.343	0.336
0.45	1.98	1.97	1.96	1.95	1.94	0.95	0.329	0.321	0.314	0.307	0.299
0.46	1.93	1.92	1.91	1.90	1.89	0.96	0.292	0.284	0.276	0.268	0.259
0.47	1.88	1.87	1.86	1.85	1.84	0.97	0.251	0.242	0.232	0.223	0.213
0.48	1.83	1.82	1.81	1.80	1.79	0.98	0.203	0.192	0.181	0.169	0.156
0.49	1.78	1.77	1.76	1.75	1.74	0.99	0.143	0.127	0.110	0.090	0.063

NOTE: This table is to be used like a table of logarithms, *e. g.*, the reactance factor corresponding to the power-factor $k=0.816$ is $t=0.708$.

PARALLEL DISTRIBUTION.

When the translating devices, whether lamps or motors, are scattered over a considerable area, the usual method of supplying them with power is to run a single feeder to some point near the "center of gravity" of the load, and from this center run out branches to feed groups of lamps or motors in parallel. The center of gravity of the load can be readily determined as follows:

Let w_1, w_2, w_3, etc.

represent the individual loads,

and x_1, x_2, x_3, etc.

and y_1, y_2, y_3, etc.,

represent the distances of these loads from any two fixed lines OX and OY at right angles to each other. Then the center of gravity is that point which is the distance

$$X_0 = \frac{x_1w_1 + x_2w_2 + x_3w_3 + \dots}{w_1 + w_2 + w_3 + \dots} \text{ from } OX$$

and

$$Y_0 = \frac{y_1w_1 + y_2w_2 + y_3w_3 + \dots}{w_1 + w_2 + w_3 + \dots} \text{ from } OY.$$

The center of gravity of the load is by no means always the most economical location for the center of distribution, as considerations of the relative cost of establishing the center at this point in comparison with the cost at other points, the probable change in the distribution of the load with the growth of the system, etc., have all to be taken into account.

The general scheme of feeders, centers of distribution, and branches can be developed still further, and sub-centers, sub-feeders, etc., established, until a point is reached where the saving in the cost of copper is balanced by the increase in the cost of the centers of distribution.

Calculation of Cross Section, Weight, &c.

When a transmission line is loaded at more than one point, the conductor should have such dimensions that the pressure drop at the end of the line, when the line is supplying the maximum load at each point, shall not exceed a given amount. Whether the conductor shall be made of uniform section throughout the length of the line, or be reduced in size as the current carried diminishes, will depend on the relative amounts of energy supplied at, and the distances between, the various points at which the line is loaded. Below will be found formulæ for determining the weight and cross section of a line of uniform cross section, *and having no reactance*, supplying a distributed load. When the line has no inductive reactance the weight and cross section of the conductor for a given pressure drop are to a close approximation independent of the power factor of the loads at the various points. When the line has reactance, the formulæ will give only a first approximation to the correct weight and cross section. The error involved can be determined by considering each section of the line separately, and calculating the drop in each section, assuming the dimensions given by the approximate formulæ. (See page 264.) If the pressure drop at the end of the line thus calculated differs considerably from the permissible drop given, choose a larger size wire and make another trial calculation, etc., until the proper size is found.

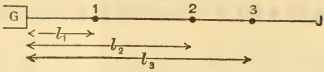


FIG. 15.

In the figure let G be the generating end of the line; J the far end of line

Given:

E = pressure between adjacent wires at far end of line in volts.

W_1, W_2, W_3, etc., the loads in kilowatts at the points 1, 2, 3, etc.

l_1, l_2, l_3, etc., the distances of these points from the generating end in feet.

P = per cent pressure drop at far end of line in terms of delivered pressure.

Required:

A = cross section of each wire in million C.M.

w = total weight of conductors in pounds.

Put

$W = W_1 + W_2 + W_3 + \ldots$ total power delivered in kilowatts.

$l = l_1 + l_2 + l_3 + \ldots$ total length of circuit (length of each wire) in feet.

$$F = \frac{l_1W_1 + l_2W_2 + l_3W_3 + \ldots}{E^2}.$$

Then, for a line *having no reactance:*

		Copper. 100% conductivity. 20° Centigrade.	Aluminum. 62% conductivity. 20° Centigrade.	Any Material. ρ = microhms per cu. in. δ = lbs. per cu. in.
Single Phase.				
Cross section in million C.M.	$A =$	$\frac{2.08F}{P}$	$\frac{3.34F}{P}$	$\frac{3.06\rho F}{P}$
Total weight of conductors	$w =$	$6.06lA$	$1.83lA$	$18.9\delta lA$
Or total weight of conductors	$w =$	$\frac{12.6Fl}{P}$	$\frac{6.11Fl}{P}$	$\frac{57.8\delta lF}{P}$
Three Phase.				
Cross section in million C.M.	$A =$	$\frac{1.04F}{P}$	$\frac{1.67F}{P}$	$\frac{1.53\rho F}{P}$
Total weight of conductors	$w =$	$9.09lA$	$2.74lA$	$28.3\delta lA$
Or total weight of conductors	$w =$	$\frac{9.48Fl}{P}$	$\frac{4.58Fl}{P}$	$\frac{43.2\rho\delta lF}{P}$

Economical Tapering of Conductor.

When the distances between the points at which the line is loaded are considerable, it is usually advantageous to taper the conductor; the most economical pressure drop per section must be determined, and each section of the line calculated independently. The following formulæ give the most economical division of the drop, taking into account the cost both of conductor and insulation. For short runs the saving in cost of conductor and insulation may be more than offset by the extra cost of handling two or more sizes of wire.

The same notation as in the preceding paragraph is used. In addition, let

$U_1 = W_1 + W_2 + W_3 + \ldots =$ total load in kilowatts at and beyond point 1.
$U_2 = W_2 + W_3 + \ldots =$ total load in kilowatts at and beyond point 2.
$U_3 = W_3 + \ldots =$ total load in kilowatts at and beyond point 3.
etc.

$\lambda_1 = l_1 =$ distance in feet from generating end to point 1.
$\lambda_2 = l_2 - l_1 =$ distance in feet between points 1 and 2.
$\lambda_3 = l_3 - l_2 =$ distance in feet between points 2 and 3.
etc.

Then the most economical per cent pressure drop for the ith section is

$$Pi = \frac{\lambda_i \sqrt{U_i}}{\lambda_1 \sqrt{U_1} + \lambda_2 \sqrt{U_2} + \lambda_3 \sqrt{U_3}} \times P.$$

House Wiring.

As a rule, the size of wire used in wiring ordinary buildings for light and power as fixed by the permissible heating of the wire (see p. 265) is of sufficient size to keep the pressure drop within the prescribed limit, since the distances the wires are run are comparatively short. It is always well, however, to calculate the drop in the heaviest and longest circuits, to be sure that one is on the safe side as regards regulation.

Chart and Table for calculating Alternating-Current Lines.

RALPH D. MERSHON, in *American Electrician.*

The accompanying table, and chart on page 282 include everything necessary for calculating the copper of alternating-current lines.

The terms, resistance volts, resistance E.M.F., reactance volts, and reactance E.M.F., refer to the voltages for overcoming the back E.M.F.'s due to resistance and reactance respectively. The following examples illustrate the use of the chart and table.

PROBLEM. — Power to be delivered, 250 k.w.; E.M.F. to be delivered, 2000 volts; distance of transmission, 10,000 ft.; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; alternations, 7200 per minute. Find the line loss and drop.

The power factor is that fraction by which the apparent power or volt-amperes must be multiplied to give the true power or watts. Therefore the apparent power to be delivered is $\frac{250 \text{ k.w.}}{.8} = 312.5$ apparent k.w., or 312,500 volt-amperes, or apparent watts. The current, therefore, at 2000 volts will be $\frac{312,500}{2000} = 156.25$ amperes. From the table of reactances, under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant, .228. Bearing the instructions of the table in mind, the reactance volts of this line are 156.25 (amperes) × 10 (thousands of feet) × .228 = 356.3 volts, which are 17.8 per cent of the 2000 volts to be delivered.

From the column headed "Resistance Volts," and corresponding to No. 0 wire, is obtained the constant .197. The resistance volts of the line are, therefore, 156.25 (amperes) × 10 (thousands of feet) × .197 = 307.8 volts, which are 15.4 per cent of the 2000 volts to be delivered.

Starting, in accordance with the instructions of the sheet, from the point where the vertical line, which at the bottom of the sheet is marked "Load Power Factor .8," intersects the inner or smallest circle, lay off horizontally and to the right the resistance E.M.F. in per cent (15.4), and "from the point thus obtained," lay off vertically the reactance E.M.F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop in per cent of the *E.M.F. delivered*. The drop in per cent of the *generator* E.M.F. is, of course, $\frac{23}{100+23} = 18.7$ per cent.

The resistance volts in this case being 307.8, and the current 156.25 amperes, the energy loss is 307.8 × 156.25 = 48.1 k.w. The percentage loss is $\frac{48.1}{250+48.1} = 16.1$. Therefore, for the problem taken, the drop is 18.7 per cent, and the energy loss is 16.1 per cent.

If the problem be to find the size of wire for a given drop, it must be solved by trial. Assume a size of wire, and calculate the drop in the manner above indicated; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The table is made out for 7200 alternations per minute, but will answer for any other number. For instance, for 16,000 alternations, multiply the reactances by 16000 ÷ 7200 = 2.22.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of the table and chart in calculating low-voltage mains, the following example is given: —

PROBLEM. — A single-phase, induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7200 per minute; power factor, .78. The distance from transformer to motor is 150 ft., and the line is No. 5 wire, 6 inches between centres of conductors. The transformer reduces in the ratio 2000 : 200, and has a capacity of 25 amperes at 200 volts; when delivering this current and voltage, its resistance E.M.F. is as 2.5 per cent, and its reactance E.M.F. 5 per cent, both of these constants being furnished by the makers. Find the drop.

The reactance of 1000 ft. of circuit, consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts, therefore, are $.204 \times \frac{150}{1000} \times 20 = .61$ volts. The resistance-volts are $.627 \times \frac{150}{1000} \times 20 = 1.88$ volts. At 25 amperes, the resistance-volts of the transformers are 2.5 per cent of 200, or 5 volts. At 20 amperes they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are 8 + .61 = 8.61, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are 1.88 + 4, or 5.88, which is 2.94 per cent of the E.M.F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E.M.F., or $\frac{5}{105} = 4.8$ per cent of the impressed E.M.F. The transformer must therefore be supplied with 2000 ÷ .952 = 2100 volts, in order that 200 volts shall be delivered to the motor.

To calculate a four-wire, two-phased transmission circuit, compute, as above, the single-phased circuit required to transmit one-half the power at the same voltage. The two-phase transmission will require two such circuits.

To calculate a three-phase transmission, compute, as above, a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size obtained for the single-phase circuit, and with the same distance (triangular) between centres.

By means of the table calculate the *Resistance-Volts* and the *Reactance-*

Volts in the line, and find what per cent each is of the E.M.F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with power factor of the load intersects the smallest circle, lay off in per cent the resistance E.M.F. horizontally and to the right; from the point thus obtained lay off upward in per cent the reactance E.M.F. The circle on which the last point falls gives the drop in per cent of the E.M.F. delivered at the end of the line. Every tenth circle-arc is marked with the per cent drop to which it corresponds.

Size of Wire B.&S.	Weight-Pounds per 1000 ft. Single Wire.	Resistance-Volts in 1000 ft. of Line (2000 ft. of wire) for One Ampere ($\sqrt{\text{Mean Square}}$).	Reactance-Volts in 1000 ft. of Line (=2000 ft. of Wire) for One Ampere ($\sqrt{\text{Mean Square}}$) at 7200 Alternations per Minute for the Distance given between Centers of Conductors.										
			½″	1″	2″	3″	6″	9″	12″	18″	24″	30″	36″
0000	639	.098	.046	.079	.111	.130	.161	.180	.193	.212	.225	.235	.244
000	507	.124	.052	.085	.116	.135	.167	.185	.199	.217	.230	.241	.249
00	402	.156	.057	.090	.121	.140	.172	.190	.204	.222	.236	.246	.254
0	319	.197	.063	.095	.127	.145	.177	.196	.209	.228	.241	.251	.259
1	253	.248	.068	.101	.132	.151	.183	.201	.214	.233	.246	.256	.265
2	201	.313	.074	.106	.138	.156	.188	.206	.220	.238	.252	.262	.270
3	159	.394	.079	.112	.143	.162	.193	.212	.225	.244	.257	.267	.275
4	126	.497	.085	.117	.149	.167	.199	.217	.230	.249	.262	.272	.281
5	100	.627	.090	.121	.154	.172	.204	.223	.236	.254	.268	.278	.286
6	79	.791	.095	.127	.158	.178	.209	.228	.241	.260	.272	.283	.291
7	63	.997	.101	.132	.164	.183	.214	.233	.246	.265	.278	.288	.296
8	50	1.260	.106	.138	.169	.188	.220	.238	.252	.270	.284	.293	.302

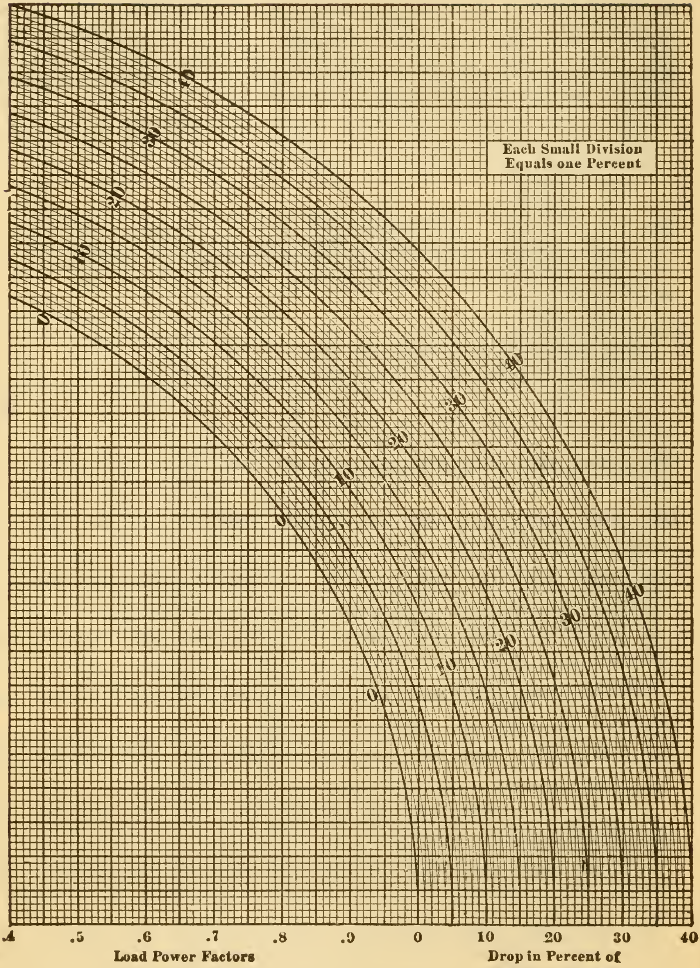

Each Small Division
Equals one Percent
0
10
20
30
40
0
10
20
30
40
0
10
20
30
40
.4
.5
.6
.7
.8
.9
0
10
20
30
40
Load Power Factors
Drop in Percent of
E.M.F. Delivered

FIG. 16.

The following curves published by the General Electric Company give the pounds of copper per kilowatt delivered for various percentages of power loss and various pressure gradients (volts per mile). It is to be noted that these curves are correct only for unity power factor.

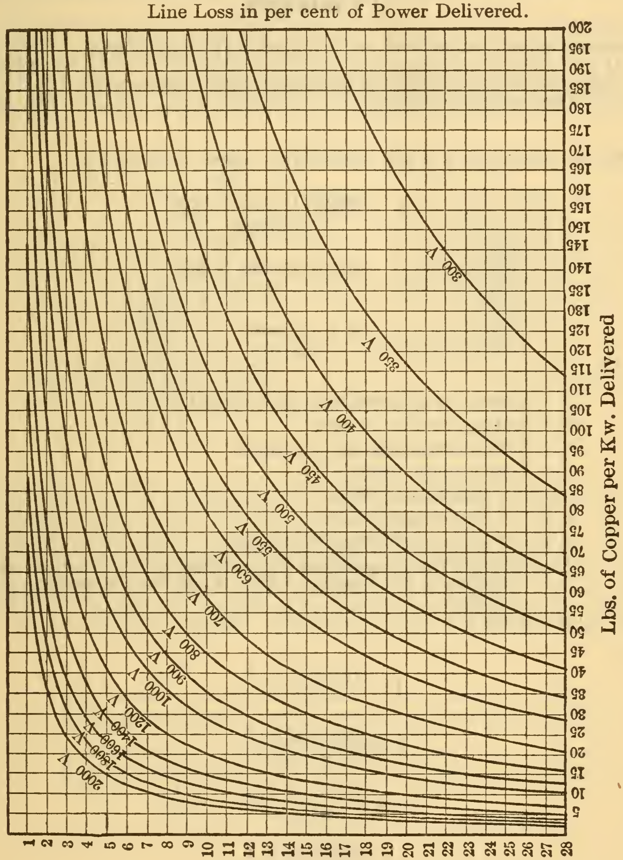


FIG. 17.

EXPLANATION: Figures on curves indicate volts per mile, i.e., potential of line divided by distance. Weight of copper, potential, and line loss are in terms of power delivered at end of line and not of generated power. Curves are correct only for 100% power factor. Two-phase, single-phase or continuous current transmission requires one-third more copper. 5% has been allowed for sag and tie wires in weights of copper given.

EXAMPLE: Assuming that 1000 kw. at 10,000 volts are to be delivered over a line 10 miles long with 5% loss, we have $\frac{10{,}000 \text{ volts}}{10 \text{ miles}} = 1000$ volts per mile. Looking on the 1000 volt curve, we find 5% line loss corresponds to 57 lbs. of copper per kilowatt delivered.

DETERMINATION OF SIZE OF CONDUCTORS FOR PARALLEL DISTRIBUTION OF DIRECT CURRENT.

Resistance of one cir.-mil-foot of pure hard drawn copper wire at 20° C. (68° F.) (see page 200)	10.57 ohms
Resistance of one cir.-mil-foot of pure hard drawn copper wire at 97.5 per cent conductivity	10.8 ohms

Thus the resistance R of any hard drawn copper conductor is,

$$R = \frac{\text{length in feet} \times 10.8}{\text{cir. mils}},$$

and

$$\text{Cir. mils} = \frac{\text{length in feet} \times 10.8}{R},$$

or

$$\text{Length in feet} = \frac{R \times \text{cir. mils}}{10.8}.$$

Let I = Current in amperes flowing in circuit.
W = Watts, power in circuit.
E = Volts at receiving end of circuit.
v = Volts drop in circuit.
A = Cir. mils area of wire.
P = Per cent of power lost.
p = Per cent of volts drop in circuit.
d = Distance from generating to receiving end of circuit or center of load $= \frac{1}{2}$ the length of wire if the load is uniformly distributed.
$21.6 = 10.8 \times 2.$

Then

$$A = \frac{21.6 \times d \times I}{v},$$

or

$$A = \frac{2160 \times d \times I}{p \times E},$$

or

$$A = \frac{2160 \times d \times W}{P \times E^2},$$

$$v = \frac{21.6 \times d \times I}{A},$$

$$v = \frac{p \times E}{100}.$$

TRANSPOSITION OF LINES.

F. F. Fowle.

The transposition of overhead lines is a means for eliminating induction between them and is universally employed on telephone lines and quite frequently on power and lighting circuits.

Transpositions are effective only under certain conditions. Fig. 18 shows the electric and the magnetic fields about a line consisting of a single wire whose circuit is completed through the earth. Fig. 19 shows the fields

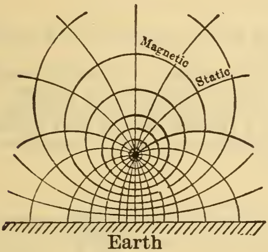


Fig. 18.

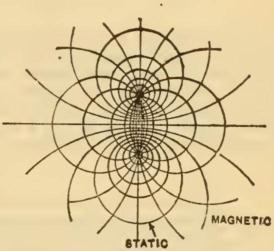


Fig. 19.

about the two wires of a metallic circuit, with equal and opposite currents in the wires and no connection to earth at any point on the circuit. In telephony this condition of line is termed "balanced."

The intensity of the induced current depends on the extent to which the field of one circuit threads into the other, and therefore upon the distance between the wires and the extent to which their fields spread into the surrounding dielectric. The spread of the field of a single-wire circuit, shown in Fig. 18, is equal to that of an imaginary metallic circuit of which one wire is the existing overhead wire and the other a similar wire parallel to

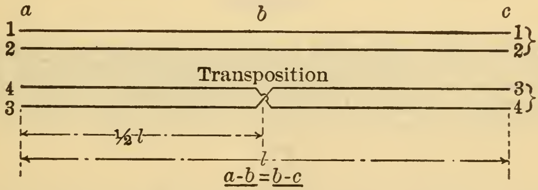


Fig. 20.

the existing wire but beneath the earth's surface a distance equal to the elevation of the existing wire. The spread of the field of single-wire earth-return circuits is therefore excessive.

Fig. 20 shows the manner of neutralizing mutual inductive effects of two metallic circuits by the transposition of the wires of one circuit. By the transposition of wires 3 and 4 midway in the section the field of the circuit 3–4 from *a* to *b* is opposite in its direction and polarity to that between *b* and *c*, so that the induced E.M.F.'s in circuit 1–2 between *a* and *b* are opposite to those between *b* and *c*. The same is true of induced E.M.F.'s in circuit 3–4 produced by circuit 1–2. The effects would have been identical had 1 and 2 been transposed instead of 3 and 4.

Referring to Fig. 20, the length of the section *l* must not be so great that the current and the potential in the section *a–b* are materially different from

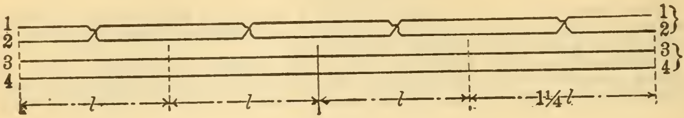


FIG. 21.

those in the section *b–c*, or the induced E.M.F.'s in the section *a–b* will now be equal as well as opposite to those in *b–c*.

After determining the proper length of the section *l*, the section may be applied consecutively to a line which is to be transposed, by laying it off in the manner of using a foot rule in the measurement of a distance. If the total length of line is not a multiple of *l*, the last section may be taken somewhat longer or shorter than the standard section, but it should be not

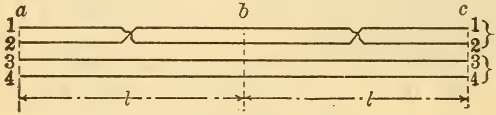


FIG. 22.

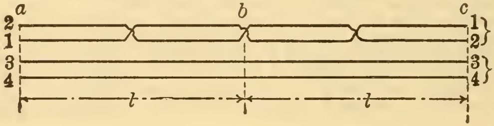


FIG. 22A.

more than one and a half regular sections nor less than half a regular section. Fig. 21 shows a line having four and a quarter transposition sections.

A transposition at the junction of two adjacent sections is without effect on those sections, therefore the Fig. 22A is equivalent to Fig. 22. This

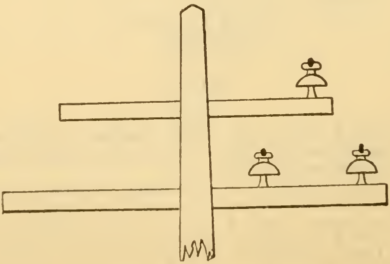


FIG. 23.

is true only when the standard section length is not in excess of that permissible, as outlined above.

The transposition of power and lighting circuits is not often necessary. In complicated networks it is almost unknown, because the troublesome

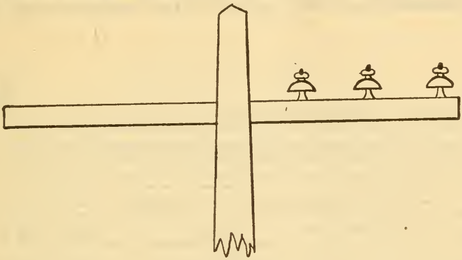


FIG. 24.

circuits are usually short. At the frequencies used in power and lighting the transposition section may be several miles in length, much longer than in telephone practice.

The transposition of polyphase lines is sometimes employed to balance inductive effects which would otherwise be troublesome.

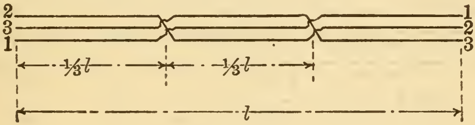


FIG. 25.

Fig. 23 shows a balanced three-phase line, which would be transposed only to avoid inductive interference with other lines.

Fig. 24 shows an unbalanced three-phase line and Fig. 25 shows the method of transposing it to secure a balanced circuit, or equal inductance per phase. Fig. 26 illustrates the application of the section shown in Fig. 8.

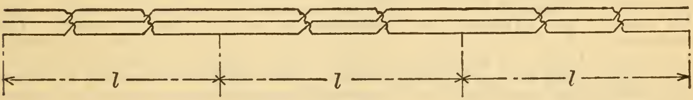


FIG. 26.

The transposition of telephone lines becomes a complicated problem when there are many circuits, as it is necessary to arrange the transpositions in such a manner that each circuit is transposed with respect to all the others;

also the circuits that are adjacent must have more frequent relative transpositions than those further apart. The method of deriving differently transposed types of circuits is given in an American Institute paper on "The Transposition of Electrical Conductors." *

Fig. 27 shows fifteen different types of transposition. The "exposure," as it is termed, of circuit 1 to circuit 2 is $\frac{1}{4}$; of 1 to 3 is $\frac{1}{4}$; of 2 to 3 is $\frac{1}{2}$; because a transposition at the junction of two sections, each transposed at

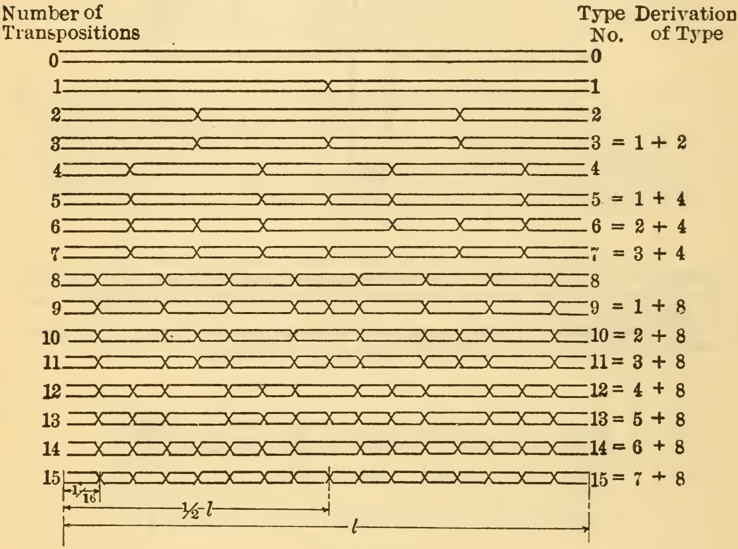


FIG. 27.

its center, has almost no beneficial effect. The exposure of 1 to 5 is $\frac{1}{8}$; of 2 to 6 and 3 to 7, $\frac{1}{8}$; of 2 to 8 and 2 to 9, $\frac{1}{16}$; and so on. The tabulated exposures are given in Fig. 28, in terms of the length 1 of a transposition section. The method may be extended as far as desired, but 15 types are usually sufficient.

It has been found experimentally that one-fourth mile exposures are satisfactory in telephone work for circuits immediately adjacent to each other; for circuits not adjacent the transpositions may be farther apart. The distance l in Fig. 27 may then be taken at four miles, and fifteen differently transposed types are available. The method may be extended to thirty-two types with an eight mile section. The eight mile section is rather cumbersome for most work and a four mile section is more adaptable to general conditions.

The transposition of telephone circuits against power and lighting circuits should be treated on the sectional principle. It is possible to improve some cases by reducing the separation between the wires of the power or lighting circuit; this is usually the cheapest plan if the transposition section

* Vol. XXIII, page 659, Oct. 28, 1904.

is long and there are many telephone circuits. For the voltages less than 5000, in distribution systems, a separation of 18 to 24 inches is ample for spans less than 150 feet.

At points where telephone lines are transposed against power and lighting circuits, all the telephone circuits should be transposed; the cross-talk exposures will not be altered.

Exposure of Type No.

To	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	$\frac{1}{2}$														
2	$\frac{1}{4}$	$\frac{1}{4}$													
3	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$												
4	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$											
5	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$										
6	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$									
7	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$								
8	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$							
9	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{2}$						
10	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{4}$					
11	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$				
12	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$			
13	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$		
14	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{5}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	
15	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$

FIG. 28.

Fig. 29 shows a typical case and its treatment. The procedure is to lay out transposition sections to take care of the induction from the power or lighting circuits, the "induction sections," so that they will not interfere with the "cross-talk sections;" to do this it is necessary that the junction of two induction sections occur at the same place as the cross-talk transpositions; the induction sections should also terminate at points opposite changes in the distributing circuits, as on opposite sides of these points the induction will not be equal.

When telephone lines are exposed to complicated distribution systems, transposition, as a rule, is not effective.

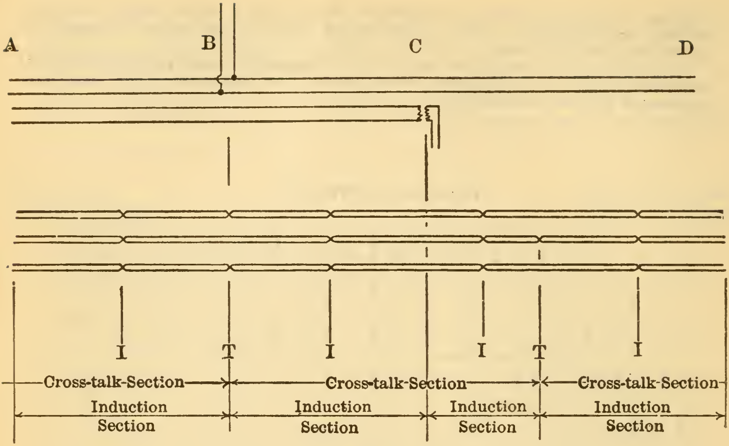


FIG. 29.

Niagara Line. — The conductors on this line are bare cables of 19 strands, equivalent to 350,000 circuit mils, and are arranged as shown in the following diagram. The first arrangement was with two three-wire cir-

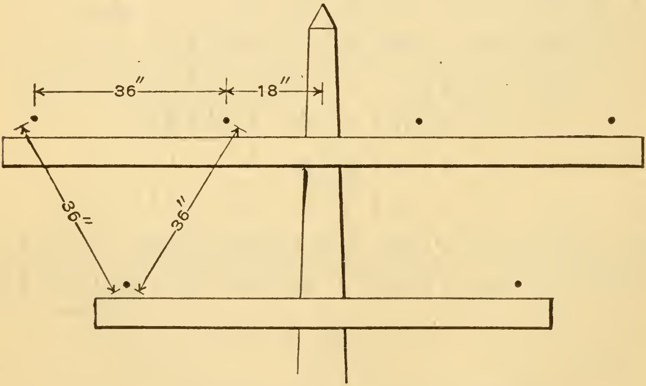


FIG. 30. Niagara-Buffalo Line. 11000 to 22000 Volts.

cuits on the upper cross-arm, the wires being 18 inches apart. So much trouble was experienced from short circuits by wires and other material being thrown across the conductors, that the middle wire was lowered to the bottom cross-arm as shown, since which time no trouble has been experienced. With porcelain insulators tested to 40,000 volts there is no appreciable leakage. These circuits are interchanged at a number of points to avoid inductive effects.

Three-Phase Circuits. — The diagram (Fig. 31) shows another arrangement now seldom used although it makes lines conveniently accessible for repairs. Under the ordinary loads usual in the smaller plants the unbalancing effect is so small as to be inappreciable.

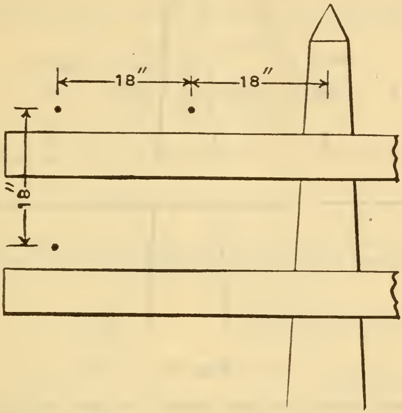


FIG. 31. Convenient Arrangement of Three-Phase Lines for, 6000–10,000 Volts.

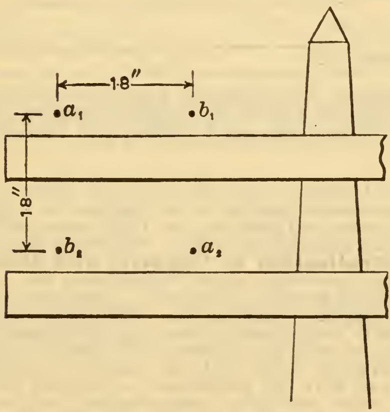


FIG. 32. Arrangement of Two-Phase Circuit. No Reversal of Phases necessary.

Two-Phase, Four-wire Circuits. — The arrangement of conductors shown in Fig. 32 is probably the best for two-phase work; as no reversals of wires are needed, the inductive effects of the wires of one circuit on those of the other are neutralized.

Two-Phase Circuits in Same Plane. — If the phases are treated as separate circuits, and carried well apart, as shown in Fig. 33, the interfer-

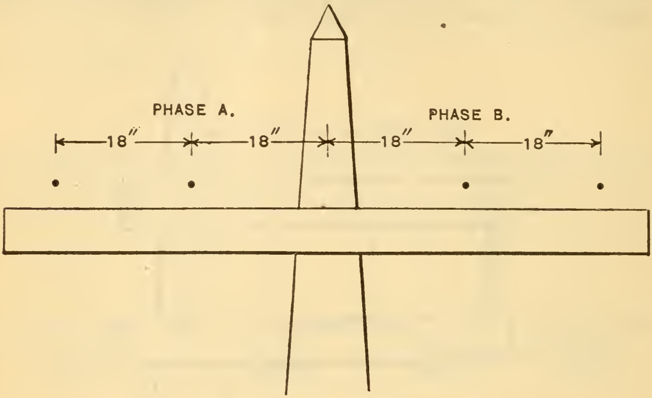


Fig. 33.

ence is trifling; and should the loads carried be heavy enough to cause noticeable effect, the reversal of one of the phases in the middle of its length will obviate it. The following diagram illustrates the meaning.

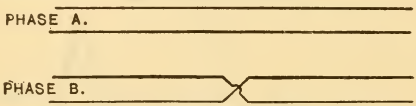


Fig. 34. Arrangement of Two-Phase, Four-Wire Circuit with Wires on same Plane. Wires of One Phase should be interchanged at the Middle Point of the Distance between Branches, and between its Origin and First Branch.

Messrs. Scott and Mershon of the Westinghouse Electric and Manufacturing Co. have made special studies of the question of mutual induction of circuits, both in theory and practice; and their papers can be found in the files of the technical journals, and supply full detail information.

Mutual Neutralization of Capacity and Inductance. — In order to completely neutralize phase displacement due to distributed inductance a distributed capacity is essential. Localized capacity can, however, produce a partial neutralization. Excessive distributed capacity can also be partially neutralized by inserting inductances at proper intervals. In treating of local neutralization of capacity by inductance, the assumption is frequently made that the capacity is constant irrespective of the voltage, and that the inductance is constant irrespective of the current. Under these conditions neutralization can be obtained. As, however, inductance is dependent upon the permeability of the associated magnetic circuit, and permeability varies with the saturation of the iron, — that is, with the current, — complete neutralization cannot be obtained with iron inductances.

Over-excited synchronous motors, or synchronous converters, take currents which lead the electromotive force impressed upon them, and they therefore operate as condensers, and they may be utilized advantageously in neutralizing the line inductance. The power factor of the transmission system can therefore be varied by varying their excitation.

LOSS IN SHEATH OF THREE-CONDUCTOR LEAD COVERED CABLES.

JOHN T. MORRIS (*Electrician, London*) gives the following formula, confirmed by experiments, for the loss of power in the lead sheath of a three-conductor cable.

Let I = current in amperes.
f = frequency.
l = length of cable in 1000 ft.
t = thickness of sheath in mils.

Then: $\text{Watts loss} = 123 \times 10^{-10} I^2 f^2 l t^{0.7}$.

If the cable is placed in an iron pipe the loss is increased about 75%.

BELL WIRING.

The following diagrams show various methods of connecting up-call bells for different purposes, and will indicate ways in which incandescent lamps may also be connected to accomplish different results.

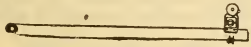


FIG. 35. One Bell, operated by One Push.

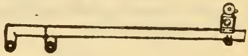


FIG. 36. One Bell, operated by Two Pushes.

FIG. 37. Two Bells, operated by One Push.

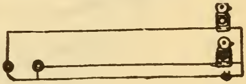


FIG. 38. Two Bells, operated by Two Pushes.

When two or more bells are required to ring from one push, the common practice is to connect them in series, i.e., wire from one directly to the next, and to make all but one single-stroke ends. Bells connected in multiple arc, as in diagram No. 24, give better satisfaction, although requiring more wire.

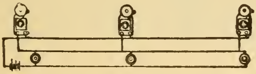


FIG. 39. Three-Line Factory Call. A number of Bells operated by any number of pushes. All bells rung by each push.

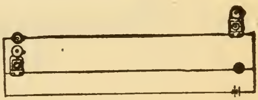


FIG. 40. Simple Button, Three-Line Return Call. One set of battery.

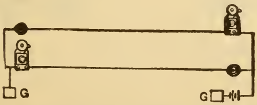


FIG. 41. Simple Button, Two-Line and Ground Return Call. One set of battery.

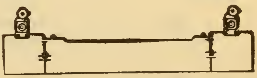


FIG. 42. Two-Line Return Call. Illustrating use of Return Call Button. Bells ring separately.

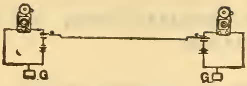


FIG. 43. One-Line and Ground Return Call. Illustrating use of Return Call Button. Bells ring separately.

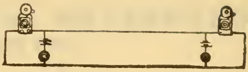


FIG 44. Simple Button, Two-Line Return Call. Bells ring together.

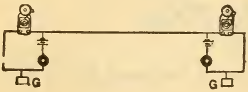


FIG. 45. Simple Button, One-Line and Ground Return Call. Bells ring together. The use of complete metallic circuit in place of ground connection is advised in all cases where expense of wire is not considerable.

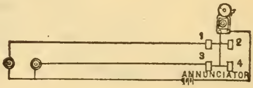


FIG. 46. Four Indication Annunciator. Connections drawn for two buttons only. A burglar alarm circuit is similar to the above, but with one extra wire running from door or window-spring side of battery to burglar alarm in order to operate continuous ringing attachment.

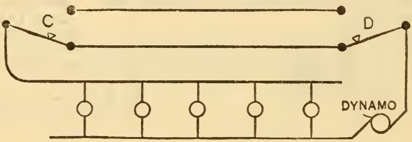


FIG. 47.

Diagram of connections for control of lights from two points.

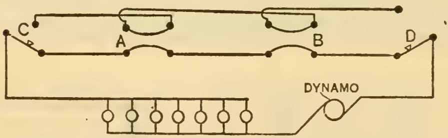


FIG. 48.

Diagram of connections for control of lights from four points. By introducing other switches like *A* and *B* control can be had from any number of points.

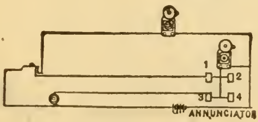


FIG. 49. Four Indication Annunciator, with extra Bell to ring from one Push only. Illustrating use of three-point button.

FIG. 50. Acoustic Telephone with Magneto Bell Return Call. Extension Bell at one end of line.

In running lines between any two points, use care to place the battery, if possible, near the push-button end of the line, as a slight leakage in the circuit will not then weaken the battery.

When mat is to be used, throw it into the circuit by the switch, so that when the circuit is closed by a person stepping on the mat, the automatic drop will keep it closed, and both bells will continue to ring until the drop is hooked up again.

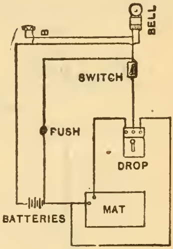


Fig. 51. Diagram of Burglar-Alarm Mat, two Bells, one Push and Automatic Drop; all operated by one battery. Both bells ring from one push or mat, as desired, by changing the switch.

GAS-LIGHT WIRING.

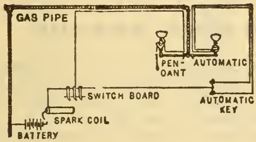


Fig. 52. Pendant and Automatic Gas-Lighting Circuit, with Switchboard.

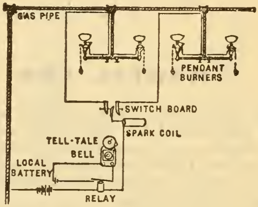


Fig. 53. Pendant Gas-Lighting Circuit, with Switchboard, Relay and Tell-Tale Bell.

WIRING FOR GENERATORS.

The generators are rated by their volt-ampere capacity and their apparent watts, and not their actual watts, so that the size has to be increased if the power-factor of the system is low.

WIRING FOR TRANSFORMERS.

For lighting circuits using small transformers, the voltage at the primaries of the step-down transformers should be made about 3% higher than the secondary voltage multiplied by the ratio of transformation, to allow for the drop in transformers. In large lighting transformers this drop may be as low as 2%. Standard lighting transformers have a ratio of 10 to 1 or some multiple thereof.

For motor circuits, the voltage at the primaries of step-down transformers should be made about 5% higher than the secondary voltage multiplied by the ratio of transformation. Transformers used with 110 volt motors on any 60-cycle system should have a ratio of 4½ to 1, 9 to 1, or 18 to 1 respectively for 1040, 2080, and 3120 volt generators. The transformer capacity in *kilowatts* should be the same as the motor rating in *horse-power* for medium-sized motors, and slightly larger for small motors and where only two transformers are used.

Capacities of Transformers to be used with 60-Cycle Induction Motors.

Size of Motor. Horse-Power.	Kilowatts per Transformer.	
	Two Transformers.	Three Transformers.
1	.6	.6
2	1.5	1
3	2	1.5
5	3	2
7½	4	3
10	5	4
15	7.5	5
20	10	7.5
30	15	10
50	25	15
75		25

WIRING FOR INDUCTION MOTORS.

The standard (General Electric) induction motors for three-phase circuits are wound for 110 volts, 220 volts, and 550 volts; motors of 50 H.P. and above are, in addition, wound for 1040 volts and 2080 volts. Motors for the two latter voltages are not built in sizes of less than 50 H.P. Where the four-wire, three-phase distribution system is used, motors can also be wound for 200 volts.

The output of an induction motor varies with the square of the voltage at the motor terminals. Thus, if the volts at the terminals happen to be 15% low, that is, only 85% of the rated voltage, a motor, which at the rated voltage gives a maximum of 150% of its rated output, will be able to give at the 15% lower voltage, only $(\frac{85}{100})^2 \times 150 = 108\%$ of its rated output, and at full load will have no margin left to carry over sudden fluctuations of load while running.

Thus it is of the utmost importance to take care that the volts at the motor terminals are not below the rated volts, but rather slightly above at no load, so as not to drop below rated voltage at full-load or over-load.

The output of the motor may be increased by raising the potential; in this case, however, the current taken is increased, especially at light loads.

The direction of rotation of an induction motor on a three-phase circuit can be reversed by changing any two of the leads to the field.

Like all electrical apparatus, the induction motor works most efficiently at or near full load, and its efficiency decreases at light load. Besides this, when running at light load, or no load, the induction motor draws from the lines a current of about 30% to 35% of the full-load current. This current does not represent energy, and is not therefore measured by the recording watt-meter; it constitutes no waste of power, being merely what is called an idle or "wattless" current. If, however, many induction motors are operated at light loads from a generator, the combined wattless currents of the motors may represent a considerable part of the rated current of the generator, and thus the generator will send a considerable current over the line. This current is wattless, and does not do any work, so that in an extreme case an alternator may run at apparently half-load or nearly full-load current, and still the engine driving it run light. While these idle currents are in general not objectionable, since they do not represent any waste of power, they are undesirable when excessive, by increasing the current-heating of the generator. Therefore it is desirable to keep the idle currents in the system as low as possible, by carefully choosing proper capacities of motors. These idle currents are a comparatively small per cent of the total current at or near full-load of the motor, but a larger per cent at light loads. Therefore care should be taken not to install larger motors than necessary to do the required work, since in this case the motors would have to work continuously at light loads, thereby producing a larger per cent of idle current in the system than would be produced by motors of proper capacity; that is, motors running mostly between half-load and full-load.

Current taken by General Electric Co., Three-Phase Induction Motors at 110 Volts.

H.P. of Motor.	Full-Load Current.	Starting Current at 150% of Full-Load Torque.	Starting Current at Full-Load Torque.
1	6.5	19	
2	12	36	
3	17	54	
5	28	*42–84	28
10	55	70	55
15	80	120	80
20	105	167	105
30	150	252	150
50	250	400	250
75	370	585	370
100	500	825	500
150	740	1180	740

The current taken by motors of higher voltage than 110 will be proportionally less. The above are average current values, and in particular cases the values may vary slightly.

CONNECTIONS OF TRANSFORMERS FOR WIRING.

The connection of three transformers, with their primaries, to the generator and their secondaries to the induction motor, in a three-phase system, are shown in Fig. 26. The three transformers are connected with their primaries between the three lines leading from the generator, and the three secondaries are connected to the three lines leading to the motor, in what is called delta connection.

The connection of two transformers for the supply of an induction motor from a three-phase generator is shown in Fig. 55. It is identical with the

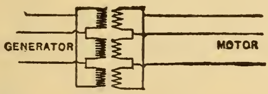


FIG. 54.

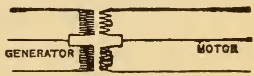


FIG. 55.

arrangement in Fig. 54, except that one of the transformers is left out, and the two other transformers are made correspondingly larger. The copper required in any three-wire, three-phase circuit for a given power and loss is 75%, as compared with the two-wire, single-phase, or four-wire, two-phase system, having the same voltage between lines.

* The 5 H.P. motor is made with or without starting-switch.

The connections of three transformers for a low-tension distribution system by the four-wire, three-phase system are shown in Fig. 56. The three transformers have their primaries joined in delta connection, and their secondaries in " Y " connection. The three upper lines are the three main three-phase lines, and the lowest line is the common neutral. The difference of potential between the main conductor is 200 volts, while that between either of them and the neutral is 115 volts. 200 volt-motors are joined to the

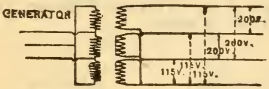


FIG. 56.

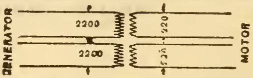


FIG. 57.

mains while 115 volt-lamps are connected between the mains and the neutral. The neutral is similar to the neutral wire in the Edison three-wire system, and only carries current when the lamp load is unbalanced.

The potential between the main conductors should be used in the formulæ, and the section of neutral wire should be made in the proportion to each of the main conductors that the lighting load is to the total load. When lights only are used, the neutral should be of the same size as either of the three main conductors. The copper then required in a four-wire, three-phase system of secondary distribution to transmit a given power at a given loss is about 33.3 %, as compared with a two-wire, single-phase system, or a four-wire, two-phase system having the same voltage across the lamps.

The connections of two transformers for supplying motors on the four-wire, two-phase system are shown in Fig. 57. This system practically consists of two separate single-phase circuits, half the power being transmitted over each circuit when the load is balanced. The copper required, as compared with the three-phase system to transmit given power with given loss at the same voltage between lines, is 133⅓ % — that is, the same as with a single-phase system.

STANDARD SYMBOLS FOR WIRING PLANS AS ADOPTED BY THE NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION.

(Copyrighted.)

Ceiling Outlet; Electric only. Numeral in center indicates number of Standard 16 C.P. Incandescent Lamps.

Ceiling Outlet; Combination. $\frac{4}{2}$ indicates 4-16 C.P. Standard Incandescent Lamps and 2 Gas Burners. If gas only

Bracket Outlet; Electric only. Numeral in center indicates number of Standard 16 C.P. Incandescent Lamps.

Bracket Outlet; Combinations. $\frac{4}{2}$ indicates 4-16 C.P. Standard Incandescent Lamps and 2 Gas Burners. If gas only

Wall or Baseboard Receptacle Outlet. Numeral in center indicates number of Standard 16 C.P. Incandescent Lamps.

Floor Outlet. Numeral in center indicates number of Standard 16 C.P. Incandescent Lamps.

Outlet for Outdoor Standard or Pedestal; Electric only. Numeral indicates number of Standard 16 C.P. Incandescent Lamps.

Outlet for Outdoor Standard or Pedestal; Combination. $\frac{6}{6}$ indicates 6-16 C.P. Standard Incandescent Lamps; 6 Gas Burners.

Drop Cord Outlet.

One Light Outlet, for Lamp Receptacle.

Arc Lamp Outlet.

Special Outlet, for Lighting, Heating and Power Current, as described in Specifications.

Ceiling Fan Outlet.

S^1 S. P. Switch Outlet.
S^2 D. P. Switch Outlet.
S^3 3-Way Switch Outlet.
S^4 4-Way Switch Outlet.
S^D Automatic Door Switch Outlet.
S^E Electrolier Switch Outlet.

Show as many Symbols as there are Switches. Or in case of a very large group of Switches, indicate number of Switches by a Roman numeral, thus; S′ XII; meaning 12 Single Pole Switches.
Describe Type of Switch in Specifications, that is, Flush or Surface, Push Button or Snap.

Meter Outlet.

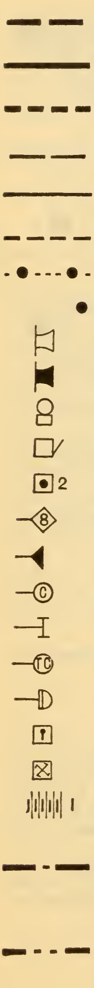
Distribution Panel.

Junction or Pull Box.

Motor Outlet; Numeral in center indicates Horse Power.

Motor Control Outlet.

Transformer.



Main or Feeder run concealed under floor.

Main or Feeder run concealed under floor above.

Main or Feeder run exposed.

Branch Circuit run concealed under floor.

Branch Circuit run concealed under floor above.

Branch Circuit run exposed.

Pole Line.

Riser.

Telephone Outlet; Private Service.

Telephone Outlet; Public Service.

Bell Outlet.

Buzzer Outlet.

Push Button Outlet; Numeral indicates number of Pushes.

Annunciator; Numeral indicates number of Points.

Speaking Tube.

Watchman Clock Outlet.

Watchman Station Outlet.

Master Time Clock Outlet.

Secondary Time Clock Outlet.

Door Opener.

Special Outlet; for Signal Systems, as described in Specifications.

Battery Outlet.

Circuit for Clock, Telephone, Bell or other Service, run under floor, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

Circuit for Clock, Telephone, Bell or other Service, run under floor above, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

Heights of Center of Wall Outlets (unless otherwise specified):

Living Rooms	5 ft. 6 ins.
Chambers	5 ft. 0 ins.
Offices	6 ft. 0 ins.
Corridors	6 ft. 3 ins.

Heights of Switches (unless otherwise specified):
4 ft. 0 ins.

In writing circular mill sizes a quick and handy method is to draw a circle and place in it the size in hundred thousands of circular mills, as,

(3) = 300,000, (7½) = 750,000, (2½) = 250,000. This is unhandy to print.

UNDERGROUND CONDUITS AND CONSTRUCTION.

WITH the establishment of the first commercial Morse telegraph line probably commences the history of the "underground wire" when a gutta-percha covered cable was laid in a trench made by an ox-drawn plough.

Stages in the evolution of the present "monolithic" conduit are prominently marked by the system of grouping wires permanently installed and separated by the pouring about them in the trench of various insulating compounds; by the "built up system" made of creosoted boards so placed as to form square channels or ducts; by the "pump log" system or squared timber bored to required size and creosoted; by the cement lined iron pipe system; by the use of paper moulded and treated with dielectric compounds; and by the now very largely used vitrified clay. Clay conduits should be manufactured from a clay which will vitrify to a highly homogeneous and non-absorbent condition and be free from chemical elements (iron, sulphur, etc.) which under the action of heat in the kilns result in nodes or blisters in the ware.

There are two established styles of clay conduit commonly designated as "single duct" and "multiple duct." The standard unit of the single duct is of square cross section measuring $4\frac{3}{4}''$ by $4\frac{3}{4}''$ with corners chamfered, is 18 inches in length, and has a $3\frac{1}{4}$ inch round bore or hole. The standard multiple duct units are of two, three, four, or six duct sections, the bore of each duct of any section being square and measuring $3\frac{1}{4}$ by $3\frac{1}{4}$, the interior and exterior wall being $\frac{5}{8}''$ thick; the lengths of units are, for two and three duct, 24 inches, and for four or six duct 36 inches. The demand for $3\frac{1}{2}$ inch and 4 inch bores or even larger is constantly increasing. Multiple duct conduit of nine duct and twelve duct sections have been offered to the trade but so far have not come into extensive use.

Single duct conduits being more flexible are better adapted to use where service pipes, curves, or obstacles are frequently encountered. Laid with broken joints the possibility of the heat from a burning cable, being communicated to a neighboring cable, is precluded. Where high construction on a small base (two ducts wide by more than five ducts high) is required, singles are not used to advantage. A mason should, under fair working conditions, average in a day of eight hours from twelve hundred to sixteen hundred duct feet of single duct conduit.

Multiples have in their favor fewer joints, greater weight per unit, and the fact that their installation requires only unskilled labor. Two men selected from a gang of laborers will lay from eighteen hundred to twenty-four hundred duct feet per day of ten hours.

Through town or city streets the conduit should have a foundation of concrete at least 3 inches thick. Where frequent excavations for other works are probable a complete encasement of 3 inches to 4 inches of concrete should be placed on both sides and on top of the ducts. The side protection is, however, sometimes omitted and creosoted boards substituted for concrete on top. The top covering over ducts should be not less than 24 inches below the surface of the street.

The several conduit terms are generally defined as follows:

The word "Conduit" means the aggregation of a number of hollow tubes of duct material and includes all of the ducts in a cross section of the subway. In general a conduit will consist of four ducts or more.

The word "Duct" means a single continuous passageway between manholes or through any portion of the conduit or laterals.

The word "Manhole" means an underground chamber built to receive electrical equipment and suitable to give access to the conduit.

The word "Service Box" means an underground chamber similar to a manhole but of smaller size, and designed primarily to give access to distributing conductors.

The word "Lateral" means one or more ducts extending from a manhole or service box or from one or more of the main conduit ducts to some distributing point. In general laterals will consist of one or two ducts for the same service connections. One or more laterals may be installed in the same trench.

Manholes vary so much according to the ideas of the different engineers that it is difficult to give data that would suit all of them. However, the average size of manhole is 5′ × 6′ × 6′ in the clear with a 12″ wall. The covers for same vary from 800 to 1400 lbs. The general practice is to have ventilated covers and sewer connections with automatic back-water traps.

The Service Boxes are made generally of concrete with an 8″ wall, either 2′ × 2′ or 2′ × 3′ in length and width, and extending in most cases to the top layer of the conduit system, which would make the depth of the service boxes vary according to the depth of the conduit system proper, the upper tier of ducts being used for distribution. Covers for service boxes, including inside pan, weigh from 400 to 600 lbs.

Usual Practice of Conduit Work.

Manhole walls, where built of concrete are generally 8 to 12 inches thick, made of Portland Cement concrete, using, 1½ inch stone, mixed in the proportion of an 1-2-5 and in some instances as high as 1-3-8. While in some cases the conduits proper are surrounded with Portland Cement concrete, the usual practice throughout the country is with casing of hydraulic cement concrete in a 1-2-5 mixture, stone ¾ inches to 1 inch.

The Cost of Conduits.

(A. V. Abbot in *Electrical World and Engineer.*)

The items of cost of conduit construction are:

1. Duct material. 2. Pavement per square yard. 3. Street excavation per cubic foot, including the removal of paving, the refillment of the excavation after the ducts are laid, and the temporary replacement of the paving. 4. Concrete deposited in place. 5. Labor of placing duct material 6. Engineering expenses. 7. Manholes. 8. Removal of obstacles.

TABLE No. 1.

Cost of Manholes in Dollars.

A. Brick with Brick Roof.

Item.	Amount.	Rate (Dollars).			Min. Amt. $	Per Ct.	Av. Am. $	Per Ct.	Max. Amt. $	Per Ct.
		Min.	Ave.	Max.						
Excavation	375 cu. ft.	.02	.03	.04	7.50	12.6	11.25	11.8	15.00	11.2
Concrete .	.7 yard	5.00	7.00	9.00	3.50	5.9	4.90	5.3	6.00	4.4
Brick . .	2200	12.00	15.00	18.00	26.40	44.5	33.00	35.3	39.60	29.4
Cover . .	1	5.00	10.00	15.00	5.00	8.4	10.00	10.6	15.00	11.2
Iron . . .	500 lbs.	.015	.03	.05	7.50	12.6	14.00	16.1	25.00	18.6
Repaving .	6 yards	.75	2.00	4.00	4.50	7.6	15.00	12.8	24.00	17.8
Cleaning .	10 loads	.50	.75	1.00	5.00	8.2	7.50	8.1	10.00	7.4
Totals . .	. . . .	. .	. .	. .	59.40	100.0	93.65	100.0	134.00	100.0

B. Brick with Concrete Roof.

Item.	Amount.	Rate (Dollars) Per Unit. Min.	Ave.	Max.	Min. Amt. $	Per Ct.	Av. Am. $	Per Ct.	Max. Amt. $	Per Ct.
Excavation	375 cu. ft.	.02	.03	.04	7.50	14.8	11.25	14.4	15.00	13.8
Concrete .	1.9 yards	5.00	7.00	9.00	9.50	18.7	13.30	17.0	17.10	15.7
Brick . .	1600	12.00	15.00	18.00	19.20	37.8	24.00	30.9	28.80	25.7
Cover . .	1	5.00	10.00	15.00	5.00	9.0	10.00	12.8	15.00	13.8
Repaving .	6 yards	.75	2.00	4.00	4.50	8.9	12.00	15.4	24.00	21.9
Cleaning .	10 loads	.50	.75	1.00	5.00	9.9	7.50	9.5	10.00	9.1
Totals . .	. . . .	. .	. .	. .	50.70	100.0	78.05	100.0	109.90	100.0

C. Concrete Manhole.

Item.	Amount.	Rate (Dollars) Per Unit. Min.	Ave.	Max.	Min. Amt. $	Per Ct.	Av. Am. $	Per Ct.	Max. Amt. $	Per Ct.
Excavation	375 cu. ft.	.02	.03	.04	7.50	16.8	11.25	15.5	15.00	14.3
Concrete .	4.5 yards	5.00	7.00	9.00	22.50	50.5	31.50	43.6	40.50	38.8
Cover . .	1	5.00	10.00	15.00	5.00	11.2	10.00	13.9	15.00	14.4
Repaving .	6 yards	.75	2.00	4.00	4.50	10.2	12.00	16.6	24.00	23.0
Cleaning .	10 loads	.50	.75	1.00	5.00	11.2	7.50	10.4	10.00	9.5
Totals . .	. . . .	. .	. .	. .	44.50	100.0	72.25	100.0	104.50	100.0

Whenever practicable, a sewer connection to each manhole is desirable to provide exit for street drainage. Such sewer connections are essential in all cases where manholes are equipped with ventilating covers, otherwise the manholes will fill during every storm.

TABLE No. 2.

Cost of Sewer Connections in Dollars.

Item.	Amount.	Rate (Dollars) Per Unit. Min.	Ave.	Max.	Min. Amt. $	Per Ct.	Ave. Am. $	Per Ct.	Max. Amt. $	Per Ct.
Excavation	225 cu. ft.	.02	.03	.04	4.50	35.1	6.75	26 0	9.00	21.4
Concrete .	5 yards	.75	2.00	4.00	3.75	29.2	10.00	38.8	20.00	47.0
Brick . .	1	1.00	2.50	4.00	1.00	7.6	2.50	19.6	4.00	9.3
Cover . .	16 feet	.04	.07	.10	.64	5.0	1.12	4.4	1.60	3.6
Repaving .	2 loads	.50	.75	1.00	1.00	7.6	1.50	5.8	2.00	4.7
Cleaning .	1	2.00	4.00	6.00	2.00	15.5	4.00	15.4	6.00	14.0
Totals . .	. . .	. .	. .	. .	12.89	100.0	25.87	100 0	42.60	100.0

Manholes will occur at intervals of from 250 to 500 feet, consequently the constant cost per conduit foot for this item is obtained by dividing the various manhole costs by the distances between them.

TABLE No. 3.

Constant Cost per Conduit Foot for Manholes in Dollars.

		Distance between Manholes in Feet.				
		250	300	350	400	500
Brick manhole with brick roof . . .	Min.	.238	.196	.170	.148	.118
	Ave.	.372	.310	.248	.236	.186
	Max.	.536	.427	.384	.335	.268
Brick manhole with concrete roof . .	Min.	.203	.169	.145	.127	.102
	Ave.	.300	.260	.223	.195	.156
	Max.	.440	.363	.314	.272	.218
Concrete manhole .	Min.	.176	.148	.127	.111	.089
	Ave.	.278	.242	.209	.180	.144
	Max.	.416	.347	.298	.260	.208
Sewer connection .	Min.	.051	.043	.038	.032	.025
	Ave.	.104	.086	.074	.064	.051
	Max.	.170	.142	.121	.105	.084

Engineering expense will vary from a minimum of 5 cents per conduit foot to a maximum of 12 cents, depending chiefly upon the difficulty of the work.

The cost of the removal of obstacles is an item impracticable to estimate *a priori* with any degree of certainty, as it is impossible to foresee, and usually impracticable to ascertain, even with the greatest care, the impediments to be encountered beneath street surface. Experience indicates that this expense will vary for small subways from 10 cents to 62 cents per foot of conduit; for medium-sized ones from 12 cents to $1.10, and for large conduits from 15 cents to $2.25.

The cost of paving is partially dependent upon the number of ducts. It is impracticable for workmen to perform their avocations in a trench less than 18 inches wide, and, therefore, a strip of pavement of this width must be opened irrespective of the number of ducts to be installed.

The cost of repaving will further vary with the kind of paving. In Table No. 4, the usual kinds of pavement encountered, the minimum, average, and maximum prices per square yard, and cost per conduit foot are given.

Allowing a disturbance of paving for six inches on each side of the trench, the cost per lineal foot for small conduits will vary from 2.3 to 26.3 cents; for medium-sized ones from 4.6 to 29.2 cents, and for large conduits from 6.9 to 35.0 cents.

Similarly the cost of excavation is only partially dependent upon the number of ducts.

TABLE No. 4. — Cost of Paving per Square Yard and per Foot of Conduit in Dollars.

Kind of Paving.	Min. Price per Sq. Yd.	Cost per Conduit Foot. Ducts from			Ave. Price per Sq. Yd.	Cost per Conduit Foot. Ducts from			Max. Price per Sq. Yd.	Cost per Conduit Foot. Ducts from		
		1–9	10–16	17–25		1–9	10–16	17–25		1–9	10–16	17–25
Quantity per conduit foot	. . .	.0925 Sq. Yd.	.105 Sq. Yd.	.117 Sq. Yd.	. . .	.0925 Sq. Yd.	.105 Sq. Yd.	.117 Sq. Yd.	. . .	.0925 Sq. Yd.	.105 Sq. Yd.	.117 Sq. Yd.
Asphalt	1.75	.163	.183	.205	2.00	.185	.210	.234	3.00	.276	.315	.350
Asphalt block	2.25	.208	.218	.263	2.50	.231	.262	.292	3.00	.276	.315	.350
Granite block	1.50	.138	.157	.176	1.75	.163	.172	.205	2.50	.231	.262	.293
Cedar block	.60	.056	.063	.070	.75	.069	.079	.088	1.00	.092	.105	.117
Brick	1.25	.115	.131	.146	1.50	.138	.157	.176	2.50	.231	.262	.293
Telford	.80	.074	.084	.093	1.00	.092	.105	.117	1.25	.116	.132	.146
Macadam	.25	.023	.026	.029	.50	.046	.052	.058	.75	.069	.079	.088

Experience shows that 3 feet 6 inches is a minimum permissible depth for the bottom of subway construction, and that the cost of street excavation will vary from two to four cents per cubic foot of material excavated, including the removal of the pavement, the refillment of the trench, and the replacement of temporary paving. The cost of excavation will, therefore, stand as in Table No. 1.

TABLE No. 5.

Cost of Street Excavation per Conduit Foot in Dollars.

	Minimum .02 per Cu. Ft.	Average .03 per Cu. Ft.	Maximum .04 per Cu. Ft.
1 to 9 ducts . . .	.105	.1575	.210
10 to 16 ducts . . .	.160	.240	.320
17 to 25 ducts . . .	.225	.3375	.450

Table No. 5 summarizes these constant items; for conduits of from one to nine ducts, ten to sixteen ducts, and seventeen to twenty-five ducts, giving the minimum, average, and maximum prices of all, together with the percentage that each bears to the total.

Table No. 6 enumerates the probable prices for the various forms of duct material laid into place, calculated in a manner similar to the preceding tables, including a percentage column showing the effect of each item upon the total expense.

TABLE No. 6.

Constant Cost per Conduit Foot in Dollars.

Item.	Minimum.		Average.		Maximum.	
	Cost.	Per Cent.	Cost.	Per Cent.	Cost.	Per Cent.
1 to 9 ducts.						
Excavation	.105	32.6	.1575	23.4	.210	13.0
Paving	.0695	21.2	.185	27.5	.279	17.4
Engineering	.05	15.2	.08	11.9	.12	7.5
Removal of obstacles .	.10	32.0	.25	37.2	1.00	62.1
Total	.3245	100.0	.6725	100.0	1.609	100.0
10 to 16 ducts.						
Excavation	.16	38.6	.24	29.1	.32	17.0
Paving	.0845	20.2	.222	27.0	.3315	17.7
Engineering	.05	12.1	.08	9.8	.12	6.5
Removal of obstacles .	.12	29.1	.28	34.1	1.10	58.8
Total	.4145	100.0	.822	100.0	1.8715	100.0
17 to 25 ducts.						
Excavation	.225	43.0	.3375	32.8	.45	19.2
Paving	.0970	18.6	.26	25.3	.52	22.2
Engineering	.05	9.6	.08	7.8	.12	5.1
Removal of obstacles .	.15	28.8	.35	34.1	1.25	53.5
Total	.522	100.0	1.0275	100.0	2.34	100.0

From the data thus collected, the total cost of a conduit of any size is readily determined by taking first the cost per foot of street for manholes and sewer connections; second, the cost of the constant street items as given in Table No. 6 depending upon the number of ducts, and third, the cost per duct foot determined from Table No. 5 multiplied by the number of ducts to be laid, and adding these three items together, giving immediately the total cost per conduit foot.

TABLE No. 7.

Cost of Duct Material in Place in Dollars.

Item.	Minimum.		Average.		Maximum.	
	Cost.	Per Cent.	Cost.	Per Cent.	Cost.	Per Cent.
Hollow brick.						
Duct material . . .	.02	44.4	.035	36.8	.05	34.5
Placing	.005	11.2	.01	10.5	.015	10.3
Encasement	.02	44.4	.05	52.7	.08	55.2
Total	.045	100.0	.095	100.0	.145	100.0
Multiple duct.						
Duct material . . .	.035	67.5	.05	50.0	.065	46.7
Placing	.011	2.2	.0025	2.5	.004	2.9
Encasement	.015	30.3	.0475	47.5	.07	50.4
Total	.061	100.0	.10	100.0	.139	100.0
Cement-lined pipe.						
Cement pipe.						
Wood pulp.						
Duct material . . .	.04	62.5	.06	53.6	.08	48.2
Placing	.002	3.2	.004	3.4	.006	3.6
Encasement	.022	34.3	.05	43.0	.088	48.2
Total	.064	100.0	.114	100.0	.174	100.0
Creosoted wood.						
Duct material . . .	.04	98.04	.05	98.0	.06	95.0
Placing	.0008	1.96	.0015	3.0	.003	5.0
Encasement	.00	0.00	.00	0.0	.00	0.0
Total	.0408	100.00	.0515	100.0	.063	100.0

Cost per Conduit Foot in Cities.

Cost per Trench Foot.	Number of Ducts.						
	2	4	6	12	16	20	24
Atlanta . . .	$.88	$1.14	$1.43	$2.31	$2.76	$3.22	$3.53
Louisville . .	.89	1.12	1.40	2.29	2.76	3.19	3.63
Cincinnati . .	.92	1.18	1.48	2.36	2.82	3.26	3.72
Boston . . .	1.06	1.34	1.65	2.66	3.13	3.66	4.10
Springfield . .	.90	1.16	1.45	2.34	2.78	3.24	3.68
Brooklyn . .	.95	1.21	1.51	2.45	2.91	3.39	3.84

Underground Work at New Orleans, La.

WALTER J. JONES.

Ducts, or Ducts and Drain.	Length in feet.	2200	1390	1250	1070	1020	1480	1480	1110	2445	Average cost per Lineal ft.
		4 & 6 Way.	4 Way.	4 Way & Drain.	14 Way & Drain.	4 Way & Drain.	4 Way & Drain.	4 Way & Drain.	4 Way & Drain.	4 Way & Drain.	
Pavements . . . . Removing and replacing	Total cost . . .	257.37	328.68	193.14	260.43	196.87	275.10	299.54	466.00	578.93	
	Cost per foot . .	.116	.236	.154	.243	.193	.186	.202	.419	.236	.22
Excavating . . . . Backfill and spoil bank	Total cost . . .	735.03	526.47	1259.74	1288.72	1191.44	1843.20	1907.68	1277.49	5117.48	
	Cost per foot . .	.33	.378	1.007	1.204	1.168	1.245	1.289	1.15	2.097	1.096
Drain pipe . . . . Laying	Total cost . . .			26.30	41.75	47.08	39.85	56.89	25.22	88.27	
	Cost per foot . .			.021	.039	.045	.027	.038	.022	.036	.032
Conduits . . . . . Laying	Total cost . . .	69.70	40.30	46.22	84.15	31.25	77.65	82.45	43.35	142.30	
	Cost per foot . .	.031	.029	.036	.078	.03	.052	.055	.039	.058	.045
Concrete . . . . . Laying	Total cost . . .	147.62	103.07	74.75	150.98	79.35	152.22	116.04	76.03	297.04	
	Cost per foot . .	.067	.074	.059	.14	.077	.103	.078	.068	.12	.087
Obstructions . . . Gas and Water . .	Total cost . . .	10.95	77.77	.90	37.72	14.85	81.82	106.34	76.14	373.37	
	Cost per foot . .	.004	.055	.0007	.035	.014	.055	.07	.068	.15	.05
Pumping	Total cost	4.30	1.75	5.10	.60	6.00	5.40	17.70	30.57	39.80	
	Cost per foot . .	.0019	.0012	.004	.0006	.006	.003	.012	.027	.016	.0084
General Exp. Supt., timekeeper, watchman, etc.	Total cost . . .	362.34	297.38	438.22	422.60	413.76	504.24	541.42	402.80	1307.33	
	Cost per foot . .	.16	.21	.35	.39	.40	.34	.36	.36	.53	.333
Manholes and sweeps	Total cost . . .			294.60	271.65	203.92	199.02	247.00	240.77	519.79	
	Cost per M. H. .			49.10	54.33	50.98	49.75	49.40	48.15	57.75	
No. of manholes . .	. . . .			6	5	4	4	5	5	9	
Distribut'g manholes	Total cost . . .	7.00	42.00	7.00	35.00	35.00	49.00	63.00	28.00	84.00	
	Cost per M. H. . . (Brick work only)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	
No. of manholes . .	. . . .	1	6	1	5	5	7	9	4	12	
Labor cost	Total	1594.31	1417.42	2345.97	2593.60	2219.52	3227.50	3438.06	2666.37	8548.31	
	Average cost per ft.	.72	1.02	1.87	2.42	2.17	2.18	2.32	2.40	3.49	2.06

Average per foot (not including manholes), $1.88. Glazed conduit. 4″ Tile drain.

Boston Edison Company Construction.

Following are a few cuts illustrating the practice of the Boston Edison Co. as described by W. P. Hancock. There are also two tables giving itemized cost of manholes and of conduits.

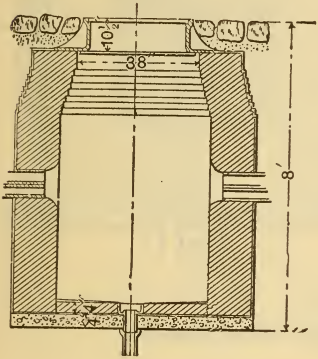


FIG. 1. Construction for Small Manhole.

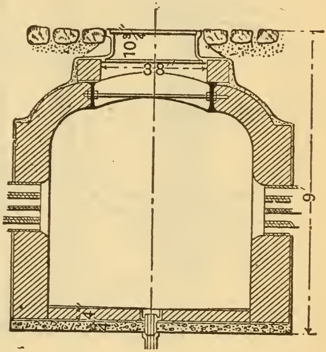
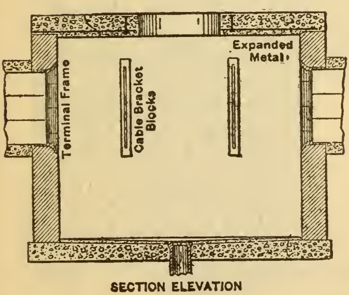
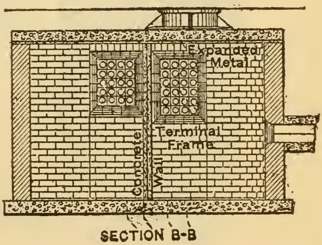


FIG. 2. Arched Construction for Large Manhole.





FIGS. 3 and 4. Manholes.

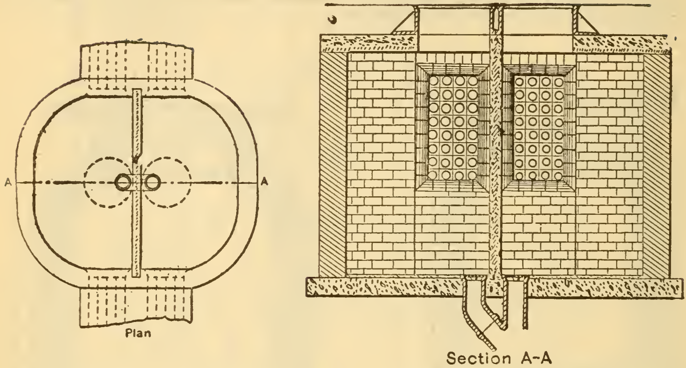


FIG. 5. Plan and Sectional View of Manholes.

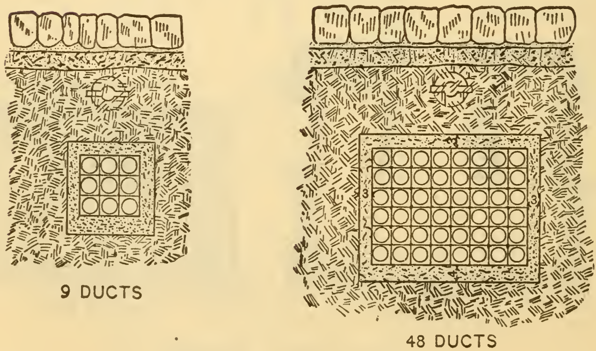


FIG. 6. Feeder Ducts in Position.

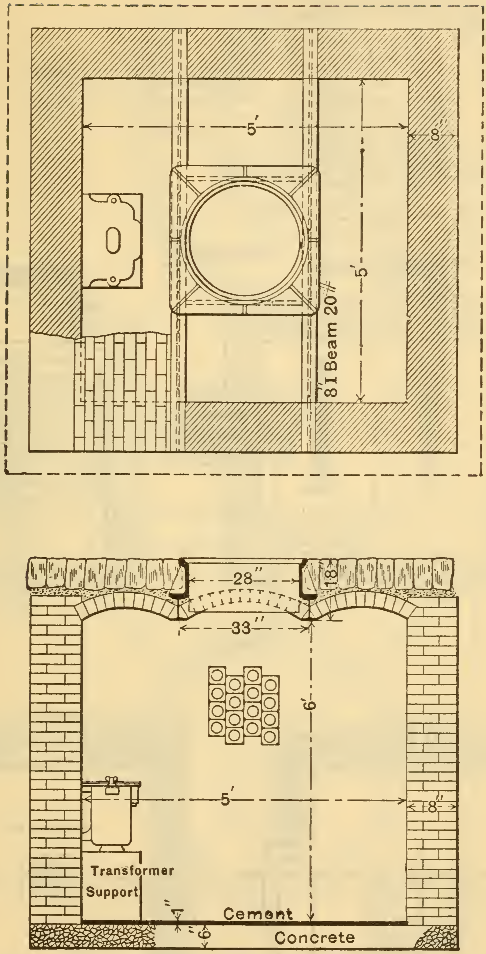


FIG. 7. Transformer Manhole.

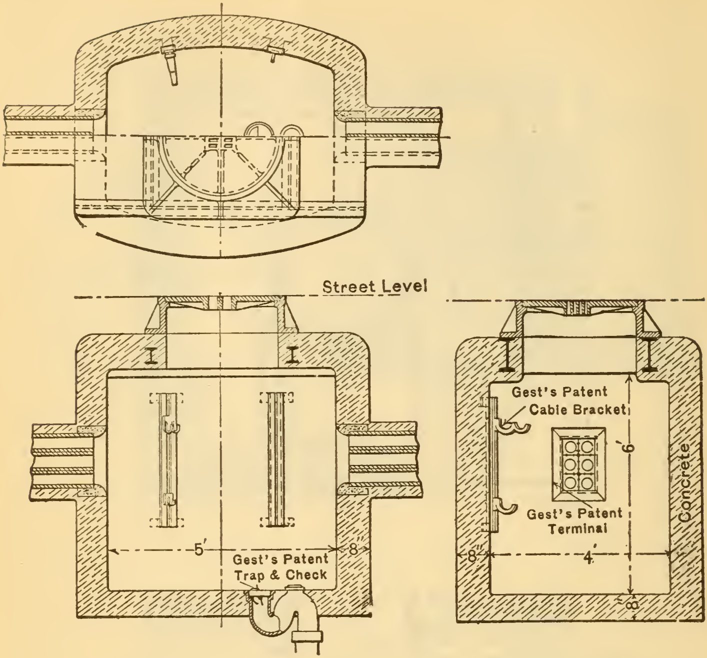


FIG. 8.

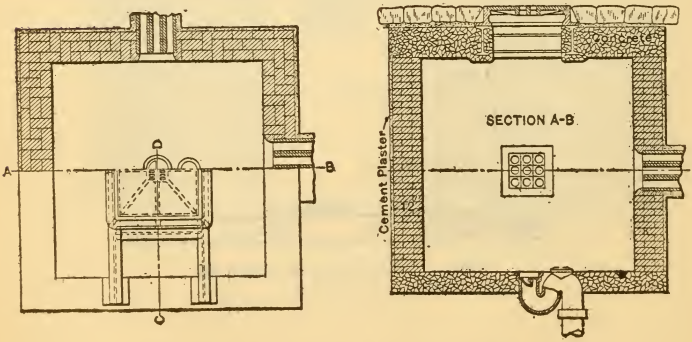


FIG. 9. Gest's Patent Manhole Designs.

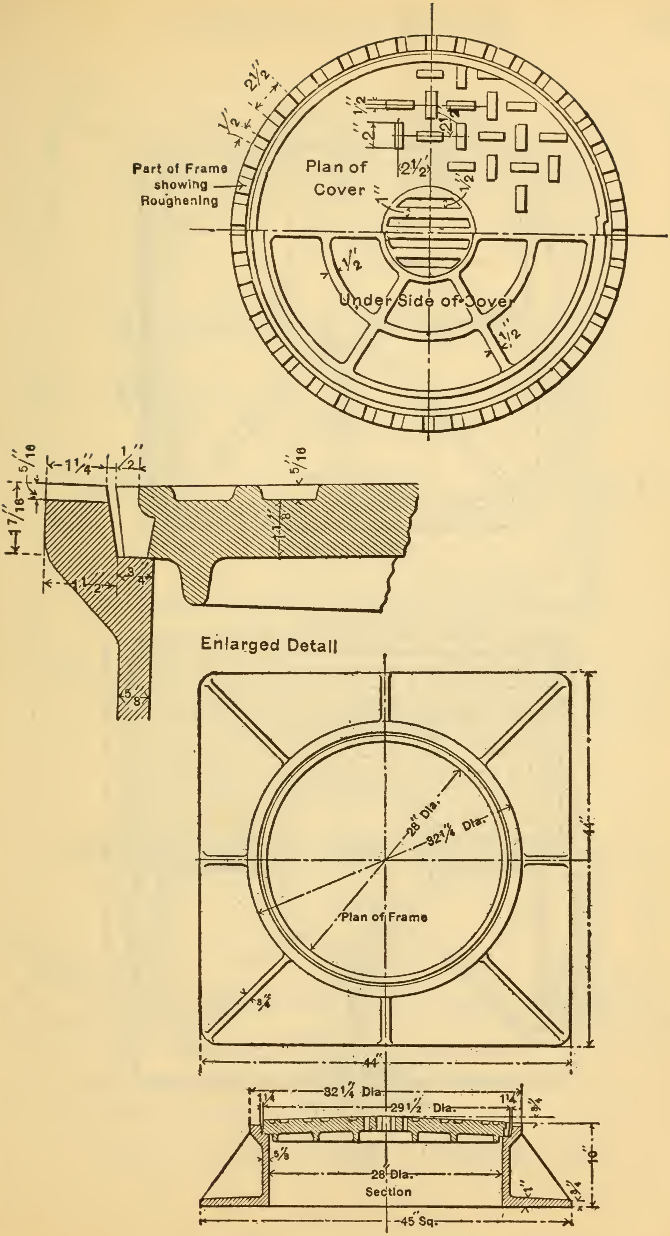


FIG. 10. Sectional View of Manhole Covers.

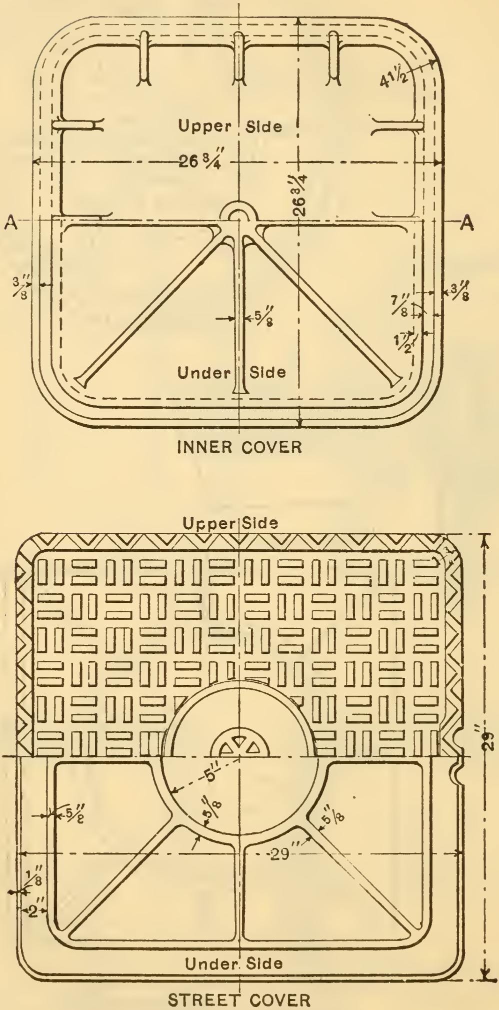


FIG. 11A. Manhole Covers.

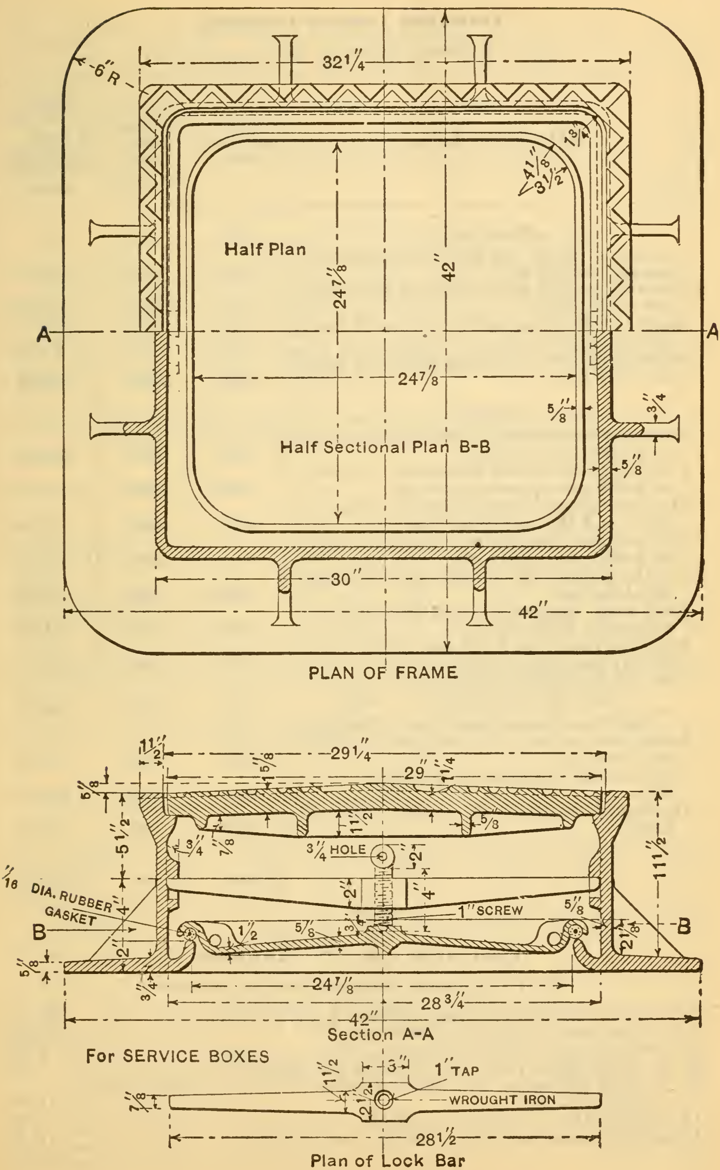


FIG. 11B. Manhole Covers.

Itemized Cost of Conduit.

W. P. Hancock, Boston Edison Company.

Material and Labor.	Cost per Duct Foot.	Cost per Conduit Foot. Total Expense.	Total Cost for each Item for the Total Line.
Material.	$	$	$
Lumber at $15.00 per M., or .015 cents per square foot, B. M.	.0105	.1575	233.10
Concrete at $4.85 per cubic yard, or 18 cents per cubic foot	.0231	.3465	514.15
Mortar at $3.98 per cubic yard, or 14 cents per cubic foot	.0026	.0390	58.90
Ducts laid down beside the trench at $.0502 per duct foot	.0502	.7530	1114.44
Labor.			
Excavate and backfill at 15 cents per hour or $.0278 per cubic foot	.0266	.3990	592.06
Cut and place lumber at 20 cents per hour, or $.0006 per square foot B. M.	.0004	.0060	9.32
Mix and place concrete at 15 cents per hour, or $.0222 per cubic foot	.0029	.0435	63.48
Mix and place mortar at 25 cents per hour, or $.0925 per cubic foot	.0016	.0240	37.00
Lay the ducts at 60 cents per hour, or $.0040 per duct foot	.0040	.0600	88.00
Haul away the dirt at 50 cents per hour, or $.0142 per cubic foot	.0047	.0705	104.72
Pave the trench at $1.44 per square yard, or $.16 per square foot	.0500	.7500	1109.92
Cost of manholes per duct foot $= \frac{\text{Total cost of manholes}}{\text{Total number of duct feet}} = \frac{490.28}{22{,}200}$.	.0221	.3315	490.28
Inspection at 50 cents per hour, or $.0033 per duct foot	.0033	.0495	73.26
Engineering expenses at $.0214 per duct foot	.0214	.3210	475.08
Incidental expense at 5 per cent of total	.0116	.1740	248.22
	$.2350	$3.5250	$5212.73

Cost of 5′ × 5′ × 7′ Manhole.

W. P. Hancock, Boston Edison Company.

23.76 cubic feet concrete, cost in place $.202 per foot	$4.78
2,500 hard sewer bricks, cost $9.00 per M.	22.50
1¾ S. 6″ trap and connections cost	5.65
30′ 6″ Akron sewer pipe, cost 30 cents per foot.	9.00
R. R. steel (60 lbs. to the yard), 8 pieces 6′ 4″ long (1013 lbs.) cost $.0125 per lb.	12.67
1⅛ yards mortar, cost per yard $3.98	4.47
1 manhole frame and cover, 962 lbs., cost $.015 lb.	14.43
	$73.50

We shall need labor that will cost as follows:

Excavate and backfill part of same, including that for sewer connections, 785 cubic feet, cost $.0278 per foot	$21.82
Remove from street 304 cubic feet of dirt, cost 50 cents double load or $.0142 per foot	4.30
Pave 11.08 yards (including manhole and sewer connection), cost $1.44 per yard	15.95
1 mason, 10 hours, cost 40 cents per hour	4.00
2 mason helpers, 10 hours each = 20 hours, cost 15 cents per hour,	3.00
	$49.07
Total cost 1 manhole, complete	$122.57

Cost of Underground Conduits in Chicago.

G. B. Springer, civil engineer of Chicago Edison Co., says:

The difference in local conditions, variations in cost of material and labor, make it very difficult to give a set of figures which will hold good in many places or in fact in the same place under different circumstances.

The following table, however, is submitted as a guide in approximating the cost of work of this character as a result of conduit construction covering ten years in Chicago. The cost of manholes is not included in this table, but is given in the one following.

Table for Estimating Cost of Conduit, Per Duct Foot, in Different Groups, in Various Pavements:

Kinds of Pavement	Number of Ducts.								
	2	4	6	9	12	16	20	25	30
No pavement	$.18	$.18	$.18	$.18	$.18	$.18	$.18	$.18	$.18
Macadam	.24	.21	.20	.20	.19	.19	.19	.19	.19
Cedar	.26	.22	.21	.20	.20	.19	.19	.19	.19
Cedar reserve and granite .	.31	.24	.23	.21	.21	.20	.20	.20	.19
Granite reserve	.43	.31	.28	.24	.24	.23	.22	.21	.21
Asphalt and brick reserve .	.68	.43	.37	.31	.29	.26	.24	.24	.23

The following table contains approximate figures based on conditions prevailing in Chicago, and may be used as a guide in estimating the cost of conduit construction in connection with the table preceding.

Table for Estimating Total Cost of Manholes in Different Kinds of Pavements:

Kinds of Pavement.	Size of Manholes in Feet.									
	3×3	3×4	4×4	4×5	5×5	6×6	6×7	7×7	8×8	9×9
No pavement	$41	$47	$53	$64	$109	$133	$142	$160	$189	$222
Macadam	42	48	55	66	111	135	146	163	193	226
Cedar	43	49	56	67	112	136	146	164	194	227
Cedar reserve and granite	44	50	57	68	113	138	149	167	198	231
Granite reserve . . .	46	53	60	72	117	144	155	174	207	243
Asphalt and brick reserve	50	58	67	80	126	156	168	188	224	264

The above figures are based on the same prices for repaving, labor, bricklayers, cement and sand, as given in the table for conduit, and upon the following unit prices:

Brick work including labor and material	$12.50 per cu. yd.
Concrete tops and bottoms	$7.50 per cu. yd.
Back water gates	$6.50 each.
Sewer grates	30 cents each.
Sewer connections	$12.50 each.
Sewer permits	$5.50 each.
Manhole frames and covers	$15.00 each.

Grouping of Ducts in Manholes.

H. W. Buck in *Electric Club Journal*, April, 1904.

Attention is called to the grouping of ducts and construction of manholes. Ordinarily ducts are bunched together and brought out at the center of the manhole, as shown in Fig. 12. Here the cables divide, half passing on one side and half on the other side of the manhole, being racked on the manhole walls. This design is objectionable for a number of reasons.

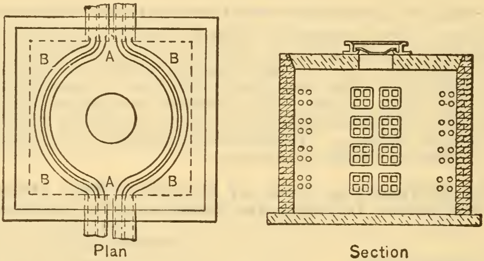


Fig. 12. Ordinary Type of Manhole.

First, it exposes every cable in the conduit to damage from short-circuit at the points *A–A*, where they are in close proximity to each other. Secondly, it necessitates bending every cable sharply at points *A* and *B* in every manhole, which tends to crack the insulation and cause trouble. Most break-downs in underground work *do* **occur** at these points. Another objection to this form of conduit construction is from the standpoint of heating. The cables in the inner ducts, if heavily loaded, will rise to a

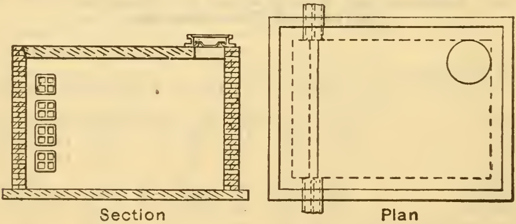


Fig. 13. Improved Form of Manhole Construction.

high temperature, for there is no way for the heat to get away by conduction. The inner ducts are surrounded by chambers containing still air, which constitute the best possible insulator of heat.

Ducts should never be grouped more than two in width, so that every duct will have an outlet for heat conduction through the surrounding earth. A much better form of construction is shown in Fig. 13. Here the ducts are grouped only two in width, and the conduit enters the manhole at the side, so that the cables can pass straight through on the side without bending. A further step in design leads to the arrangement shown in Fig. 14. Here the ducts are still laid in one trench but the ducts are placed in four separate groups, spaced apart by concrete, as shown. The

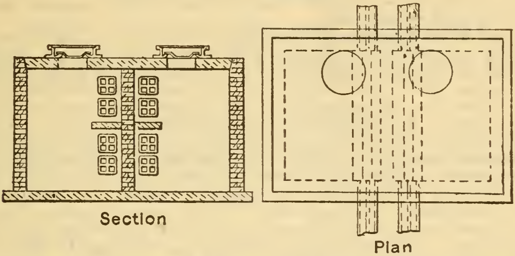


FIG. 14. Manhole Construction Adopted by Niagara Falls Power Company.

manholes are built with a vertical division wall through the center and two entrance holes. Removable soapstone shelves divide the groups of cables horizontally, so that not more than one-quarter of the number of

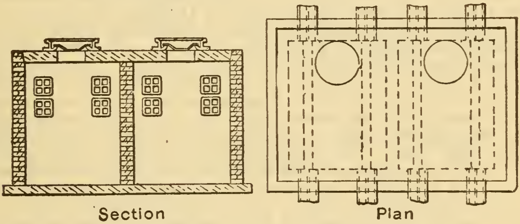


FIG. 15. Manhole Construction of Shallow Trenches.

cables in the conduit can be damaged by short-circuit at any time. In this design the cables also run straight through the manhole without bending.

In places where rock is near the surface of the ground the construction shown in Fig. 15 is adopted.

UNDERGROUND CABLES.

Cables are placed underground in several different ways, chief among which are the "solid" and "drawing in" systems, as noted on page 301. One type of the solid systems is that in which the conductors, properly insulated, lead covered and protected by armor, are laid directly in the earth, a plan that has been widely adopted in Europe.

The "Drawing In" Plan is the one now most generally adopted in this country. This plan utilizes the manholes and conduits just described. The cables are drawn into the ducts from manhole to manhole by means of a rope that has been previously drawn through the duct by a process termed "rodding." Rodding consists of screwing one rod on to another in the manhole and pushing them through the duct until the further end is reached. The rope is attached to the last rod and the rods are withdrawn from the ducts bringing the rope with them. Sometimes in place of rods a stiff steel wire is pushed through the ducts. The rope is attached to the cable by a mechanical device which securely grips the end of the cable.

Various means of drawing the cables into the ducts are availed of, depending somewhat on the size of the cable and the length of the run; hand power, man power with windlass, horses, electric motors and gasoline engines being thus employed.

Types of Underground Cables.—The type of cable employed for underground service varies largely with the requirements. Virtually all underground cables are lead covered to prevent injury to the insulation by moisture, gases, etc. For telephone purposes, lead covered, dry paper, insulated cables are universally used, to obtain low static capacity. (See pages 180 and 188.) For telegraph purposes rubber insulation (see page 229) and oil saturated cotton or paper are utilized, as in the telegraph service; static capacity is not of so much importance, but still cannot always be disregarded, especially in high speed telegraph signaling. The conductor commonly used in underground telegraph cable is No. 14 B. & S. copper, having a conductivity of 98 per cent. In the case of cotton fiber or paper cable, each conductor is insulated to six thirty-seconds ($\frac{6}{32}$) of an inch outside diameter. The insulating material is thoroughly dried and then saturated with an insulating oil or compound.

For Electric Light and Power purposes rubber, paper and varnished cambric insulation are largely used. (See pp. 174 and 180.) Owing to its high cost, rubber cables are not now in as high demand as formerly, especially as oil saturated paper cables appear to be quite as durable, efficient and reliable as rubber insulation for high potential work.

It was formerly the practice to place as many as six lead covered electric light cables in one duct, but experience demonstrated that this was not advisable owing to the difficulty in withdrawing when necessary one or more cables from the duct without injury to the remaining cables. A burn-out in one cable also frequently injured adjoining cables in the duct. Present practice favors having only one cable in each duct, although there may be several conductors within the lead covering. (See page 185.)

To prevent burning of light and power cables due to short circuits in the manholes and other places where the cables are bunched, the cables are frequently covered with asbestos strips about 3 inches wide and $\frac{3}{16}$ inch thick, well impregnated with a solution of silicate of soda which soon hardens over the lead. The lead covers of cables carrying alternating currents of high amperage and low E. M. F. should be bonded or carefully insulated in the manholes to prevent sparking and possible consequent damage, due to induced currents in the lead cover of the cables.

All lead covered cables used on high potential circuits should be protected from damage by static discharge by flared ends or bells, that is, by enlargement of the lead sheath to fully twice the diameter of the lead over the cable, for a distance of about a foot. The bell should then be filled with some good insulating material like Chatterton Compound, the conductor ends, in case of multiple conductor cable, being carefully separated.

Cable Heads.—To prevent the entrance of moisture to the ends of telegraph and telephone paper cables the conductors of a short length (about two feet) of rubber covered cable are spliced to those of the paper cable. These splices are then insulated. A lead sleeve is passed over the rubber insulated conductors and the lead casing of the paper cable to which it is then soldered. The outer terminal of the rubber cable is led into a metal box or head to which the lead sleeve is soldered. The free conductors are solidly connected to insulated binding posts on the inside of the box, which binding posts extend to the outside of the head, thus giving access to the conductors externally. The sleeve and box are then filled with a melted rubber compound, the temperature of which must be below that at which the rubber insulation will soften; otherwise the rubber will be seriously damaged.

Bells for Cable Ends.—All lead-covered cable ends should be protected from damage by static discharge by flared ends or bells, that is, by enlargment of the lead sheath to fully twice the diameter of the lead over the cable, for a distance of about a foot. Lead or brass cable heads or bells are much used on the ends of high potential underground cables. This bell should then be filled with some good insulating material like Chatterton Compound, the conductor ends, in case of multiple conductor cables, being carefully separated and arranged

CABLE TESTING.

REVISED BY WM. MAVER, JR.

Cables — Underground and Submarine.

The majority of the methods of tests and measurements given herein are applicable to aërial, underground, and submarine cables.

Insulation Resistance.

Direct Deflection Method, with Mirror Galvanometer.— This method, Fig. 1, is generally used in this country in underground and submarine work.

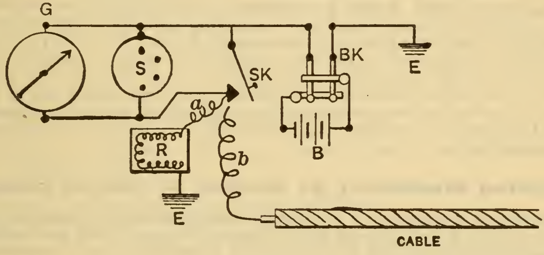


FIG. 1.

a and b = leads.
G = galvanometer, Thomson or D'Arsonval, mirror type.
S = shunts for G, usually $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$.
B = battery, 20, 50, or 100 chloride silver cells.
R = resistance box of megohm or more.
BK = battery reversing key.
SK = short-circuit key for G.

First connect a to lower contact point of SK, and take constant of G, using $\frac{1}{1000}$ shunt, and small number of cells, say 5 (depending upon the sensitiveness of G), with standard resistance R only in circuit, b being disconnected as shown. If 5 cells are used in taking constant, and 100 cells are to be used for test,

$$\text{Constant} = \frac{\text{G deflec.} \times \text{shunt} \times R \times 20}{1{,}000{,}000} = \text{megohms.}$$

After obtaining the constant, measure insulation resistance of lead b, by joining it instead of SK to a, disconnecting the far end of b from the cable. The result should be infinity; but if not, deduct this deflection from the deflection to be obtained in testing the cable proper. Now connect the far end of b to the conductor of the cable, the far terminal of latter being free. Then open SK carefully, and observe if there are any earth currents from the cable. If any, note deflection due to the same, and deduct from battery reading if in the same direction, or add to it if in opposite direction. Short-circuit G with SK, and close one knob of BK, using, say, the $\frac{1}{100}$ shunt. After a few seconds open SK; if spot goes off the scale, use a higher shunt. If deflection is low, use a lower shunt. After one minute's electrification, note the deflection. The result may be worked out from this reading, but the current should be kept on for three or five minutes longer, and readings taken at end of each minute. The deflection should decrease gradually. At the end of the last minute of test, open BK, and allow the cable to discharge fully. Then close SK and press the other knob of BK, reversing the battery. After a few moments, open SK, and take readings of deflections as before.

The insulation resistance in megohms $= \frac{\text{constant}}{d \times S}$,

where d is the deflection at a given time, and S is the shunt used. If no shunt is used, $x = \frac{\text{constant}}{d}$.

Note that in the above constant, the ordinary constant is multiplied by 20 for the reason that the battery is increased 20-fold, or 5 :: 100. In case the same battery is used for testing as for obtaining the constant, then

$$\text{constant} = \frac{G \text{ deflec.} \times S \times R}{1{,}000{,}000}.$$

Insulating Cable Ends for Tests.—Much care must be employed in order to insure accurate results in measuring insulation resistance. The ends should be well cleaned and thoroughly dried. For this purpose they are sometimes immersed in boiling paraffin for a few seconds; or the ends may be dried by the careful application of heat from an alcohol lamp.

If there be no earth currents, the readings with opposite poles of battery to the cable should not vary appreciably at any given minute. Pronounced variation between the readings at given times and unsteady deflections indicate defective cable.

Insulation Resistance by Method of Loss of Charge.

The insulation resistance of a cable or other conductor having considerable capacity may be measured by its loss of charge. Let one end of the conductor be insulated, and the other end attached to an electrometer, in the manner shown in FIG. 2.

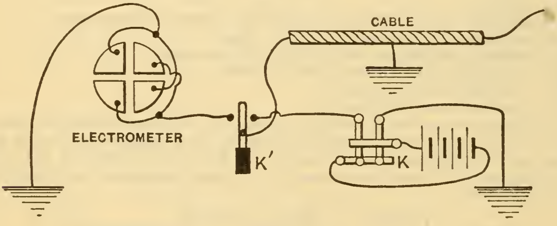


FIG. 2.

Let $R =$ Insulation resistance in megohms per mile.
$C =$ Capacity in microfarads per mile.
$E =$ potential of cable as charged.
$e =$ potential of cable after a certain time.

Depress one knob of key K, and throw key K' to the right, and charge the cable for one minute; then throw key K′ to the left, thus connecting the cable to the electrometer. Note the deflection E. Noting the movement of the spot for one minute, take reading e at end of minute, then

$$R = \frac{26.06}{C \log \frac{E}{e}}$$

If an electrometer is not conveniently at hand, use a reflecting galvanometer, and after charging cable as before, take an instantaneous discharge, noting deflection E due thereto. Recharge cable as before, then open K' and at end of one minute, the galvanometer having been disconnected from cable in the meantime, take another discharge-reading of cable, and apply the same formula as before. If a condenser of low capacity be inserted between K' and the galvanometer, the latter need not be disconnected. The advantage of the use of the electrometer is that the actual loss of potential of the cable may be observed as it progresses.

Testing Joints of Cables by Clark's Method.

In the figure (FIG. 3) the letters refer to the parts as follows:

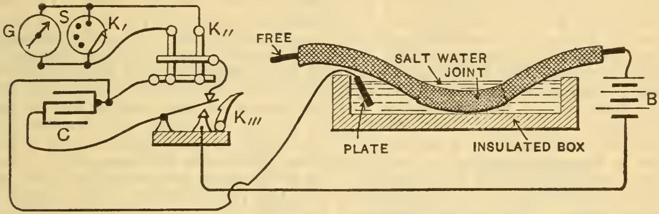


FIG. 3.

G is a high-resistance mirror galvanometer.
S is the shunt.
$K_{,}$ is the short-circuit key. It may be on the shunt box or separate.
$K_{,,}$ is a reversing key.
$K_{,,,}$ is a discharge key.
B the battery, usually 100 cells chloride of silver.
C is a ⅓ microfarad standard condenser.

The joint to be tested is placed in a well-insulated trough, nearly filled with salt water. A copper plate attached to the lead wire is placed in the water to ensure a good connection with the liquid. The connections are made as shown in the figure, one end of the cable being free. To make test close $K_{,,,}$ for a half minute; then release it (first depressing one knob of key $K_{,,}$), thereby discharging the condenser *C*, through the galvanometer, and note the deflection, if any. A perfect piece of cable of the same length as the joint is then placed in the vessel, and if the results with the joint are practically equal to those obtained with the perfect cable, the joint is passed. When the deflection is very low, it is evident that the joint is sound, and it may then be considered unnecessary to compare it with the piece of cable. It is very important that the trough and apparatus be thoroughly insulated.

Electrometer Method. — This method possesses the advantage that it dispenses with a condenser, and thereby avoids possible misleading results due to electric absorption by that instrument. The connections for the electrometer test are shown in the accompanying figure (Fig. 4).

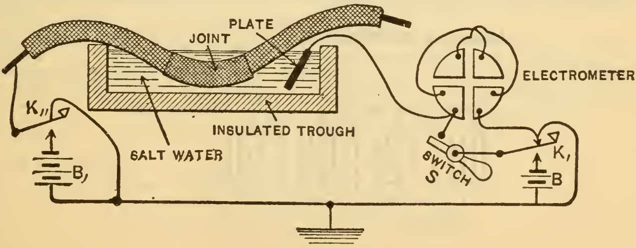


FIG. 4.

B is a battery of about 10 cells.
B_1 is a battery of 100 or more cells.

As in the preceding test, it is here highly essential that the insulation of the trough should be practically perfect, or at least known, so that if not perfect, proper deductions may be made for deflections due to it alone.

To test the insulation of the trough, depress $K_{,,}$ and close switch S. This charges the quadrants of the electrometer, and produces a steady deflection of its needle, and shows the potential due to the small battery B. Now open switch S, still keeping $K_{,}$ closed, and watch the deflection of needle for about two minutes. If the insulation of the trough is not perfect, there will be a circuit, so to speak, from the earth at the trough to the earth shown in the figure, and a fall in the deflection will be the result. If, however, the drop of potential is not more than is indicated by a fall of two or three divisions, the insulation of the trough will suffice. The electrometer is discharged by closing switch S, which short-circuits the quadrants, $K_{,}$ being open at this time. The joint is now connected as in the figure. Switch S is opened, and key $K_{,,}$ depressed, thus charging the joint with the large battery $B_{,}$. This produces a quick throw of the needle, due to the charging of the joint. Next, keeping $K_{,,}$ closed, discharge the electrometer by closing switch S for a moment. The switch is then opened, and if the joint is imperfect as to its insulation, the deflection will rise as the electricity accumulates in the trough. The deflections are recorded after one and two minutes, and are compared, as in the previous test, with a piece of perfect cable. The results obtained with the joint should not greatly exceed those with the cable proper.

Capacity.

Capacity tests are usually made by the aid of standard condensers. Condensers, or sections of the plates of condensers, may be arranged in parallel or in series (cascade).

Arrangement of Condensers—Parallel.—Join like terminals of the condensers together, as in the figure; then the joint capacity of the condensers is equal to the sum of the respective capacities.

Capacity, $C = c + c_{,} + c_{,,} + c_{,,,}$.

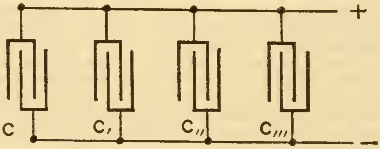


FIG. 5.

Condensers in Series or Cascade.—Join the terminals, as in Fig. 6. The total capacity of the condensers as thus arranged is equal to the reciprocal of the sum of the reciprocals of the several capacities, or

$$\text{Capacity in series} = \frac{1}{\frac{1}{c} + \frac{1}{c_{,}} + \frac{1}{c_{,,}} + \frac{1}{c_{,,,}}}$$

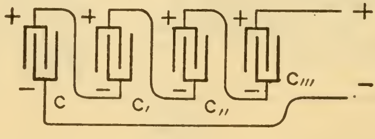


FIG. 6.

Condensers are now constructed so that these two methods of arranging the plates of a condenser may conveniently be combined in one condenser, thereby obtaining a much wider range of capacities.

Testing Capacity by Direct Discharge.—It is frequently desirable to know the capacity of a condenser, a wire, or a cable. This may be ascertained by the aid of a standard condenser, a trigger key, and an astatic or ballistic galvanometer. First, obtain a *constant*. This is done by noting the deflection d, due to the discharge of the standard condenser after a charge of, say, 10 seconds from a given E.M.F. Then discharge the other condenser, wire, or cable through the galvanometer after 10 seconds charge, and note the deflection d'. The capacity c' of the latter is then

$$c_{,} = c\frac{d_{,}}{d},$$

c being the capacity of the standard condenser.

Capacity by Thomson's Method.—This method is used with accurate results in testing the capacity of long cables. In the figure (Fig. 7)

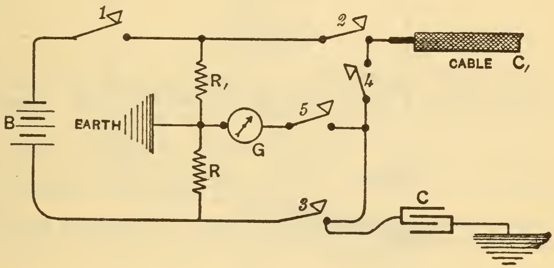


FIG. 7.

$B =$ battery, say 10 chloride silver cells.
$R =$ adjustable resistance.
$R_{,} =$ fixed resistance.
$G =$ galvanometer.
$C =$ standard condenser.
1, 2, 3, 4, 5, keys.

To test, close key 1, thus connecting the battery B, through the resistances R, $R_{,}$, to earth. Then

$$V : V_{,} :: R : R_{,}$$

where V and $V_{,} =$ the potentials at the junctions of the battery with R $R_{,}$.

Next close keys 2 and 3 simultaneously for, say 5 minutes, thereby charging the condenser to potential V, and the cable to potential $V_{,}$

Let C be the capacity in microfarads of the condenser, and $C_{,}$ capacity of cable, and let Q and $Q_{,}$ be their respective charges when the keys were closed. Then $Q : Q_{,} :: VC : V_{,}C_{,}$.

Open keys 2 and 3, keeping key 1 closed for say 10 seconds, to allow the charges of cable and condenser to mix or neutralize, in which case, if the charges are equal, there will be no deflection of the galvanometer when key 5 is closed. If there is a deflection, it is due to a preponderance of charge in C or $C_{,}$. Change the ratio of R to $R_{,}$, until no deflection occurs.

Then, $VC = V_{,} C_{,}$
or $V_{,} : V :: C : C_{,}$.
But we found $V_{,} : V :: R_{,} : R$
or $R_{,} : R :: C : C_{,}$.

and $C_{,} = \frac{R}{R_{,}} C$ microfarads.

Capacity by Gott's Method.—Fig. 8 shows the connections for testing the insulation of a cable by this method, which is considered somewhat better than Kelvin's, as it does not necessarily require a well insulated battery.

First adjust the resistances R and R_1 to the proportions of C_1 to C, as nearly as may be, by moving the slider S. Depress K for five seconds, which will charge both cable and condenser. At the end of the time, depress k and observe if there is any deflection of the galvanometer G. If there be any such deflection, open k again, let up the key K, and short-

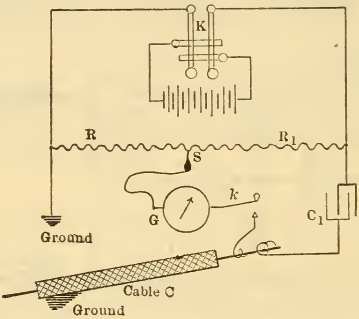


FIG. 8. Gott's Method of Cable Testing with Condenser.

circuit the condenser C_1 with its plug for a short time, then readjust R and R_1 and repeat the operation until there is no deflection of the galvanometer G; then

$$C : C_1 :: R_1 : R \qquad \text{and } C = \frac{R_1}{R} C_1.$$

The best conditions for this test are when R and R_1 are as high as possible, say 10,000 ohms, and C_1 and C are as nearly equal as possible.

Testing Capacities by Lord Kelvin's Dead-Beat, Multicellular Voltmeter. — Suitable for short lengths of cable (See Fig. 9.)

MV = multicellular voltmeter.
AC = air condenser.

B=battery.
S=switch.
Q=total charge in condenser and MV, due to battery.
Ca=capacity of AC.
Cb=capacity of cable.

First close switch S on upper point 1 and charge MV and AC to a desired potential, V. Next move switch S from point 1 to lower point 2, and note the potential $V_{\prime}$ and MV.

Then $Q = V (C + Ca) = V_{\prime}(C + Ca + Cb)$, where C is the capacity of voltmeter. Ordinarily C can be neglected, as compared with the capacities of AC and the cable, in which case, by transposition,

$$Cb = (V - V_{\prime})\, Ca \div V_{\prime}.$$

Conductors of telephone cables are measured for capacity with the lead sheathing of armor and all conductors but the one under test grounded.

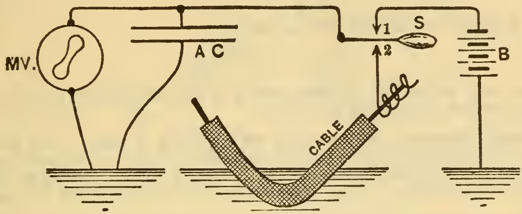


FIG. 9.

Locating Breaks in Cables or Overland Wires by Capacity Tests.—When the capacity per mile or knot of the conductor of a cable is known its total capacity up to the break is measured by comparison with a standard condenser. Then $x = \frac{m}{m'}$, x being distance to fault in miles, m' capacity of conductor per mile and m total capacity of conductor from the testing station to break. A clear break in the cable or conductor is assumed.

Locating Crosses in Cables or Aërial Wires.—Prof. Ayrton Method.—To locate the cross at d (Fig. 10) arrange the connections

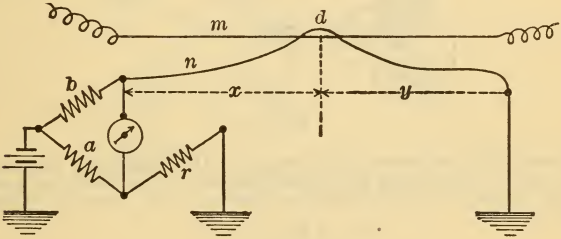


FIG. 10.

as shown. This is virtually a Wheatstone bridge, in which one of the wires, n, is one of the arms of same. Adjust r until $a(x + y) = br$, when r will be equal to $x + y$, if $a = b$.

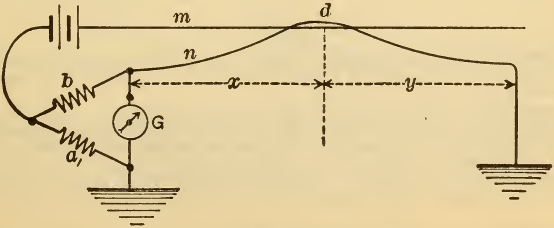


FIG. 11.

Next connect the battery to line m instead of to earth, as in Fig. 11, and adjust a until $ax = by$.

Then
$$\frac{x}{x+y} = \frac{b}{b+a}$$
and as $x + y = r$ in the first arrangement,

hence,
$$x = \frac{b \times r}{b+a}.$$

This test may be varied by transposing G and the battery, in Fig. 9, which is the old method of making this test.

Locating Faults in Aerial Wires or Cables by the Loop Test. — Two conductors are necessary for this test, or both ends of a cable must be available at the testing-point. Also it is assumed there is but one defect in the conductor. The resistance of the fault itself is negligible in this test.

Measure the resistance L of the loop by the ordinary Wheatstone bridge.

Murray Method. — Connect as in Fig. 12, in which a and b are the arms of a Wheatstone bridge, and y x are resistances to fault, the conductors being joined at J (in the case of aerial wire, for instance). Close key and note the deflection of needle due to E.M.F. of chemical action at fault if any. This is called the false zero.

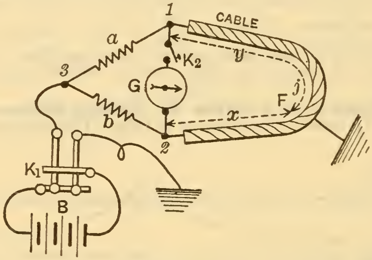


FIG. 12.

Now apply the positive or negative pole of the battery, by depressing one of the knobs of reversing key K, and balance to the false zero previously obtained by varying the resistance in arms a or b. Then, by Wheatstone bridge formula,

$$ax = by,$$

and
$$l = x + y$$
$$y = l - x$$
$$x = \frac{b}{a+b}l$$
$$y = \frac{a}{a+b}l.$$

To ascertain distance in knots or miles from 2 to F, divide x by resistance per knot or mile; to ascertain distance from 1 to F, divide y by resistance per knot or mile.

The foregoing test is varied in the case of comparatively short lengths of cable, in the manner shown in Fig. 13, in which the positions of the battery and galvanometer are transposed. Otherwise the test and formula are the same. It is advisable to reverse the connections of cable or conductors at 2 and 1, and take the average of results obtained in the different positions. In this latter method, battery B should be of low resistance, and well insulated.

Best conditions for making test, according to Kempe.— Resistance of b should be as high as necessary to give required range of adjustment in a.

Resistance of galvanometer should not be more than about five times the resistance of the loop.

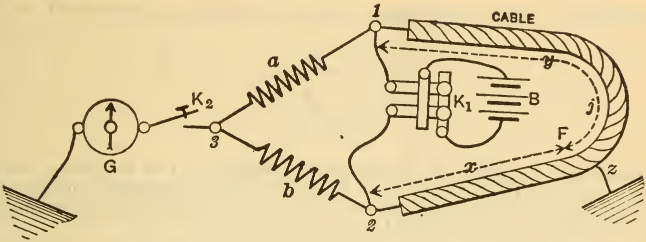


FIG. 13.

Varley Loop Test.—Measure resistance of looped cable or conductors as before. Then connect, as shown in Fig. 14, in which r is an adjustable resistance. If currents due to fault be present, obtain false zero as before. Then close key K, and adjust r for balance. In testing, when earth current is present, the best results are obtained when the fault is cleared by the negative pole, and just before it begins to polarize.

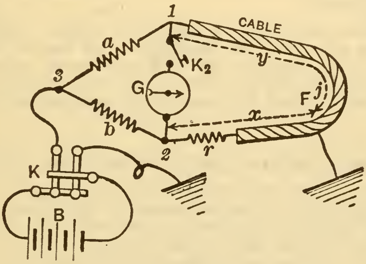


FIG. 14.

Then $$x = \frac{L - r}{2},$$

where x is the distance of fault, in ohms, from point 2 of cable proper.

Then $x \div$ by the resistance of the cable or conductor per knot or mile gives the distance of fault in knots or miles.

When the resistance of the "good" wire used to form a loop with the defective wire, together with that portion of the defective wire from J to F, is less than the resistance of the defective wire from the testing station to fault, the resistance r must be inserted between point 1 and the good conductor, the defective wire being connected directly to point 1. The formula in this case is $x = \frac{L + R}{2}$, x, as before, being the distance to fault in ohms.

To Localize Fault when Resistance of Conductor is Known and a Parallel Good Wire is not Available.—Measure by Wheatstone bridge resistance (r) from A to earth through fault F, and resistance (r') from A' to earth through fault, Fig. 15. Let R be resistance of conductor from A to A', x the actual resistance of conductor from A to F and y actual resistance of conductor from A' to F.

Then $$x = \frac{R + r - r'}{2}$$

and
$$y = \frac{R - r + r'}{2}$$

in ohms, from which the distance in feet or miles may be calculated.

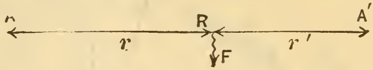


FIG. 15.

Locating Faults in Insulated Wires.—The following, so to speak, "rule of thumb," or point to point electro-mechanical methods of locating faults in unarmored cables, in which the defect is not a pronounced one, have been found successful.

Warren's Method.—The cable should be coiled on two insulated drums, one-half on each drum. The surface of the cable between the drums is carefully dried. One end of the conductor is connected to a battery which is grounded. The other terminal is connected to the insulated quadrants of an electrometer, the other pairs of quadrants of which are connected to the earth. Both drums being well insulated, no loss of potential is observed after three or four minutes. An earth wire is now connected first to one and then another of the drums, and the fault will be found on the drum which shows the greater fall on the electrometer. The coil is now uncoiled from the defective drum to the other drum, and tests are made at intervals until the defect is found.

F. Jacob coils the core from a tank to a drum. The battery is connected between the tank and the conductor, one end of which is free. A galvanometer is joined between the tank and drum, which need only be partially insulated. The needle shows when the fault has passed to the drum, and it can be localized by running the galvanometer lead along the insulated wire.

Copper Resistance, or Conductivity of Cables.

The copper resistance of the submarine and underground cables used in telephony and telegraphy is always tested at the factory, usually by the Wheatstone bridge method. In such a case both ends of the cable are accessible. When the cable is laid, if the far end is well grounded, the copper resistance may be measured, either by the Wheatstone bridge method, or by a substitution method, as follows: First, note the deflection due to copper resistance of conductor. Then substitute an adjustable resistance box and vary the resistance in the box until the deflection equals that due to cable. This latter resistance is the resistance of the cable. If there are earth currents on the cable, take readings of cable resistance with each pole of battery. Should there be any difference between the results obtained with the respective poles of the battery, the actual resistance will, according to F. Jacob, be equal to the harmonic mean of the two results, i.e.,

$$R = \frac{2\,rr'}{r + r'}.$$

where R is the actual resistance, r is the resistance with + pole, r' is the resistance with − pole.

To measure copper resistance of conductors by the voltmeter, first measure the E.M.F., V of testing battery. Then place the voltmeter in series with the battery and conductor or instrument to be tested, exactly as a galvanometer would be placed, and note the deflection V' in volts. It will be less than in the first instance. Unknown resistance x will be found by the formula:

$$x = r\left(\frac{V - v'}{v'}\right),$$

where r is the resistance of the voltmeter coil.

Testing Submarine Cable During Manufacture and Laying.

The Core of the cable, that is, the insulated copper conductor, is made, as a rule, in lengths of 2 knots, which are coiled upon wooden drums, and are then immersed in water at a temperature of 75° F. for about 24 hours. The coils are then tested for copper resistance, insulation resistance, and capacity; the results of which tests, together with data as to length of coils, weight, etc., are entered on suitably prepared blanks.

After the tests of some of the coils have been made, the jointing up of the cable begins, which is followed by the sheathing or armoring. The joints are tested after 24 hours immersion in water. During the sheathing process, continuous galvanometer or electrometer tests are made of the core, to see that no injury befalls the cable during this process. In fact, practically continuous tests of the cable for insulation resistance, copper resistance, and capacity should be made until the laying of the cable begins.

During laying, the cable should be tested continuously, and communication should be practically constant between the ship and the shore. An arrangement to permit such tests and communication is shown in Fig. 14.

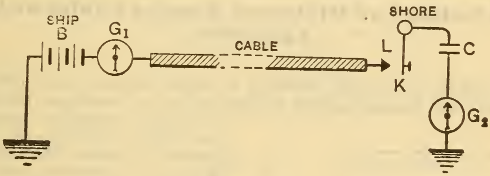


Fig. 16.

In this figure, G_1 is a marine galvanometer, B is a battery of about 100 cells on ship-board. In the shore station, L is a lever of key K, C is a condenser, G_2 is a galvanometer. Normally key K is open and the cable is charged by battery B. If, while the cable is being paid out a defect occurs in the insulation, or if the conductor breaks, a noticeable throw of the galvanometer follows, and the ship should be stopped and the cause ascertained. By pre-arrangement the lever of shore key K is closed, say every 5 minutes. thereby charging the condenser C, which causes a throw of the galvanometers' needles. If the ship or shore fails to get these periodic signals, or if they vary as to their strength, it indicates the occurrence of a defect. At the end of every hour the ship reverses the battery, which reverses the direction of the deflection of the galvanometers. If the ship desires to communicate with the shore, the battery is not reversed at the hour, or is reversed before the hour. If the shore wishes to speak with the ship, the key K is opened and closed several times in succession. In either event both connect in their regular telegraphing apparatus for conversation.

Compound Cables, that is, cables of more than one conductor, have their conductors connected in series for these tests. If there is an even number of conductors, two of them must be connected in parallel.

Locating Faults in Underground Cables.

To localize a fault in a conductor of a cable, form a loop consisting of the defective conductor and a good conductor of equal resistance and length, with battery E as shown, Fig. **17**. Place an ammeter in each leg of loop L. If current in leg A to fault F is I, and current in leg A' to fault is I'; D being length of loop L and x the distance from A' to fault F,

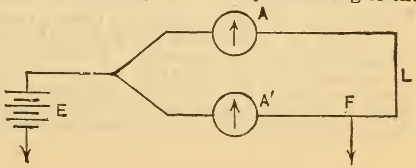


Fig. 17.

then $$\frac{I}{I'} = \frac{x}{D - x} \text{ and } x = \frac{IL}{I + I'}.$$

The compass method of locating faults in underground cables consists, briefly, in sending a constant continuous current of about 10 amperes into the cable through the ground, the current first passing into an automatic reverser which reverses the direction of the current flow every ten seconds. A manhole is then opened near the center of the cable length and a pocket compass laid on the lead sheathing of the faulty cable and observed for say half a minute. If the ground is further from the source of reversed current the compass needle will swing around approximately 180° upon every reversal at the end of each ten seconds interval. The manhole is immediately closed and another opened, say a mile further away from the source of test current, and if no motion of the compass needle occurs, then the fault has been passed and another manhole is opened between the two first positions, and so on until the fault is finally located in a section between two manholes. *H. G. Stott, in Trans. A. I. E. E.*

High Voltage or Dielectric Tests of Cables or Other Apparatus.

Cables intended for high pressure circuits ranging from 500 to 60,000 volts or more are usually tested at the factory to ascertain their ability to withstand specified voltages. For the lower voltages the cables are generally tested for three or four times the contemplated working pressure. For higher voltages the cables are usually tested for one and a half to twice the working electromotive force. *See standardization rules of A. I. E. E.* The present limit for underground power cables is about 30,000 volts. The alternating electromotive force for these tests is supplied by specially designed step-up transformers, which must be of sufficient kw. capacity to supply the charging current called for by the cable to be tested. The charging current varies directly as the frequency, directly as the E.M.F., and directly as the static capacity, and as apparent energy (Skinner, *Electrical Age*, July, 1905) is equal to current multiplied by E.M.F., the apparent output of the transformers required must vary directly as the frequency, directly as the square of the E.M.F., and directly as the static capacity in microfarads of the cable or apparatus under test. For example, an underground cable having a static capacity of one microfarad, and tested at 20,000 volts, 60 cycles, requires a testing transformer of 150 kilowatt capacity; tested at 40,000 volts the same cable would require a testing transformer of 600 kilowatt capacity. The testing electromotive force is regulated in several ways, for instance, by means of a rheostat in the field of the generator, as in Fig. 18, or by employing a number of small transformers capable of being connected up, as indicated in Fig. 19, in which the range is from 10,000 to 40,000 volts in steps of 10,000 volts. The voltmeter or vol-

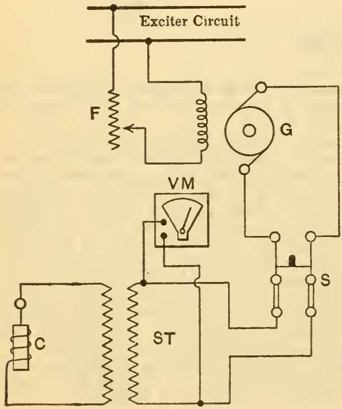


FIG. 18.

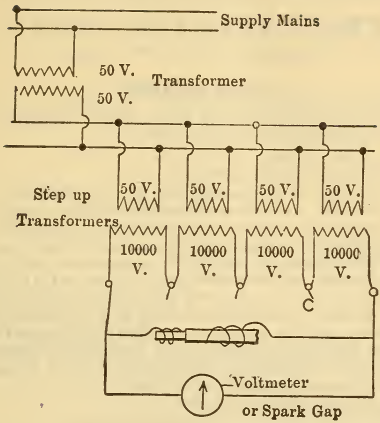


FIG. 19.

tage indicator may be placed in the primary circuit of the transformer, in which case the E.M.F. in testing circuit is calculated by the ratio of primary to secondary of the transformer, or the voltmeter may be placed directly in the testing circuit. A spark gap in the testing circuit is frequently employed across the cable or apparatus under test (Fig. 19), the E.M.F. in this case being obtained from a table of voltages of spark lengths in air. (See p. 233.)

In applying high voltage, say anything above 5000 volts, to a cable or to a piece of apparatus for the purpose of testing its insulation, care should be taken to build it up gradually to the point required; and for this it is best to place a voltmeter across the primary of the testing transformer and place needles for a spark gap across the secondary, gauging their points at the distance given in the rules of the committee of standards of the *A.I.E.E.* Run the voltage up gradually, reading the voltmeter as the pressure is built up, until the current jumps the gap, when the indication of the voltmeter should be carefully taken. When the test is being made the needles should be set about 10% farther apart, and the pressure obtained can be read on the voltmeter direct. Choke coils of many turns, and other high resistances should be placed in series with each side of the spark gap so as not to cause damage when the gap closes. Water rheostats consisting of glass tubes about 3 feet long, ½″ diameter, and filled with water, make good high resistance for this purpose.

DIRECT-CURRENT DYNAMOS AND MOTORS.

PRINCIPLES AND DESIGN.

REVISED BY CECIL P. POOLE.

NOTATION.

Except where other definitions are given, the definitions of the symbols used throughout this section are as follows: —

A = Area in square inches.
A_b = Aggregate area of all brush faces.
B_a = Magnetic density in armature core body at full load.
B_m = Magnetic density in field magnet core at full load.
B_p = Average magnetic density over pole-face at full load.
B_T = Magnetic density in armature tooth tops at full load.
B_T' = Approximate magnetic density in armature tooth tops at full load.
B_t = Magnetic density in armature tooth roots at full load.
B_t' = Approximate magnetic density in armature tooth roots at full load.
B_τ = Magnetic density in armature teeth at a specified point.
B_τ' = Approximate density in armature teeth at a specified point.
b = Brush-face dimension crosswise of commutator bars.
γ = Average distance between interpolar edges of adjacent pole-faces.
D_a = Diameter of armature core over teeth.
D_k = Diameter of commutator barrel.
D_o = Diameter of central hole in armature core.
D_p = Diameter of pole-face bore.
D_t = Diameter of circle drawn through narrowest parts of armature core teeth.
d = Diameter of bare round wire, in *mils*.
Δ = Depth or thickness of winding in a magnet coil.
δ = Air-gap length from pole-face to tops of armature teeth.
E = Total E.M.F. generated in an armature.
E_w = E.M.F. delivered by a dynamo or applied to a motor.
e = E.M.F. at terminals of one magnet coil.
F = Ampere-turns per pole required by complete magnetic circuit at full load.
F_0 = Ampere-turns per pole required by complete magnetic circuit at no load.
F_a = Ampere-turns per pole required by armature core at full load.
F_g = Ampere-turns per pole required by air-gap at full load.
F_m = Ampere-turns per pole required by magnet core at full load.
F_p = Ampere-turns per pole required by pole-piece or shoe at full load.
F_r = Ampere-turns per pole required to balance full-load armature reaction.
F_s = Ampere-turns per pole in series field-winding at full load.
F_{sh} = Ampere-turns per pole in shunt field-winding at full load.
F_t = Ampere-turns per pole required by armature teeth at full load.
F_y = Ampere-turns per pole required by field-magnet yoke at full load.
f = Ampere-turns per inch length of magnetic path at full load: Subscripts a, m, p, t and y apply to armature core, magnet core, pole-shoe, armature teeth and magnet yoke, respectively.
G = Girth or perimeter of a complete magnet coil.
g = Girth or perimeter of form or bobbin on which a magnet coil is wound.
h = Depth of armature coil slot.
I_a = Total armature current.
I_{sh} = Shunt field current.
I_w = Current delivered from a dynamo.
i = Current in a specified conductor, or coil.
i_a = Current in each armature conductor.
k_{ch} = $\sin (180\,\psi \div p)$; $k_{ch}\,D_p$ = chord of polar arc.
k_g = a coefficient; $k_g\,\delta$ = increase of air-gap span due to flux spread.
k_{g_2} = a coefficient; $k_{g_2}\,\delta$ = increase of air-gap width due to flux spread.
k_s = Number of commutator bars between the two to which the terminals of each armature coil are connected.

L_a = Length of magnetic path in armature core beneath slots.
L_f = Length of a specified field-magnet coil parallel to flux path.
L_m = Length of magnetic path in one field-magnet core.
L_p = Length of magnetic path in one magnet pole-piece or shoe.
L_y = Length of magnetic path in field-magnet yoke between adjacent poles.
l_c = Total length of each armature conductor.
m = Number of windings in a multiplex armature winding.
N_c = Total number of armature conductors around armature periphery.
N_k = Number of commutator bars and armature coils
N_t = Number of armature teeth (and slots).
n_k = Maximum number of commutator bars simultaneously in contact with one brush at any instant.
ν = Coefficient of magnetic leakage.
P_A = Total watts lost in armature.
P'_A = Total watts lost in armature exclusive of projecting parts of the winding.
P_b = Watts lost at all brush faces.
P_e = Watts lost by eddy currents.
P_h = Watts lost by hysteresis.
P_r = Watts lost in entire armature winding alone.
P_r' = Watts lost in armature winding exclusive of projecting parts.
P_s = Watts lost in series field-magnet winding.
P_{sh} = Watts lost in shunt field-magnet winding.
P_w = Watts of dynamo armature output or motor armature intake.
p = Number of field-magnet poles.
q = Number of parallel paths through an armature winding;
NOTE:—In a multiplex winding, q = total paths in all the windings.
R = Resistance of armature, commutator and brushes, warm.
R_a = Resistance of armature winding, warm.
R_a' = Resistance of embedded part of armature winding, warm.
R_b = Effective resistance of all brush-face contacts; $I_a R_b$ = Volts drop at brush faces.
r = Resistance of a specified conductor or coil in ohms.
r.p.m. = Revolutions per minute.
r.p.s. = Revolutions per second.
s = Width of one armature coil slot.
T = Torque in pound-feet.
T = Width of one armature tooth at the top.
t = Width of one armature tooth at the narrowest part, except in equation 32 and Table V.
t = Number of turns per armature coil; only in equation 32 and Table V.
θ_A = Temperature rise of armature, Fahrenheit degrees.
θ_k = Temperature rise of commutator, Fahrenheit degrees.
θ_f = Temperature rise of field winding, Fahrenheit degrees.
τ = Width of one armature tooth at a specified point.
Φ = Magnetic flux passing from one pole-face to armature at full load.
Φ_m = Magnetic flux in magnet core at full load.
Φ_0 = Magnetic flux in one air-gap at no load.
Φ_{m_0} = Magnetic flux in magnet core at no load.
Ψ = Polar span ÷ pole-pitch = proportion of armature circumference covered by all pole-faces.
v = Volume of iron or steel, cubic inches.
v_a = Volume of iron or steel in armature core body.
v_t = Volume of iron or steel in armature teeth.
W_a = Gross length of armature core, between end plates.
w_a = Net measurement of armature core iron parallel to shaft $= 0.9 \times (W_a -$ ventilating ducts).
W_k = Width of commutator barrel, parallel to shaft.
W_p = Width of pole-face parallel to shaft.

NOTE.—All dimensions are in inches, except wire diameters.

FUNDAMENTALS.

One volt is generated in an electrical conductor by the "cutting" of 100,000,000 maxwells per second.

One volt is generated in a looped or coiled conductor by a uniform variation of magnetic flux threaded through the loop or coil when the average rate of change is 100,000,000 maxwells per second.

Consequently, the E.M.F. generated in any direct-current armature is

$$E = \Phi\, N_c \frac{p}{q}\, \text{r.p.s.}\, 10^{-8} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Dynamos are

Series-wound, to deliver constant current,
Shunt-wound, to deliver approximately constant E.M.F.,
Compound-wound, to deliver strictly constant E.M.F. at some point in the work circuit.

The entire field winding of a series-wound machine is in series with its armature, and therefore carries the full current; an auxiliary regulator is required to maintain the current constant under varying loads.

The field winding of a shunt-wound dynamo is connected to its brushes in series with an adjustable resistance (rheostat); as the load increases, the drop in the armature winding and connections increases and the available E.M.F. at the terminals is thereby reduced, necessitating adjustment of the rheostat to strengthen the field excitation and bring the terminal E.M.F. up to normal.

A compound-wound dynamo is provided with a shunt field winding connected either to its brushes or to its main terminals, in series with a rheostat, and an auxiliary winding of relatively large conductor connected in series with the armature. The shunt winding excites the machine to normal voltage at no load; the application of a load causes the field excitation to be strengthened by reason of the current flowing in the series winding. The series winding is proportioned to increase the field strength in response to any increase in load, to such an extent as to maintain the proper E.M.F. at a predetermined point in the work circuit. The rheostat in the shunt field circuit is for the purpose of adjusting the no-load E.M.F. within practical limits.

The relation between field excitation and generated E.M.F. is shown by the "magnetization characteristic" curve. See Fig. 1. The early part of the curve is practically a straight line because the iron or steel in the magnetic circuit has such high permeability at low degrees of magnetization that the flux is almost directly proportional to the exciting force. As the iron or steel approaches saturation, the permeability decreases rapidly and a given increase in excitation will not produce an increase in flux equal to the increase produced by the last previous equal increase in excitation; hence the sharp bend in the curve. In constant-potential machines, the magnetic circuit should be proportioned so that at no load the characteristic curve has commenced to bend sharply, as at the intersection of the lines a and c in the diagram; the lines b and d indicate respectively the total internal E.M.F. generated at full load and the ampere-turns required to produce it, and their intersection establishes the point on the magnetization curve corresponding to full load.

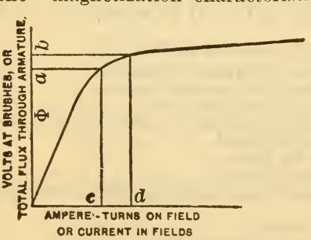


Fig. 1. Magnetization Curve.

External Characteristic.—This curve is a curve of results, in which the dynamo is excited from its own current, and with the speed constant, the terminal voltage is read for different values of load.

The curves for series, shunt, and compound wound machines all differ.

The observations are best plotted in a curve in which the ordinates represent volt values, and abscissæ amperes of load.

Series dynamo. In a series machine all the current flowing magnetizes the field, the volts increase with the current, and if fully developed the curve is somewhat like the magnetization curve, being always below it, however, due to the loss of pressure in overcoming internal resistance and armature reactions. The diagram, Fig. 2 (armature reaction being neglected), is a sample of the external characteristic of a series dynamo.

To construct this curve from an existing machine, the curve of terminal voltage can be taken from the machine itself by driving its armature at a constant speed, and varying the load in amperes.

The curve "drop due to internal resistance," sometimes called the "loss line," can be constructed by learning the internal resistance of the machine, and computing one or more values by ohm's law, and drawing the straight line through these points, as shown.

The curve of total voltage is then constructed by adding together the ordinates of the "terminal voltage" and "drop due to internal resistance."

A very good sample of curve from a modern series machine is to be found in the following description of the Brush arc dynamo.

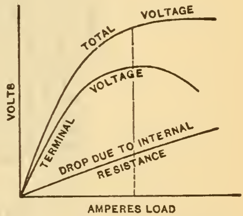


FIG. 2. External Characteristic of Series Dynamo.

Fig. 3 is a characteristic curve of the new Brush 125-lt. Arc Dynamo

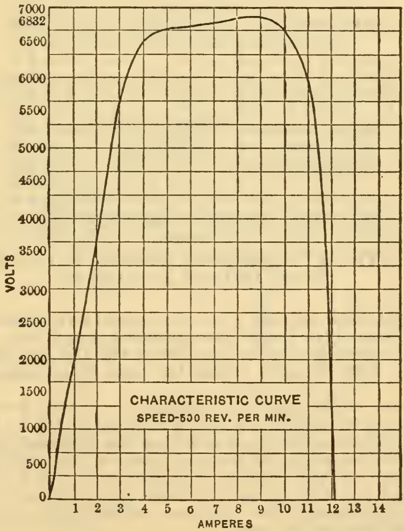


FIG. 3. Characteristic curve of Brush 125-Light Arc Dynamo without Regulator.

machine without any regulator. The readings were all taken at the sparkless position of commutation. This curve is remarkable from the fact that after we get over the bend, the curve is almost perpendicular, and is probably the nearest approach to a constant current machine ever attained. By winding more wire on the armature the machine could have been made to deliver a constant current of 9.6 amperes at all loads, without shunting

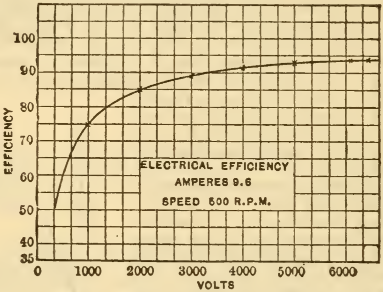


FIG. 4. Electrical Efficiency Curve of Brush 125-Light Arc Dynamo.

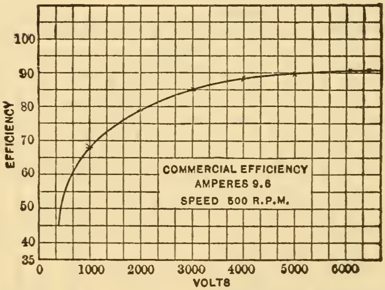


FIG. 5. Commercial Efficiency Curve of Brush 125-Light Arc Dynamo.

any of the current from the field; but this would have increased the internal resistance, and also have made the machine much less efficient at light loads. By the present method of regulation the I^2R loss at one-quarter load is reduced from 4,018 to 3,367 watts, the gain being almost one electrical horse-power.

Fig. 4 is a curve of the electrical efficiency. It will be noticed that this at full load reaches 94 per cent, which is accounted for by the liberal allowance of iron in the armature, thus reducing the reluctance of the magnetic circuit, and by the large size of the wire used on both field and armature.

Fig. 5 is a curve of the commercial efficiency. At full load this is over 90 per cent, and approaches very closely the efficiency of incandescent dynamos of equal capacity, but the most noteworthy point is the high efficiency shown at one-quarter load.

Fig. 6 is a curve of the machine separately excited, with no current in the armature. The ordinates are the volts at the armature terminals, and the abscissæ the amperes in the field. This is in reality a permeability curve of the magnetic circuit. By a comparison of the voltage shown here when there are nine amperes in the field, with that of the machine when delivering current, can be seen the enormous armature reaction. The curve also

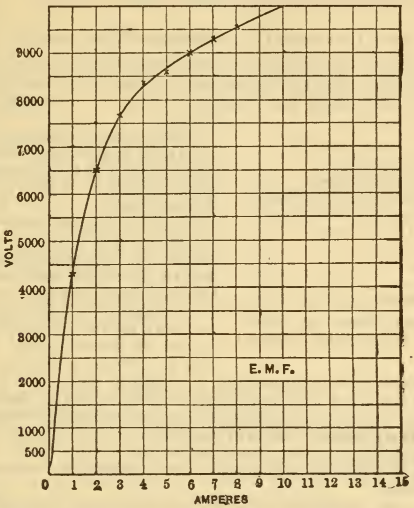


FIG. 6. Permeability Curve of Magnetic Circuit of Brush 125-Light Arc Dynamo.

indicates a new departure in arc dynamo design, namely, that the magnetic circuit is not worked at nearly as high a point of saturation as in the old types.

Shunt dynamo. The shunt dynamo has, besides an *external characteristic,* shown below, an *internal characteristic.* The first is developed from the volts read while the load in amperes is being added, the armature revolutions being kept constant (See Fig. 7.)

Adding load to a shunt dynamo means simply reducing the resistance of the external circuit. With all shunt machines there is a point of external resistance, as at *n*, beyond which, if the resistance is further reduced, the volts will drop away abruptly, and finally reach zero at a short circuit.

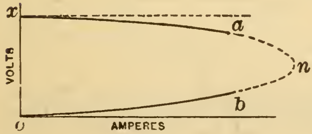


FIG. 7. External Characteristic of Shunt-wound Dynamo.

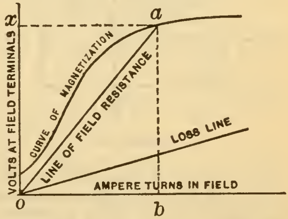


FIG. 8. Internal Characteristic of Shunt Dynamo.

The *internal characteristic*, Fig. 8, or, more correctly, curve of magnetization, of a shunt dynamo, is plotted on the same scale as those previously described, from the volts at the field terminals and the amperes flowing in the field winding.

The resistance line $o\ a$ only applies to the point a on the curve, and the resistance value $a\ b$ for that point is determined by ohms law, or as follows: As the curve of magnetization is determined from the reading of volts plotted vertically and amperes horizontally, and as $r = \frac{v}{I}$ or $r = \frac{a\ b}{o\ b}$ and $\frac{a\ b}{o\ b} =$ tang $a\ o\ b$, therefore the resistance at any point on the curve will be the tangent of the angle made by joining that point to the origin o.

Compound dynamo. As the compound dynamo is a combination of the series and shunt machines, the characteristics of both may be obtained from it.

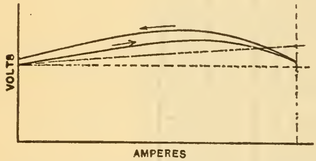


FIG. 9. Characteristic of Over-compounded Compound-wound Dynamo.

The external characteristic is of considerable importance where more than one dynamo is to be connected to the same circuit, or when close regulation is necessary.

Fig. 9 is a sample curve from a compound-wound dynamo, where the increase of magnetization of the fields due to the series coils and load causes the terminal voltage to rise as the load is increased. This is commonly done to make up for drop in feeders to the centre of distribution. It is impossible in ordinary commercial dynamos to make this curve closely approach a straight line, and the author has found it difficult for good makes to approach a straight line of regulation nearer than $1\frac{1}{2}$ per cent either side of it for the extreme variation.

Curve of Magnetic Distribution.—This curve is constructed from existing dynamos to show the distribution of the field about the pole-pieces; it can be plotted on the regular rectangular co-ordinate plan, or on the polar co-ordinate.

The following cuts illustrate the commonest methods of getting the data for the curve. With the dynamo running at the speed and load desired, the

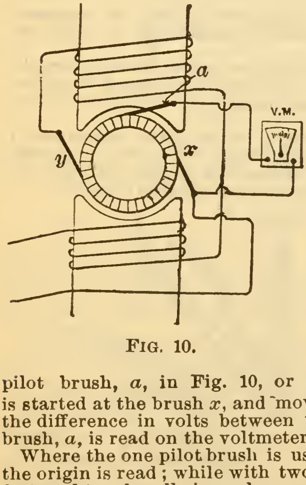


FIG. 10.

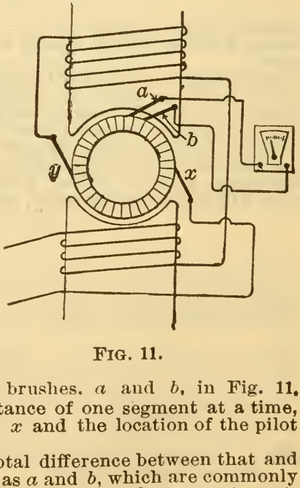


FIG. 11.

pilot brush, a, in Fig. 10, or the two brushes. a and b, in Fig. 11, is started at the brush x, and moving a distance of one segment at a time, the difference in volts between the brush x and the location of the pilot brush, a, is read on the voltmeter.

Where the one pilot brush is used, the total difference between that and the origin is read; while with two brushes, as a and b, which are commonly fastened to a handle in such a manner as to be the width of a segment apart, just the difference between the two adjacent segments is read, and the total difference is determined by adding the individual differences together.

ARMATURES.

Direct-current armatures are divided into two general forms, — *drum* armatures, in which the conductors are placed wholly on the surface or ends of a cylindrical core of iron; and *ring* armatures, in which the conductors are wound on an iron core of ring form, the conductors being wound on the outside of the ring and threaded through its interior.

Another form used somewhat abroad is the *disk* armature, in which the conductors are arranged in disk form, the plane of which is perpendicular to the shaft, and without iron core, as the disk revolves in a narrow slot between the pole-pieces.

Armatures of the slotted or toothed core type are almost exclusively employed now. The coils are set into the slots, with the results that eddy currents in the conductors are prevented and the conductors are positively driven by the core teeth. The cores are built up of sheet steel disks in small sizes, annular sheets in medium sizes, and staggered circular segments in large sizes; the steel is from 15 to 25 mils thick and the sheets are clamped firmly together by end-plates. In order to prevent eddy currents in the core, the disks or sheets are either coated with an insulating varnish or separated by tissue paper pasted over the entire surface of one side of each disk or sheet.

The toothed armature has the following advantages and disadvantages as compared with the smooth body:

Advantages.

1. The reluctance of air-gap is minimum.
2. The conductors are protected from injury.
3. The conductors cannot slip along the core by action of the electrodynamic force.
4. Eddy currents in the conductors are almost entirely obviated.
5. If the teeth are practically saturated by the field magnetism, they oppose the shifting of the lines by armature reaction.

Disadvantages.

1. More expensive.
2. The teeth tend to generate eddy currents in the pole-pieces.
3. Self-induction of the armature is increased.

If the slots can be made less in width than twice the air-gap, so that the lines spread and become nearly uniform over the pole-faces, but little effect will be felt from eddy currents induced in the pole-faces. When it is not possible to make such narrow slots, pole-pieces must be laminated in the same plane as the disks of the armature core, or the gap must be considerably increased.

Hysteresis in the armature core can be avoided to a great extent by using the best soft sheet iron or mild steel, which must be annealed to the softest point by heating to a red heat and cooling very slowly. Disks are always punched, and are somewhat hardened in the process; annealing will entirely remove the hardness, and any burrs that may have been raised.

Disks should be punched to size so carefully as to need no filing or trueing up after being assembled. Turning down the surface of a smooth-body armature core burrs the disks together, and is apt to cause dangerous heating in the core when finished. Light filing is all that is permissible for truing up such a surface. Slotted cores should be filed as little as possible, and can sometimes be driven true with a suitable mandrel.

Armature shafts must be very strong and stiff, to avoid trouble from the magnetic pull should the core be out of center. They are made of machinery steel, and have shoulders to prevent too much endwise play.

Core Insulation. — A great variety of material is used for insulating the core, including asbestos, which is usually put next to the core to prevent damage from heating of that part, oiled or varnished paper, linen, and silk; press board; mica and micanite. For the slots of slotted cores the insulation is frequently made into tubes that will slide into the slots, and the conductors are then threaded through. Special care must be taken at corners and at turns, for the insulation is often cut at such points.

Armature Windings.

For all small dynamos, and in many of considerable size, the winding is of double cotton-covered wire. Where the required carrying capacity is more than that of a No. 8 wire, B. & S. gauge, the conductor should be stranded for smooth-core armatures. In large dynamos, rectangular copper bars, cables of twisted copper, and in some cases large cable compressed into rectangular shape, are more commonly used. If the copper bars are too wide, or wide enough so that one edge of the bar enters the field perceptibly before the remaining parts of the bar, eddy currents are induced in it; such bars are therefore made quite narrow, and it is common to slope the pole-face a trifle, so that the bars may enter the field gradually.

Methods or arrangement of windings are of a most complex nature, and only the most general in use will be described here, and these only in theory; Parshall & Hobart have described about all the possible combinations; S. P. Thompson, Hawkins & Wallis, and others have also written quite fully on the subject.

Ring or Gramme Windings.

There are two fundamental types of armature winding: ring and drum. In a ring-wound armature, the core is necessarily annular, the wire being wound through the core as well as along the exterior, as indicated in Figs. 12 to 15. This form of winding is now used only in arc-light dynamos and very small motors.

The simplest form of ring winding is the *two-circuit single winding*, where a continuous conductor is wound about the ring, and taps taken off to the commutator at regular intervals.

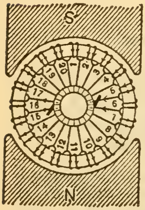


FIG. 12.

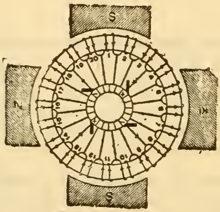


FIG. 13.

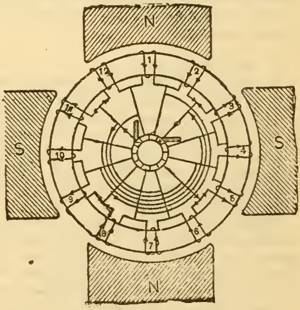


FIG. 14.

The first variation on this will be the *multi-circuit single winding*, used where there are more than one pair of poles. Fig. 13 shows the *four-circuit single winding*.

Where it is advisable to reduce the number of brushes in use, the multi-circuit winding can be cross-connected; that is, those parts of the winding occupying similar positions in the various fields are connected in parallel to the same commutator bar. Fig. 14 shows one of the simplest forms of cross-connected armatures.

Where, from the shape of the frame, the magnetic circuits are somewhat unequal, the winding shown in Fig. 15 will average up the unequal induction values, and prevent sparking to some extent. It also halves the number of commutator segments; that is, there are two coils connected to each segment instead of one, as in the previously mentioned windings. If N_k = number of coils, and p = number of poles, each coil is connected across to a coil $\left(\frac{N_k}{p} \pm 1\right)$ in advance of it.

Two-Circuit Windings for Multipolar Fields.—This is an important class of windings, and, as it has but two circuits irrespective of the number of poles, has the advantage over the multiple-circuit windings that it needs but $\frac{2}{p}$ as many conductors as are necessary in that class.

But two sets of brushes are necessary for the two-circuit windings, unless the current is heavy enough to require a long commutator, in which case other sets of brushes can be added, up to the number of poles.

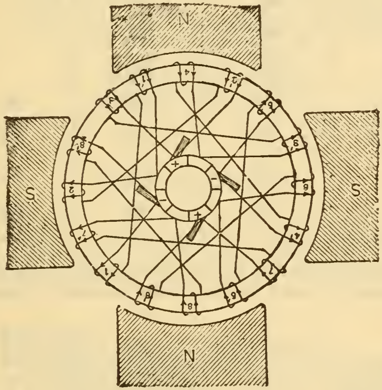


FIG. 15. Ring Winding Cross-connected to Reduce Unequal Induction.

In the *short-connection* type of this class, conductors under adjacent field poles are connected together so that the circuits from brush to brush are influenced by all the poles and are therefore equal.

In the *long-connection* type the conductors under every other pole are connected, so that the conductors from brush to brush are influenced by but one-half the number of poles.

The number of coils in a *two-circuit long-connection multipolar winding* is determined by the formula

$$N_k = \frac{p}{2} y \pm 1,$$

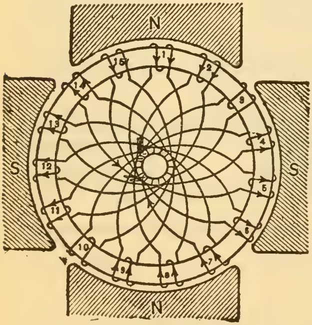
where N_k = the number of coils, p = the number of poles, and y = the pitch. The number of commutator segments is equal to the number of coils and must be a number not divisible without a remainder by the number of *pairs* of poles.

The pitch, y, is the number of coils advanced over for the connections, as, for instance, in an armature with a pitch of 7 the end of coil number 1 is connected to the beginning of coil $1 + 7 = 8$, and from 8 to $8 + 7 = 15$, and so on. In multipolar *ring* long-connection windings y may be any integer.

Mr. Kapp gives in the following table the best practice as to angular distance between brushes for this class of windings.

Number of poles.	Angular distance between brushes.				
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
2	180				
4	90				
6	60	180			
8	45	135			
10	36	108	180		
12	30	90	150		
14	25.7	77	128	180	
16	22.5	67.5	112	158	
18	...	60	100	140	180
20	...	54	90	126	162

Fig. 16 shows a simple form of *two-circuit multipolar single winding*, and Fig. 17 another sample as used with a greater number of poles.



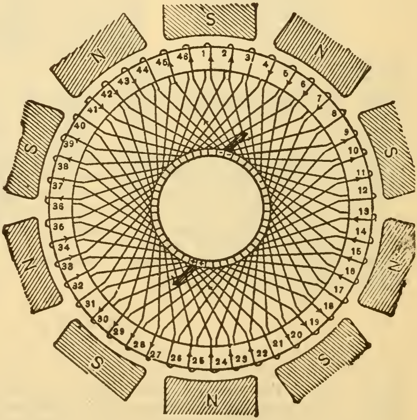


FIG. 16. Two-path Multipolar Windings. FIG. 17.

Both of the above samples are of the *long-connection* type. In the *short-connection* type the formula for determining the number of the coil is

$$N_k = py \pm 2,$$

and Fig. 18 is a sample diagram of this type.

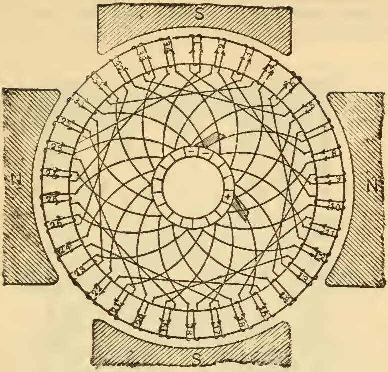


FIG. 18. Short-connection Two-path Ring Winding.

Drum Windings.

In order that the E.M.F.'s generated in the coils of a drum armature may be in the same direction, it is necessary that the two sides of each coil be in fields of opposite polarity, and therefore the sides of the coils are connected across the ends of the core; directly across, for bipolar machines, and part way so for those of the multipolar type.

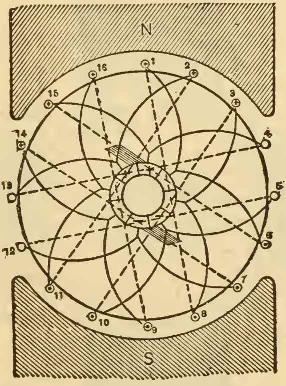


FIG. 19. Bipolar Drum Winding.

The drum winding is wholly on the exterior of the core. Fig. 19 is a diagram of a bipolar drum winding on a smooth core; the dotted lines indicate the crossings of the wires over the rear head of the core. Drum windings are mostly of the two-layer type, of which Fig. 20 is a diagram; with a slotted core, the numbered conductors would lie within the slots. In this diagram each pair of conductors having numbers differing by 15 compose the two "sides" of one coil, and are therefore integral with each other.

There are two general types of drum winding: lap and wave. If each coil has more than one turn, "lap-connected" and "wave-connected" are more appropriate distinguishing terms. Bipolar machines necessarily

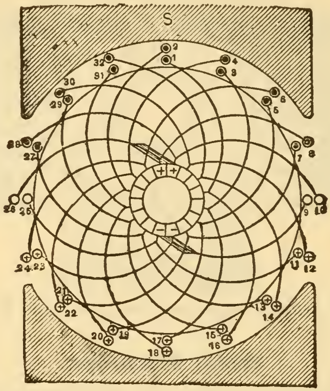


FIG. 20. Bipolar two-layer drum winding.

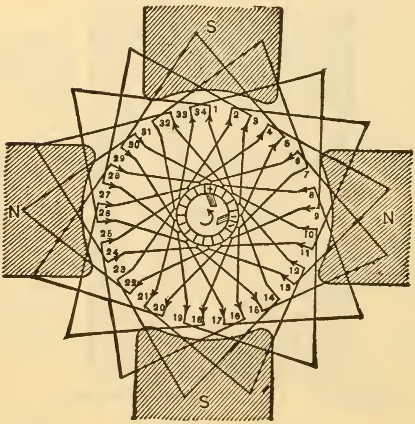


FIG. 21. Two-path single four-pole winding

have lap-connected windings. In multipolar machines the two "sides" of each coil are located a distance apart approximately equal to the pole pitch instead of on opposite sides of the core (see Fig. 21). The proportion of armature circumference spanned by each coil is preferably a trifle less than the pole pitch; for a toothed armature the number of teeth embraced by each coil should be equal to $N_t \div p - x_t$. If $N_t \div p$ is a whole number, $x_t = 1$; if it is a mixed number, $x_t =$ the fractional part or $1 +$ that part; it should seldom exceed 2 in any case.

All lap windings have $p\,m$ parallel paths. A multiplex winding consists of two or more distinct windings, the conductors of which are arranged in regular sequence around the core; the windings are connected to m sets of commutator segments assembled in a single commutator, as indicated

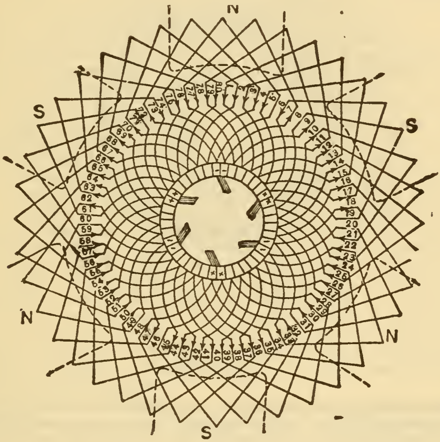


FIG. 22. Six-path single drum winding.

by Fig. 23. The terminals of each coil of any lap winding must be connected to two commutator segments between which there are $m - 1$ other segments.

Wave-connected windings may have any even number of parallel paths regardless of the number of magnet poles, within practical limits. The number depends on the number of coils and method of connecting them. The relation between the number of coils (and commutator segments), number of paths, number of magnet poles and method of connection is as follows:—

$$N_k = \frac{(1 + k_s)\,p \pm q}{2} \qquad (2)$$

and

$$k_s = \frac{2\,N_k \pm q}{p} - 1 \qquad (3)$$

The smaller value of k_s is preferable, but choice between the two is usually determined by the choice between the resulting classes of winding. If $k_s + 1$ and N_k have a common factor, the winding will be of the plural or multiplex type; if not, a simple wave-connected winding will result, provided $q \leqq p$.

In slotted armatures the number of conductors must be a multiple of the number of conductors per slot.

Fig. 23 is a diagram of a two-path triplex winding, *i.e.*, three two-path windings connected in parallel by the brushes. It is mathematically the equivalent of a single six-path winding.

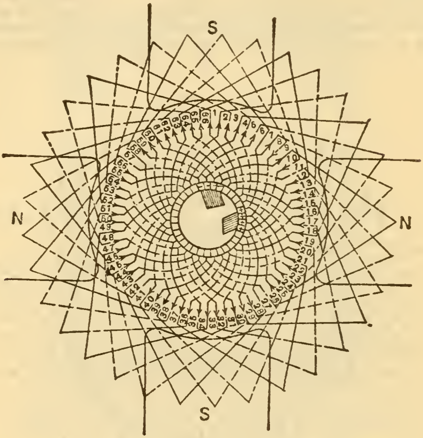


FIG. 23.

Fig. 24 shows diagrammatically the characteristics of the usual two-path armature winding used on street railway motors, in which there are three times as many coils as there are slots. In this case $x_t = 0.25$ and $k_s = 48$.

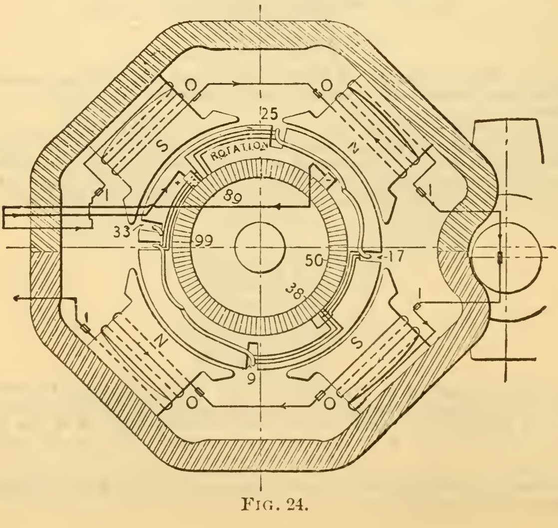


FIG. 24.

Balancing the Magnetic Circuits in Dynamos.

Difficulty has been experienced in the operation of large multipolar direct-current machines with parallel wound armatures, owing to differing magnetic strengths in the poles. The potential generated in conductors under one pole differed from that generated in conductors similarly situated under another pole of the same polarity, the result being a slight difference of potential between brushes of similar polarity. This caused currents to flow from one brush to another, and from one section of the armature winding to another, attended by wasteful heating of conductors and sparking at the brushes. This difficulty is obviated by the Westinghouse Electric & Manufacturing Company by the following method of balancing:

A number of points in the armature winding corresponding to the number of pairs of poles, which are normally of equal potential, are connected by leads through which currents may pass from one section to the others with which it is connected in parallel. The currents are alternating in character and lead or lag with reference to their respective E.M.F.'s. They thus magnetize or demagnetize the field magnets and automatically produce the necessary balance. This method of balancing is also of advantage in eliminating the sparking at the brushes and the wasteful heating, which occur when an armature becomes decentralized, owing to wear of the bearings, or to other causes. When an armature gets out of center the air-gap on one side is greater than the air-gap on the opposite side. The potential generated in the coils — if the armature has the ordinary multiple winding — will be much greater on the side having the smaller air-gap than that generated under poles of the same polarity on the opposite side. Consequently, a current corresponding to this difference of potential flows through the brushes from one section of the winding to another. This flow of current will act the same as if two generators were coupled rigidly on one shaft and the potential of the one raised above that of the other. The machine having the higher potential would act as a generator, and the other would run as a motor. This, of course, would result in bad sparking and the burning of the brushes.

By the use of the above balancing method, however, the armature could be considerably out of center and no injurious results occur, as the balancing currents flow, not through the brushes, but, as explained above, through specially provided connections. In addition, the currents in these conductors are alternating currents — "leading" in some coils and "lagging" in others — a fact which enables a relatively small current to balance the circuits effectively.

Heating of Armatures.

The temperature an armature will attain during a long run depends on its peripheral speed, the means adopted for ventilation, the heating of the conductors by eddy currents, the heating of the iron core by hysteresis and eddy currents, the ratio of the diameter of the insulated conductor to that of its copper core, the current density in the conductor, the radial depth of winding, whether the armature is of cylinder or drum type, and the amount and character of the cooling surface of the wound armature.

The higher the peripheral speed of the armature the less is the rise of temperature in it. Mr. Esson gives, as the result of some experiments on armatures with smooth cooling surfaces, the following approximate rule:

$$\theta_A = \frac{55\, P_A}{S\,(1 + 0.00018\, V)} = \frac{350\, P_A}{S'(1 + 0.00059\, V')},$$

where θ_A = difference of temperature between the hottest part of the armature and the surrounding air in degrees, Centigrade,

P_A = watts wasted in armature,

S = active cooling surface in square inches,

S' = active cooling surface in square centimeters,

V = peripheral speed of armature in feet per minute,

V' = peripheral speed in meters per minute.

The more efficient the means adopted for ventilating the armature by currents of air, the smaller is the temperature rise. Some makers leave spaces between the winding at intervals, thus allowing the air free access to the core and between the conductors. A draught of air through the interior of the armature assists cooling and should be arranged for whenever possible.

For heavy currents it is sometimes necessary to subdivide the conductors to prevent eddy currents; stranded conductors, rolled or pressed hydraulically, of rectangular or wedge-shaped section, have been used. Such subdivision should be parallel to the axis of the conductor, and preferably effected by the use of stranded wires rather than laminæ. Few armature conductors of American dynamos of to-day are divided or laminated in any degree whatsoever. Solid copper bars of approximately rectangular cross-section are often used, and little trouble is found from Foucault currents.

Mr. Kapp considers 1.5 square inches (9.7 square centimeters) of cooling surface per watt wasted in the armature a fair allowance.

Esson gives the following for armatures revolving at 3000 feet per minute:

P_A = watts wasted in heat in winding and core,
S = cooling surface, exterior, interior, and ends, in square inches,
S' = cooling surface, exterior, interior, and ends, in square centimeters,
θ_A = temperature difference between hottest part of armature and surrounding air in $C°$.

Then
$$\theta_A = \frac{35\ P_A}{S} \text{ or } \frac{225\ P_A}{S'}.$$

Specifications for standard electrical apparatus for U. S. Navy say, "No part of the dynamo, field, or armature windings shall heat more than 50° F. above the temperature of the surrounding air after a run of four hours at maximum rated output."

According to the British Admiralty specification for dynamos, the temperature of the armature one minute after stopping, after a six hours' run, must not exceed 30° F. above that of the atmosphere. In this test the thermometer is raised to a temperature of 30° F. above that of the atmosphere before it is placed in contact with the armature, and the dynamo complies (or does not comply) with the specification according as the thermometer does not (or does) indicate a further rise of temperature.

The best dynamo makers to-day specify 40° and 45° C. as the maximum rise in temperature of the hottest part of a dynamo, or 55° if the temperature of the commutator surface is to be measured.

Armature Reactions.

In many direct-current dynamos having no special devices for reversing the current in each armature coil as it passes through the "commutating zone," it is necessary to give the brushes a forward lead so that the magnetic fringe from the pole-tip toward which the coil is moving may induce an E.M.F. in the coil and reverse the current. In motors the brushes are shifted rearward instead of forward, the polarity of the approaching pole-tip being of the wrong sign.

With the forward lead given to the brushes the effect of the armature current is to weaken and distort the magnetic field set up by the field magnets; a certain number — depending on the lead of the brushes — of the armature ampere-turns directly oppose those on the field-magnets and render a somewhat larger number of these ineffective, except as regards wasting power; the remaining armature ampere-turns tend to set up a magnetic field at right angles to the main field, with the result that the resultant field is rotated forward in the direction of motion of the armature, and that the field strength is reduced in the neighborhood of every trailing pole-piece horn, and is increased in that of every leading pole-piece horn. When, therefore, the brushes have a forward lead each armature section as it comes under a brush enters a part of the field of which the strength is reduced by the armature cross-induction; and, if this reduction is great, the field strength necessary for reversing the current in the section (in the short time that the section is short-circuited under the brush) may not be obtained, and sparkless collection may thus be rendered impossible.

Various devices for reversing the currents in the armature sections, as they pass successively under the brushes, without giving a forward lead to the brushes, have been proposed; a number of these were described in a paper by Mr. Swinburne; an improvement by Mr. W. B. Sayers consists in interposing auxiliary coils between the joints of adjacent armature sections and the corresponding commutator bars. Each auxiliary coil is wound on the armature with a lead relative to the two main armature sections and the commutator bar which it connects together. The result of this arrangement is that the difference between the E.M.F.'s in the two auxiliary coils connecting any given armature section to the two corresponding commutator bars may be made sufficient to reverse the current in the armature section when short-circuited under a brush, even if the brush has a backward instead of a forward lead.

In the Thompson-Ryan dynamo the effects of armature reaction are neutralized by a special winding through slots across the faces of the pole-pieces, parallel with the axis of the armature; this winding is in series with the armature, and the same current flowing in both, but in such direction that all effects on the field magnets are neutralized, the ampere-turns of the shunt are therefore much less than in other dynamos, there is no sparking under any ordinary conditions of load, the brushes are placed permanently when the machine is set up, and the efficiency is high through a wide range.

The method which is most widely employed is to put small auxiliary field-magnet poles between the main poles and connect their windings in series with the armature. This method is applied chiefly to constant-potential motors designed to run at several speeds.

Drag on Armature Conductors.—In dynamos, each armature conductor has to be driven in opposition to an effort or drag proportional at every instant to the product of the current carried by the conductor into the strength of the magnetic field. This drag on a conductor varies, therefore, with the position of the conductor relative to the field-magnet poles, and is a maximum when the conductor passes through that part of the air-gap at which the magnetic induction is greatest. The arrangements for driving the armature conductors must, of course, be adapted to the greatest value of the drag to which a conductor is exposed, and this is given for smooth core armatures by the formula below.

Let i_a = current in amperes carried by each conductor,
$\mathcal{B}$ = maximum induction in air-gap per square centimeter,
$\mathbf{B}$ = maximum induction in air-gap per square inch,
W_a = length of armature core in inches.

Then $\dfrac{\mathcal{B} W_a i_a}{1{,}752{,}300} = \dfrac{\mathbf{B} W_a i_a}{11{,}302{,}360}$ = Maximum pull in lbs. on each conductor.

In slotted armatures the core teeth take the drag.

COMMUTATORS AND BRUSHES.

Commutators are built up of the best grade of copper, preferably hard drawn. The insulation between segments should invariably be of the best quality of amber mica; white mica is usually too hard and brittle, and does not wear down as rapidly as the copper segments, so that eventually the mica strips project above the surface and cause the brushes to chatter and spark. The insulation at the ends is usually of micanite, and should be as hard as possible.

Brushes are invariably of carbon except on machines built for very low voltages. The high resistance of the carbon reduces the "short-circuit" current in a coil undergoing commutation and also reduces the inductive opposition to the reversal of current in the coil, thereby facilitating commutation.

The current density under brush faces should not exceed 60 amperes per square inch for carbon, 200 for woven wire, or 250 amps. per sq. in. for soft leaf copper brushes. The proper density to be used in any given case depends upon other features of commutator and brush proportions. See "Practical Design," page 361.

FIELD MAGNETS.

Field magnets are bipolar in small sizes and multipolar in large sizes; the dividing line between bipolar and multipolar construction varies from 1 kilowatt to 10 kilowatts; it is quite common practice to make machines of 5 kilowatts and over multipolar. Magnet cores are made either of wrought iron or steel, except in very small machines in which cast iron is used. Pole-pieces or shoes are of either cast iron or steel, according to their shape and disposition. Cast-iron shoes are attached to the sides of the pole and merely extend the pole-face surface; steel shoes are bolted against the free ends of the poles so that the entire air-gap flux passes through the shoe. In many cases no shoes are used, the poles being carried to the air-gap without change in cross-section, or else provided with integral polar extensions at the free ends.

Field magnet yokes are either of cast steel or cast iron. The latter is preferable on every score except weight, for the reason that steel castings are seldom perfectly sound throughout and rarely within $\frac{1}{8}$ inch of calculated dimensions. Magnet cores are generally bolted to the yoke, but a few builders still "cast-weld" them in.

Coil Surface Necessary for Safe Temperature.

Esson gives the following method of determining the surface necessary for a magnet coil to keep its heat within assigned limits.

Let P = watts wasted in heating,
S = cooling surface in square inches of coil, not including end flanges and interior,
S_1 = same as above in square centimeters,
θ = temperature of hottest part above surrounding air,

then

$$\theta \text{ F.}^\circ = 99\frac{P}{S} \text{ or } \theta \text{ C.}^\circ = 335\frac{P}{S_1}.$$

$$\text{Maximum current} = \sqrt{\frac{\text{degs. F.} \times \text{sq. ins.}}{99 \times \text{hot } r}}.$$

$$\text{Hot } r = \text{cold } r + 1\% \text{ for each additional } 4.5^\circ \text{ F.}$$

Table of Cooling Surfaces.

Excess temperature above surrounding air.		Cooling surface per watt in	
F.°	C.°	square inches.	sq. centimeters.
—	15	3.67	23.7
30	—	3.30	21.3
—	20	2.75	17.8
40	—	2.48	16.0
—	25	2.20	14.2
50	—	1.98	12.8
—	30	1.83	11.8
60	—	1.65	10.7
—	35	1.57	10.1
70	—	1.41	9.1
—	40	1.38	8.9

Gyrostatic Action on Dynamos in Ships.

(Lord Kelvin.)

$$L = \frac{W k^2 \Omega \omega}{g} \text{ and } P = \frac{W k^2 \Omega \omega}{gl}$$

where $L =$ moment of couple on axis,
$P =$ pressure on each bearing,
$W =$ weight of armature,
$k =$ radius of gyration about axis,
$\Omega = \frac{2\pi}{T} A =$ maximum angular velocity of dynamo in radians per second due to rolling of ship,
$A = \frac{\pi d}{180} =$ amplitude in radians per second,
(Radian is unit angle in circular measure.)
$d =$ degrees of roll from mean position,
$T =$ periodic time in seconds,
$\omega = 2\pi n =$ angular velocity of armature in radians per second,
$n =$ number of revolutions of armature per second,
$l =$ distance between bearings,
$g =$ acceleration due to gravity.

NOTE.—On applying the above formula to dynamos, where W, k, and ω are great, it will be found advisable to place their plane of rotation athwartships, in order to avoid as far as possible wear and tear of bearings due to the gyrostatic action.

DIRECT-CURRENT MOTORS.

The counter E.M.F. generated in a motor armature is given by equation (1). This E.M.F. is equal to the E.M.F. applied at the motor brushes minus the drop in the armature winding and connections; consequently, the speed of a motor is

$$\text{R.p.m.} = \frac{60\,(E_w - I_a R)\, q\, 10^8}{\Phi\, N_c\, p} \quad \ldots\ldots\ldots \quad (4)$$

At no load, the drop in the armature circuit is so small that $E_w - I_a R$ may be considered equal to E_w, for the purpose of computing the no-load speed.

The torque of a motor armature, in pound-feet, is

$$T = 117\, \Phi\, N_c\, i_a\, p\, 10^{-11} \quad \ldots\ldots\ldots \quad (5)$$

Motors for operation on constant-potential circuits are:

Shunt-wound, for service requiring practically constant speed and imposing small load at starting;

Series-wound, for starting heavy loads from standstill and running at speeds inversely varying as the load;

Compound-wound, for starting heavy loads and running at nearly constant speed.

Differentially-wound, for starting under light loads and running at strictly constant speed. (This type is not much used now.)

The remarks concerning dynamo magnets, armatures, etc., apply also to direct-current motors. The magnetization curve may be obtained by driving the machine as a dynamo; or it may be plotted from readings of field excitation and armature speed; in the latter case, the curve will be the inverse of Fig. 1, as indicated by Fig. 25.

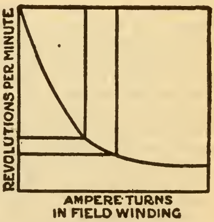


FIG. 25. Magnetization Curve of Motor.

Brushes on a motor must usually be set *back* of the neutral point, or with a "backward lead." This tends to demagnetize the fields, and as weakening the fields of a motor tends to increase the speed, the increase of load on a shunt-wound motor tends to prevent the speed falling, and the shunt motor is very nearly self-regulating.

Leonard's System of Motor Control.

Wherever it becomes necessary to vary the speed and torque of a continuous current electric motor to any considerable degree, any of the rheostat methods introduce very considerable losses, and are apt to induce bad sparking at the commutator.

H. Ward Leonard invented the method shown in Fig. 26, which gives most excellent results, although to some extent complicated, and is highly efficient.

The driving motor, or rather motor which it is wished to control, is provided with a separately excited field, which can be varied by its rheostat to produce any rate of speed, from just turning to the full speed of which it may be capable. Current is supplied to its armature from a separate generator, and by varying the separately excited field of this generator, the amount of current supplied to the motor armature can be varied at will, and the torque therefore changed to suit the circumstances.

The generator is driven at constant speed by direct connection to a motor which gets its current from an outside source, or to another generator

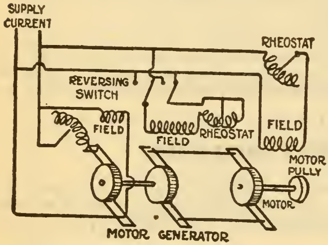


FIG. 26. Leonard's System of Motor Control.

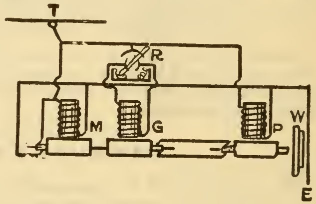


FIG. 27. Leonard's System of Electric Propulsion.

driven by some other motive power, say a steam engine. This driven generator supplies current for exciting the fields of the secondary generator and main motor.

By reversing the field of the generator, the current in its armature is reversed, and therefore so is the direction of rotation of the motor armature.

Fig. 27 shows the Leonard system adapted to electric street railway motor control.

Three-Wire System for Variable Speed Motor Work.

Omitting cranes, street railways, hoists, and other classes of service where the series motor with rheostatic control is used, variable speed motor work may be divided into three classes :

(1) Machines requiring a torque increasing with the speed. Blowers and fans belong to this class. The power required for the machine increases very rapidly as the speed increases, and care should be exercised in selecting motors for such service. However, as the variation required is usually small, the requirements can be met with standard motors on a single voltage system. Motors should preferably be compound-wound and the speed should be varied by means of a resistance in the shunt field.

(2) Machines requiring a constant torque. In this class pumps and air compressors are examples. The speed variation required for such service is usually small, and it is generally best and most economical to supply compound motors and to vary the speed by means of the shunt field rheostat, as in the case of the fans and blowers. A series winding is especially beneficial for this class of work in preventing the heavy fluctuations of current that would take place with a constant speed motor in passing through the different parts of the cycle. A compound motor may be used for this

work because a constant speed at any point on the controller is not necessary.

(3) Machines requiring approximately the same maximum output at any speed, or a torque varying inversely as the speed. This class includes most of the machine tool work where automatically constant speed regulation on any notch of the controller is especially desirable. It is, therefore, necessary to use a shunt motor having good inherent regulation.

The Generator. — The standard Edison three-wire system for general distribution consists of two 125-volt generators connected in series with the neutral wire brought out from between them. A single generator of the over-all voltage, with a motor-generator set of sufficient capacity to carry the unbalanced current, is used in many places. Still another system consists broadly of a standard direct-current generator designed for the maximum required E.M.F. having collector rings connected to the armature winding like a two-phase rotary converter. The leads from these rings are connected to auto-transformers or balancing coils, the middle points of which are connected to the neutral wire. With no external devices whatever, the neutral wire is thus maintained at a voltage midway between the outside wires of the system (see Fig. 28). These generators may be operated in multiple with any standard three-wire system, whether it consists of two machines operated in series, a single voltage generator with a balancing set or a double commutator generator. Any standard single-voltage system may be changed into a three-wire system by adding collector rings to the generator and using balancing coils to supply the neutral wire.

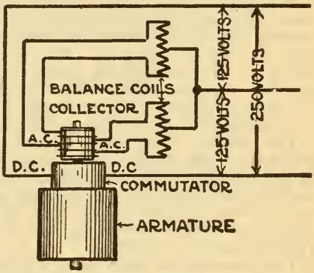


FIG. 28.

PRACTICAL DYNAMO DESIGN.*

It is safe to follow the rule of using bipolar field-magnets for machines of 4 kilowatts or less and multipolar magnets for larger machines.

For commutation reasons the current passing any one set of brushes should not exceed 250 amperes; this gives a criterion of the number of poles for machines of 250 amperes output or more. Lap windings should be used on such machines. Then

$$p = \frac{0.008\ I_a}{m} \qquad (6)$$

The number of poles on machines having wave-connected armatures is determined by commutation considerations chiefly; more than six poles are seldom used.

The best construction is a laminated magnet pole with extensions at the air-gap end, bolted to a cast-steel yoke. Fairly good results are obtained, however, with cast-steel poles. Laminated cores, cast-welded into either iron or steel yoke and provided with cast-iron shoes embracing the ends at the air-gap, give excellent results if the cast-welding is properly done. When the ratio of air-gap length to the width of each armature core-slot opening is much less than 0.5, the pole-face should be laminated in order to prevent excessive eddy curents in it; otherwise it may be solid. A cast-iron pole-shoe must not cover the end of the magnet core, but should surround it and serve merely as lateral extensions; the cross section of the core should be slightly reduced where it is surrounded by the pole-shoe.

* Cecil P. Poole.

The E.M.F. generated in the direct-current armature is, from eq. (1),

$$E = \frac{\pi D_p W_p \psi}{p} \mathsf{B}_p N_c \frac{p}{q} \frac{\text{r.p.m.}}{60} 10^{-8}$$

which reduces to

$$E = 0.05236\ D_p\ W_p\ \psi\ \mathsf{B}_p\ N_c\ \text{r.p.m.}\ 10^{-8} \div q.$$

The output in watts is $P_w = E_w\ I_w$, which for preliminary purposes may be considered the equal to $E\ i_a\ q$; whence

$$P_w = 0.05236\ D_p\ W_p\ \psi\ \mathsf{B}_p\ i_a\ N_c\ \text{r.p.m.}\ 10^{-8} \quad . \quad . \quad . \quad . \quad (7)$$

For economical use of material, the projected outline of a pole-face should be square, so that the width parallel to the armature shaft should approximately equal the chord of the average polar arc; whence W_p should be $= D_p \sin(180\ \psi \div p)$. For moderately high-speed machines, ψ may be taken at 0.7; for slightly lower speeds, at 0.72, and for slow-speed machines, at 0.75. For reversing motors it is best put at 0.6666, except series-wound reversing motors; for these, let $\psi = 0.7$.

Representing $\sin(180\ \psi \div p)$ by k_{ch}, page 371, results.

The average magnetic density over the pole-face ranges from 25,000 to 60,000 lines per square inch, according to the designer's method and the size of the machine. It is rational to make $\mathsf{B}_p = c \times D_p^{0.15}$, c being a coefficient varying according to the type of machine. For constant-potential dynamos and motors for general service, 28,120 is a suitable value for c; for shunt or compound-wound reversing motors, 33,850 is appropriate, and for series reversing motors, 36,620.

The permissible number of ampere-conductors around the armature periphery ranges from 1200 to 2200 per inch of armature diameter. For machines designed according to the method outlined herein, it is good practice to apply the formula:

$$i_a N_c = \frac{k_c D_p^{1.15}}{\psi}.$$

The values of k_c are as follows:

Dynamos and motors for general service,	$k_c = 679.$
Shunt and compound reversing motors,	$k_c = 564.$
Series-wound reversing motors,	$k_c = 678.$

From the foregoing equation an equivalent is obviously obtainable for $i_a N_c\ \psi$, and substituting this and the equivalents for B_p and W_p previously obtained, equation (7) reduces to the following two:

For all machines except series-wound reversing motors:

$$P_w = \frac{k_{ch}\ D_p^{3.3}\ \text{r.p.m.}}{100} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

For series-wound reversing motors:

$$P_w = 0.013\ k_{ch}\ D_p^{3.3}\ \text{r.p.m.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

For belted machines which need not have any particular rate of speed, an economical rate is

$$\text{r.p.m.} = \frac{8500}{D_a^{0.8}}.$$

Considering D_a and D_p equal, which is allowable in preliminary "roughing out," and substituting in equation (8) the above equivalent for r.p.m.:

$$P_w = 85\ k_{ch}\ D_p^{2.5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Armature Details.—Core disks 25 mils thick may be used in most armatures; only those in which the core is subjected to high rates of magnetic reversal need have thinner disks. When $p \times$ r.p.m. exceeds 3000, it is advisable to use disks 20 mils thick, or less; when $p \times$ r.p.m. exceeds 4000, 15 mils should be the limiting thickness. The final criterion, however, is the eddy current loss in the core and teeth.

Having a means of determining the pole-face width parallel to the armature shaft, the length of the armature core follows within close limits. The armature core should extend beyond the edges of the pole-face at each end by a small amount — not less than the air-gap length, and preferably 1.5 times the air-gap.

Armature cores more than 5 inches long should have ventilating ducts not less than ⅜ inch wide at intervals of 2½ to 3½ inches. The exact duct width is usually determined by the amount of steel required parallel to the shaft in order to keep the magnetic density in the teeth within suitable limits.

The "nominal" magnetic density at the narrowest part of the teeth should be between 140,000 and 155,000 lines per square inch of net cross section. The "nominal" density is that which would exist if the flux did not spread beyond the geometrical contour of the pole-face in passing from the latter to the armature, and if *all* of the flux passed through the teeth; that is,

$$\frac{\Phi p}{N_t \psi t w_a} = \text{nominal density at tooth roots,}$$

$$w_a = 0.9\,(W_a - \text{ventilating ducts}).$$

In order to obtain dimensions that will result in a "nominal" density at the roots of the teeth that will be within the specified range, the number of teeth (and slots) may be approximated by means of the formula

$$N_t = \frac{\pi D_t - \dfrac{k_t}{w_a}}{s} \qquad (11)$$

The number of teeth must, of course, be an integer; if the result of eq. (11) should be a mixed number, therefore, the fractional part should be discarded if it is 0.8 or less; if it be more than 0.8, the next higher integer is to be taken as the number of teeth. The net measurement of the armature iron parallel with the shaft must then be corrected to satisfy the equation,

$$w_a = \frac{k_t}{\pi D_t - s N_t}. \qquad (12)$$

The value of k_t for all cases is

$$k_t = \frac{0.053\, D_p^2 W_p}{p\,\delta}.$$

When the armature conductors are round wires, the size of the coil slot is determined chiefly by the size and arrangement of the wires. Form-wound

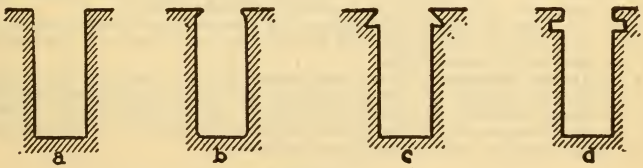


FIG. 29.

and separately-insulated coils are generally used, so that the coil slot is ordinarily of one of the shapes shown in Fig. 29, the slots *a* or *b* being used when binding wires are employed to keep the wires in their slots, and one of the others when the coils are held in by wedges. Two-layer windings are almost invariably used in this country. Fig. 30 shows two half-coils "abreast" in each layer, each coil having three turns of wire; this makes the total number of coils twice the number of slots. Fig. 31 shows three half coils "nested," with two turns per coil; this gives three times as many coils as there are slots, "three coils per slot." It is extremely objectionable to "nest" the coils, but sometimes unavoidable when round wires are used.

Table II, p. 372, gives slot widths and depths suitable for various arrangements of round conductors drawn to B. & S. gauge, based on two-layer windings and the insulation indicated in Fig. 32. The individual coils are wrapped

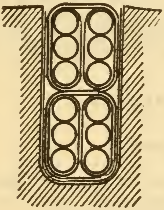


FIG. 30.

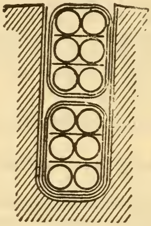


FIG. 31.

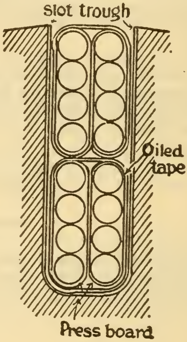


FIG. 32.

each in a single fold of 0.015-inch mica-treated press-board, each group of coils is wrapped with a single covering of 0.01-inch oiled tape, half lapped, and the slot is lined with a trough of 0.02-inch mica-treated press-board. If the press-board is well varnished with insulating compound, and the coils are dipped and baked before being assembled in the slots, this insulation will be adequate for 550-volt armatures.

The width of a coil slot should not be less than $\frac{1}{5}$ of its depth nor more than $\frac{1}{3}$ the depth. The depth of the coil slot, for armature of 16 inches diameter or over, may be estimated for preliminary purposes by means of the formula

$$h = 1 + \frac{\sqrt{D_a}}{10} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (13)$$

Appropriate trial depths for the coil slots of smaller cores are given by Table III, page 373.

Table IV, page 373, gives empirical but practical trial values for the minimum allowable number of armature coils, and Table V, page 374, gives values for the maximum allowable number of turns per coil, for use in preliminary "roughing-out." The former are somewhat elastic, but the latter can seldom be exceeded without risk of sparking at the brushes.

Table VI, page 375, gives trial values for armature conductor sizes; the actual allowable current density in the conductors, however, is determined by the heating of the armature.

Armature Losses.—The total losses in the armature should not exceed the value which will give a temperature rise, under full load, of 70°F. The relation between lost watts, radiating surface, peripheral velocity and temperature rise is, for fairly well ventilated armatures in non-enclosed field magnet frames, approximately as follows:

$$\theta_A = \frac{35\, P'_A}{D_a W_a \left(1 + \frac{\sqrt{(D_a \text{ r.p.m.})^3}}{420{,}000}\right)},$$

and allowing a rise of 70° this transposes to

$$P'_A = D_a\, W_a \left(2 + \frac{\sqrt{(D_a \text{ r.p.m.})^3}}{210{,}000}\right) \quad . \ . \ . \ . \ . \ . \ . \quad (14)$$

The reason for taking P'_A instead of P_A as the criterion of heating is that the projecting parts of the winding do not act effectively in radiating the heat produced by the core and teeth losses, although their radiating surface is always ample for the i^2r loss in them. Since they are not included in the radiating surface, the loss in them is not included in considering the heating.

With round conductors, the watts lost in the embedded part of the winding will be, with sufficient accuracy,

$$P_r' = W_a N_c \frac{i_a^2}{d^2};$$

if the conductors are rectangular in cross section, $\frac{\pi i_a}{4 a_c}$ must be substituted for $\frac{i^2_a}{d^2}$ in this equation.

The losses in the armature teeth must be estimated separately from those in the body of the core, the densities being widely different in the two parts. The general formula for hysteresis loss in either part of the core is

$$P_h = 48\, k_h\, v\, p \text{ r.p.m. } 10^{-7}$$

and the formula for eddy current loss is

$$P_e = 4\, k_e\, v\, p^2 \text{ (r.p.m.)}^2\, 10^{-8}$$

in which k_h is the loss per cubic foot of iron due to hysteresis, as given in the table on page 100 and k_e the corresponding eddy current loss as given in the table on page 106. It should be borne in mind that although the constants taken from the tables mentioned are based on losses per cubic foot of iron or steel, the volume of iron or steel represented by v in the equations is in cubic inches. Combining the three equations just given, the total loss to be considered in estimating the heating of the armature is

$$P_A' = W_a N_c \frac{i_a^2}{d^2} + p \text{ r.p.m. } 10^{-7} [48 (v_a k_{ha} + v_t k_{ht}) + 0.4 p \text{ r.p.m. } (v_a k_{ea} + v_t k_{et})] \quad . \; . \; . \; . \; . \quad (15)$$

In order to allow for the crowding of the magnetic flux toward the slots the cross section of the armature core body may be taken at 0.8 of the actual cross section, making the effective volume

$$v_a = 0.2\, \pi\, (D_t^2 - D_0^2)\, w_a \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (16)$$

and the effective density will be, accordingly,

$$\mathbf{B}_a = \frac{\Phi}{0.8\, (D_t - D_0)\, w_a} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

For computing the probable losses in the teeth the following relations may be assumed without appreciable error:

$$\left.\begin{array}{c}\text{active teeth}\\ \text{per pole}\end{array}\right\} = \left(\frac{2 k_g \delta}{\pi D_p} + \frac{\psi}{p}\right) N_t;$$

average width of each tooth $= (\tau + 2\, t) \div 3$;
and since $(\tau + 2\, t) \div 3 = [\pi\, (D_a - 1.33\, h) - N_t\, s] \div N_t$, and the average density in the teeth, for the present purpose, is equal to the flux per pole $\div$ active teeth per pole $\times$ average cross section per tooth, the average density will be

$$\text{Avg. } \mathbf{B}_\tau = \frac{\Phi}{\left(\frac{2 k_g \delta}{\pi D_p} + \frac{\psi}{p}\right) [\pi\, (D_a - 1.3\, h) + N_t\, s]\, w_a} \quad . \; . \; . \quad (18)$$

The volume of iron in the teeth is

$$v_t = \left[\frac{\pi}{4} D_a^2 - \frac{\pi}{4} D_t^2 - h\, s\, N_t\right] w_a \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (19)$$

The value of k_g in eq. (18) depends upon the relation between the interpolar space (distance between neighboring pole-tips of opposite polarity) and the air-gap length, and also upon the slope of the pole from the tip toward

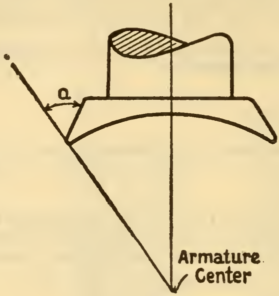


FIG. 33.

the main part of the core. Table VII, page 376, gives practical values of k_g within ordinary limits, and Fig. 33 indicates the angle represented in the table heading by α.

Fig. 34 affords a simple method of estimating roughly the armature core losses which is favored by Messrs. Parshall and Hobart; the curves here

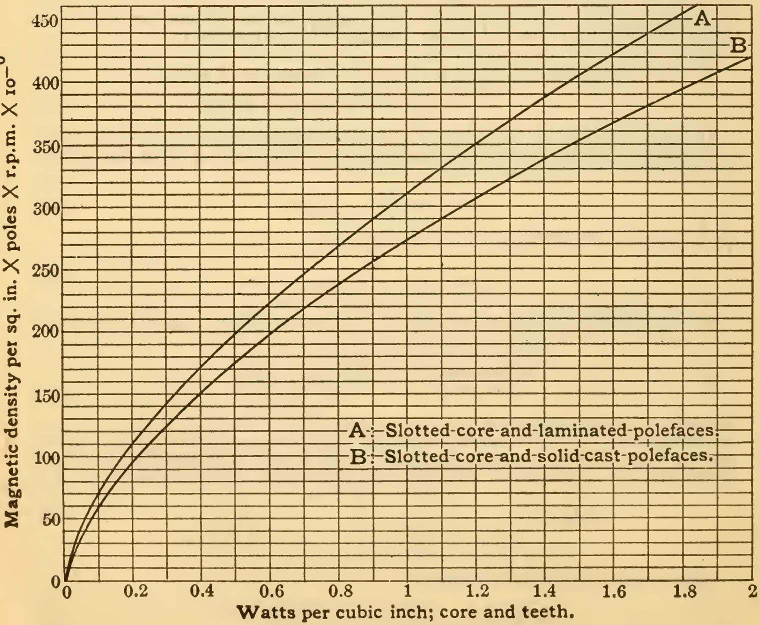


FIG. 34.

shown were plotted by Messrs. Esterlein and Reid from tests made on a large number of actual machines.

In estimating before hand the efficiency of a machine, the loss in the projecting parts of the armature winding must, of course, be considered. The actual total losses in the armature winding and core will be approximately

$$P_A = l_c N_c \frac{i_a^2}{d^2} + p \text{ r.p.m. } 10^{-7} [48 (v_a k_{ha} + v_t k_{ht}) + 0.4 p \text{ r.p.m. } (v_t k_{et} + v_a k_{ea})] \quad (20)$$

In a barrel winding, the length of each conductor (l_c) will be practically that given by the formula

$$l_c = W_a + k_w (D_a - h) + 0.8 (1 + h),$$

if the conductors are bent around ½-inch pins, as indicated in Fig. 35, and

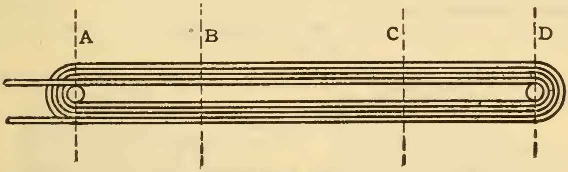


FIG. 35.

afterward pulled out to span the proper number of teeth. Table VIII, page 376, gives values of k_w for different numbers of poles. Each coil will project beyond the armature core at each end about

$$\frac{k_w}{4} (D_a - h) + \frac{1 + h}{2} \text{ inches,}$$

and the distance from center to center of the winding pins must be equal to

$$W_a + k_w (D_a - h) \text{ inches.}$$

Commutator and Brushes.—The number of commutator bars = number of armature coils or elements, in practically all modern windings. The diameter of the commutator barrel must be kept as small as possible in order to reduce the friction loss at the brush faces as well as to keep down the cost of the commutator and to favor good commutation. From purely mechanical considerations,

$$D_k > 0.06 \times \text{Number of segments} \quad (21)$$

For commutation reasons and to keep down friction,

$$D_k < 10{,}000 \div \text{r.p.m.} \quad (22)$$

In finally rounding out the dimensions, the following relation should be observed, if possible,

$$D_k = \frac{N_k b}{3 n_k} \quad (23)$$

and n_k should preferably be an integer.

The current density in each commutator segment should not much exceed 2000 amperes per square inch in the horizontal part and 2500 amperes per square inch in the connecting lugs or risers.

The brush faces should be of such area and number that the current density at the faces will not exceed 40 amperes per square inch for carbon brushes, 150 amperes per square inch for woven wire or gauze brushes, or

200 amperes per square inch for leaf copper brushes. Good average face densities are 30, 120, and 160 amperes per square inch, respectively.

With pressures of 1¼ to 2¼ lbs. per square inch of brush face, the effective resistance of the brushes will usually be

Carbon brushes:

$$\frac{0.125}{A_b} = R_b;$$

Copper brushes:

$$\frac{0.0125}{A_b} = R_b.$$

The total drop in volts at the brush faces, therefore, will be

Carbon brushes:

$$\frac{I_a}{8\ A_b} = \text{volts drop} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

Copper brushes:

$$\frac{I_a}{80\ A_b} = \text{volts drop} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24a)$$

The loss in watts due to the friction of the brush contacts with the commutator is

$$\frac{A_b\ D_k \text{ r.p.m.}}{k_b};$$

k_b varying according to the brush pressure, condition of commutator and quality of brush. The total losses at the brush faces, therefore, are

Carbon brushes:

$$\frac{A_b\ D_k \text{ r.p.m.}}{k_b} + \frac{I_a^2}{8\ A_b} = P_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

Copper brushes:

$$\frac{A_b\ D_k \text{ r.p.m.}}{k_b} + \frac{I_a^2}{80\ A_b} = P_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25a)$$

With ordinary grades of copper and carbon brushes and a commutator in reasonably good condition,

$$k_b = \frac{560}{\text{brush pressure in lbs. per sq. inch}}.$$

The maximum efficiency is obtained when the two terms of eqs. (25) and (25*a*) are equal, *i. e.*, when the friction loss equals the $I^2 R$ loss.

The temperature rise of the commutator will usually be

$$\frac{85 \times \text{total lost watts}}{W_k \left(D_k + \dfrac{D_k^2 \text{ r.p.m.}}{76{,}000}\right)} = \theta_k \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

If the lugs of the commutator segments are of considerable length, the rise of temperature will be somewhat less than calculated; on the other hand, if the commutator and brushes are not in good condition, the losses will be considerably more than given by eq. (25) or (25*a*) and the temperature rise will be correspondingly greater. The temperature rise should in no case exceed 75° Fahrenheit, and it is preferable to keep it down to 65° or 70°.

The dimension of the brush face transverse to the commutator segments, is determined almost solely by commutation requirements, and these involve so many widely varying factors that no hard-and-fast general rule can be laid down. For machines of ordinary types and fairly large sizes — 100 kilowatts and over, say — the span of a carbon brush may be roughly estimated by means of the formula

$$b = \frac{D_k}{p}\left[\pi(1-\psi) - \frac{i_a N_c}{1900\ D_a}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

This formula will apply with sufficient closeness for all practical work by determining the value, for a given type of design, of the coefficient in the denominator of the bracketed fraction. For reversing motors of a certain type, for example, it is 1600, and for small, shunt-wound motors of conventional design, it ranges from 800 to 1000.

Air-Gap.— The mechanical air-gap, from the pole-face to the tops of the armature teeth, should be made the nearest commercial dimension to that given by the formula

General Service Machines.		All Other Machines.	
$\delta = \dfrac{D_p}{18p}$	or	$\delta = \dfrac{D_p}{20p}$	. . . . (28)

Thus, if the formula gives 0.188 inch as the proper air-gap length and the machine is to be built by English measure, the actual value to be used would be $\frac{3}{16}$ inch. In such cases a revision of the pole-face density should be made in order that the ampere-turns devoted to the air-gap shall conform to

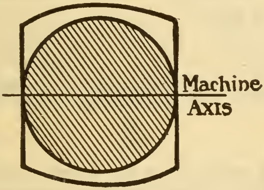


FIG. 36.

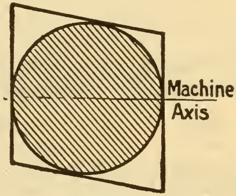


FIG. 37.

the plan of design which is the basis of this section. See "Checking up Preliminary Dimensions below."

Pole-Face.—The dimensions of the pole-face are determinable as previously described, the average chord being equal to $k_{ch}\ D_p$ and the width parallel to the shaft being preferably equal to the chord.

If solid pole-faces are used, the interpolar edges should not be strictly parallel to the armature slots. A common expedient for avoiding this parallelism is to round the interpolar edges as in Fig. 36, or to make them slightly oblique with respect to the axis of the machine, as in Fig. 37. If laminated poles without shoes are used, the corners of alternate sheets of

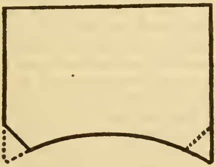


FIG. 38.

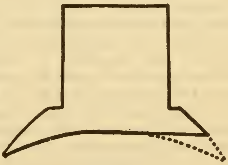


FIG. 39.

steel should be cut away as in Fig. 38 for straight poles, or the tips cut off, as in Fig. 39, for polar extensions.

The length of the pole-face span should never exceed $2.5\ D_p \div p$; practical values are given in the beginning of this section (page 356.)

Checking up Preliminary Dimensions.—Before passing on to the field-magnet proportions, and preferably before taking up the probable armature losses, the preliminary dimensions should be checked up in order to make sure that the desired E.M.F. is obtainable at the desired speed without entailing the use of excessive magnetic densities.

Having ascertained by means of eq. (11) the maximum number of coil slots allowable and adjusted the net armature iron dimension axially by eq. (12) the E.M.F. or counter E.M.F. of the armature should be tested by the formula:

$$E = \frac{k_v D_p^{2.15} W_p \psi N_c \text{ r.p.m. } 10^{-8}}{p q \delta} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (29)$$

and if the E.M.F. is not what is desired, the armature diameter should be changed to correct it rather than change the value of either W_p or ψ or both. On the basis of the author's method, the E.M.F. is proportional to $D_p^{3.15}$, if it be assumed that the number of wires will increase or diminish in proportion to small variations in the diameter; therefore, if the preliminary dimensions do not give the proper E.M.F., the correct dimensions may be closely approximated by

$$\frac{\text{Trial } D_p^{3.15} \times E}{\text{Trial } E} = \text{Correct } D_p^{3.15};$$

the word "trial" referring to the diameter and E.M.F. first obtained.

If the air-gap length actually adopted is not precisely the value given by eq. (28), the pole-face density should be adjusted to satisfy the equation,

$$\mathbf{B}_p = \frac{k_d D_p^{1.15}}{p \delta} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (30)$$

The values of k_v and k_d are as follows:

Type of Machine:	General Service.	Shunt or Comp. Rev'g.	Series Rev'g Motors.
$k_v =$	81	88	95
$k_d =$	1562	1692	1831

The tendency to field distortion and sparking at the brushes should also be checked (after correcting the armature dimensions and pole-face density as just explained) before taking up the field magnet proportions.

Armature Reaction and Commutation.—In order to guard against excessive field distortion the relation between the air-gap ampere-turns and armature ampere-turns should be as indicated by the following formula, for operation with fixed brushes at all loads:

$$\mathbf{B}_p p \delta \geqq k_r i_a N_c \psi \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (31)$$

The value of k_r varies as follows:

In general service machines,	$k_r \geqq 2.3$.
In shunt and compound reversing motors,	$k_r \geqq 3$.
In series-wound motors,	$k_r \geqq 2.7$.

The formula is based on the facts that $\mathbf{B}_p \delta$ is approximately proportional to the ampere-turns required by the air-gap, and $i_a N_c \psi \div p =$ armature ampere-turns tending to distort the field under each pole-face.

The tendency to sparking at the brushes is proportional to the inductance of each coil, the number of coils simultaneously short-circuited by one brush, the number of coils in series between one positive and one negative brush and the current in the coil being commutated, and inversely proportional to the length of time the coil is short-circuited by the brush. The inductance of the coil is proportional to the length of the conductor and the square of the number of turns per coil. The following formula, based on these considerations, is an excellent criterion as to the sparklessness of a machine:

$$(W_a + 0.1\, l_c)\, t^2 i_a n_k \frac{D_k}{b} \frac{p}{q} \text{ r.p.m. } 10^{-6} \leqq K_k \quad . \; . \; . \; . \; . \quad (32)$$

The value of K_k varies as below:

Kilowatts of machine:	Up to 15	30	60	100	500	1000 or over.
$K_k =$	80	70	60	50	40	35

Field Magnet.—Cores of circular cross section are most economical of wire in the field windings, and a square cross section is next best in this respect. The temperature rise is greater, however, in a round coil of given magnetizing power than in a square one, the cross section of the core and length of coil along the core being the same in both cases. Round coils are easier to wind, and are usually preferred.

The length of a magnet core from the yoke to the pole-shoe or beginning of polar extensions, *i.e.*, the space available for windings, parallel to the flux path in the core, may be roughly estimated for preliminary laying-out as follows:

$$L_m = \frac{B_p \delta}{900 \left(1 + \frac{0.3\, B_p \delta p}{i_a N_c \psi}\right)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; (33)$$

The trial core length obtained by means of this formula will usually require revision in order to obtain the proper radiating surface for the coils.

The magnetic density in field-magnet cores ranges from 90,000 to 100,000 lines per square inch for cast steel, and from 100,000 to 110,000 for sheet steel. The density in magnet yokes ranges from 35,000 to 45,000 maxwells per square inch in cast iron, and 85,000 to 95,000 for cast steel. In railway motors and others of extraordinarily light weight, the yoke density is considerably higher than in stationary machines; the core density is also somewhat higher, but the difference is not so great as in the yoke.

The density is not uniform throughout the length of path in the core, nor is it so in the yoke, but for convenience the maximum density is assumed to exist throughout the length of each path.

Leakage of magnetic lines between adjacent poles and between each pole and the yoke surfaces makes the flux in the field magnet considerably

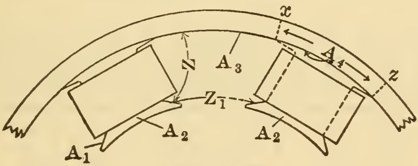


FIG. 40.

greater than that in the air-gap. The relation between the magnet-core flux and the air-gap flux is

$$\Phi_m = \nu \Phi.$$

The value of ν varies widely with different types of machines and different sizes of a given type. For well-designed machines of conventional types it may be assumed tentatively to have the values given in Table X. It is considerably higher for poor designs. In the absence of data from existing machines of the type being designed, the field magnet may be proportioned on the basis of the values in Table X, page 376, tentatively, and the leakage roughly checked up as follows:

Lay out to a rather large scale two poles of the machine and the corresponding portion of the yoke, as shown in Fig. 40 for a circular yoke. The average length of the leakage path between the upper surface of the polar extension and the inner surface of the yoke will be about as indicated by the dotted line Z, and the length of the leakage path between the neighboring polar extensions will be about as shown by the line Z_1. The mean length of the leakage path between the flanks of neighboring pole-ends is practically equal to the distance between the centers of the two measured along a circular arc concentric with the armature; represent it by Z_2. The mean length of the leakage path between each pole-piece flank and the yoke surface lying between x and z may be called equal to Z. The maximum flux in the magnet core will be approximately as given by the equation,

$$\Phi_m = \Phi + 3.2\, F_g \left(\frac{2\,A_1 + A_2 + A_3 + A_4}{Z} + \frac{4\,A_1}{Z_1} + \frac{3\,A_2}{Z_2}\right) \quad . \; . \; (34)$$

Field-Magnet Excitation.—In order to estimate beforehand the excitation required by the machine, the quality of the iron and steel to be used in its construction should be known. In the absence of such data however, the curves in Fig. 41 will serve for estimates.

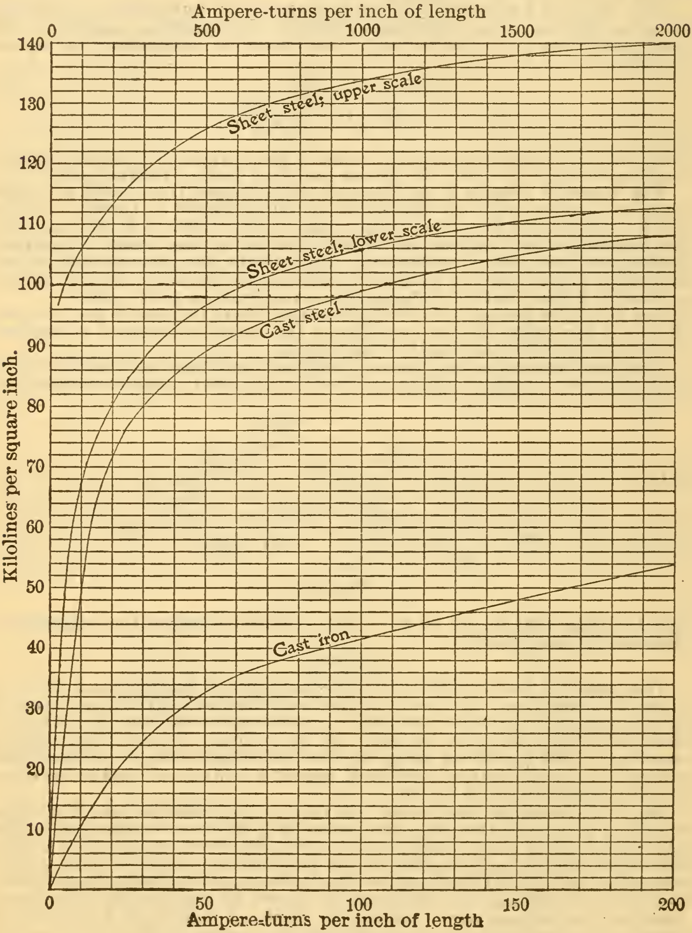


FIG. 41.

The flux in the air-gap of a dynamo at no load is

$$\Phi_0 = \frac{60\, q\, E_w\, 10^8}{p\, N_c \text{ r.p.m.}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

The flux at full load is

$$\Phi = \frac{60\, q\, (E_w + R\, I_a)\, 10^8}{p\, N_c \text{ r.p.m.}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

For a motor the flux is the same at full load as at no load, except in special cases where a series winding is used in order to start a heavy load, and excepting series-wound motors. The maximum air-gap flux for a motor having to start under a load is

$$\Phi_T = \frac{T\,10^{11}}{117\,p\,i_a\,N_c} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (37)$$

The full-load ampere-turns per pole for a dynamo or motor are $F + F_r$. $F = F_a + F_T + F_g + F_p + F_m + F_y$; $F_a = f_a\,L_a \div 2$; $F_T = f_T\,h$; $F_p = f_p\,L_p$; $F_m = f_m\,L_m$; $F_y = f_y\,L_y \div 2$.

The ampere-turns per inch for the armature teeth will be the mean between the ampere-turns per inch required to produce the density at the tops and those required to produce the density at the roots — not the ampere-turns required to produce the average density in the teeth. The approximate density at the roots of the armature teeth will be, at full load,

$$\mathbf{B}_{t}' = \frac{\Phi}{w_a\,(\pi D_t - s\,N_t)\left(\frac{\psi}{p} + \frac{0.64\,k_g\,\delta}{D_p}\right)} \quad . \; . \; . \; . \; . \; . \quad (38)$$

and the approximate density at the tops of the teeth will be

$$\mathbf{B}_{T}' = \frac{\Phi}{w_a\,(\pi D_a - s\,N_t)\left(\frac{\psi}{p} + \frac{0.64\,k_g\,\delta}{D_p}\right)} \quad . \; . \; . \; . \; . \; . \; . \quad (39)$$

As some of the flux passes to the armature core body through the slots and ventilating spaces, the actual densities in the roots and tops of the teeth are less than the approximate densities given by the above formulas. The actual densities cannot be computed directly, but may be derived from the relation between the actual and approximate densities, which is as follows:

$$\mathbf{B}_{\tau}' = \mathbf{B}_{\tau} + 3.192\,f_{\tau}\left[\frac{W_a}{w_a}\left(1 + \frac{s}{\tau}\right) - 1\right] \quad . \; . \; . \; . \; . \quad (40)$$

Since the formula cannot be transposed to solve for $\mathbf{B}_{\tau}$ because $\mathbf{B}_{\tau}$ and f_{τ} are interdependent and vary at different rates, a table should be prepared showing values of $\mathbf{B}_{\tau}'$ corresponding to different values of f_{τ} at different ratios of $s \div \tau$ and $W_a \div w_a$. The preparation of such a table is greatly facilitated by first preparing a table of values for

$$3.192\left[\frac{W_a}{w_a}\left(1 + \frac{s}{\tau}\right) - 1\right],$$

representing this expression by k_{τ}, and thereby reducing eq. (40) to

$$\mathbf{B}_{\tau}' = \mathbf{B}_{\tau} + k_{\tau}\,f_{\tau} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (41)$$

Table XI, page 377, gives values for k_{τ} for practical ranges of values for the two ratios mentioned. From eq. (41) and curves such as those in Fig. 41, a table of corresponding values for $\mathbf{B}_{\tau}'$ and f_{τ} is easily prepared. From such a table the value of f_{τ} should be ascertained for the root and top of the tooth and also for two or three equidistant intermediate points between the root and top; the average of these will be the working value.

The ampere-turns per pole required by the air-gap will be

$$F_g = \frac{0.3133\,\Phi}{(W_p + k_{g_2}\,k_{\delta}\,\delta)\left(\frac{\pi\,D_p\,\psi}{k_{\delta}\,p\,\delta} + k_g\right)} \quad . \; . \; . \; . \; . \; . \quad (42)$$

Table IX, page 376, gives values of k_{g2} and Fig. 42 gives those of k_δ within ordinary ranges. The constant k_{g2} is merely the number which, multiplied by the air-gap length, gives the extent to which the air-gap dimension parallel to the shaft is increased by the bowing outward of the magnetic flux in pass-

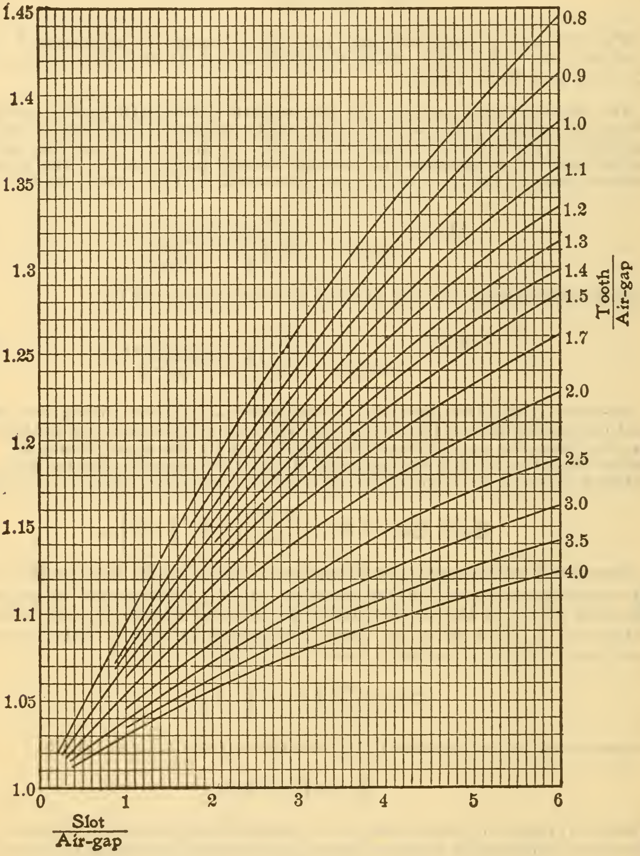


FIG. 42.

ing from the pole-face edges to the armature core teeth. The constant k_δ is the proportion of the physical air-gap length, δ, by which the gap is increased effectively by the passage of flux into the sides of the armature core teeth. This has been taken from Mr. F. W. Carter's article in the *Electrical World and Engineer* for Nov. 30, 1901.

The value of F_r cannot be predetermined with any approach to accuracy unless one has data from existing machines of corresponding type and output. The following empirical formula will serve to estimate roughly the value of $F + F_r$ for modern American dynamos and non-reversing motors:

$$F + F_r = \frac{(0.5 - 0.55\,\psi)\,i_a\,N_c}{p} + \sqrt{F^2 + \left(\frac{0.55\,\psi\,i_a\,N_c}{p}\right)^2} \quad . \quad . \quad (43)$$

For reversing motors,

$$F + F_r = \sqrt{F^2 + \left(\frac{0.6\,\psi\,i_a\,N_c}{p}\right)^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (43a)$$

The no-load excitation of a shunt-wound dynamo need not be predetermined. The no-load excitation of a compound-wound dynamo is

$$F_o = F_{ao} + F_{to} + F_{go} + F_{po} + F_{mo} + F_{yo}.$$

The ampere-turns of the several parts of the magnetic circuit are determined as in the case at full load, taking into account the differences in magnetic density in each part.

After the first machine of a given type has been constructed, with the exception of the field-magnet coils, it should be tested with temporary exciting coils; the results of these tests should be taken as the foundation of the magnet coil calculations.

Field-Magnet Windings. — The field winding of a series or shunt-wound dynamo must be capable of giving the excitation required at full load.

The field winding of a shunt-wound motor must give the excitation required at the proper full-load speed.

The field winding of a series-wound motor must give the excitation required to produce the starting flux, Φ_T.

The shunt winding of a compound-wound dynamo must give the excitation required at no load; the series winding must give the difference between this and the excitation required at full load.

The shunt winding of a compound-wound motor must give the excitation required at normal no-load speed; the series winding must give the difference between this and the excitation required to produce the starting flux, Φ_T.

The surface of any field magnet coil on a dynamo or motor of open construction (non-enclosed frame giving the external air free access to the windings), should be

$$L_f\,G = \frac{80\,i^2\,r}{\theta_f} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (44)$$

r being the resistance of the coil when warm. For enclosed or poorly ventilated frames, the coil surface per watt per degree of temperature rise must be determined by trial; no general rule will apply. In all cases θ_f should not exceed 70°.

The proper size of wire to be used in a shunt field coil is approximately given by

$$d^2 = \frac{F_{sh}\,(g + \pi\,\Delta)}{e} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (45)$$

Should the calculated value of d^2 not correspond with any standard size, the nearest standard size should be adopted and the depth of the winding adjusted to suit it by transposing eq. (45) and solving for Δ, thus:

$$\Delta = \frac{\frac{d^2\,e}{F_{sh}} - g}{\pi} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (46)$$

See also Magnet Windings, page **112**.

The minimum number of turns per pole for the series coils of a compound-wound machine is

$$\text{Turns} = \left\{ \begin{array}{ll} \dfrac{F + F_r - F_{sh}}{I_w} & \text{(short shunt)} \\ \text{or} & \\ \dfrac{F + F_r - F_{sh}}{I_a} & \text{(long shunt)} \end{array} \right\} \quad . \; . \; . \; . \; . \quad (47)$$

The cross section of the series conductor need not exceed 0.0015 square inches per ampere actually carried by the coil, and should not be less than 0.0011 square inch per ampere ordinarily; it will be finally determined by the heating.

In both the series and shunt field magnet coils, the maximum possible number of ampere-turns should be made from 10% to 15% greater than the calculated maximum in order to provide a margin for differences in the qualities of the copper and steel used, as well as other uncontrollable discrepancies.

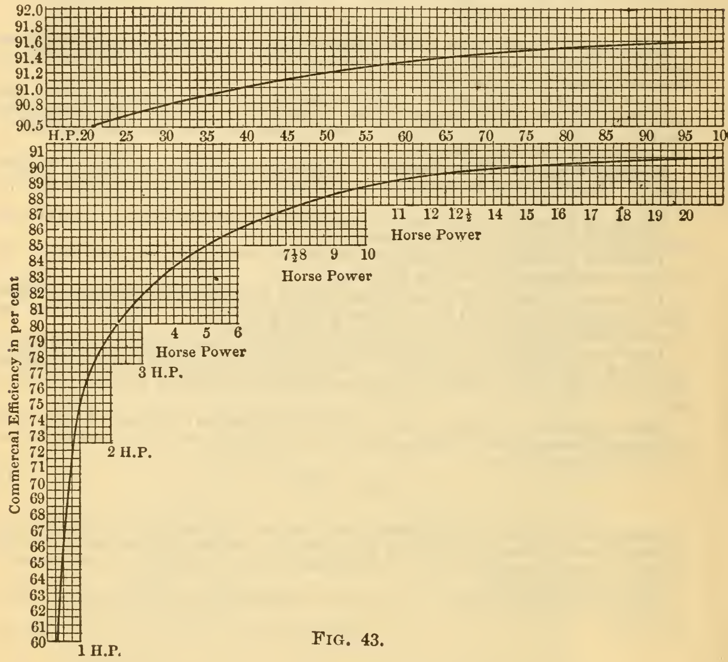


FIG. 43.

Efficiency.—Efficiencies range from 60% to 95%, according to the size of the machine and the character of service. Table XII, page 377, gives average values for ordinary constant-potential dynamos, and Fig. 43 gives similar values for motors for general service. Traction and automobile motors differ considerably from these values.

Procedure in Laying out a Design.—The following will be found an expeditious procedure in applying the method described in the preceding pages:

Determine

1. A trial polar bore, eq. 8 or 9 or 10.
2. Type of armature winding; number of paths.
3. Number of poles; eq. 6, for lap-wound machines.
4. Ratio of pole-face span : pole pitch (ψ).
5. Maximum pole-face width ($W_p \overline{\overline{<}} k_{ch} D_p$).
6. Air-gap, eq. 28; the armature diameter follows.
7. Turns per armature coil, Table V.
8. Trial size of conductor, Table VI.

9. Size of coil slot, based on number of conductors per slot, either Table III or eq. 13, and rules $s \gtreqless 2\delta$ and $s = \frac{h}{3}$ to $\frac{h}{5}$.

10. Possible number of coil slots, eq. 11; hence, total number of armature conductors, keeping in view type of winding, eq. 2.

11. Corrected pole-face density, eq. 30.

12. Field-distorting armature reaction, eq. 31; if k_r comes out too small, the polar bore must be increased, thereby increasing the pole-face density and air-gap; then solve eq. 31 for N_c, taking the nearest smaller value that will fit the winding.

13. Corrected pole-face width, by solving eq. 29 for W_p; if the result $\gtreqless k_{ch} D_p$, accept it; if not, take a still larger polar bore, with the corresponding air-gap, and start over from Determination No. 11.

14. Net axial iron measurement in armature, eq. 12.

15. Gross length of armature core ($= W_p + 2\,\delta$ to $W_p + 4\,\delta$); the difference between this and the net iron to be occupied by ventilating ducts.

16. Number of armature coils; check by Table IV roughly; a discrepancy of 25% is not prohibitive.

17. Diameter of commutator barrel, eqs. 21 and 22; D_k should never exceed 0.9 D_a, and 0.7 D_a is an excellent limit; if the diameter comes out too great, the number of armature coils must be reduced and the axial dimensions of the machine increased correspondingly, if practical; if not, a larger polar bore must be taken and the determinations revised from No. 11, also revising the air-gap by eq. 28.

18. Complete commutator and brush dimensions, eqs. 25, 26, and 27.

19. Probable tendency to sparking, eq. 32; if K_k is excessive, and the turns per coil cannot be reduced without entailing an unwieldy number of coils, the polar bore must be increased in order to permit reducing the length of the armature core, the determinations being revised from No. 11 after finding the new air-gap, eq. 28.

20. Armature losses with respect to heating, eq. 15 *et seq.*; if P_A' exceeds the limit set by eq. 14, and cannot be brought within the limit by reducing the hole in the center of the core, the ventilating ducts may be reduced sufficiently to accomplish the result; if not, and if W_a cannot be sufficiently increased on account of eq. 32, the polar bore must be increased, the corresponding air-gap adopted, and the determinations revised, beginning with No. 11.

Having progressed this far, the remainder of the design is straight work, only a slight revision of the trial magnet core length being probably necessary to obtain the minimum quantity of field copper within the heating limit.

TABLE I.

Values of k_{ch}.

Poles.	$\psi = 0.666$.	$\psi = 0.7$.	$\psi = 0.72$.	$\psi = 0.75$.
2	0.866	0.891	0.9048	0.9239
4	0.5	0.5225	0.5358	0.5556
6	0.342	0.3584	0.3681	0.3827
8	0.2588	0.2714	0.279	0.2903
10	0.2079	0.2181	0.2244	0.2334
12	0.1736	0.1822	0.1874	0.1951
14	0.149	0.1564	0.1609	0.1676
16	0.1305	0.137	0.1409	0.1467
18	0.1161	0.1219	0.1253	0.1305
20	0.1045	0.1097	0.1129	0.1175
22	0.0949	0.0998	0.1026	0.1069
24	0.0872	0.0915	0.0941	0.0979

TABLE II.

Armature Slot Sizes for Different Practical Arrangements of Standard Wires.

NOTE.—The table is computed for double cotton-covered wires, B. & S. gauge. Allowance is made in the slot widths for 0.125″ total insulation, besides the cotton wrapping on the wire, when there is only one coil per slot in the armature. For each additional coil per slot, 0.0125″ of extra insulation is allowed. In slot depths, 0.17″, besides the cotton on the wires, is allowed for.

Wire Size.	Widths of Slot, in Inches. Number of Wires Abreast.							Wire Size.	Depths of Slot, Inch Measurement. Total Number of Wires Depthwise of the Slot.								Wire Size.
	1	2*	2	3*	3	4*	4		2	4	6	8	10	12	14	16	
4	.35	.57	.59	. .	. .	. .	. .	4	.62	1.062	1.51	1.95	. .	. .	. .	. .	4
5	.33	.53	.54	. .	. .	. .	. .	5	.57	.97	1.37	1.77	. .	. .	. .	. .	5
6	.30	.48	.50	. .	. .	. .	. .	6	.53	.88	1.24	1.6	. .	. .	. .	. .	6
7	.29	.45	.46	. .	. .	. .	. .	7	.49	.81	1.13	1.45	. .	. .	. .	. .	7
8	.27	.42	.43	. .	. .	. .	. .	8	.46	.74	1.03	1.31	. .	. .	. .	. .	8
9	.25	.38	.39	.50	.53	. .	. .	9	.42	.68	.93	1.18	. .	. .	. .	. .	9
10	.24	.35	.37	.46	.49	. .	. .	10	.4	.62	.85	1.07	. .	1.52	. .	. .	10
11	.23	.33	.34	.43	.46	. .	. .	11	.37	.58	.78	.98	. .	1.39	. .	. .	11
12	.22	.31	.32	.40	.43	. .	. .	12	.36	.54	.73	.91	1.09	1.28	. .	1.65	12
13	.21	.29	.31	.37	.40	.46	.50	13	.34	.5	.67	.83	1.	1.16	. .	1.49	13
14	.20	.28	.29	.35	.38	.42	.47	14	.32	.47	.62	.77	.91	1.07	1.22	1.36	14
15	. .	.26	.27	.33	.35	.39	.44	15	.3	.44	.57	.7	.83	.97	1.1	1.23	15
16	. .	.25	.26	.31	.34	.37	.41	16	.29	.42	.54	.66	.78	.91	1.03	1.15	16
17	. .	.24	.25	.29	.32	.34	.39	17	. .	.39	.5	.61	.72	.83	.94	1.05	17
18	. .	.23	.24	.28	.31	.33	.37	18	. .	.37	.47	.57	.67	.77	.87	.97	18
19	. .	.22	.23	.26	.29	.31	.35	19	. .	.35	.44	.53	.62	.71	.81	.89	19
20	. .	.21	.22	.25	.28	.29	.33	20	. .	.333	.41	.49	.57	.65	.73	.81	20

* All in the same coil, therefore requiring no insulation between.

TABLE III.

Trial Armature Coil Slot Depths.

Core Diameter.	Slot Depth.	Core diameter.	Slot Depth.
6	$\frac{5}{8}$	$10\frac{1}{2}$	$1\frac{3}{32}$
$6\frac{1}{2}$	$\frac{11}{16}$	11	$1\frac{1}{8}$
7	$\frac{3}{4}$	$11\frac{1}{2}$	$1\frac{5}{32}$
$7\frac{1}{2}$	$\frac{13}{16}$	12	$1\frac{3}{16}$
8	$\frac{7}{8}$	$12\frac{1}{2}$	$1\frac{7}{32}$
$8\frac{1}{2}$	$\frac{15}{16}$	13	$1\frac{1}{4}$
9	1	$13\frac{1}{2}$	$1\frac{9}{32}$
$9\frac{1}{2}$	$1\frac{1}{32}$	14	$1\frac{5}{16}$
10	$1\frac{1}{16}$	15	$1\frac{3}{8}$

TABLE IV.

Trial Values for Minimum Number of Armature Coils.

Formula: $N_s = 0.8\,p^{0.8} \times \sqrt{E} \times \sqrt[3]{\text{KW.}}$*

The numbers in the table are values of $\sqrt{E} \times \sqrt[3]{\text{KW.}}$*

KW.*	125 volts.	250 volts.	600 volts.
1	11.2	15.8	24.5
2	14.1	19.9	30.9
3	16.1	22.8	35.3
4	17.8	25.1	38.9
5	19.1	26.9	41.9
6	20.3	28.7	44.5
8	22.4	31.6	49.
10	24.1	34.1	52.8
15	27.6	39.	60.4
20	30.4	42.9	66.5
25	32.7	46.2	71.6
30	34.7	49.1	76.1
40	38.2	54.1	83.8
50	41.2	58.2	90.2
60	43.7	61.9	95.9
75	47.1	66.7	103.3
100	51.9	73.4	113.7
125	55.9	79.	122.5
150	59.4	84.	130.
200	65.4	92.5	143.
250	70.4	99.6	154.
300	74.8	105.8	164.
400	82.4	116.5	180.
500	88.7	125.	194.
600	94.3	133.	207.
700	99.3	140.	218.
800	103.8	147.	227.
1000	112.	158.	245.

*KW. = Kilowatts output of dynamo or intake of motor.

For $p = 2$	4	6	8	10	12	14	1.6
$0.8\,p^{0.8} = 1.4$	2.4	3.35	4.2	5	5.8	6.6	73

TABLE V.

Trial Values for Maximum Allowable Number of Turns per Armature Coil.

Formula: $t^2 \leqq 240\, q \div i_a p$.

Lap Winding.	Two-path Windings.			Turns per Coil.
$p = q$.	$p = 4$.	$p = 6$.	$p = 8$.	t
i_a	i_a	i_a	i_a	
240	120	80	60	1
60	30	20	15	2
26	13	9	6.6	3
15	7.5	5	3.75	4
9.6	4.8	3.2	2.4	5
6.6	3.3	2.2	1.66	6
4.9	2.4	1.6	1.22	7
3.75	1.87	1.25	0.93	8
3	1.5	1	0.75	9
2.4	1.2	0.8	0.6	10
1.8	0.9	0.6	0.45	11
1.66	0.83	0.55	0.42	12
1.42	0.71	0.47	0.35	13
1.22	0.61	0.41	0.3	14
1.06	0.53	0.35	0.26	15

TABLE VI.

Trial Values for Carrying Capacity of Armature Conductors.

2 or 4 Wires in Parallel Considered a Single Conductor.

Round Wires, Drawn to B. & S. Gauge.					Rectangular Conductors.		
			$D_a \times$ r.p.m. =		$D_a \times$ r.p.m. =		
Single.	2 in parallel.	4 in parallel.	4000 to 6000.	8000 to 10,000.	10,000 to 12,000.	15,000 to 17,000.	20,000 to 22,000.
No.	No.	No.	Amperes.				
20	. .	. .	2	2½	Current density of 1600 amperes per square inch.	Current density of 2000 amperes per square inch.	Current density of 2500 amperes per square inch.
19	. .	. .	2¼	3¼			
18	. .	. .	3	4			
17	20	. .	4	5			
16	19	. .	5	6			
15	18	. .	6	7½			
14	17	20	7¼	9¼			
13	16	19	9	11½			
12	15	18	11	14			
11	14	17	13½	17½			
10	13	16	17	21½			
9	12	15	21	26½			
8	11	14	26	33			
7	10	13	32½	40			
6	9	12	40	50			
	8	11	52	66			
	7	10	65	80			
	6	9	80	100			
		8	104	132			
		7	130	160			
		6	160	200			

TABLE VII.

From "The Dynamo," by Hawkins & Wallis.

Values of k_g.

a	$\frac{\gamma}{\delta} = 8.$	$\frac{\gamma}{\delta} = 10.$	$\frac{\gamma}{\delta} = 12.$	$\frac{\gamma}{\delta} = 14.$	$\frac{\gamma}{\delta} = 16.$
0°	1.95	2.18	2.38	2.55	2.7
10°	1.85	2.05	2.23	2.38	2.52
20°	1.75	1.95	2.10	2.25	2.38
30°	1.66	1.84	1.98	2.12	2.24
40°	1.58	1.75	1.89	2.00	2.12
50°	1.52	1.666	1.80	1.90	2.00

TABLE VIII.

Barrel Armature Winding Constants.

Poles =	4	6	8	10	12	14	16	18	20	24
k_w =	0.8	0.56	0.42	0.36	0.3	0.256	0.225	0.2	0.18	0.15

TABLE IX.

From "The Dynamo," by Hawkins & Wallis.

Values of k_{g_2}.

$\frac{W_d - W_p}{\delta}$ =	1	1.5	2	2.5	3	3.5	4
k_{g_2} =	0.74	1.0	1.2	1.38	1.54	1.68	1.8

TABLE X.

Average Magnetic Leakage Coefficients.

Kilowatts =	10	25	40	50	75	100	200	300	500	1000
ν =	1.35	1.3	1.27	1.25	1.23	1.2	1.18	1.15	1.13	1.12

TABLE XI.

Values of k_τ.

$\frac{s}{\tau}$	$\frac{W_a}{w_a} = 1.16$	1.17	1.18	1.19	1.20	1.22	1.24
0.70	3.10	3.16	3.21	3.26	3.32	3.43	3.54
0.75	3.29	3.34	3.40	3.45	3.51	3.62	3.73
0.80	3.47	3.53	3.59	3.64	3.70	3.82	3.93
0.85	3.66	3.72	3.78	3.84	3.89	4.01	4.13
0.90	3.84	3.90	3.96	4.02	4.09	4.21	4.33
0.95	4.03	4.09	4.15	4.21	4.28	4.40	4.53
1.00	4.21	4.28	4.34	4.40	4.47	4.60	4.72
1.05	4.40	4.46	4.53	4.59	4.66	4.79	4.92
1.10	4.58	4.65	4.72	4.78	4.85	4.98	5.12
1.15	4.77	4.84	4.91	4.97	5.04	5.18	5.32
1.20	4.95	5.02	5.09	5.16	5.23	5.37	5.52
1.25	5.14	5.21	5.28	5.35	5.43	5.57	5.71
1.30	5.32	5.40	5.47	5.54	5.62	5.76	5.91
1.35	5.51	5.58	5.66	5.73	5.81	5.96	6.11
1.40	5.69	5.77	5.85	5.92	6.00	6.15	6.31
1.45	5.88	5.96	6.04	6.11	6.19	6.35	6.51
1.50	6.06	6.14	6.22	6.30	6.38	6.54	6.70
1.55	6.25	6.33	6.41	6.49	6.57	6.74	6.90
1.60	6.43	6.52	6.60	6.68	6.77	6.93	7.10
1.65	6.62	6.70	6.77	6.87	6.96	7.13	7.30
1.70	6.80	6.89	6.98	7.06	7.15	7.32	7.49
1.75	6.99	7.08	7.17	7.25	7.34	7.52	7.69
1.80	7.18	7.26	7.35	7.44	7.53	7.71	7.89
1.85	7.36	7.45	7.54	7.63	7.72	7.91	8.09
1.90	7.55	7.64	7.73	7.82	7.92	8.10	8.29
2.00	7.92	8.01	8.11	8.20	8.30	8.49	8.68

TABLE XII.

Average Dynamo Efficiencies.

Kilowatts.	Per cent. Efficiency.	Appropriate Distribution of Losses in Per Cent.				Per cent. Loss; Total.
		Armature Losses.		Entire Field Windings.	Friction.	
		Copper.	Iron.			
30	90	4.0	3.0	2.5	0.5	10
40	90.5	3.8	2.8	2.4	0.5	9.5
50	91	3.6	2.7	2.3	0.4	9
75	91.5	3.4	2.5	2.2	0.4	8.5
100	92	3.2	2.4	2.0	0.4	8
200	93	2.7	2.15	1.8	0.35	7
300	93.5	2.5	2.0	1.65	0.35	6.5
500	94	2.3	1.8	1.55	0.35	6
750	94.5	2.0	1.7	1.5	0.3	5.5
1000	95	1.8	1.5	1.4	0.3	5

TESTS OF DYNAMOS AND MOTORS.

REVISED BY CECIL P. POOLE AND E. B. RAYMOND

All reliable manufacturers of electrical machinery and apparatus are now provided with the necessary facilities for testing the efficiency and other properties of their output, and where the purchaser desires to confirm the tests and guaranties of the maker, he should endeavor to have nearly, and in some cases all such tests carried out in his presence at the factory, unless he may be equipped with sufficient facilities to enable him to carry out like tests in his own shops after the apparatus is in place.

Some tests, such as full load and overload, temperature, and insulation (except dielectric) tests are best made after the machinery has been installed and is in full running order.

Owing to the ease and accuracy with which electrical measurements can be made, it is always more convenient to make use of electrical driving power for dynamos, and electrical load for the dynamo output, and in the case of motors, a direct-current dynamo with electrical load makes the best load for belting the motor to.

No really accurate tests of dynamo efficiencies can be made with water-wheels, and only slightly better are those made by steam-engines, owing to unreliability of friction cards for the engine itself and the change of friction with load.

Where it is necessary to use a steam-engine for dynamo testing, all friction and low load cards should be taken with the steam throttled so low as to cut off at more than half stroke, and to run the engine at the same speed as when under load.

The tests of the engine as separated from the dynamo are as follows: —

a. Friction of engine alone.

b. Friction of engine and any belts and countershaft between it and the dynamo under test.

Consult works on indicators and steam-engines for instructions for determining power of engines under various conditions.

The important practical tests for acceptance by the purchaser, or to determine the full value of all the properties of dynamos and motors, are to learn the value of the following items: —

Rise of temperature under full load.
Insulation resistance.
Dielectric strength of insulation.
Regulation.
Overload capacity.
Efficiency, core loss.

Bearing friction, windage and brush friction.

I^2R loss in field and field rheostat,
I^2R loss in armature and brushes.

NOTE. — If a separate exciter goes with the dynamo, its losses will be determined separately as for a dynamo.

Methods of determining each of the above-named items will be described, and then the combinations of them necessary for any test will be outlined.

Temperature. — The rise of temperature in a dynamo, motor, or transformer, is one of the most important factors in determining the life of such piece of apparatus; and tests for its determination should be carried out according to the highest standards that can be specified, and yet be within reasonable range of economy. The A. I. E. E. standards state the allowable rise of temperature above surrounding air for most conditions, but special conditions must be met by special standards. For instance, no ordinary insulation ought to be subjected to a degree of heat exceeding 212° F., or 100° C. And yet in the dynamo-room of our naval vessels the temperature is said to at times reach 130° F., or even higher, which leaves a small margin for safety. It is obvious that specifications for dynamos in such locations should call for a much lower temperature rise in order to be safe under full load.

For all practical temperature tests it is sufficient to run a machine under its normal full-load conditions until it has developed its highest temperature, although at times a curve of rise of temperature may be desired at various loads.

Most small dynamos, motors, and transformers, up to, say, 50 K.W., will reach maximum temperature in five hours run under full load, if the temperature rise is normal; but larger machines sometimes require from 6 to 18 hours, although this depends quite as much on the design and construction of the apparatus as on size, as, for instance, the 5,000 h.p. Niagara Falls Generators reach full temperature in five hours. Temperature tests can be shortened by overloading the apparatus for a time, thus reaching full heat in a shorter period.

On dynamos and motors the temperatures of all iron or frame parts, commutators, and pole-pieces, have to be taken by thermometer laid on the surface and covered by waste. Note that when temperatures are taken with the machine running, care must be taken not to use enough waste to influence the machine's radiation. Where there are spaces, as air spaces, in armature cores or in the field laminations, that will permit the insertion of a thermometer, it should be placed there. Temperature of field coils should be taken by thermometer laid on the surface and covered with waste, and by taking the resistance of the coils first at the room temperature and again while hot immediately after the *heat run*. Temperature rise of armature windings can be taken by surface measurement and by the resistance method also; although being nearly always of low resistance, very careful tests by fine galvanometer and very *steady* current are required in order to get anything like accurate results.

The formula for determining the rise of temperature from the rise of resistance is as follows:

Temperature by rise in resistance; for copper. — The increase in resistance due to increase in temperature is approximately 0.4% for each degree Cent. above zero, the resistance at zero being taken as the base. If then

t_1 = temperature of copper when cold resistance is measured (Cent.),
R_1 = resistance at temperature t_1,
t_2 = temperature of copper when hot resistance is taken,
R_2 = resistance at temperature t_2,

Then first reducing to zero degrees, we have

$$R_0 = \frac{R_1}{1 + 0.0042\, t_1} \quad \ldots\ldots\ldots\ldots (1)$$

The increase in resistance from 0 to t_2 degrees is $R_2 - R_0$, and hence we have for final temperature,

$$t_2 = \frac{R_2 - R_0}{R_0} \div 0.0042 \quad \ldots\ldots\ldots (2)$$

Substituting (1)

$$t_2 = \frac{R_2\,(1 + 0.0042\, t_1) - R_1}{0.0042\, R_1} \quad \ldots\ldots\ldots (3)$$

It is often convenient to correct all cold resistances to a temperature of 20° C., in which case we first reduce to zero and then raise to 20°.

The general formula for obtaining the resistance at t degrees is

$$R_t = (1 + 0.0042\, t)\, R_0.$$

Hence $R_{20} = 1.084\, R_0$ and in terms of the cold resistance at temperature t.

$$R_2 = \frac{(1.084\, R_0)}{(1 + 0.0042\, t)} \quad \ldots\ldots\ldots\ldots (4)$$

Formula (3) then becomes, when the cold resistance is at 20°,

$$t_2 = \frac{1.084}{0.0042} \times \frac{R_2}{R_{20}} - \frac{1}{0.0042} = 258\, \frac{R_2}{R_{20}} - 238 \quad \ldots\ldots (5)$$

As the first formula requires but one setting of the slide rule, and the subtraction of the constant 238 can usually be done mentally, the advantage of the temperature equation in this form is very great as regards both speed and accuracy.

The temperature coefficients most generally used are

For copper	.0042
For iron	.0045
For German silver	.00028 to .00044

The following parts should be tested by the resistance method and the surface method also:

Field coils series, and shunt.

Armature coils. In 3-phase machines, take resistance between all three rings.

The following parts should be tested by thermometer on the surface: —

Room, on side opposite from steam-engine, if direct connected, and always in two or more parts of the room, within six feet of machine.
Bearings, each bearing, thermometer held against inner shell, unless oil from the well is found to be of same temperature as the bearing.
Commutators and *collector rings*.
Brush-holders and *brushes*, if thought hotter than the commutator.
Pole-tips, leading and following.
Armature teeth, windings, and spider.
Field frame.
Terminal blocks, for leads to switch-board, and those for leads from the brushes.
Series shunt, if in a compound-wound machine.
Shunt field rheostat.

On transformers which are enclosed in a tank filled with oil, temperatures by thermometer should be taken on —

Outside case, in several places.
Oil, on top, and deeper by letting down thermometer.
Windings, by placing thermometer against same, even if under oil.
Laminations, by placing thermometer against same, even if under oil.
Terminals.
Room, as with dynamos and motors.
Also resistance measurements of primary and secondary windings, from which the temperature by resistance can be calculated as shown.

On transformers cooled by air forced through spaces between windings and spaces in laminations, temperatures by thermometer should be taken on —

Outside frame.
Air, outgoing from coils.
Air, outgoing from iron laminations.
Windings.
Terminals.
Room, in two or more places.
Also resistance measurements, hot and cold, should be taken, from which rise of temperature by resistance can be calculated.
Finally, the cubic feet of air, and pressure to force same through spaces (easily measured by "U" tube of water), should be measured.

When other fluids are used for cooling, such as water passing through piping submerged in oil, in which also the windings and core are submerged, or through windings of transformers themselves (made hollow for the purpose), the temperature of incoming and outgoing fluid should be measured, the quantity used and the pressure necessary to force it through the path arranged, besides the other points mentioned above.

Careful watch of thermometers is necessary in all cases, as they will rise for a time and then begin to fall; and the maximum point is what is wanted.

British authorities state a definite time to read the thermometers after stopping the machine.

Care must also be taken to stop the machine rotating as soon as possible, so that it will not fan itself cool.

A handy method of constructing a curve showing the rise of temperature in the stationary parts of a machine at full load is to insert a small coil of fine iron wire in some crevice in the machine in the part of which the temperature is desired. Connect the coil with a mirror galvanometer and battery.

The temperature coefficient of iron is high, and the gradual increase in resistance of the coil will cause the readings on the galvanometer to grow gradually less; and readings taken at regular intervals of time can be plotted on cross-section paper to form a curve showing the changes in temperature.

Records of temperature test. — During all heat runs readings should be taken every fifteen (15) minutes of the following items:

On direct and alternating current motors and generators —

Armature, Volts (between the various rings where machine is more than single-phase, in the case of alternators, and between brushes, in the case of a D. C. machine).
Amperes (in each line).
Speed.
Field, Volts.
Amperes.

On synchronous converters: —

Armature, Volts (between all rings on A. C. end, and between brushes on D. C. end).
Amperes, per line A. C. end, also D. C. end.
Speed.
Field, Volts.
Amperes.

On transformers, compensators, potential regulators: —
Volts, primary.
Volts, secondary.
Amperes, primary.
Amperes, secondary.
Cycles.
Amount and pressure of cooling-fluid (if any is used).

On induction motors: —
Volts, between lines.
Amperes, in line.
Speed.
Cycles.

Overload. — The A. I. E. E. standards contain suggestions for overload capacity (see page 303).

The writer has uniformly specified a standard overload of 25% for 3 hours, and there seems to be no especial difficulty in getting machines for this standard that do not heat dangerously under such conditions.

Insulation test. — Insulation resistance in ohms is of much less importance than resistance against breakdown of the insulation under a *strain* test, with alternating current of high pressure.

Make all insulation tests with a voltage as high, at least, as that at which the machine is to be worked.

The following diagram shows the connections to be made with E some external source of E.M.F. The formula used is

R = resistance of voltmeter.
E = E.M.F. of the external source.
e = reading of voltmeter connected as in diagram.
x = insulation resistance in ohms.

$$\text{Then } x = R\left(\frac{E}{e} - 1\right).$$

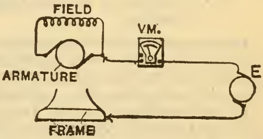


FIG. 1. Connections for voltmeter test of insulation resistance of a dynamo.

According to the A. I. E. E. standards, the insulation resistance must be such that the rated voltage of the machine will not send more than $\frac{1}{1000000}$ of the full-load current through the insulation. One megohm is usually considered sufficient, if found by such a test. Where one megohm is specified as sufficient, the maximum deflection that will produce that value, and that must not be exceeded in the test, may be found by the following variation of the above formula:

$$e = \frac{R \times E}{1{,}000{,}000 + R}$$

Strain test. — The dielectric strength of insulation should be determined by a continued application of an alternating E.M.F. for at least one (1) minute. The transformer from which the alternating E.M.F. is taken should have a current capacity at least four (4) times the amount of current necessary to charge the apparatus under test as a condenser. Strain tests should only be made with the apparatus fully assembled.

Connect on a D.C. machine as in the following diagram.

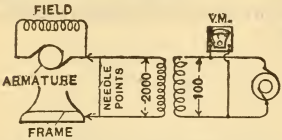


Fig. 2. Connections for strain test of dynamo or motor or transformer insulation.

Strain tests should be made with a sine wave of E.M.F., or with an E.M.F. having the same striking distance between needle points in air.

See article 219 A. I. E. E. standards for proper voltages.

Regulation.—The test for *regulation* in a dynamo consists in determining its change in *voltage* under different loads, or output of current, the speed being maintained constant.

The test for *regulation* in a motor consists in determining its change of *speed*, under different applied loads, when the voltage is kept constant.

Standards.—For full details of standards of regulation of different machines, see report of the Committee on Standardization of the A. I. E. E. at the beginning of this chapter.

Regulation Tests, Dynamos, Shunt or Compound, and Alternators.

The dynamo must be run for a sufficient length of time at a heavy load to raise its temperature to its highest limit; the field rheostat is then adjusted, starting with voltage a little low, and bringing up to proper value to obtain the standard voltage at the machine terminals, and since a constant temperature condition has been reached, must not again be adjusted during the test. Adjust the brushes, in the case of a D. C. machine, for full-load conditions, and they should not receive other adjustment during the test. This is a severe condition, and not all machines will stand it; but all good dynamos, with carbon brushes, will stand the test very well, provided the brushes are adjusted at just the non-sparking point at no load.

Load is now decreased by regular steps, and when the current has settled the following readings are taken:—

Speed of dynamo (adjusted at proper amount).
Current in output (a non-inductive load should be used).
If alternator, current in each line if more than single-phase.
Volts at machine terminals.
Amperes, field.
Volts, field.
Note sparking at the brushes (they should not spark any with carbon brushes).

Readings should be taken for at least ten intervals, from full load to open circuit (no load); and load should then be put on gradually and by the same steps as it was brought down; and the same records should be made back to full-load point, and beyond to 25% overload.

If the readings are to be plotted in curves, as they always should be, it will make little difference if the intervals or steps are not all alike; and should the steps be overreached in adjusting the load, the load must not, in any circumstances, be backed up or readjusted back to get regular intervals or a stated value, as the conditions of magnetization change, and throw the test all out. In case the current is broken, or the test has to be slowed down in speed or stopped, it must be commenced all over again. Finally, when the curves are plotted, draw, in the case of a compound-wound machine, a straight line joining the *no-load* voltage and the *full-load* voltage; and the ratio of the point of maximum departure of the voltage from this line to the voltage indicated by the line at the point will be the *regulation* of the machine.

The readings as obtained give what is called a field compounding curve. In the case of a shunt or separately excited machine, the procedure for the test is the same; but when the curve is plotted, the regulation is figured as equal to the difference between the no-load voltage and full-load voltage, divided by the full-load voltage. The curve is called a characteristic in this case.

For alternators that are too large to apply actual load as suggested above, another "no-load" method commonly used with satisfactory results upon alternators designed upon the usual lines is to short-circuit the alternator armature upon itself and determine the amperes in the field required to produce normal current in the armature so short-circuited, the speed of the machine being normal at the time; call this current F. Take another reading of the field current required to produce normal voltage at the machine terminals, with the armature on open circuit and the speed normal; call this current C. Then the current required in the field winding for full non-inductive load will be $I = \sqrt{F^2 + C^2}$.

Having calculated the value of this current, pass it through the field windings of the alternator with the armature on open circuit and running at normal speed, and read the volts V. Let E = normal voltage, then the regulation $= \frac{V - E}{E}$.

The current F is called the "Synchronous impedance" field current, being so named by Mr. C. P. Steinmetz, who proposed and has used the above-described method.

When regulation is desired for a power factor other than unity the field currents F and C must be combined at the proper angle corresponding to the power factor. For instance, for a power factor of 0 (i.e., 90° lag) the field currents would be directly added. This method is used extensively and gives results agreeing very well with those of actual tests.

Regulation Tests, Motors, Shunt, Compound, and Induction.

After driving the motor under heavy load for a length of time sufficient to develop its full heat, full-rated load should be applied, the field rheostat, if any is used, and brushes adjusted for the standard conditions; then the load should be gradually removed by regular steps, and the following readings be made at each such step: —

Amperes, input.
Volts at machine terminals (kept constant).
Watts, if induction motor.
Speed of armature.
Note sparking at brushes.
Amperes, field (in D. C. machines).

At least ten steps of load should be taken from full-rated load to no load.

The ratio of the maximum drop in speed between no-load and full-load, which will be at full-load, to the speed at full-load, is the *regulation* of the motor.

Efficiency Tests. Dynamos.

The term *efficiency* has two meanings as applied to dynamos; viz., *electrical* and *commercial*. The *electrical* efficiency of a dynamo is the ratio of electrical energy delivered to the line at the dynamo terminals to the total electrical energy produced in the machine. The *commercial* efficiency of a dynamo is the ratio of the energy delivered at the terminals of the machine to the total energy supplied at the pulley. Otherwise the *electrical* efficiency takes into account only electrical losses, while the *commercial* efficiency includes all losses, electrical, magnetic, and frictional.

Core-Loss Test, and Test for Friction and Windage.

These losses are treated together for the reason that all are obtained at the same time, and the first can only be determined after separating out the others.

A core-loss test is ordinarily run only on new types of dynamos and motors, but is handy to know of any machine, and if time and the facilities are available, should be run on acceptance tests by the consulting engineer. It consists in running the armature at open circuit in an excited field, driving it by belt from a motor the input to which, after making proper deductions, is the measure of the power necessary to turn the iron core in a field of the same strength as that in which it will work when in actual use.

Connect as in the following diagram, in which A is the dynamo or motor under test, and B is the motor driving the armature of A by means of the belt. The field of A must, of necessity, be separately excited, as its own armature circuit must be open so that there may be no current generated in its conductors.

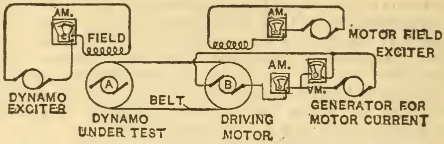


FIG. 3. Connections for a test of core loss.

The motor field is separately excited and kept constant, so that its losses and the core loss of the motor itself, being constant for all conditions of the test, may be cancelled in the calculations. The motor B should be thoroughly heated; and bearings should be run long enough to have reached a constant friction condition before starting this test, so that as little change as possible will take place in the different "constant" values. It is necessary to know accurately the resistance of the armature, B, in order to determine its I^2R loss at different loads, and to use copper brushes to practically eliminate the I^2R of brushes.

It is well to make a test run with the belt on in order to learn at what speed it is necessary to run the motor in order to drive the armature A at its proper and standard speed.

Friction, core loss, and windage of motor.—The speed having been determined, the belt is removed, and the motor field kept at its final adjustment, and enough voltage is supplied to the motor armature to drive it free at the standard speed. The watts input to the armature is then the measure of the loss (I^2R) in the motor armature plus the friction of its bearings, plus its windage, plus core loss, or the total loss in the motor at no load. This is called the "running light" reading.

Friction and windage of dynamo.—After learning the losses in the driving motor, the belt is put on and the dynamo is driven at its standard speed without excitation, and in order to be sure of this a voltmeter may be connected across the armature terminals; if the slightest indication of pressure is found, the dynamo field can be reversely excited, to be demagnetized, by touching its terminals momentarily to a source of E.M.F. Take a number of readings of the input to the motor in order to obtain a good mean, and the friction and windage of dynamo is then the input to the motor, less the "running light" reading previously obtained, the I^2R of motor armature having been taken out in each case.

Let $P =$ watts input to motor,
$P_1 = I^2R$ loss in motor armature when driving dynamo,
$f =$ "running light" reading of motor,
$f_1 =$ friction and windage of dynamo armature,
$P_2 = I^2R$ loss of motor armature when "running light,"
then $f_1 = P - (P_1 + f - P_2)$.

Brush friction.—The friction of brushes is ordinarily a small portion of the losses; but when it is desirable that it should be separated from other losses, it can be done at the same time and in the same manner as the test for bearing friction. The brushes can be lifted free from the commutator or collector rings when the readings of input to the driving motor for bearing friction are taken; dropping the brushes again onto the commutator and taking other readings, the difference between these last readings and those taken with brushes off will be the value of brush friction. Note, that allowance must be made as before for increase of I^2R loss in the motor armature.

Test for core loss.—Having determined the friction and other losses that are to be deducted from the total loss, a current as heavy as will ever be used is put on the dynamo field, the motor is supplied with current enough to drive the dynamo at its standard speed, and the reading of watts and current input to the motor armature is taken.

The dynamo field current is now gradually decreased in approximately regular steps, readings of the input to the motor being taken at each such step until zero exciting current is reached, when the exciting current is reversed and the current increased in like steps until the highest current reading is again reached. This may now be again decreased by intervals back to zero, reversed and increased back to the starting-point, which will thus complete a cycle of magnetization; ordinarily this refinement is not, however, necessary.

This test must always be carried through without stop; and although it is desirable to make the step changes in field excitation alike, if the excitation be changed in excess of the regular step it must not be changed back for the purpose of making the interval regular, as it will change the conditions of the residual field. When the readings are plotted on a curve, regularity in intervals of magnetization is not entirely necessary.

The following ruling makes a convenient method of tabulation:—

DYNAMO.		MOTOR.			
Speed	amperes in field	Speed	amperes in field	amperes in armature i	volts in armature e
Constant		Constant.	Constant.		

COMPUTATIONS.

Watts in armature, belt on $P_{\prime\prime} = i\,e$	Running light reading f	$I^2 R$ in arm, belt on P_1	$I^2 R$ in arm, belt off P_2	Core loss $P_{\prime\prime} - (P_1 + f - P_2)$

Plot on curve with exciting-current values on the horizontal scale, and the core loss on the vertical, and the usual core-loss curve is obtained.

Separation of Core Loss into Hysteresis and Eddy Current Loss.

Losses due to hysteresis and friction vary directly with the speed; losses due to eddy currents vary as the square of the speed.

Current and voltage must now be applied to the dynamo armature to drive it as a motor at proper speed, with the current in the separately excited field kept constant at proper value. Drive the motor (dynamo) at say two different speeds, one of which may be K times the other; let

$$P = \text{total loss in watts},$$
$$f_1 = \text{loss in friction},$$
$$H = \text{loss by hysteresis},$$
$$D = \text{loss by eddy currents, or}$$
$$P = f_1 + H + D \text{ at the first speed},$$
$$P_1 = Kf_1 + KH + K^2 D \text{ at second speed},$$
$$KP = Kf_1 + kH + KD,$$
$$P_1 - KP = K^2 D - KD,$$
$$P_1 - KP = KD(K-1)$$
$$D = \frac{P_1 - KP}{K(K-1)}.$$

If $K = 2$, then $$D = \frac{P_1 - 2P}{2(2-1)} = \frac{P_1}{2} - P.$$

Kapp and Housman separately devised the above method of separating the losses, but stated them somewhat differently.

With the field separately excited at a constant value, different values of current are supplied to the armature at different voltages to drive it as a motor. The results are plotted in a curve which is a straight line, rising as the volts are increased.

The following diagram shows how the losses are plotted in curves. The test as a separately excited motor is run at a number of different values of voltage and current in the armature, and the results are plotted in a curve as shown in the following diagram. The line *a*, *b*, is plotted from the results of the current and volt readings.

The line *a*, *c*, is then drawn parallel to the base, and represents the sum of all the other losses, as shown by previous tests, and they may be further separated and laid off on the chart.

The triangle *a*, *b*, *c*, represents one-half of the value of the foucault current loss.

If another run be made with a different value of excitation, a curve, a_1, b_1, or one below the original *a*, *b*, will be gotten, according to whether the total losses have been increased or decreased.

If the higher values of current tend to demagnetize, by reason of the eddy currents in the armature, the curve *a*, *b*, will curve upward somewhat at the upper end.

Knowing the core-loss, friction and windage of a dynamo and the resistance of the various parts, the efficiency is quickly calculated, thus

Let P = core-loss + friction (obtained as shown),
V = voltage of armature,
I = current of dynamo armature,
I_1 = current of dynamo field,
R = resistance of armature and brushes,
R_1 = resistance of field.

Then, considering the above as the only losses (i.e., neglecting rheostats, etc.),

$$\text{Efficiency} = \frac{V_1}{V_1 + I^2 R + I_1^2 R_1 + P}.$$

This is a satisfactory method of getting the efficiency, but does not take in "load losses" if any should exist.

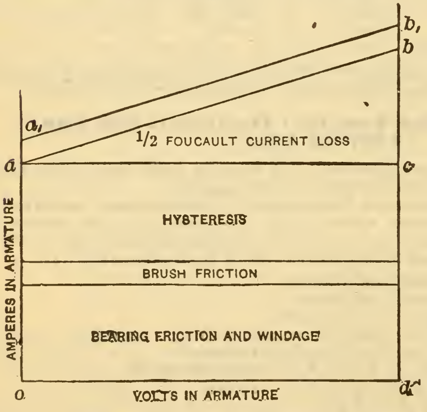


FIG. 4. Diagram showing separation of losses in dynamos.

The simplest method of determining the efficiency of a direct-current machine is to run it light as a motor, without load or belting or gearing, at its proper field strength and its proper speed and measure the input to the armature. From this value subtract the I^2R loss in the armature and the remainder is the core and friction loss. Knowing this and the resistance of the remaining circuits, all the losses are known, and hence the efficiency can be calculated. This method is an accurate one and is easy to carry out.

Another test for efficiency. — If the dynamo under test is not of too large capacity, and a load for its full output is available, either in the form of a lamp bank, water rheostat, or other adjustable resistance, then one form of test is to belt it to a motor.

By separately exciting the motor fields, and running the motor free with belt off, its friction can be determined, and with the resistance of the armature known, the input to the motor in watts, less the friction and the I^2R loss in its armature at the given load, is a direct measure of the power applied at the pulley of the dynamo. The output in watts, measured at the dynamos terminals, then measures the efficiency of the machine.

Let $P =$ watts input to motor,
$Pl =$ losses in motor, friction, I^2R, and core-loss,
$P_1 =$ watts output at dynamo terminals.

$$\% \text{ of efficiency} = 100 \times \frac{P_1}{P - Pl} = \text{commercial efficiency.}$$

Knowing the current flowing in the armature and in the fields, and also knowing the resistance of the same, the I^2R losses in each may be calculated, which, added to the output at the dynamo terminals, shows the total electrical energy generated in the machine.

If $a =$ the I^2R loss in the armature,
$f =$ the I^2R loss in the fields.

The electrical efficiency in percentage will be

$$100 \times \frac{P_1}{P_1 + a + f}.$$

The adjoining diagram shows the connections for this form of test.

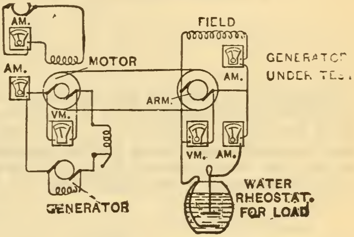


FIG. 5. Connections for efficiency test of a generator, driven by an electric motor.

It must be obvious that a steam-engine, or other motive power that can be accurately measured, may be used in place of the electric motor; but measurements of mechanical power are so much more liable to error that they should be avoided where possible.

The only objection to this method is that the friction of the driving-motor varies with the load, and the loss in the belt is not considered.

Kapp's Test with Two Similar Direct-Current Dynamos.

Where two similar dynamos are to be tested, and especially where their capacity is so great as to make it difficult to supply load for them, it is common to test them by a sort of opposition method; that is, their shafts are either coupled or belted together, the armature leads are connected in series, the field of one is weakened enough to make a motor of it; this motor drives the other machine as a generator, and its current is delivered to the motor. The difference in currents between the two machines, and for exciting the fields of each, is supplied by a separate generator.

The following diagram shows the method of connecting two similar

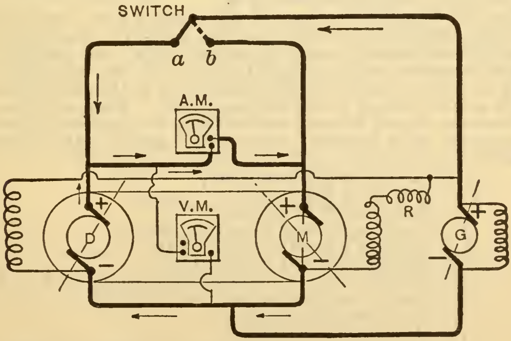


FIG. 6. Connections for Kapp's method of efficiency test of two similar dynamos.

dynamos for Kapp's test. D is the dynamo; M the machine with field weakened by the resistance R, that acts as a motor, and G is the generator that supplies the energy necessary to make up the losses, excitation and differences.

Start the combination and get them to standard voltage, as shown by the voltmeter; then take a reading of the current with the switch on b, and another with the switch on a. Let the first reading be m, and the second d, and let x be the efficiency of either machine, then

$$\text{Per cent efficiency of the combination} = 100 \times \frac{m}{d}, \text{ and}$$

$$x = \sqrt{\left(100 \times \frac{m}{d}\right)}.$$

In using this formula the efficiency of the dynamo at its load is assumed the same as the motor at its simultaneous load, which is usually true above the ¾ load point. The loss in motor-field rheostat should also be allowed for. Another similar method, called "*pumping back*," is to connect the shafts of the two machines as before, by clutch or belt; arrange the electrical connections and instruments as in the following diagram:

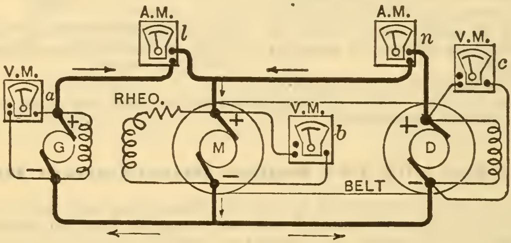


FIG. 7. Efficiency test of two similar dynamos.

D is the dynamo under test; M is the similar machine used as a motor; and G is the generator for supplying current for the losses and differences between M and D. The speed of the combination, as well as the load on D, can be adjusted by varying the field of M.

The motor, M, drives D by means of the shaft or belt connection. M gets its current for power from two sources, viz., G and D. In order to determine the amount of mechanical power developed by M, and also to be able to separate the magnetic and frictional losses in the two machines, a *core-loss* test should have been made on the machine M at the same speed, current, and E.M.F. as it is to have in the efficiency test. The loss in the cable connections between M and D must also be taken into account, and is equal to the difference in volts between voltmeters c and b, × the current flowing in ammeter n.

Let V = E.M.F. of D, shown on c,
$V_{\prime}$ = E.M.F. of M by vm. b,
$V_{\prime\prime}$ = E.M.F. of G by vm. a,
I = amperes current from D by am. n,
$I_{\prime}$ = amperes current from G by am. l,
$I_{\prime\prime}$ = amperes current in M $= I + I_{\prime}$,
e = drop in connections between D and M $= V - V_{\prime\prime}$,
L = loss in connections between D and M $= e \times I$,
r = D's internal resistance,
r_1 = M's internal resistance,
w = core loss + armature loss + field loss + friction of M in watts + L (loss in connections).

Then

$W =$ the useful output of D $= V \times I$,

$W_{,} =$ energy supplied by G $= V_{,,} \times I_{,,}$

$W + W_{,} =$ total energy supplied to M,

$W + W_{,} - w =$ energy required to drive D,

$$\% \text{ commercial efficiency of D} = \frac{W}{W + W_{,} - w} \times 100.$$

$I^2r =$ electrical loss in D,

$$\% \text{ electrical efficiency} = \frac{W}{W + I^2r} \times 100.$$

The other way of calculating the efficiency with this arrangement is to measure the output $= W_1$ from G, with full load on D. W_1 then is the losses of both machines under load; and knowing the I^2R loss in the armature and field of each, the efficiency is quickly and accurately calculated. This method is best, as no core loss is required, and includes the "load losses."

Electrical Method of Supplying the Losses at Constant Potential.

Modification of "Kapp Method," by Prof. Wm. L. Puffer, from notes privately printed for the students of the Massachusetts Institute of Technology.

Specification.

Two similar shunt dynamos under full load, one as a motor driving the other as a loaded dynamo through a mechanical coupling. Mains at same voltage as dynamos, and only large enough to supply the full-load losses of both dynamos.

Line up the two dynamos carefully, and mechanically connect them by a good form of mechanical coupling, strong enough to transmit the full load to the dynamo.

Connect the field magnet windings of each machine to the supply mains, putting a suitable field rheostat in each. If desirable for any reason, the field of the dynamo may be left connected as designed; but the field of the motor, which does not in any way enter as a quantity to be measured during the test, should be connected to the supply mains.

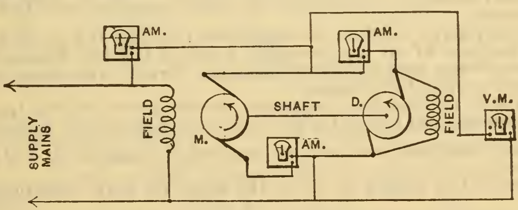


FIG. 8. Diagram of Connections for Professor Puffer's Modification of Kapp's Dynamo Test.

Method of Starting.

Close the field circuit of the motor, and by the motor starting rheostat gradually bring the motor up to full speed. The dynamo armature will be also at proper speed and on open circuit. Now close the dynamo field and adjust the field rheostat until the dynamo is at about normal voltage. Adjust the speed roughly at first by the use of the field rheostat of the motor, remembering that an added resistance will cause the speed to rise. Next see that the voltage of the dynamo is equal to that of the motor, or, in other words, that there is no difference of potential between opposite sides of the main switch on the dynamo. Close this switch and there may, or may not, be a small current in the dynamo armature. Now carefully increase the armature voltage of the dynamo, watching the ammeter, and weaken that of the motor; a current will flow from the dynamo to the motor, and the motor will transmit power mechanically to the dynamo.

The current which was first taken from the supply wires to run the motor and dynamo armatures will increase somewhat. By a careful adjustment of the two rheostats and the lead on each machine, the conditions of full load of the dynamo may be produced. The motor is overloaded and its armature will carry the sum of the dynamo and supply currents. Great care must be taken in adjusting the brushes of the machines, because of great changes in the armature reactions which take place as the brushes are moved. It is well to remember that a backward lead to the motor brushes will increase the speed, as the armature reactions will considerably weaken the effective field strength.

Cautions.

The increase of speed will raise the dynamo voltage, and cause the current flowing in the armatures to greatly increase. A forward movement of the motor brushes will reduce both speed and current. A forward movement of the dynamo brushes will increase the armature reaction, and cut down the current through the armatures, while a backward movement will cause it greatly to increase. Very great care must be taken in adjusting the brush lead, as a movement of the brushes of either machine, which would be of little importance usually, will produce sometimes a change in current value equal to the full-load current. It is quite possible but poor practice to produce the load adjustment by use of the brushes alone.

It is best to have ammeters of proper size in all circuits, but those actually required are in the dynamo leads and in the supply mains. A single voltmeter is all that is required.

The field magnet circuits ought to be connected as shown, and the ammeters placed so that the energy in the fields does not come into the test of the losses in the armatures. The magnet of the machine under test, a dynamo in this case, should be under the proper electrical conditions for the load, yet not in the armature test, because the object of the test can best be made the determination of the stray power loss under the conditions of full load; then having found this, assume the exact values of E, I, and speed, and so build up the data for the required efficiency under a desired set of conditions which might not have been exactly produced during the test.

Immediately after the run, all hot resistances should be measured as rapidly and carefully as possible, to avoid any error due to a change in temperature.

The energy given to the two armatures less the I^2R in each armature, will be the sum of all the armature losses of the two dynamos under the conditions of the test, so that we measure directly the armature losses of the dynamos while fully loaded.

It is evident that the two armatures are not under *exactly* the same conditions, except as to speed, for the dynamo armature will have an intensity of magnetic field that will give an armature voltage of $V_t + I_A R_A$, while the motor will be weaker as V_t is the same for both armatures, and the motor armature voltage will be $V_t - I_A R_A$. All the iron core losses will be made much greater in the dynamo than in the motor. The motor armature must carry a current equal to the sum of the dynamo and supply currents, and will get much hotter; its reaction will also be greater, and there will be a tendency for greater sparking at the brushes.

The total stray power thus obtained may be divided between the two armatures equally, but preferably in proportion to the armature voltages, unless the true law for the armatures is known. All resistances of wires, etc., must be noted and corrections applied, unless entirely negligible.

Two 15-H.P. dynamos were tested by the class of '93, using this method. One of the full-load tests is here given as a sample of calculation. The exact rating of the dynamos is not known, but is nearly 45 amperes at 220 volts, with the dynamo at a speed of 1600 r.p.m.

The averages of the observed readings taken during the test, and after a run of about five hours to become heated, was as below.

Example of Calculation.

(Connections as shown in Fig. 8.)

Volts at supply point	220.3
Amperes of	15.71
Output of dynamo, amperes	45.80
Dynamo field current	1.945
Speed	1594.

To Measure Armature Resistance.

Motor	$V = 1.952$	$I = 10.18$
Dynamo	$V = 2.406$	$I = 10.08$

The motor field is out of the test while the dynamo field is in the test.

Calculation.

Watts supplied $220.3 \times 15.71 = 3461.$

Dynamo armature R. =

$$R_{ad} = \frac{2.406}{10.08} = .2387$$

$I^2{}_{ad} R_{ad}$

$I_a = 45.80 + 1.94 = 47.74$

$47.74^2 \times .2387 = 554 = I^2{}_a R_{ad}$

Motor armature R. =

$$R_{am} = \frac{1.952}{10.18} = .1918$$

$I^2{}_{am} R_{am}$

$I_a = 45.80 + 15.71 = 61.51$

$61.51^2 \times .1918 = 725.4 = I^2{}_a R_{am}$

Dynamo Field $= 1.945 \times 220.3 = 428.4$

Watts supplied =		3461
Dynamo field	= 428.4	
I^2R M	= 725.4	
I^2R D	= 554.0	
Total heat lost	= 1697.8	1698
Total stray power		= 1763 watts, for both machines.

V_{ad}

$V_t + I_a R_a$

$47.74 \times .2387 = 11.4 + 220.3$
$= 231.7 = V_{ad}.$

V_{am}

$V_t - I_a R_a$

$61.51 \times .1918 = 11.8 + 220.3$
$= 208.5 = V_{am}.$

Divide the total stray power between the two armatures as their armature voltages.

Stray power of dynamo, $\dfrac{231.7}{231.7 + 208.5} \times 1763 = 928.$

Stray power of motor $= 1763 - 928.0 = 835.0.$

The quantity 928.0 is the object of our test, i.e., the stray power when as nearly as may be under actual running conditions.

Calculation of Efficiencies.

As run.

Output of dynamo $= 220.3 \times 45.80 = 10090$ Watts output

554	$I^2 R_{ad}$
428	Field
928	Stray power
11990	Watts input to the dynamo.

10090
544
428
11062 = Work done by current.

Efficiency of Conversion:

$$\frac{11062 \times 100}{11990} = 92.2 \text{ per cent.}$$

Commercial efficiency:

$$\frac{10090 \times 100}{119.90} = 84.1 \text{ per cent.}$$

Power required to run dynamo:

$$\frac{11990}{746} = 16.1 \text{ H.P.}$$

In this test, carbon brushes were used, and the lead adjusted as carefully as possible. If the exact rating of this dynamo had been 45 amperes and 220 volts at a speed of 1600, and we wished to find the efficiencies corresponding, we should proceed in this way.

The test was made under conditions as nearly as possible to the rating, and the stray power as found will not be perceptibly different from what it would be under the exact conditions.

When the load has been as carefully adjusted as in this test, it is seldom worth while to make these corrections, as they are smaller than changes produced by accidental changes of oiling, temperature, brush pressure, etc., of two separate tests.

Advantages of the Method.

Small amount of energy used in making the test, namely, only the losses. No wire or water rheostat required. Test made under full load, and yet the losses are directly measured. All quantities are expressed in terms depending on the same standards, and therefore the efficiency will be but little affected by any error in the standards. No mechanical power measurements are made, and all measurements are electrical.

Disadvantages.

Requires two similar machines. Armature reactions are not alike in both machines. Leads are not alike. The iron losses are not the same. No belt pull on bearings. Must line up machines and use a good form of mechanical coupling. Sometimes difficult to set the brushes on the motor. The motor armature is much overloaded.

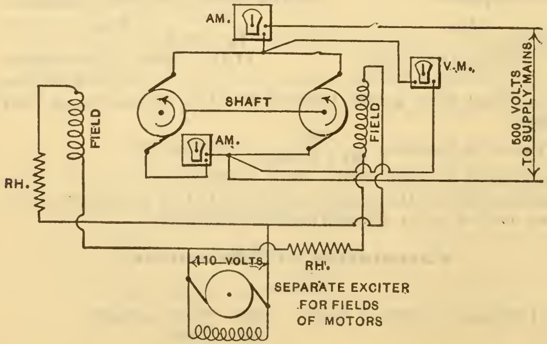


FIG. 9. Diagram of Connections for Test of Street Car Motors, Prof. Puffer.

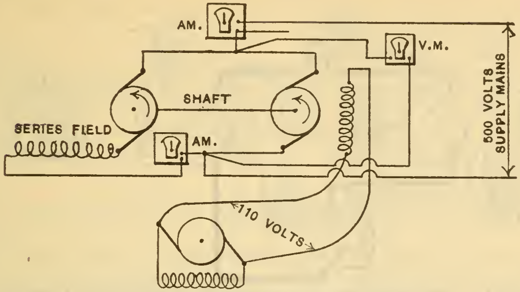


FIG. 10. Diagram of Connections of Modification of the Previous Diagram, by Prof. Puffer.

This method is of advantage in the test of railway series motors, if slightly modified by the separate excitation of the motor fields. If the series field windings be not separately excited there will be a great deal of unnecessary difficulty from great changes of speed as the load is varied. However, one field may be kept in circuit on the machine used as a motor, as the test can then be made with the motor under its exact conditions. There will be a very great change of speed during adjustment of load, but there will be no danger of injuring anything, as the separate excitation of the dynamo field is an aid to steadiness. Railway motors, as generally made, will not stand their full rated load continuously, and the motor is likely to get too hot if not watched; the machine used as a dynamo will run cold, as it will not have a large current in it. The friction of brushes is very large in these motors, and in general there is a want of accuracy in the division of the total stray power between the two armatures. It can only be very approximately done by the aid of curves showing the relation between speed and stray power, and armature voltage and stray power.

Hopkinson's Test of two Similar Direct-Current Dynamos.

In the original Hopkinson method, the two dynamos to be tested were placed on a common foundation with their shafts in line, and coupled together. The combination was then driven by a belt from an engine, or other source of power, to a pulley on the dynamo shafts. The leads of both machines were then joined in series, and the fields adjusted so that one acted as a motor driven by current from the other. The outside power in that case supplied, and was a measure of the total losses in the combination, the efficiency of either machine being taken as the square root of the efficiency of the combination.

Many modifications of this test have been used, especially in the substitution of some method of electrically driving the combination, as the driving-power is so much easier measured if electrical.

This test is somewhat like that last given, but the two machines are connected in *series* through the source of supply for the *difference* in power, such as a storage battery or generator. The following diagram shows the connections for the Hopkinson test, with a generator for supplying the difference in power.

In this test the output of G plus energy taken by M_1 (motor driving the system), gives losses of motor and dynamo (the losses of M_1 being taken out). These losses being known, the efficiency can be calculated.

If the two machines D and M are alike, G supplies the I^2R losses of armatures, and M the friction, core losses, and I^2R of fields.

Another method useful where load and current are both available, is to drive one of two similar dynamos as a motor, and belt the second dynamo to it. Put the proper load on the dynamo, and the efficiency of the combination is the ratio of the watts taken out of the dynamo to the watts supplied to the motor. The efficiency of either machine, neglecting small differences, is then the square root of the efficiency of both.

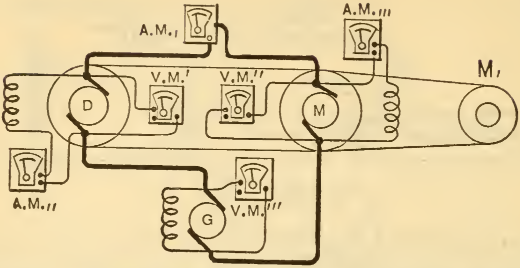


FIG. 11. Diagram of connections for Hopkinson's test of two similar dynamos.

If

$P =$ watts put into the motor,
$P_1 =$ watts taken from the dynamo,
$x =$ per cent efficiency of the combination,
$y =$ efficiency of either machine,

$$x = \frac{P_1 \times 100}{P},$$

$$y = \sqrt{x}.$$

The above test is especially applicable to rotary converters, the belt being discarded, and the *a c* sides being connected by wires; thus the first machine supplies alternating current to the second, which acts as a motor generator with an output of direct current. The only error (usually small) is due to the fact that both machines are not running same load, since that one supplies the losses of both.

Fleming's Modification of Hopkinson Test.—In this case the two dynamos under test are connected together by belt or shafts, and are

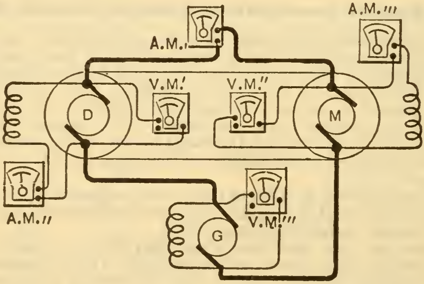


FIG. 12.

driven electrically by an external source of current, say a storage battery or another dynamo, which is connected in series with the circuit of the two machines. Figure 12 shows the connections for this test, which will be found carried out in full in Fleming's "Electrical Laboratory Notes and Forms."

Motor Tests.

Probably the most common method of testing the efficiency and capacity of motors is with the prony brake, although in factories where spare dynamos are to be had, with load available for them, there can be no question that belting the motor to the dynamo with an electrical load is by far the most accurate, and the easiest to carry out.

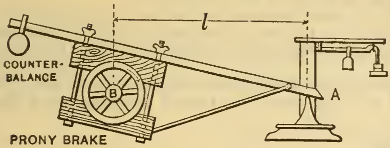


FIG. 13.

Prony brake test.—In this test a pulley of suitable dimensions is applied to the motor-shaft, and some form of friction brake is applied to the pulley to absorb the power. The following diagram shows one of the simplest forms of prony brake; but ropes, straps, and other appliances are also often used in place of the wooden brake shoes as shown.

NOTE.—See Flather, "*Dynamometers and the Measurement of power*."

As the friction of the brake creates a great amount of heat, some method of keeping the pulley cool is necessary if the test is to continue any length of time. A pulley with deep inside flanges is often used; water is poured into the pulley after it has reached its full speed, and will stay there by reason of the centrifugal force until it is evaporated by the heat, or the speed is lowered enough to let it drop out. Rope brakes with spring balances are quite handy forms.

The work done on the brake per minute is the product of the following items:

l = the distance from the centre of the brake pulley to the point of bearing on the scales, in feet,
n = number of revolutions of the pulley per second,
w = weight in lbs. of brake bearing on scales.

Power $= 2\pi\, l\, n\, w =$ foot-pounds per second, and

$$\text{H.P.} = \frac{2\pi l n w}{550} = 0.011424\, l\, n\, w.$$

The input to the motor is measured in watts, and can be reduced to horsepower by dividing the watts by 746; or the power absorbed by the brake can be reduced to watts as follows: Brake watts $= 8.52\, l\, n\, w = P$.

If the length, l, be given in centimeters, and the weight, w, be taken in kilograms, the horsepower absorbed by the brake is given by the formula

$$\text{H.P.} = 826\, l\, n\, w\, 10^{-6}.$$

Again taking the length in centimeters and the weight in kilograms, the watts absorbed by the brake are

$$\text{Brake watts} = 0.616\, l\, n\, w.$$

The watts input $= Pi$ and efficiency in percentage $= \frac{P}{Pi} \times 100$.

Using feet and pounds in the measurements, the efficiency in percentage will be

$$\text{Eff.} = \frac{852\, l\, n\, w}{Pi}.$$

Using centimeters and kilograms the efficiency will be

$$\text{Eff.} = \frac{61.6\, l\, n\, w}{Pi}.$$

If it is desired to know the friction and other losses in the motor, after the brake test has been made, the brake can be removed, and the watts necessary to drive the motor at the same speed as when loaded, can be ascertained.

Electrical load test (*including loss in belting, and extra loss in bearings due to pull of belt*).—This test consists in belting a generator to the motor and measuring the electrical output of the generator, which added to the friction and other losses in the generator, makes up the load on the motor. The efficiency is then measured as before, by the ratio of output to input. The great advantage of this form of test is, that it can be carried on for any length of time without trouble from heat, and the extra loss in bearings due to pull of belt is included, which is therefore an actual commercial condition.

In this form of test the losses in the generator are termed *counter torque*, and the method of determining them is given following this.

Counter torque. — In tests of some motors, especially induction motors, the load is supplied by belting the motor under test to a direct current generator having a capacity of output sufficient to supply all load, including overload.

In determining the load applied to the motor and the *counter torque*, it is necessary to know, besides the *I. E.* or watts output of the generator, the following: —

I^2R of generator armature,
Core loss of generator armature,
Bearing and brush friction and windage of generator,
Extra bearing friction due to belt tension.

It is necessary to know the above items for all speeds at which the combination may have been run during the testing. This is especially useful in determining the breakdown point on induction and synchronous motors, both of which can be loaded to such a point that they "fall out of step."

While the motor is under test especial note should be made of the speeds at which the motor armature and generator armature rotate, and of the watts necessary to drive the motor at the various speeds without load.

The *counter torque* will then be the sum of the following three items: —

$P = I^2 R$ of generator armature,
$P_c =$ core loss of generator armature,
$F =$ bearing and brush friction and windage of the generator armature.

The field of the dynamo must be separately excited and kept at the same value during the load tests and the tests for "*stray power*," and does not enter into any of these calculations.

Belt-on test. — After disconnecting current from the motor under test, and with the belt or other connection still in place, supply sufficient voltage to the dynamo armature to drive it as a motor at the speeds run during the motor test, holding the field excitation to the same value as before, but adjusting the voltage supplied to the armature for changing the speed.

Take readings of

Speed, *i.e.*, number of revolutions of dynamo armature.
Volts at dynamo armature.
Amperes at dynamo armature.

Construct a curve of the power required to drive the combination at the various speeds shown during the motor test.

Belt-off test. — Throw the belt or other connection off, and take readings similar to those mentioned above, which will show the power necessary to drive the dynamo without belt.

Then for any speed of the combination the "*stray power*" will be found as follows: —

$P_{,} =$ watts from *belt-off* curve, required to drive the dynamo as a motor.
$P_{,,} =$ watts from *belt-on* curve, required to drive the combination.
$P_c =$ core loss in dynamo armature.
$F =$ friction of dynamo *belt-off*.
$F_{,} =$ friction of motor under test, running light and without belt.
$f =$ increase in bearing friction of dynamo, due to belt tension.
$f_{,} =$ increase in bearing friction of motor, due to belt tension.

From the *belt-off* curve,

$$P_{,} = P_c + F \quad \ldots \ldots \ldots \quad (1)$$

From the *belt-on* curve,

$$P_{,,} = P_c + F + F_{,} + f + f_{,} \quad \ldots \ldots \ldots \quad (2)$$

Subtract (1) from (2)

$$P_{,,} - P_{,} = F_{,} + f + f_{,} \quad \ldots\ldots\ldots\ldots \quad (3)$$

The values of f and $f_{,}$ cannot be determined accurately; but if the machines are of about the same size as to bearings and weights of moving parts, it is very close to call them of equal value, when,

$$f \text{ or } f_{,} = \frac{(P_{,,} - P_{,} - F_{,})}{2} \quad \ldots\ldots\ldots\ldots \quad (4)$$

The friction $F_{,}$ of the motor under test has been previously found by noting the watts necessary to drive it at the various speeds. If it is an *induction* motor, the impressed voltage is reduced very low in determining the friction in order that the core loss may be approximately zero.

As all the values of the quantities on the right-hand side of the equation (4) are now known, f is determined, and may be added to $P_{,}$ to give the total "*stray power*." A curve is then plotted from the values of "*stray power*" at different speeds.

Counter torque $= (P_{,} + f)$.
Total load $= IE + I^2R + (P_{,} + f)$,
where $IE =$ watts load on the D. C. machine when it is being driven by the motor.

If $S = P_{,} + f =$ "*stray power*," then
Total load $= IE + I^2R + S$.

The value of f is so small when compared with the total load, that any ordinary error in its determination will be unimportant.

Test of Street-Railway Motors.

The "*pumping-back*" test, as described before, with some little modification serves for testing street-railway motors. The following diagram shows the arrangement and electrical connections.

The motors are driven mechanically by another motor, the input to which is a measure of the losses, frictional, core losses, gears, bearings, etc., in the two motors; the two motors are connected in series, through a booster, B, care being taken to make the connections in such a manner as to have the direction of rotation the same; and their voltages opposing.

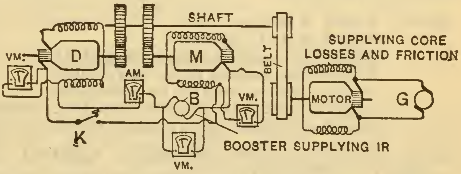


FIG. 14. Diagram of connections and arrangement of street-railway motors.

Readings are taken and the efficiencies are calculated as in the "pumping-back" test.

In eliminating the friction of bearings, etc., and of the driving-motor, it is run first without belts, the input being recorded as taken, at the speed necessary. The belt is then put on and a reading taken at proper speed, with both the motors under load.

The load being adjusted by varying the field of booster B, the total losses of the system are then IE from booster plus the difference between belt-on reading with full load through the motors, and belt-off reading as noted (allowance being made for change of I^2R of driving-motor). If the two motors are similar, half this value is the loss in one motor, from which the efficiency can be calculated as previously shown.

Induction motors. — In addition to the tests to which the D. C. motor is ordinarily submitted, there are several others usually applied to the induction motor, as follows: —

Excitation; Stationary impedance; Maximum output; and some variations on the usual heat and efficiency tests.

Excitation: This is also the test for core loss + friction, allowance being made for I^2R of field; with no belt on the pulley the motor is run at full impressed voltage. Read the amperes of current in each leg, and total watts input. The amperes give the excitation or "running-light" current, and the watts give core loss + friction + I^2R of excitation current.

Stationary impedance: Block the *rotor* so it cannot move, and read volts and amperes in each leg, and total watts input. This is usually done at half voltage or less, and the current at full voltage is then computed by proportion. This then gives the current at instant of starting, and a measure of impedance from which, knowing the resistance and core loss, other data can be calculated, such as maximum output, efficiency, etc.

Maximum output: This might be called a *break-down* test; as it merely consists in loading the motor to a point where the maximum torque point is passed and thus the motor comes to rest.

Keep the impressed voltage constant and apply load, reading volts, amperes in each leg, the total watts input, and revolutions; also record the load applied at the time of taking the input. Then take counter torque as explained before, from which the efficiency, the apparent efficiency, the power factor, and maximum output are immediately calculated.

Heat test.—Run motor at full load for a sufficient length of time to develop full temperature, then take temperatures by thermometer at the following points: —

1. Room, not nearer to the motor than three feet and on each side of motor.
2. Surface of field laminations.
3. Ducts (field).
4. Field or stator conductors, through hole in shield.
5. Surface of rotor.
6. Rotor spider and laminations.
7. Bearings, in oil.

During heat run, read amperes and volts in each line.

Efficiency test.—Apply load to the motor, starting with nothing but friction; make readings at twelve or more intervals, from no load to breakdown point. Keep the speed of A. C. generator constant, also the impressed voltage at the motor.

Read, Speed of motor.
Speed of A. C. dynamo.
Amperes input to motor, in each leg.
Volts impressed at motor terminals.
Watts input to motor, by wattmeter.
Current and volts output from D. C. machine belted to motor,
Counter torque as explained above, and excitation reading watts.

From the above the efficiency, apparent efficiency, power factor $\left(=\frac{\text{apparent efficiency}}{\text{real efficiency}}\right)$, and maximum output can be calculated.

In reading watts in three-phase motors, it is best to use two wattmeters, connected as shown in following sketch: —

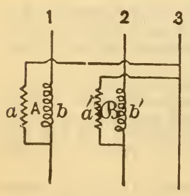


FIG. 15.

1, 2, 3, are the three-phase lines leading to the motor.

A and B are two wattmeters.

b is the current coil of A, and b^1 of B.

a is voltage coil of A, and a^1 of B.

The sum of the deflections of A and B give total watts input. At light loads one wattmeter usually reads negative, and the difference is the total watts.

Results.—At the end of the preceding tests the following results should be computed, and curves plotted from them.

$$\% \text{ synchronism} = \frac{\text{Speed of motor} \times 100.}{\text{Synchronous speed.}}$$

$$\% \text{ real efficiency} = \frac{\text{Output of motor} \times 100}{\text{Input by wattmeter}}.$$

$$\% \text{ apparent efficiency} = \frac{\text{Output of motor} \times 100}{\text{volt} \times \text{amperes}}.$$

$$\text{Power factor} = \frac{\text{Watts}}{\text{Volt} \times \text{amperes}} = \frac{\text{apparent efficiency}}{\text{real efficiency}}.$$

$$\text{Torque-pounds pull at 1 ft. radius} = \frac{5{,}250 \text{ H.P.}}{\text{revolutions per minute}}.$$

The above results should be plotted on a sheet in curves similar to Fig. 16, taken from Steinmetz's article on "Induction Motors."

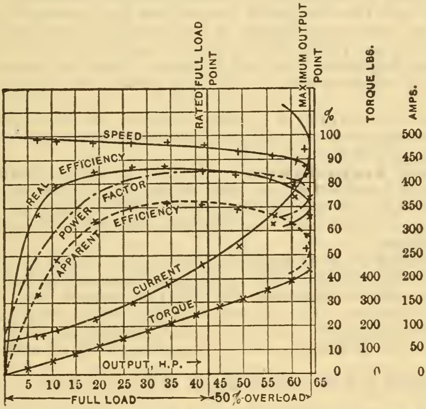


FIG. 16. Curves of results of tests of induction motor.

Synchronous motor.—Synchronous motors are separately excited, and the D. C. exciter should have its qualities tested as a dynamo. Synchronous motors are tested for *Break-down point; Starting current* at different points of location of the rotor; *Least exciting current* for various loads. All these in addition to the regular efficiency and other tests. Core losses, friction, I^2R losses, etc., can be found by any of the usual methods previously described.

Break-down point. Synchronous motors have but little starting-torque; and it is necessary to start them without load, throwing it on gradually after the motor has settled steadily and without "hunting" on its synchronous speed. The break-down point is found by applying load to the point where the motor falls out of step, which will be indicated by a violent rush of current in the ammeter simultaneous with the slowing down.

This test is usually carried out at about half voltage, the ratio of the load on the motor at the moment of dropping out of step will be to the full load of break-down as the square of the voltages, the load being adjusted at minimum input in each case. For example, say a certain motor, built tc run at 2,000 volts, breaks down at 150 K.W., with an impressed voltage of 1,000. Then the true full break-down load will be

$$\frac{2{,}000^2}{1{,}000^2} \times 150 = 600 \text{ K.W.}$$

Starting current. Owing to consequent disturbance to the line, it is desirable that the starting current of a synchronous motor be cut down to the lowest point; but it is difficult to reduce this starting current lower than 200% of full-load current. A synchronous motor also starts easier at certain positions of its *rotor* as related to poles. With the *rotor* at rest, and the location of the centre of its pole-pieces chalked on the opposite member, the circuit is closed, the impressed voltage is kept constant, and the current flowing in each leg of the circuit is read, and the time to reach synchronism. Care should be taken to note the amount of the *first rush* of current, and then the settling current at speed.

Least exciting current. The *power factor* of a synchronous motor will be 100 only when, with a given load on the motor, the exciting current is adjusted so that there is neither a *leading* nor *lagging* current in the armature. Sometimes it is desirable to produce a *leading* current in order to balance the effect of induction motors on the line, or inductance of the line itself. This is done by *over-exciting* the fields.

With a given load on the motor, the 100 power-factor is found by comparing the amperes in the motor armature with the exciting current in the field. Starting with the excitation rather low, the armature current will be high and *lagging;* as the excitation is increased, the armature current will drop, until it reaches a point where, as the excitation is still increased, the armature current begins to rise, and keeps on rising as the exciting current is increased, and on this side of the low point the armature current is *leading.*

With no reason for making a leading current, the best point to run the motor at is, of course, that at which the armature current is the lowest; and at that point the power-factor is 100.

Synchronous Impedance.—The E.M.F. of an alternating dynamo is the resultant of two factors, i.e., the *energy E.M.F.* and *inductive E.M.F.*

The *energy E.M.F.* may be determined from the saturation curve by running the machine without load, and learning the field strength necessary to produce full voltage.

The *inductive E.M.F.* is at right angles to the *energy E.M.F.*, and is determined by driving the machine at speed, short-circuiting the armature through an ammeter, and exciting the field just enough to produce full-load current in the armature. The amount of field current necessary to produce full load is a measure of the *inductive* E.M.F., which can be determined from the saturation curve as before, and the *resultant E.M.F.* will be

$$\text{Resultant E.M.F.} = \sqrt{\text{energy E.M.F.}^2 + \text{inductive E.M.F.}^2}.$$

Saturation test.—This test shows the quality of the magnetic circuit of a dynamo, and especially the amount of current necessary to saturate the field cores and yokes to a proper intensity. In this test it is important that the brushes and commutator be in good condition, and that all contacts and joints be mechanically and electrically tight.

The dynamo armature must be driven at a constant speed, and the leads from the voltmeter placed to get readings from the brushes of the dynamo must have the best of contacts.

The fields of the dynamo must be separately excited, and must have in the circuit with them an ammeter and rheostat capable of adjusting the field current for rather small changes of charge.

The armature must be without load, and a voltmeter must be connected across its terminals.

Should there be residual magnetism enough in the iron to produce any pressure without supplying any exciting current, such pressure should be recorded; or perhaps a better way is to start at zero voltage by entirely demagnetizing the fields by momentary reversal of the exciting current.

To start the test, read the pressure, due to residual magnetism if not demagnetized, or if demagnetized, start at zero. Give the fields a small exciting current, and read the voltage at the armature terminals; at the same time read the current in the fields, and the revolutions of the armature. Increase the excitation in small steps until the figures show that the knee of the iron curve has been passed by several points; then reverse the operation, decreasing the excitation by like amounts of current, until zero potential is reached.

This is usually as far as it is necessary to go in practice; but occasionally it is well to complete the entire magnetic cycle by reversing the exciting current, and repeating the steps and readings as above described.

The readings should be plotted in a curve with the amperes of exciting current as abscissae, and volts pressure as ordinates.

The E.M.F. will be found to increase rapidly at first; and this increase will be nearly proportional to the exciting current until the "*knee*" in the curve is reached, when the E.M.F. increase will not be proportional to the excitation until after the "*knee*" is passed, when the increase in E.M.F. will again become nearly proportional to the excitation, but the increase will be at such a low rate as to show that the magnetic circuit is practically saturated; and it is not economical to work the iron of a magnetic circuit too far above the knee, nor is it expedient to work it at a point much below the "*knee*," except for boosters.

The exciting current must not be broken during this test, except possibly at zero; nor must its value be reduced or receded from in case a step should be made longer than intended. Inequalities of interval in steps of exciting current will make little difference when all are plotted on a curve. For the same value of exciting current the down readings of E.M.F. will always be higher than those on the up curve.

Resistance of field coils. — The resistance of the shunt fields of a dynamo or motor can be taken in any of the usual ways: by Wheatstone bridge; by the current flowing and drop of potential across the field terminals; and it is usual, in addition, to take the drop across the rheostat at the same time. The resistance of each field coil should be taken to insure that all are alike.

Resistance of series fields, and shunts to the same, must be taken by a different method, as the resistance is so low that the condition of contacts may vary the results more than the entire resistance required. The test for resistance of armatures following this is quite applicable. Of course any test for low resistances is applicable; but the one described is as simple as any, and quite accurate enough for the purpose.

Resistance of armature. — In order to determine the I^2R loss in a generator or motor armature, its resistance must be measured with considerable care; and the ordinary Wheatstone bridge method is of no use, for the reason that the variable resistance of the contacts is often more than that of the armature itself. The drop method, so useful with higher resistance devices, is not accurate enough for the work; and the most accurate method is probably the direct comparison with a standard resistance by means of a good galvanometer and a storage battery.

Clean the brushes, commutator surface, or surface of the collector-rings, and in the case of a D. C. machine, see that opposite brushes bear on opposite segments.

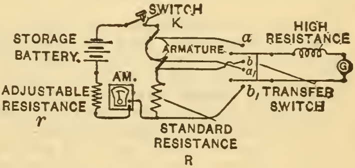


FIG. 17. Diagram of arrangement for measuring resistance of armatures.

Connect the galvanometer and its leads, the storage battery and resistances, as in the following diagram. The standard resistance, R, will ordinarily be about .01 ohm, but may be made of any size to suit the circumstances. The storage battery must be large enough to furnish practically constant current during the time of testing. The galvanometer must be able to stand the potentials from the battery; and it is usually better to connect in series with it a high resistance, so that its deflections may not be too high. The deflection of the galvanometer should be as large as possible, and proportional to the current flowing. The leads a, a_1, and b and b_1, are so arranged with the transfer switch that one pair after the other can be thrown in circuit with the galvanometer; and it is always well to take a deflection first with R, then again after taking a deflection from the armature.

The leads a and a_1 must be pressed on the commutator directly at the brush contacts, and may often be kept in place by one of a set of brushes at either side.

Test. — Close the switch, k, and adjust the resistance, r, until the ammeter shows the amount of current desired, and watch it long enough to be sure it is constant. Close the transfer switch on b and b_1, and read the galvanometer deflection, calling it d. Throw the transfer switch to the contacts a, and a_1, read the galvanometer deflection, and call it d_1. Transfer the contacts back to b, and b_1 and take another reading; and if it differs from d_1, take the mean of the two.

Let x = resistance of the armature, then

$$x = R\frac{d_1}{d}.$$

NOTE. — See Fleming's "Electrical Laboratory Notes and Forms."

Tests for Faults in Armatures.

The arrangement of galvanometer for testing the resistance of an armature is the very best for searching for faults in the same, although it is not often necessary to measure resistance.

Test for open circuit. — Clean the brushes and commutator, then apply current from some outside source, say a few cells of storage battery or low pressure dynamo, through an ammeter as in the following diagrams. Note the current indicated in the ammeter; rotate the armature slowly by hand, and if the break is in a lead, the flow of current will stop when one brush bears on the segment in fault. Note that the brushes must not cover more than a single segment.

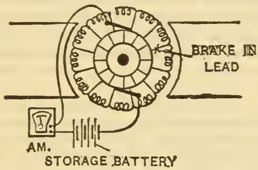


FIG. 18. Test for break in armature lead.

If on rotating the armature completely around the deflection of the ammeter does not indicate a broken lead, then touch the terminals of the galvanometer to two adjacent bars, working from bar to bar. The deflection between any two commutator bars should be substantially the same in a perfect armature; if the deflection suddenly rises between two bars it is indicative of a high resistance in the coil or a break (open circuit).

The following diagram shows the connections.

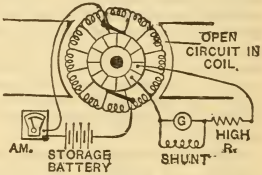


FIG. 19. Bar to bar test for open circuit in coil.

A telephone receiver may be used in place of the galvanometer, and the presence of current will be indicated by a "tick" in the instrument as circuit is made or broken.

Test for short circuit. — Where two adjacent commutator bars are in contact, or a coil between two segments becomes short-circuited, the bar to bar test with galvanometer will detect the fault by showing no deflection. If a telephone is used, it will be silent when its terminal leads are connected with the two segments in contact. See diagram below for connections. If there be a short circuit between two coils the galvanometer terminals should include or straddle three commutator bars. The normal deflection will then be twice that indicated between two segments until the coils in fault are reached, when the deflection will drop. When this happens, test each coil for trouble; and if individually they are all right, the trouble is between the two. The following diagram shows the connections.

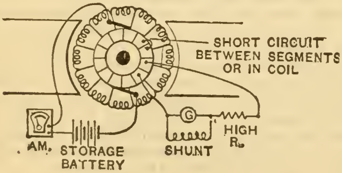


FIG. 20. Bar to bar test for short circuit in one coil or between commutator segments.

Test for grounded armature. — Place one terminal of the galvanometer on the shaft or frame of the machine, and the other terminal on the commutator. (The storage battery, ammeter, and leads must be thoroughly insulated from ground.) If, under these circumstances, there is any deflection of the galvanometer, it indicates the presence of a *ground*, or contact between the armature conductors and the frame of the machine. Move the terminal about the commutator until the least deflection is shown, and at or near that point will be found the contact in the particular coil connected between two segments showing equal deflection, unless the contact happens to be close to one segment, in which case there will be zero deflection. Contacts in field coils can be located by the same method. The following diagram shows the connections.

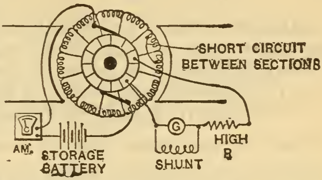


FIG. 21. Alternate bar test for short circuit between sections.

To determine if armature of multipolar dynamo is electrically centred, put down brushes 1 and 2, and take voltage of machine; put down brush 3, and lift 1, take voltage again; put down brush 4 and lift 2, again taking voltage; repeat the operation with all the brushes, and the voltage with any pair should be the same as that of any other pair if the armature is electrically central.

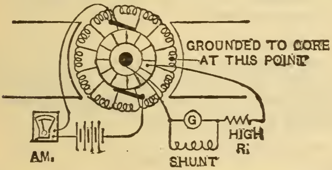


FIG. 22. Test for ground in armature coils.

The same thing can also be determined by taking the pressure curves all around the commutator as shown in the notes on *characteristics on dynamos*.

In the above the brushes should be exactly at the neutral point.

ALTERNATING-CURRENT MACHINES.

REVISED BY E. B. RAYMOND AND CECIL P. POOLE.

FOR alternating or periodically varying currents there are three values of the E.M.F. used, or of which the value is required :

a. The maximum value, or the top of the wave.
b. The instantaneous value of a point in the wave.
c. The effective E.M.F., or $\sqrt{\text{mean}^2}$ value of the full wave.

Since the maximum value of a sine curve $= \frac{\pi}{2} \times$ its average value, the maximum value of the E.M.F. of a single-phase bi-polar alternator producing an alternating sine wave of E.M.F. is

$$E_{max} = \frac{\pi}{2} \cdot \frac{\Phi\, N_c\, 2\ \text{r.p.s.}}{q} - 10^{-8} = \frac{\pi\, \Phi\, N_c\ \text{r.p.s.}\ 10^{-8}}{q}.$$

In an alternator having p poles and m phases,

$$E_{max} = \frac{\pi}{2} \cdot \frac{k\, \Phi\, N_c p\ \text{r.p.s.}\ 10^{-8}}{m q},$$

where k is a number ranging from 1 to 2.5, depending upon the shape of the coil of the armature and also upon the shape of the pole-piece. $N_c =$ number of conductors ; $q =$ number of parallel paths in each winding or phase.

The instantaneous E.M.F. in one winding at any moment

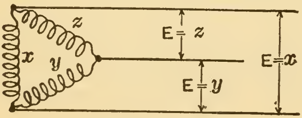
$$= \frac{\pi}{2} \times \frac{N_c \times \text{r.p.s.} \times \Phi \times p \times k\ 10^{-8}}{m q} \times \sin\theta,$$

where $\theta =$ the angle through which the armature has turned from the position where the coil embraces the maximum flux. The most important value of all is the square root of the mean square value of the sine wave of E.M.F., since this value is the effective or working value. It is equal to the maximum value of a sine E.M.F. wave $\div \sqrt{2}$,

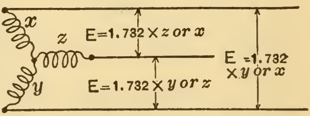
Hence

$$E = \frac{\pi}{2}\ \frac{k\, \Phi\, N_c p\ \text{r.p.s.}\ 10^{-8}}{\sqrt{2}\, m q} = \frac{1.11\, k\, \Phi\, N_c p\ \text{r.p.s.}\ 10^{-8}}{m q}.$$

In *three-phase* alternators the E.M.F. between terminals will depend upon the method of connecting the armature conductors. The two most common methods are called the delta connection and the Y or star connection, both shown in the following diagrams.



DELTA CONNECTION



Y OR STAR CONNECTION

FIGS. 1 and 2. Values of E.M.F. in three-phase connections when $x = y = z$.

In the delta-connected armature the E.M.F.'s between terminals are those generated in each coil, as shown in the diagram.

In the Y-connected armature the E.M.F. between any two terminals is the E.M.F. generated by one of the coils in that phase multiplied by the $\sqrt{3}$ or 1.732.

Two-phase circuits are sometimes connected as a three-phase circuit ; that is, both phases have a common return wire. In this case the pressure between the two outgoing wires is $\sqrt{2} \times E$, and the current in the common return will be $I\sqrt{2}$, both conditions are on the assumption that E and I in each phase is the same.

The current from an alternator depends upon inductance and resistance. The coefficient of inductance is represented by the letter L. The E.M.F. of an alternator follows approximately a sine curve, and the current from it is represented by the same kind of curve. Since in a circuit, lines of force exist in proportion to the current flowing, at each of its different current values there is a new value of lines in force. Thus, in a circuit of varying current there is a continuously varying flux, and hence there is induced a back E.M.F. This back E.M.F. is called the back E.M.F. of self-induction, and it retards the current flow just as does resistance.

This back E.M.F. of self-induction combines with the resistance, but at right angles thereto, the result being called impedance.

The coefficient of self-induction =

$$L = \frac{\text{max. flux} \times \text{turns}}{\text{amperes} \times 10^8} = \text{henrys.}$$

Henrys multiplied by $2\pi f$ = reactance ohms (f = cycles per second).

In a circuit where R = resistance ohms, and $2\pi fL$ = reactance ohms, these combine at right angles to produce impedance ohms, or the total opposing force of the current, thus:

$$\text{Impedance} = \sqrt{R^2 + (2\pi fL)^2}.$$

Hence in an alternator circuit if the coefficient of self-induction of the alternator be L, and that of the external circuit be L_1; and if the resistance of the alternator armature be R, and that of the external circuit be R_1, and the effective E.M.F. generated in the alternator armature = E, then the current flowing will be

$$I = \frac{E}{\sqrt{(R + R_1)^2 + (2\pi fL + 2\pi fL_1)^2}}.$$

Energy in an Entirely Non-Inductive and Balanced Three-Phase Circuit.

In the following diagram of a Y-connected multiphase generator and circuits, let

e_1 = E.M.F. of any phase in the armature,
i_1 = current of any phase in the armature,
E = E.M.F. between mains,
I = current in any main,

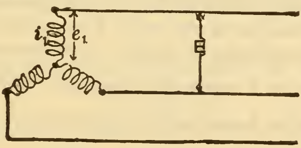


FIG. 3.

P_1 = power of one phase of the armature,
P = total power,
$P_1 = e_1 i_1$;

but $E = e_1 \sqrt{3}$,
$I = i_1$,

hence $P = 3\,w_1 = \frac{3\,EI}{\sqrt{3}} = 1.732\,EI$,

and $I = \frac{P}{1.732\,E}$.

In the following diagram of a delta-connected polyphase generator and circuits, let

$$e_2 = E,$$
$$I = i_2 \sqrt{3},$$
$$P_2 = e_2 i_2,$$
$$P = 3\ P_2 = \frac{3\ EI}{\sqrt{3}} = 1.732\ EI,$$
$$I = \frac{P}{1.732\ E}.$$

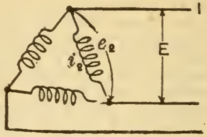


FIG. 4.

Where the circuit is inductive, in order to determine the real power the above result must be multiplied by the "power factor," or the cosine of the "angle" by which the current lags behind or leads the E.M.F. Thus the power in a circuit in which the current lags θ degrees behind the E.M.F. $=$ $IE \cos \theta$. If the current lags 90° behind the E.M.F. there will be no energy developed as $\cos 90° = 0$.

The cosine of the angle of lag θ, or the *power factor*, is equal to the ratio of the true watts to the apparent watts. In ordinary lighting distribution, the power factor is high so that rough calculations are made without its value being exactly known.

Angle of Lag: To determine with a watt meter in three-phase circuits (Fig. 5): Connect the current coil in one lead; connect

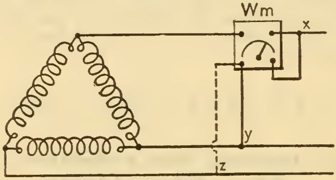


FIG. 5.

one end of the potential coil to x on the same lead; now connect the remaining end first to one of the remaining leads y, then to z, calling the first reading P_1 and the second, P_{11}; then if $\theta =$ angle of lag,

$$\tan \theta = \sqrt{3}\ \frac{P_1 - P_{11}}{P_1 + P_{11}}.$$

When θ is greater than 60 degrees, one reading will be negative, so that the difference of readings will be greater than their sum.

If $R =$ resistance per leg of Y-connected armature,
$r =$ resistance per phase of Δ-connected armature,

then,

$$I^2R \text{ loss in Y-connected armature} = 3\ I^2R$$
$$I^2R \text{ loss in } \Delta\text{-connected armature} = 3\left(\frac{I}{\sqrt{3}}\right)^2 r = I^2 r.$$

Energy in Non-Inductive Three-Phase Circuits.

$I =$ current in any one of the three wires of external circuit,
$i =$ current in one phase of the armature for delta connection,
$P =$ watts output of a balanced three-phase generator,
$1.732 = \sqrt{3}$,
$.577 = 1 \div \sqrt{3}$,
$E =$ volts between terminals (or lines) on either delta or Y system,
$v =$ volts of one phase of the armature if connected in "Y,"
$R =$ resistance per leg, of Y-connected armature,
$r =$ resistance per phase of Δ-connected armature,

$$P = 3\ I,v = \frac{3\ I,E}{\sqrt{3}} = I'\ E\ 1.732 \text{ (either with Y or } \Delta \text{ armature).}$$

For Δ

$$P = 3\,r_{,}\,i = 3\,v_{,}\,\frac{I_{,}}{\sqrt{3}}$$

$$v_{,} = E$$

$$\therefore\ P = \frac{3\,E\,I_{,}}{\sqrt{3}} = 1.732\ E\ I,$$ which shows statement in brackets to be true.

$$I_{,} = \frac{W}{E \times 1.732}$$

$I_{,} = 1.732\ i$ in delta system.

I^2R loss in Y connected armature $= 3\ I_{,}^2R$.

I^2R loss in Δ connected armature $= 3\left(\frac{I_{,}}{\sqrt{3}}\right)^2 r = I_{,}^2 r$.

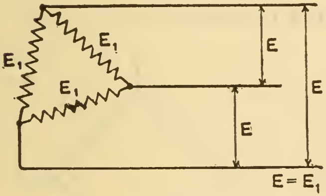


FIG. 6.

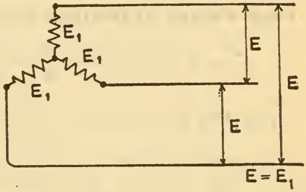
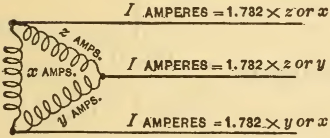
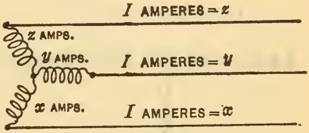


FIG. 7.

$$E = \sqrt{3}\,E_{,} = 1.732\,E_{,}.$$



Delta Connection.



Star or Y Connection.

FIGS. 8 and 9. Values of current in three-phase connections, where $x = y = z$.

Copper Loss in the Armatures of Alternators.

A. Ruckgaber.

In the armature of any alternating-current dynamo or motor of either single or polyphase the copper loss is always equivalent to $\frac{I^2R}{2}$, in which $I =$ total amperes and $R =$ the measure of resistance between leads of a phase, usually taken as an average of the measurements of the armature resistance of each phase.

Let $R =$ Resistance as measured (average).
$r =$ Resistance per phase.
$I =$ Total amperes $=$ watts $\div$ volts.
$I_1 =$ Amperes per lead.
$i =$ Amperes per phase, in winding.

Single-Phase. — Here $I = I_1 = i$; and $R = r$

$$I_1^2R \text{ loss} = I^2R.$$

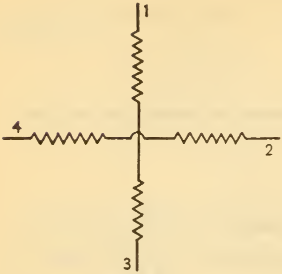


FIG. 10.

Two-Phase Independent Windings (Fig. 10).

R is measured from 1 to 3 and 2 to 4.

$$I = \frac{P}{E} = \frac{\text{watts}}{\text{volts}}.$$

$I_1 = \frac{I}{2}$. Then I^2R loss $= 2_1 I^2 R$

$$= \frac{2\,I^2R}{4} - \frac{I^2R}{2}.$$

Two-Phase Windings Connected in Series (Fig. 11).

$$\frac{P}{E} = I \quad I_1 = \frac{I}{2} \quad i = \frac{I_1}{\sqrt{2}} = \frac{I}{2\sqrt{2}}.$$

The I_1^2R loss $= 4\,i^2r = \frac{4\,I^2r}{8} = \frac{I^2r}{2}$.

R is measured from 1 to 3 and 2 to 4, the average of these two being taken for the value of R.

Then $$R = \frac{(r+r)\,(r+r)}{4\,r} = r.$$

$\therefore$ The I_1^2R loss $= \frac{I^2R}{2}$.

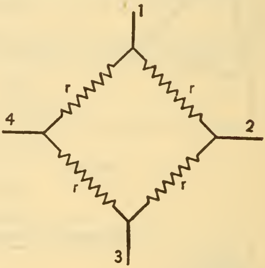


FIG. 11.

Three-Phase Star Connection (Fig. 12).

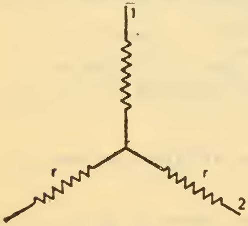


FIG. 12.

$$\frac{P}{E} = I \quad I_1 = i = \frac{I}{\sqrt{3}}.$$

Then the I_1^2R loss $= 3\,i^2r = 3\,I_1^2r = I^2r$.

R is measured from 1 to 2, 2 to 3, and 3 to 1, the average of the three being the value used for R.

Then R as measured $= 2\,r$.

$\therefore$ The I_1^2R loss $= \frac{I^2R}{2}$.

Three-Phase Delta Connection (Fig. 13).

$$\frac{P}{E} = I \quad I_1 = \frac{I}{\sqrt{3}} \quad i\,\frac{I}{\sqrt{3}} = \frac{I}{3}.$$

Then I_1^2R loss $= 3\,i^2r = \frac{I^2r}{3}$.

R is measured from 1 to 2, 2 to 3, and 3 to 1, the average of these being taken as the value of R.

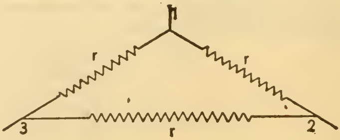


FIG. 13.

Then R as measured $= \frac{r\,(r+r)}{r+r+r} = \frac{2}{3}\,r$ and the $I_1^2\,R$ loss $= \frac{I^2R}{2}$.

Compensated Revolving Field Alternators.

The General Electric Company in October, 1899, placed on the market a new type of polyphase alternator, which is claimed to overcome many of the faults common to the old style of machine, especially when used on combined lighting and motor loads. While it has been found a comparatively easy matter to compound and over-compound for non-inductive loads, it has been heretofore quite difficult to add excitation enough to compound for inductive loads which require considerably more field current than do loads of a non-inductive nature.

The following description is taken from the bulletin issued by the makers describing the machine, which is of the revolving field type :—

"The means by which this result is accomplished are as follows: The shaft of the alternator which carries the revolving field carries also the armature of the exciter, which has the same number of poles as the alternator, so that the two operate in synchronous relation. In addition to the commutator, which delivers current to the fields of both the exciter and the alternator, the exciter has three collector rings through which it receives current from one or several series transformers inserted in the lines leading from the alternator. This alternating current, passing through the exciter armature, reacts magnetically upon the exciter field in proportion to the strength and phase relation of the alternating current. Consequently the magnetic field and hence the voltage of the exciter, are due to the combined effect of the shunt field current and the magnetic reaction of the alternating current. This alternating current passes through the exciter armature in such a manner as to give the necessary rise of exciter voltage as the non-inductive load increases, and without other adjustment, to give a greater rise of exciter voltage with additions of inductive load."

REGULATORS FOR ALTERNATING CURRENT GENERATORS.

General Electric Company.

This regulator automatically maintains the voltage of the generator at the desired value by varying the exciter voltage. This is done by rapidly opening and closing a shunt circuit across the exciter field rheostat. Fig. 14 shows the elementary connections of the regulator. The rheostat shunt circuit is opened and closed by a differentially wound relay. The current for operating this relay is taken from the exciter bus bars and is controlled by the floating main contacts. The current for operating the direct-current control magnet is also taken from the exciter bus bars. The relay and the direct-current control magnet constitute the direct-current portion of the regulator, and maintain not a constant but a steady exciter voltage. The alternating-current portion of the regulator consists of a magnet having a potential winding connected, by means of a potential transformer, to the bus bars or the circuit to be regulated. This magnet also has an adjustable compensating winding which is connected in series with the secondary of a current transformer usually inserted in the principal lighting circuit. The core of this magnet is attached to a pivoted lever carrying a counterweight which is balanced by the attraction of the magnet. If a load is thrown on the generator the voltage will tend to drop, the alternating-current magnet will weaken and destroy the balance of the core and lever and cause the main contacts to close; this in turn will close the relay contacts and entirely short-circuit the exciter field rheostat, thus increasing the exciter voltage until the original balance of the alternating-current magnet core and lever is restored and the alternating-current voltage maintained at the required value.

In some cases the exciter voltage will vary from 70 to 125 volts from no load to full load. This is especially true if the load is partly inductive and the regulator is adjusted to compensate for the line loss. In order to get the full range of regulation within the scope of the regulator in such cases, the alternating field rheostat should be turned entirely out and the exciter field rheostat adjusted to lower the alternating-current voltage about 65 per cent below normal. When the regulator is switched in, it will close the rheostat shunt circuit and instantly build the voltage up to normal, and maintain normal voltage by rapidly opening and closing the rheostat shunt circuit.

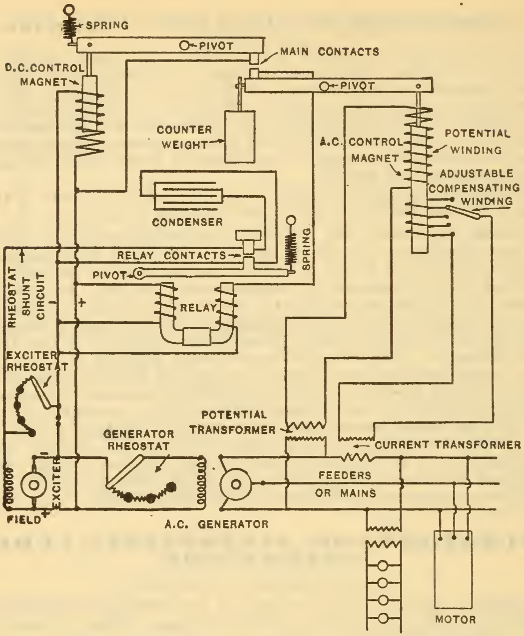


FIG. 14. Diagram of Tirrell regulator and connections for a single generator and exciter.

Alternating-Current Armatures.

Almost any continuous current armature winding may in a general way be used for alternating currents, but they are not well suited for such work, and special windings better adapted for the purpose are designed.

Alternating current armature windings are *open-circuit* windings, excepting in the rotary converter, where the rings are tapped directly on to the direct current armature windings.

Early forms of armature windings of this type, as first used in the United States, had *pan-cake* or flat coils bound on the periphery of the core. In the next type the coils were made in a bunched form, and secured in large slots across the face of the core. Both these types were used for single-phase machines. After the introduction of the multiphase dynamo, armature windings began to be distributed in subdivided coils laid in slots of the core; and this is the preferred method of to-day, especially so in the case of revolving field machines.

The single coil per pole type of winding gives the larger E.M.F., as the coils are thus best distributed for influence by the magnetic field. This type also produces the highest self-induction with its attendant disadvantages.

The *pan-cake* and *distributed-coil* windings are much freer from self-induction, but do not generate as high E.M.F. as does the single-coil windings.

In well-considered multiphase windings the E.M.F. is but little less for distributed coils than for single coils, and has other advantages, especially where the use of step-up transformers permits the use of low voltages, and consequently light insulation for the coils. The distributed-coil winding offers better chance for getting rid of heat from the armature core, and the conductor can in such case be made of less cross-section than would be required for the single-coil windings.

The greater number of coils into which a winding is divided, the less will be the terminal voltage at *no load.* Parshall & Hobart give the following ratio for terminal voltage under *no-load* conditions:

Single-coil winding = 1. for the same total number of conductors, the spacing of conductors being uniform over the whole circumference.
Two-coil winding = .707.
Three-coil winding = .667.
Four-coil winding = .654.

When the armature is loaded, the current in it reacts to change the terminal E.M.F., and this may be maintained constant by manipulation of the exciting current. With a given number of armature conductors this reaction is greatest with the single coil per pole winding, and the ratios just given are not correct for full-load conditions.

Single-phase Windings.—The following diagram shows one of the simplest forms of single-phase winding, and is a *single coil per pole* winding.

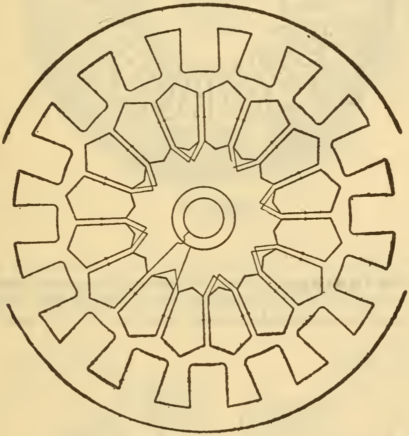


Fig. 15.

Another similar winding, but with bars in place of coils, is shown in the following figure. It can be used for machines of large output.

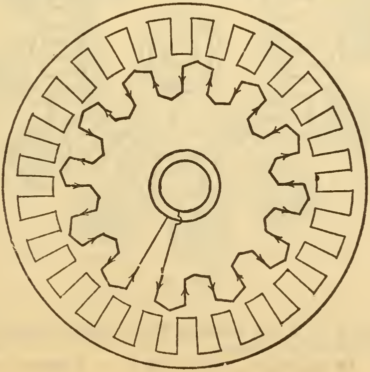


Fig. 16.

The following figure shows a good type of three bars per pole winding, which is simple in construction.

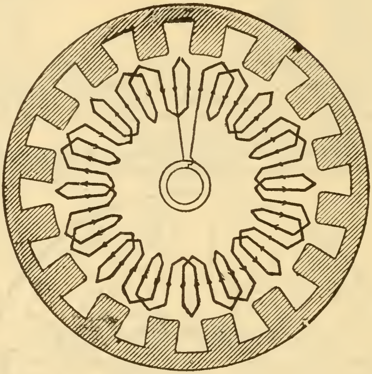


FIG. 17.

Two-phase Windings.—The following diagram shows a good type of winding for *quarter-phase* machines. It utilizes the winding space to good advantage, and is applicable to any number of coils per pole per phase.

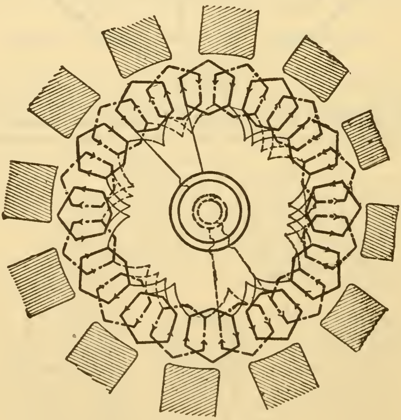


FIG. 18.

Fig. 19 is a diagram of a bar winding for a quarter-phase machine, with four conductors per pole per phase.

Three-phase Windings.—Fig. 20 is a diagram of a three-phase winding connected in Y, in which one end of each of the three windings is connected to a common terminal, the other ends being connected to three collector rings.

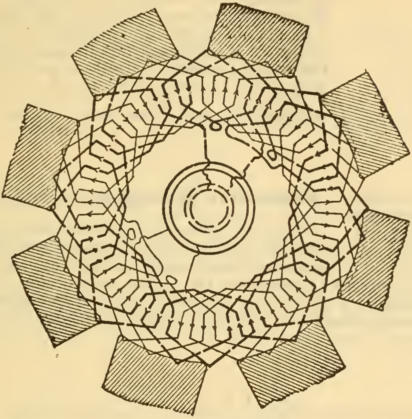


FIG. 19.

Fig. 21 is a sample of a three-phase delta winding, in which all the conductors on the armature are connected in series, a lead being taken off to a collector ring at every third of the total length.

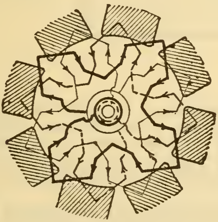


FIG. 20.

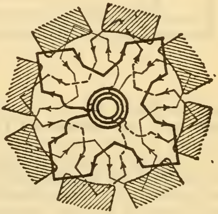


FIG. 21.

In the Y windings the proper ends to connect to the common terminal and to the rings may be selected as follows: Assume that the conductor in the middle of the pole-piece is carrying the maximum current, and mark its direction by an arrow; then the current in the conductors on either side of and adjacent to it will be in the same direction. As the maximum current must be *coming from* the common terminal, the end toward which the arrow points must be connected to one of the rings, while the other end is connected to the common terminal. It is quite as evident that the currents in the two adjacent conductors must be *flowing into* the common terminal, and therefore the ends toward which the arrows point must be connected to the common terminal, while their other ends are connected to the remaining two rings.

In a delta winding, starting with the conductors of one phase in the middle of pole-piece, assume the maximum current to be induced at the moment in this conductor; then but one-half the same value of current will be included at the same moment in the other two phases, and its path and value will best be shown in the following diagram, in which x may be taken as the middle collector-ring, and the maximum current to be flowing from x toward z. It will be seen that no current is coming in over the line y, but part of the current at z will have been induced in branches b and c.

Most three-phase windings can be connected either in Y or delta; but it must be borne in mind that with the same windings the delta-connection will stand 1.732 times as much current as the Y-connection, but gives only $\frac{1}{1.732}$ as much voltage.

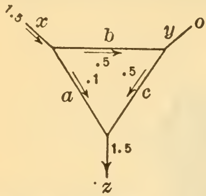


FIG. 22. Path and Value of Current in Delta-connected Armature.

Armature Reaction of an Alternator.

Since the armature core is a part of the magnetic circuit, and since the armature winding surrounds this core and also carries current, it must be expected that this current influences the total magnetism of the machine and hence its voltage. This effect, combined with the natural inductance of the winding, itself constitutes what is called armature reaction. Fig. 23

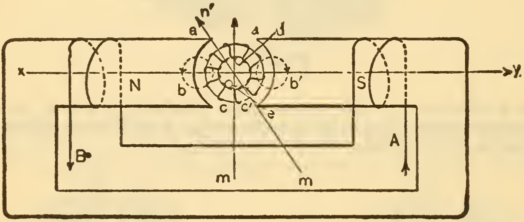


FIG. 23.

shows an alternator in its elements. The armature winding is tapped in two places and connected to the collector rings d and e, from which the current flows to the external circuit. This current passing through the winding on the armature creates a magneto-motive force, which tends to produce the flow of magnetism as shown by the dotted lines $a-b-c$; $a'-b'-c'$, or in a general direction, $m-n$.

The field current proper entering at A and coming out at B tends to product magnetism in the direction $x-y$, at right angles to $m-n$. Under such conditions, therefore, the ampere-turns of the armature are acting at right angles to the ampere-turns of the field. This is the condition under non-inductive load, the maximum current of the armature occurring in time and space simultaneously with the maximum E.M.F.

If the maximum of the current of the armature occurs later than the maximum of the E.M.F., or in other words, if the current lags behind the E.M.F., the ampere-turns of the armature are no longer acting in a direction $m-n$ when the current is a maximum, but in a direction $m'-n'$, partially opposing the main flux $x-y$. If the lag of current becomes 90° the armature reaction would turn still more around, becoming, in fact, just opposite to $x-y$.

Thus, on non-inductive load, the armature ampere-turns combine with the field ampere-turns at right angles, and with increasing lag show a higher and higher resultant until at 90° lag the two combine by direct addition. Just similar to all this is the self-induction component of the armature inductance. As has been pointed out, self-induction lags in its opposing effects behind the current, thus on non-inductive load, the opposing effect of self-induction is shown by Fig. 24.

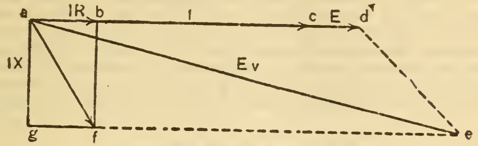


FIG. 24.

Let $a-c=I=$ the current,
$a-d=E=$ the E.M.F. generated by the revolutions of the armature,
$a-b=$ the resistance drop $=IR$ in phase always with the current,
$a-g=IX=$ the inductive drop 90° away from the current.

The resultant of these $=a-e=E_0=$ the total E.M.F. necessary to produce to give the value E under the conditions.

If the current lags these values are as shown in Fig. 25, the current lag-

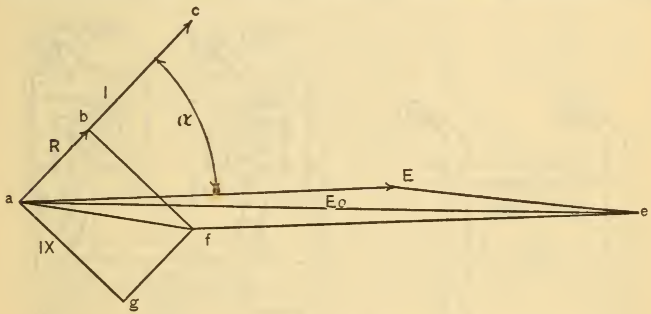


FIG. 25.

ging behind and E.M.F. by the angle θ. At 90° lag the E.M.F. of self-induction is just in line with E, hence is added directly to give the total E.M.F. E_0 necessary to generate to product E.

Thus a similarity exists between the armature reactive effect shown in Fig. 23 and the armature self-inductive effect shown in Figs. 24 and 25. On this account it has been suggested by Mr. C. P. Steinmetz that the two values be combined into one and the combined value be given the term "synchronous impedance." This value is obtained in an actual alternator by short-circuiting the armature upon itself and reading the ampere-turns in the field coils necessary to give full armature current, which is then expressed in terms of ampere-turns. Since on short-circuit the armature ampere-turns are exactly opposing the field ampere-turns, this reading gives a direct measure of the armature opposing forces, but conveniently converted into ampere-turns. To calculate from this value the amount of ampere-turns necessary in a given alternator to give a certain voltage, proceed as follows:

Let A equal the ampere-turns necessary to produce the terminal voltage E of the alternator when running on open circuit: let B equal the synchronous impedance ampere-turns obtained as above. Then the total ampere-turns required to produce the voltage E on non-inductive load $=\sqrt{A^2+B^2}$ If the current is not non-inductive the two values must be combined with proper phase relation, as shown in Figs. 24 and 25. The method has been extensively used and for ordinary designs seems a very useful one to follow. A designer can calculate this value to a very close approximation, thus predetermining the regulation. It can be seen from this that a single-phase alternator gives a pulsating armature reaction. A polyphase armature gives a constant armature reaction since it can be shown that at any instant the magnetic resultant of the current is the same.

For this reason, among others, a polyphase alternator is more efficient than a single-phase machine since the pulsating armature reaction sets up eddy currents from its variable nature, which increases the losses.

SYNCHRONIZERS.

There are numerous methods of determining when alternators are in step, some acoustic, but mostly using incandescent lamps as an indicator.

In the United States it is most common to so connect up the synchronizer that the lamp stays dark at synchronism; in England it is more usual to have the lamp at full brilliancy at synchromism, and on some accounts the latter is, in the writer's opinion, the better of the two, as, if darkness indicates synchronism, the lamp breaking its filament might cause the machines to be thrown together when clear out of step; on the other hand, it is sometimes difficult to determine the full brilliancy.

The two following cuts show theory and practice in connecting synchronizers.

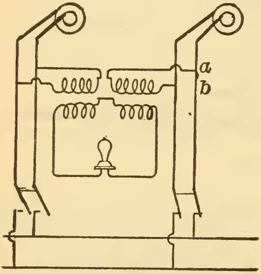


FIG. 26. Synchronizer Connections.

When connected as shown, the lamp will show full c. p. at synchronism. If a and b are reversed, darkness of lamp will show synchronism.

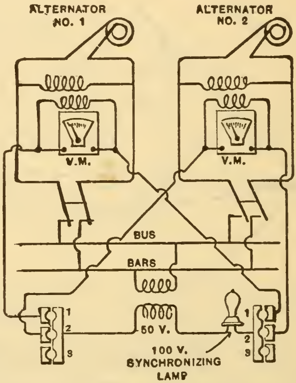


FIG. 27. Synchronizer Connections.

Lamp lights to full c.p. when dynamos are in synchronism.

Two transformers having their primaries connected, one to the loaded and the other to the idle dynamo, have their secondaries connected in series through a lamp; if in straight series the lamp is dark at synchronism; if the secondaries are cross-connected the lamp lights in full brilliance at synchronism.

The Lincoln Synchronizer is so made as to move a hand around a dial so that the angle between the hand and the vertical is always the phase angle between the two sources of electro-motive force to which the synchronizer is connected. If the incoming alternator is running too fast the hand deflects in one direction, and if too slow, in the opposite direction. Coincidence in phase occurs when the moving hand stands vertically. A complete revolution of the hand indicates a gain or loss of one cycle in the frequency of the incoming alternator as compared with bus-bars.

Suppose a stationary coil *F*, Fig. 28, has suspended within it a coil *A*, free to move about an axis in the planes of both coils and including a diameter of each. If an alternating current be passed through both coils, *A* will take up a position with its plane parallel to *F*. If now the currents in *A* and *F* be reversed with respect to each other, coil *A* will take up a position 180° from its former position. Reversal of the relative directions of currents in *A* and *F* is equivalent to changing their phase relations by 180°, and therefore this change of 180° in phase relations is followed by a corresponding change of 180° in their mechanical relations. Suppose now, that instead of reversing the relative direction of currents in *A* and *F*, the change in phase relations between them be made gradually and without disturbing the current strength in either coil. It is evident that when the phase difference between *A* and *F* reaches 90° the force between *A* and *F* will become reduced to zero, and a movable system, of which *A* may be made a part, is in condition to take up any position demanded by any other force. Let a second member of this movable system consist of coil *B*, which may be fastened rigidly to coil *A*, with its plane 90° from that of coil *A*, and the axis of *A* passing through a diameter of *B*. Further, suppose a current to circulate through *B*, whose difference in phase relative to that in *A*, is always 90°. It is evident under these conditions that when the difference in phase between *A* and *F* is 90°, the movable system will take up a position such that *B* is parallel to *F*, because the force between *A* and *F* is zero, and the force between *B* and *F* is a maximum; similarly when the difference in phase between *B* and *F* is 90°, *A* will be parallel to *F*. That is, beginning with a phase difference between *A* and *F* of 0, a phase change of 90° will be followed by a mechanical change on the movable system of 90°, and each successive change of 90° in phase will be followed by a corresponding mechanical change of 90°. For intermediate phase relations it can be proved that under certain conditions the position of equilibrium assumed by the movable element will exactly represent the phase relations. That is, with proper design, the mechanical angle between the plane of *F* and that of *A* and also between the plane of *F* and that of *B* is always equal to the phase angle between the current flowing in *F* and those in *A* and *B* respectively.

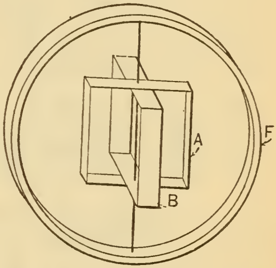


Fig. 28. Lincoln Synchronizer.

As commercially constructed coil *F* consists of a small laminated iron field-magnet with a winding whose terminals are connected with binding posts. The coils *A* and *B* are windings practically 90° apart on a laminated iron armature pivoted between the poles of the magnet. These two windings are joined, and a tap from the junction is brought out through a slip-ring to one of two other binding posts. The two remaining ends are brought out through two more slip-rings, one of which is connected to the remaining binding post, through a non-inductive resistance, and the other to the same binding post through an inductive resistance. A light aluminum hand attached to the armature shaft marks the position assumed by the armature.

INDUCTOR TYPE SYNCHROSCOPE.

From *The Electric Journal*.

This type is especially applicable where voltage transformers are already installed for use with other meters. As it requires only about ten apparent watts it may be used on the same transformers with other meters. There are three stationary coils, *N*, *M* and *C*, Fig. 29, and a moving system comprising an iron armature, *A*, rigidly attached to a shaft, *S*, suitably pivoted and mounted in bearings. A pointer, *B*, is also attached to the shaft *S*. The moving system is balanced and is not subjected to any restraining force, such as a spring or gravity control. The axes of the coils *N* and *M* are in the same vertical plane, but 90 degrees apart, while the axis of *C* is in a horizontal plane. The coils *N* and *M* are connected in "split phase" relation through an inductive resistance *P* and non-inductive resistance *Q*, and these two circuits are paralleled across the bus-bar terminals 3 and 4 of the synchroscope. Coil *C* is connected through a non-inductive resistance across the upper or machine terminals 1 and 2 of the synchroscope.

In operation, current in the coil *C* magnetizes the iron core carried by the shaft and the two projections, marked *A* and "Iron Armature" in Fig. 29. There is, however, no tendency to rotate the shaft. If current be passed through one of the other coils, say *M*, a magnetic field will be produced parallel with its axis. This will act on the projections of the iron armature, causing it to turn so that the positive and negative projections assume their appropriate position in the field of the coil *M*. A reversal of

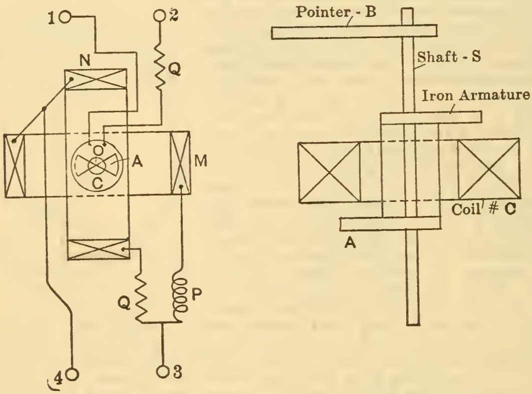


FIG. 29.

the direction of the current in both coils will obviously not affect the position of the armature; hence alternating current of the same frequency and phase in the coils *C* and *M* cause the same directional effect upon the armature as if direct current were passed through the coils. If current lagging 90 degrees behind that in the coils *M* and *C* be passed through the coil *N*, it will cause no rotative effect upon the armature because the maximum value of the field which it produces will occur at the instant when the pole strength of the armature is zero. The two currents in the coils *M* and *N* produce a shifting magnetic field which rotates about the shaft as an axis. As all currents are assumed to be of the same frequency, the rate of rotation of this field is such that its direction corresponds with that of the armature projections at the instants when the poles induced in them by the current in the coil *C* are at maximum value and the field shifts through 180 degrees in the same interval as is required for reversal of the poles. This is the essential feature of the instrument, namely, that the armature projections take a position in the rotating magnetic field which corresponds to the direction of the field at the instant when the projections are magnetized to their maximum strength by current in the coil *C*. If the frequency of the currents in the coils which produce the shifting field is less than that in the coil which magnetizes the armature, then the armature must turn in order that it may be parallel with the field when its poles are at maximum strength, consequently rotation of its armature indicates a difference in frequency, and the direction and rate of rotation show, respectively, which current has the higher frequency and the amount of the difference.

Note on the Parallel Running of Alternators.—There is little if any trouble in running alternators that are driven by water-wheels, owing to the uniform motion of rotation. With steam-engine driven machines it is somewhat different, owing to more or less pulsation during a stroke of the engines, caused by periodic variations in the cut-off, which cause oscillations in the relative motion of the two or more machines, accompanied by periodic cross currents. Experiments have proved that a sluggish governor for engines driving alternators in parallel is more desirable than one that acts too quickly; and it is sometimes an advantage to apply a dashpot to a quick-acting governor, one that will allow of adjustment while running. It is quite desirable also that the governors of engines designed to drive alternators in parallel shall be so planned as to allow of adjustment of speed while the engine is running, so that engines as well as dynamos may be synchronized, and load may be transferred from one machine to the others in shutting down. Foreign builders apply a bell contact to the same part of all engines that are to be used in this way, and throw machines together when the bells ring at the same time. These bells would also serve to determine any variation, if not too small, in the speed of the machines, and assist in close adjustment.

Manufacturers do not entirely agree as to the exact allowance permissible for variation in angular speed of engines, some preferring to design their dynamos for large synchronizing power, and relatively wide variation in angular speed, while others call for very close regulation in angular variation of engine speed, and construct their dynamos with relatively little synchronizing power.

Dynamos of low armature reaction have large synchronizing power, but if accidentally thrown out of step are liable to heavy cross-currents. On the contrary, machines with high armature reaction have relatively little synchronizing power, and are less liable to trouble if accidentally thrown out of step.

The smaller the number of poles the greater may be the angular variation between two machines without causing trouble, thus low frequencies are more favorable to parallel operation than high; and this is especially so where the dynamos are used to deliver current to synchronous motors or rotary converters.

Specifications for engines should read in such a manner as to require not more than a certain stated angular variation of speed during any stroke of the machine, and this variation is usually stated in degrees departure from a mean speed.

The General Electric Company states it as follows:—

"We have . . . fixed upon two and one-half degrees of phase departure from a mean as the limit allowable in ordinary cases. It will, in certain cases, be possible to operate satisfactorily in parallel, or to run synchronous apparatus from machines whose angular variation exceeds this amount, and in other cases it will be easy and desirable to obtain a better speed control. The two and one-half degree limit is intended to imply that the maximum departure from the mean position during any revolution shall not exceed $\frac{2\frac{1}{2}}{360}$ of an angle corresponding to two poles of a machine. The angle of circumference which corresponds to the two and one-half degrees of phase variation can be ascertained by dividing two and one-half by one-half the number of poles; thus, in a twenty-pole machine, the allowable angular variation from the mean would be $\frac{2\frac{1}{2}}{10} = .25$ of one degree."

Some foreign builders of engines state the conditions as follows: Calling N the number of revolutions per minute, the weight of all the rotary parts of the engine should be such that under normal load the variation in speed during one revolution $\frac{N\,max. - N\,min.}{N\,average}$ will not exceed $\frac{1}{250}$. Some state $\frac{1}{200}$.

Oudin says: "The regulation of an engine can be expressed as a percentage of variation from that of an absolutely uniform rotative speed. A close solution of the general problem shows that $1\frac{1}{4}°$ of phase displacement corresponds to a speed variation, or "pulsation," with an alternator of two n poles, as follows:—

In the case of a single cylinder or tandem compound engine $\frac{2.75\%}{n}$

A cross compound . . . . $\frac{5.5\%}{n}$

A working out of the problem also shows . . . that no better results are obtained from a three-crank engine than a two-crank.

The Westinghouse Company designs its machines with larger synchronizing effect by special construction between poles, and allows somewhat larger angular variation, stating it as follows: The variation of the fly-wheel through the revolution at any load not exceeding 25% overload, shall not exceed one-sixtieth of the pitch angle between two consecutive poles from the position it would have if the motion were absolutely uniform at the same mean velocity. The maximum allowable variation, which is the amount which the armature forges ahead plus the amount which it lags behind the position of absolute uniform motion is therefore one-thirtieth of the pitch angle between two poles.

The number of degrees of the circumference equal to one-thirtieth of the pitch angle is the quotient of 12 divided by the number of poles.

The cross currents of alternators can be shown by reference to Fig. 30,

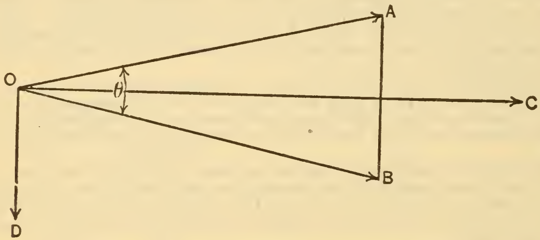


FIG. 30.

which represents the E.M.F. vectors of two alternators which have swung apart in phase due to any cause, such as variation in speed of their prime movers or fluctuations of speed during a revolution.

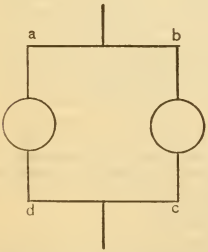


FIG. 31. Two Alternators Connected in Multiple.

Let $O—A$ = E.M.F. vector of alternator A.
$O—B$ = E.M.F. vector of alternator B.

As drawn, the vectors are displaced in phase by the angle θ. When these alternators are connected in multiple there will be acting between them the E.M.F. $A - B$, or drawn to the center point O, the E.M.F. $O - D$. This E.M.F. acts through the two armatures in series, the circuit being $a - b - c - d$, (Fig. 31); the current resulting is equal to the volts $O - D$ divided by the impedance of the two armatures in series, which is equal to

$$\sqrt{(R_a + R_b)^2 + (2\pi f L_a + 2\pi f L_b)^2}$$

where R_a and R_b = the resistance of the two alternator armatures respectively and L_a and L_b their inductances.

Since in such a circuit the proportion of inductance is greater than the resistance, the current flowing from the E.M.F. $O - D$ is *lagging* a large amount as shown by the line $O - C$. Hence the E.M.F.'s $O - A$ and $O - B$

of the alternators proper are in phase approximately with this cross current and hence under such conditions as the figure indicates there will be an exchange of energy (since E.M.F. and current are in phase) which is what actually happens, thus tending to bring the two alternators together in phase.

Fig. 32 shows the vectors of two alternators *A* and *B* in phase but the

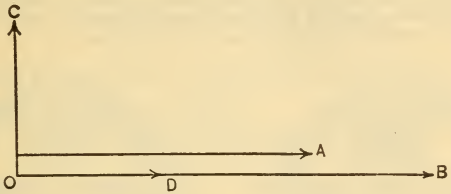


FIG. 32.

E.M.F. *O — A* smaller than the other, *O — B*, due, for instance, to the field of one being weaker than that of the other. In this case there is a difference of *O — D* volts to act through the armatures of the two alternators in series, as in Fig. 31. As shown in Fig. 32 the current from this E.M.F. *O — D* lags 90° and is indicated by the vector *O — C*. This current is, however, 90° away from the E.M.F.'s *O — A* and *O — B* of the machine proper and hence does not represent an exchange of energy ; therefore, it has no tendency to bring the machines together or increasing the dephasing.

Synchronizing.

It is plain from the foregoing that to connect an idle alternator in parallel with one or more already in use :

Excite the fields of the idle machine until at full speed the indicator shows bus-bar pressure, or the pressure that may have been determined on as the best for connecting the particular design of alternator in circuit.

Connect in the synchronizer to show when the machines are in step, at which point the idle machine may be connected to the bus bars. The load will now be unequally divided, and must be equalized by increasing the driving-power of the idle dynamo until it takes on its proper part of the load.

Very little control over the load can be had from the field rheostats.

To disconnect an alternator from the bus-bars : Decrease its driving power slowly until the other machines have taken all the load from it, when its main switch may be opened and the dynamo stopped and laid off.

ALTERNATING-CURRENT MOTORS.

The single-phase alternating-current motor has been quite well developed during the last few years, but it has as yet come into rather limited use. The polyphase motor has come into very general use, its relative simplicity being a strong feature.

Only the most elementary formulæ will be given here, and the reader is referred to the numerous books treating on the subject; among others, S. P. Thompson, Steinmetz, Jackson, Kapp and Oudin.

Following is a statement of the theory of the polyphase motor, condensed from a pamphlet of the Westinghouse Electric and Manufacturing Company.

Elementary Theory of the Polyphase Induction Motor.

If a horse-shoe magnet be held over a compass the needle will take a position parallel to the lines of force which flow from one pole to the other. It is perfectly obvious that if the magnet be rotated the needle will follow.

If a four-pole electromagnet be substituted for the horse-shoe, and current be made to flow about either one of the sets of poles separately, the needle will take its position parallel with the lines of force that may be flowing, as will be seen by the following figures.

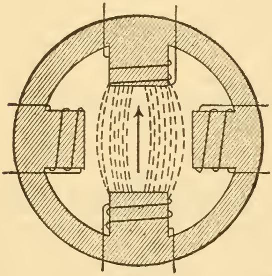


FIG. 33.

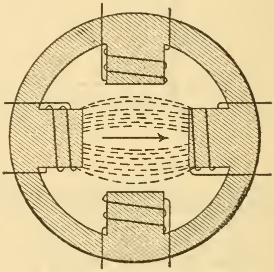


FIG. 34

If the two sets of poles are excited at the same time by currents of equal strength, then the needle will take its position diagonally, half way between the two sets of poles, as will be seen by the following diagram.

It is now easily conceivable that if one of these currents is growing stronger while the other is at the same time becoming weaker, the needle will be attracted toward the former until it reaches its maximum value, when if the currents are alternating, the strong current having reached its maximum begins to weaken, and the other current having not only reversed its direction but begun to grow strong, attracts the needle away from the first current and in the same direction of rotation. If this process be continually repeated, the needle will continue to revolve, and its direction of rotation will be determined by the phase relation of the two currents, and the direction of rotation can be reversed by reversing the leads of one phase.

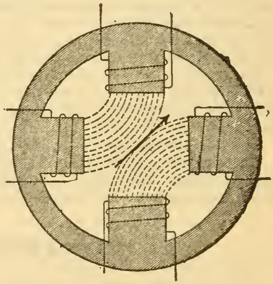


FIG. 35.

If the compass needle be replaced by an iron core wound with copper conductors, secondary currents will be induced in these windings, which will react on the field windings, and rotation will be produced in the core just as it was in the compass needle. Two cranks at right angles on an engine shaft are analogous with the quarter-phase motor, and three to the three-phase motor, which depends on the same principle for its working.

Theory of the Polyphase Induction Motor.

Condensed from C. P. Steinmetz.

The following names and symbols are used for designating the parts and properties of the induction motor : —

Stator = stationary part, nearly always corresponding to the field.
Rotor = rotating part, corresponding to the armature of the direct-current motor.

Analytical Theory of Polyphase Induction Motor.

Let r = resistance per circuit of *primary*,
r_1 = resistance per circuit of *secondary*,

being reduced to primary system by square of the ratio of turns.

Let p = number of poles,
x = reactance of *primary*, per circuit,
x_1 = reactance of *secondary*, per circuit,

reduced to primary system by square of the ratio of turns.

Let s = per cent of slip,
I = current per circuit of *primary*,
E = applied E.M.F. per circuit,
Z = impedance of whole motor per circuit,
T = torque between the *stator* and *rotor*,
f = frequency of applied E.M.F.

Let the primary and secondary consist of m circuits on an m phase system.

n = primary turns per circuit,
n_1 = secondary turns per circuit.

Let $a = \frac{n}{n_1}$ ratio of transformation.

Then

$$I \text{ (neglecting ex. current)} = \frac{sE}{\sqrt{(r_1 + s r)^2 + s^2 (x + x_1)^2}},$$

$$\text{Torque } T = \frac{m p r_1 E^2 s}{4 \pi f \, [(r_1 + s r)^2 + s^2 (x_1 + x)^2]},$$

$$\text{Power} = \frac{m r_1 E^2 s (1 - s)}{(r_1 + s r)^2 + s^2 (x_1 + x)^2},$$

$$\text{Max. torque} = \frac{m p E^2}{8 \pi f \, [r + \sqrt{r^2 + (x_1 + x)^2}]},$$

$$\text{Max. power} = \frac{m E^2}{2 [r + r_1 + Z]} \text{ at the slip } s = \frac{r_1}{r_1 + Z},$$

$$\text{Starting current} = i = \frac{E}{Z},$$

$$\text{Starting torque} = \frac{m p E^2}{4 \pi f} \times \frac{r_1}{Z^2}.$$

Note that the maximum torque is independent of *secondary resistance* r_1 and thus the speed at maximum torque depends on the *secondary resistance*. Current at maximum torque is also independent of *secondary resistance*.

The maximum torque occurs at a lower speed than the maximum output. A resistance can be chosen that when inserted in the secondary, the maximum torque will be obtained at starting; that is, the speed at which maximum torque occurs can be regulated by the resistance in the rotor.

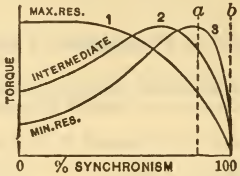


FIG. 36. Torque curves for Polyphase Induction Motor.

Curves 1, 2, and 3 show the effect of successive increases of rotor resistance, rotor run on part of curve *a—b*; for here a decrease of speed due to load increases the torque.

Speed of Induction Motor.—The speed or rotating velocity of the magnetic field of an induction motor depends upon the frequency (cycles per second) of the alternating current in the field, and the number of poles in the field frame, and may be expressed as follows:—

r.p.m. = revolutions per minute of the magnetic field,
p = number of poles,
f = frequency; then

$$\text{r.p.m.} = 120 \frac{f}{p}$$

The actual revolutions of the *rotor* will be less than shown by the formula, owing to the *slip* which is expressed in a percentage of the actual revolutions; therefore the actual revolutions at any portion of the load on a motor will be

r.p.m. × *slip* due to the part of the load actually in use.

actual speed = r.p.m. (1 — % of slip.)

The following table by Wiener, in the *American Electrician*, shows the speeds due to different numbers of poles at various frequencies.

Speed of Rotary Field for Different Numbers of Poles and for Various Frequencies.

Number of Poles.	Speed of Revolving Magnetism, in Revolutions per Minute, when Frequency is:											
	25	30	33⅓	40	50	60	66⅔	80	100	120	125	133⅓
2	1500	1870	2000	2400	3000	3600	4000	4800	6000	7200	7500	8000
4	750	900	1000	1200	1500	1800	2000	2400	3000	3600	3750	4000
6	500	600	667	800	1000	1200	1333	1600	2000	2400	2500	2667
8	375	450	500	600	750	900	1000	1200	1500	1800	1875	2000
10	300	360	400	480	600	720	800	960	1200	1440	1500	1600
12	250	300	333	400	500	600	667	800	1000	1200	1250	1333
14	214	257	286	343	428	514	571	686	857	1029	1071	1143
16	188	225	250	300	375	450	500	600	750	900	938	1000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667

Slip.—The slip, or difference in rate of rotation between rotating field and *rotor*, is due to the resistance opposed to rotor current.

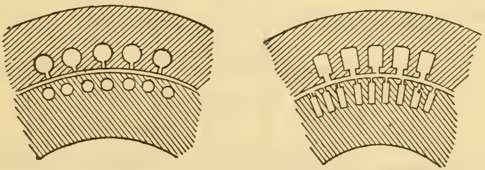
Slip varies from 1 per cent in a motor designed for very close regulation to 40 per cent in one badly designed, or designed for some special purpose. Weiner gives the following table as embodying the usual variations:

Slip of Induction Motors.

Capacity of Motor, H.P.	Slip, at full load, per cent.	
	Usual limits.	Average.
1/8	20 to 40	30
1/4	10 " 30	20
1/2	10 " 20	15
1	8 " 20	14
2	8 " 18	13
3	8 " 16	12
5	7 " 15	11
7½	6 " 14	10
10	6 " 12	9
15	5 " 11	8
20	4 " 10	7
30	3 " 9	6
50	2 " 8	5
75	1 " 7	4
100	1 " 6	3.5
150	1 " 5	3
200	1 " 4	2.5
300	1 " 3	2

Core of Stator and Rotor.—Both the field-frame core, or *Stator*, and the armature core, or *Rotor*, are built up of laminated iron punchings in much the same manner as are the armature cores of ordinary dynamos.

The windings in both cases are laid in slots across the face of either part, and for this reason both parts are punched in a series of slots or holes for the reception of the windings. The following cuts, taken from the "American Electrician," show the usual form of slots used.



FIGS. 37 and 38. Forms of Punchings of Induction Motors.

The number of slots in the *stator* must be a multiple of the number of poles and number of phases, and Weiner gives the following table, in the "American Electrician," as showing the proper number to be used in various cases, both for two- and three-phase machines. In practice the number of poles is determined by the speed required and the available frequency; then the number of slots is so designed as to be equally spaced about the whole inner periphery of the stator.

Number of Slots in Field-Frame of Induction Motors.

Capacity of Motor.	Number of Poles.	Slots per Pole.	Slots per Pole per Phase.	
			Two-Phase.	Three-Phase.
⅛ H.P. to 1 H.P.	4 to 8	3 4	1½ 2	1 —
½ H.P. to 1 H.P.	4 to 6	5 6	2½ 3	— 2
2 H.P. to 5 H.P.	4 to 10	5 6	2½ 3	— 2
	4 to 6	7 8 9	3½ 4 4½	— — 3
6 H.P. to 50 H.P.	6 to 12	7 8 9	3½ 4 4½	— — 3
	4 to 8	10 11 12	5 5½ 6	— — 4
50 H.P. to 200 H.P.	10 to 20	7 8 9	3½ 4 4½	— — 3
	8 to 12	10 11 12 13	5 5½ 6 6½	— — 4 —
	6 to 10	14 15 16	7 7½ 8	— 5 —

The number of slots per pole per phase in the *rotor* must be prime to that of the *stator* in order to avoid dead points in starting, and to insure smooth running, and commonly range from 7 to 9 times the number of poles, or any integer not divisible by the number of poles, in the squirrel cage or single conductor per slot windings. The proper number of slots may be taken from the following table by Wiener:

Number of Rotor Slots for Squirrel-Cage Induction Motors up to 5 H.P. Capacity.

Number of Poles, p.	Limits of Slots, Number 7 p. to 9 p.	Number of Rotor Slots.
4	28 to 36	29, 30, 31, 33, 34, 35, 37.
6	42 " 54	43, 44, 45, 46, 47, 49, 50, 51, 52, 53.
8	56 " 72	57, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71.

In large machines, where there is more than one conductor in each slot and in which the winding is connected in parallel, the number of slots in the *rotor* must be a multiple of both the number of phases and the number of pairs of poles.

The following table gives numbers of slots for various field-slots :

Number of Rotor-Slots for Induction Motors of Capacities over 5 H.P.

Number of Field-Slots per Pole.	Number of Rotor-Slots. (n_s = number of Field-Slots.)
8	$\frac{5}{4}n_s$. or $\frac{3}{2}n_s$.
9	$\frac{4}{3}n_s$.
10	$\frac{6}{5}n_s$. " $\frac{3}{2}n_s$.
12	$\frac{5}{4}n_s$. " $\frac{4}{3}n_s$.
14	$\frac{9}{7}n_s$. " $\frac{3}{2}n_s$.
15	$\frac{6}{5}n_s$. " $\frac{4}{3}n_s$.
16	$\frac{9}{8}n_s$. " $\frac{5}{4}n_s$.

Flux Density.—This must be settled for each particular case, as it will be governed much by the quality of iron and the particular design of the motor.

Hysteresis loss increases as the 1.6 power of the flux density ; and eddy current losses are proportional to the square of the density and also to the square of the frequency.

The following table shows practical values :

Flux-Densities for Induction Motors.

(Wiener.)

Capacity of Motor, H.P.	Flux-Density, in Lines of Force per Square Inch.					
	For Frequencies from 25 to 40.		For Frequencies from 60 to 100.		For Frequencies from 120 to 180.	
	Practical Values.	Average.	Practical Values.	Average.	Practical Values.	Aver-Age.
$\frac{1}{8}$	12000 to 18000	15000	10000 to 15000	12500	7000 to 11000	9000
$\frac{1}{4}$	15000 " 25000	20000	12000 " 18000	15000	7500 " 12500	10000
$\frac{1}{2}$	18000 " 32000	25000	15000 " 25000	20000	8000 " 17000	12500

Flux-Densities for Induction Motors — (*Continued*).

Capacity of Motor, H.P.	Flux-Density, in Lines of Force per Square Inch.					
	For Frequencies from 25 to 40.		For Frequencies from 60 to 100.		For Frequencies from 120 to 180.	
	Practical Values.	Average.	Practical Values.	Average.	Practical Values.	Average.
1	20000 to 40000	30000	18000 to 32000	25000	9000 to 21000	15000
2	25000 " 45000	35000	20000 " 40000	30000	10000 " 25000	17500
5	30000 " 50000	40000	25000 " 45000	35000	11000 " 29000	20000
10	40000 " 60000	50000	30000 " 50000	40000	12500 " 32500	22500
20	50000 " 70000	60000	35000 " 55000	45000	15000 " 35000	25000
50	60000 " 80000	70000	40000 " 60000	50000	17500 " 37500	27500
100	70000 " 90000	80000	45000 " 65000	55000	20000 " 40000	30000
150	80000 " 100000	90000	50000 " 70000	60000	25000 " 45000	35000
200†	90000 " 110000	100000	60000 " 80000	70000	30000 " 50000	40000

† And over.

In the earlier induction motors it was considered the most efficient method to connect the driving current to the revolving part or *rotor;* and as it is highly important that the number of windings on the *rotor* be *prime* to that of the *stator*, Fig. 39 shows a winding with an odd combination of conductors, being 51, or three times 17.

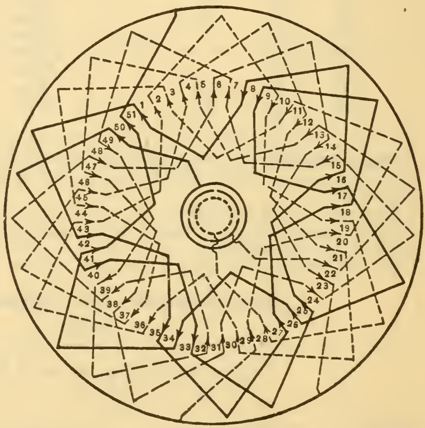


FIG. 39.

The *stator* windings would then be bars, connected at either end to a heavy copper ring, this forming a sort of "squirrel-cage."

In the modern machines the winding shown would be in coils on the stator, the three ends being carried to terminal blocks on the outside of the machine instead of to rings as shown, and the "squirrel-cage" would then be placed on the *rotor* and be made of bars as mentioned.

Starting and Regulating Devices. — Small induction motors, up to about 5 h. p. capacity, are started by closing the circuit directly to the motor. In large machines this would not be safe, as the *rotor* is standing, and would act in a lesser degree as the short-circuited secondary of a static transformer, and cause a heavy rush of current.

Resistance in Rotor. — This is a favorite method with the General Electric Company. A set of strongly constructed resistances is secured inside the rotor ring, and so arranged with a lever that they may be closed or short-circuited after the motor has reached its full speed. These resistances are in the armature circuits. In order to give maximum starting torque total armature resistance should be

$$r_{1} = \sqrt{r^2 + (x_{1} + y)^2}$$

Where r_1 = rotor resistance per circuit reduced to field system.
x_1 = rotor reactance per circuit reduced to field system.
r = resistance per field circuit.
γ = reactance per field circuit.

This method serves the double purpose of keeping down the starting current and increasing the starting torque.

Resistances in Stator.—Resistance boxes may be connected in the circuits supplying induction motors; three separate resistances in three-phase circuits, and two separate resistances in two-phase circuits. They must be all connected in such a manner as to be operated in unison. Under these conditions the pressure at the field terminals is reduced, as is of course the starting current and the starting torque. In order to start a heavy load, under this arrangement, a heavy starting-current is necessary.

Compensators or Auto-Transformers.—This method is greatly favored by the Westinghouse Electric Manufacturing Company, and is used extensively by the General Electric Company. It consists of connecting an impedance coil across the line terminals, the motor being fed, in starting, from some point on the winding where the pressure is considerably less than line pressure. This avoids heavy drafts of current from the line, thus not disturbing other appliances attached thereto, but as regards starting current and torque has the same effect as resistances directly in the line; that is, greatly reduces both.

Rotor Windings Commutated.—In this arrangement all or a part of the rotor windings are designed to be connected in series when starting, and are thrown in parallel after standard speed is attained. Another design has part of the conductors arranged in opposition to the remainder in starting, but all are thrown in parallel in regular order when running at standard speed. These commutated arrangements have not been much used in the United States.

The single-phase alternating-current motor brought out by the Wagner Electric Manufacturing Company of St. Louis, is, in mechanical construction, similar in many respects to the two and three-phase motors on the market. A field is built up of iron plates very much like *A* of Fig. 40, and an armature core is also built up from iron plates very much like *B*.

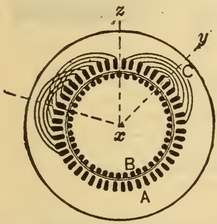


FIG. 40.

The field is wound with so-called pan-cake coils threading through the slots of the punchings, as shown at *C*, thus producing a magnetic pole of intensity, varying from a maximum along the radius $x - y$ to zero along the radius $x - z$. The armature core is wound with an ordinary direct-current progressive winding, connected up to a commutator in exactly the same fashion as is the direct-current motor winding.

The commutator of this armature is so designed that it may be completely short-circuited by introducing into it a short-circuiting circle of copper segments. When so short-circuited, the winding affords a substitute for the squirrel-cage form of winding, above described, differing from the squirrel cage, in that instead of currents being able to select paths for themselves, they are restricted to flowing in paths afforded by the individual coils. The operation of this motor, as stated, is based wholly upon the principle that an induction motor with a completely short-circuited armature will, when up to the running speed, operate on single-phase current supply in exactly the same manner as does a two or three-phase motor with two or three-phase current supply.

The armature winding is short-circuited through carbon brushes bearing upon the commutator surface, and the currents flowing in it are generated by induction from the field. These currents flow out through the carbon rushes either into an outside resistance box, or where a direct short circuit of the brushes is provided, out through one brush and back into the armature through the other. By the shifting of the brushes on the commutator surface, they are forced to take such position relative to the magnetic poles of the field, that repellant action between them and the poles of the fields is effected, and rotation results. When running speed is attained, the brushes are no longer required and the armature winding is completely short-circuited, as stated. The short-circuiting ring is made up of small copper links, which links, being in turn mounted upon a short-circuiting band, are thrown into the annular opening in the commutator and by making close contact with the individual segments, produce a very effective short-circuiting of the entire armature winding. In the operation of the motor, it is very advantageous to have this short-circuiting operation performed either at or slightly below the running speed, so these motors are built with an automatic device for performing this operation. This device consists of a set of governor weights acting against a spiral spring. The centrifugal action of the weight will, at the proper speed, force the short-

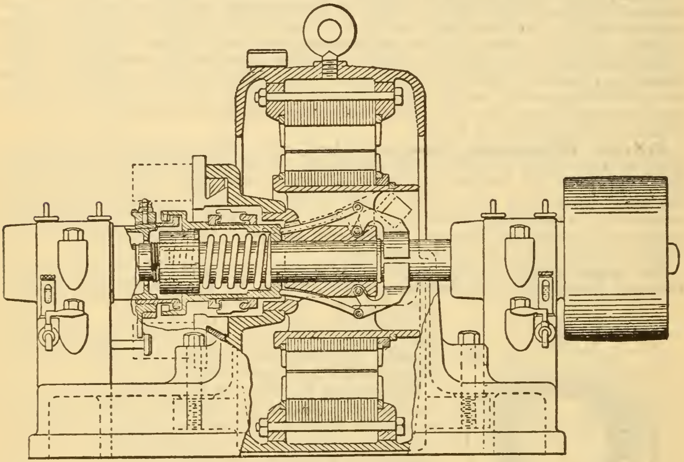


FIG. 41. Cross Section of Wagner Motor.

circuiting links into the commutator, against the action of the spring. At the same instant and by the same means, the brushes bearing upon the commutator are thrown off.

Fig. 41 shows a view in cross-section of the Wagner motor, and the diagram, Fig. 42, shows the elementary connections of the same ; the first diagrammatic motor being shown as in the starting condition, and the diagram at the right showing the condition of the armature after it has attained full running speed and the commutator is short-circuited.

SYNCHRONOUS MOTORS.

Alternators are convertible into motors ; and one alternator will run in synchronism with another similar machine after it is brought to the same speed, or, if of unlike number of poles, to some multiple of the speed of the driven dynamo, provided the number of pairs of poles on the motor is

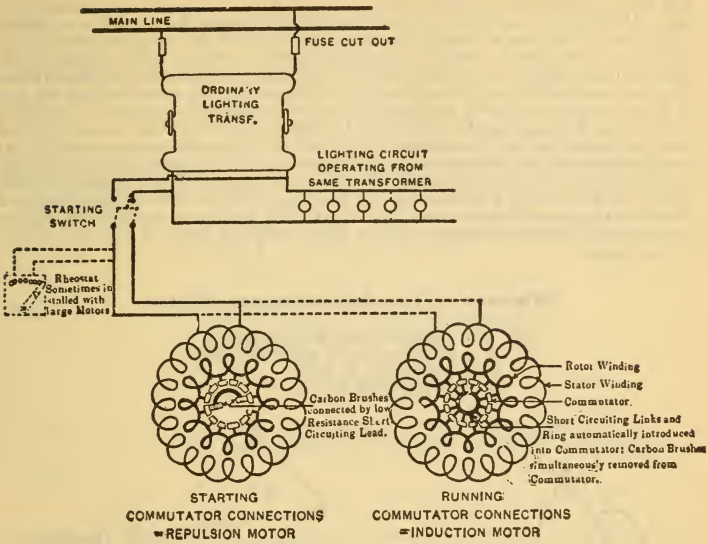


FIG. 42. Connections of Wagner Single-Phase Motor.

divisible into the multiple. Such motors will run as if geared to the driven dynamo even up to two or three times its normal full torque or capacity. Single-phase synchronous motors have no starting-torque, but synchronous motors for multiphase circuits will come up to synchronism without much load, giving about 25 % starting-torque, starting as induction motors, with the d. c. field open.

When connected to lines on which are connected induction motors that tend to cause lagging currents and low-power factor of the line, over excitation of the synchronous motor fields acts in the same manner as a condenser introduced in the line, and tends to restore the current to phase with the impressed E.M.F., and therefore to do away with inductive disturbances.

It is necessary to provide some source from which may be obtained continuous current for exciting the fields of the synchronous motor ; and this is oftenest done by the use of a small d. c. dynamo belted from the motor-shaft, the exciting current not being put into use until the motor armature reaches synchronism.

In starting a synchronous motor the field is open-circuited, and current is turned on the armature. In practice, field coils are connected in various ways to obviate the dangers of induced voltage, and a low resistance coil similar to the series winding of the d. c. machine is sometimes so arranged on the field poles as to give the necessary reaction for starting. Another way is to use a low-pressure excitation, and therefore few turns on the field coils ; also the field coils are "split up" by a switch at starting. The field excitation is thrown on after the rotating part approaches synchronism, which may be indicated by a lamp or other suitable device at the operating switchboard.

Considerable care must be exercised in the use of synchronous motors, and their best condition is where the load is quite steady, otherwise they introduce inductive effects on the line that are quite troublesome. The field of such a motor can be adjusted for a particular load, so there will be neither leading nor lagging current, but unity power factor. If the load changes, then the power factor also changes, until the field is readjusted ; if the load has been lessened the current will lead, and if it increases the current will lag. If induction motors are connected to the same line, with a synchronous motor that has a steady load, then the field of the synchronous motor can be over-excited to produce a *leading* current, which will conteract the effect of the *lagging* currents induced by the induction motors. If two or more synchronous motors are connected to the same circuit, and the load on one of them is quite variable, and its field is not changed to meet such changing conditions, a pumping effect is liable to take place in the other motors, unless especial provision has been made in the design of the motors to prevent it. It is only necessary to arrange one of the motors of the number for preventing this trouble, but better to make all alike. A copper shield between pole-pieces, and covering a portion of the pole-tip, will prevent the trouble; and the Westinghouse Electric and Manufacturing Company use a heavy copper strap around each pole-piece, with a shoe covering part of the pole-tip in the air-gap.

Theory of the Synchronous Motor.

Let $R =$ resistance of whole circuit,
$L =$ inductance of whole circuit,
$E_1 =$ generator E.M.F.,
$E_2 =$ motor E.M.F.

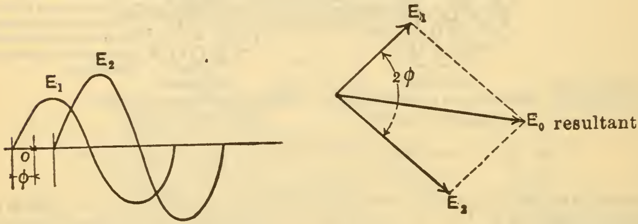


FIG. 43.

Take the origin at 0.

Let E represent maximum value,

$e =$ instantaneous value,
$e_1 = E_1 \sin(\omega t + \phi)$,
$e_2 = E_2 \sin(\omega t - \phi)$,

where $\omega = 2\pi f$, and f number of complete cycles per second.

$$e = E_0 \sin(\omega t - \psi),$$

where $\psi =$ angle of lag of E_0 with respect to the origin.

$$E_0^2 = E_1^2 + E_2^2 + 2 E_1 E_2 \cos 2\phi,$$

For $E_2 > E_1$, E_0 leads, $E_2 < E_1$, E_0 lags,

$$\begin{cases} \cos\psi = \dfrac{E_1 - E_2}{E_0}\cos\phi, \\ \tan\psi = \dfrac{E_2 - E_1}{E_2 + E_1}\tan\phi, \\ \sin\psi = \dfrac{(E_1 + E_2)}{E_0}\cos\phi. \end{cases}$$

E_0 and ϕ are known,

Energy shifts the origin by the angle ψ.

$$e_1 = E_1 \sin(\omega t + \phi + \psi).$$
$$e_2 = E_2 \sin(\omega t - \phi + \psi).$$

Now $$I = \frac{E_0}{\sqrt{R^2 + \omega^2 L^2}},$$

and I lags behind E_0 by the angle δ where

$$\tan \delta = \frac{LP}{R}.$$

By introducing the angle ψ we are referring the E.M.F.'s of both machines to the zero point of the resultant wave as origin.

In general

$$P = \frac{1}{T}\int_0^T e\ i\,dt = \frac{EI}{2}\cos \Theta,$$

where $P =$ the power in watts, and
$\theta =$ lag or lead of I with respect to E,
E and I are maximum values,

$T = \frac{1}{n}$, or the periodic time.

Let $P_1 =$ power given to the circuit by the generator,
$P_2 =$ power absorbed from the circuit by the motor,

Then

$$P_1 = \frac{1}{T}\int_0^T e, i\,dt = \frac{E_1}{2}\frac{E_0}{\sqrt{R^2 + \omega^2 L^2}} \cos(\phi + \psi + \delta)\,[i = I \sin(P_1 t - \delta)],$$

$$P_1 = \frac{E_1}{2}\frac{E_0}{\sqrt{R^2 + \omega^2 L^2}}[\cos(\phi + \psi)\cos\delta - \sin(\phi + \psi)\sin\delta],$$

$$\sin\delta = \frac{L\omega}{\sqrt{R^2 + L^2\omega^2}}, \qquad \cos\delta = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}.$$

$$\therefore P_1 = \frac{E_1 E_0}{2(R^2 + \omega^2 L^2)}\left\{R\cos(\phi + \psi) - L\omega\sin(\phi + \psi)\right\},$$

and substituting $-\phi$ for $+\phi$ we get

$$P_2 = \frac{E_2 E_0}{2(R^2 + \omega^2 L^2)}\left\{R\cos(\phi - \psi) + L\omega\sin(\phi - \psi)\right\}.$$

Now $$\sin\psi = \frac{-(E_1 + E_2)}{E_0}\sin\phi,$$

and $$\cos\psi = \frac{E_1 - E_2}{E_0}\cos\phi.$$

Substituting and reducing

$$P_2 = \frac{1}{2}\frac{E_2}{R^2 + \omega_2 L^2}\left\{E_1(R\cos 2\phi + L\omega\sin 2\phi) - E_2 R\right\}.$$

An angle ϕ^1 is introduced such that

$$\sin 2\phi^1 = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}, \text{ and } \cos 2\phi^1 = \frac{L\omega}{\sqrt{R^2 + \omega^2 L^2}}.$$

Substitute in P_2, and

$$P_2 = \frac{1}{2} \frac{E_2}{R^2 + \omega^2 L^2} \left\{ E_1 \sqrt{R^2 + \omega^2 L^2} \sin(2\phi + 2\phi') - E_2 R \right\}.$$

P_2 is a maximum when $2\phi + 2\phi' = 90°$

or $\phi + \phi' = \frac{\pi}{4}$;

that is, the "sine term" = unity.

P_2 is positive provided $\frac{E_1}{E_2} > \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$,

which shows that it is possible to have E_2 greater than E_1 if there is the proper ratio of resistance and reactance in the circuit.

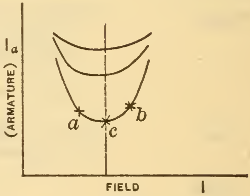


FIG. 44.

Now, if we plot from an actual motor the armature current and the field excitation we get a curve shown in Fig. 44.

This shows that the armature current varies with the excitation for a given load. The flatter curves are for increase of load.

Point *a* shows under excitation,
b shows over excitation,
c shows the excitation which makes the power factor unity; it is well from the point of stability of operation to slightly over excite, and this makes $E_2 > E_1$, and also counteracts the inductive drop in the line, thus showing that the action of an over excited synchronous motor is similar to a condenser.

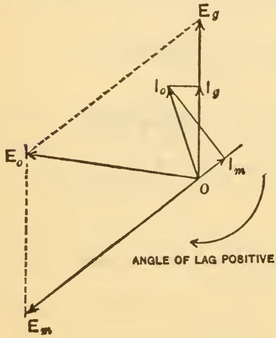


FIG. 45.

Graphical treatment.

E_g = generator E.M.F.
E_m = motor E.M.F.
E_o = resultant E.M.F.
I_o = resultant current.
$O\,I_g$ = projection of I_o on $O\,E_g$.
$O\,I_m$ = projection of I_o on $O\,E_m$.
$O\,I_g \cdot O\,E_g = \omega_g$ = energy given up by the generator.
$O\,I_m \cdot O\,E_m = \omega_m$ = energy absorbed by the motor from the circuit.

ω_m is negative, which shows that ω_m is the motor, because it is taking energy from the circuit; and similarly ω_g is the generator, because $O\,E_g \cdot O\,I_g$ is positive, and gives up energy to the circuit.

[For further discussion see Jackson's *Alternating Current* and *Alternating Current Machines*; also *Electrical World* for March 30 and April 6, 1895, by Bedell and Ryan. The latter is the classic paper on the subject.]

DYNAMOTORS.

These are of two styles, one for changing direct current of one voltage into direct current of a different voltage, and usually called in America *motor-generators*; the second class changes alternating current into direct current or *vice versa*, the voltage not being changed excepting from alternating $\sqrt{\text{mean}^2}$ values to direct-current values equal to the top of the alternating wave; these latter machines are now called *rotary converters*, and are largely used.

Dynamotors are now largely used in telegraph offices for reducing the pressure of the supply current to voltages suitable for use in telegraphy and for ringing and charging generators in telephone offices.

Theory. Let

E = voltage at motor terminals.
e = voltage at generator terminals.
I = current in motor armature.
R = resistance of motor armature.
N_c = number of conductors in motor armature.
I_1 = current in generator armature part.
R_1 = resistance of generator armature part.
N_{c_1} = number of conductors in generator armature part.
$\frac{N_c}{N_{c_1}} = k$ = coefficient of transformation.
E = induced E.M.F. in motor part.
E_1 = induced E.M.F. in generator part.
E = r.p.s. $\times N_c \times \phi$.
E_1 = r.p.s. $\times N_{c_1} \times \phi$.
$E = E - RI$.
$E_1 = e + R_1 I_1$.
$ke = E = RI - kr_1 I_1$.

If it be assumed that losses by hysteresis and eddy currents be negligible, or that $EI = E_1 I_1$ whence $I_1 = kI$, then

$$e = \frac{E}{k} - \left(R_1 + \frac{R}{k^2}\right) I_1.$$

Such machines run without sparking at the commutator, as all armature reactions are neutralized.

DIRECT-CURRENT BOOSTERS.

This is a type of *motor generator* much in use for *raising* or *lowering* the pressure on long feeders on the low-pressure system of distribution, and is to be found in most of the larger stations of the Edison companies. It is also much used in connection with storage-battery systems in charging cells.

The "*booster*" consists of a series generator driven by a motor direct connected to its armature shaft. The terminals of the generator are connected in series with one leg of the feeder; and it is obvious that the current in the feeder will excite the series field just in proportion to the current flowing, provided the design of the iron magnetic circuit is liberal enough so that the field is way below saturation (on the straight part of the iron curve way below the knee). As the armature is being independently rotated in this field, it will produce an E.M.F. approximately in proportion to such excitation, which E.M.F. will be added to that of the feeder or will oppose that E.M.F., according as the terminal connections are made. On three-wire systems two generators are direct connected to one motor, and for convenience on one bed-plate.

Such a booster can be so adjusted as to make up for line loss as it increases with the load.

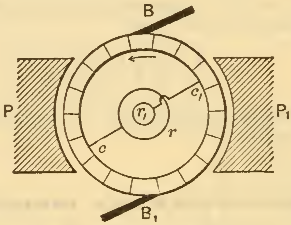
One danger of a booster that is not always taken into account is. that if the shunt of the driving-motor should happen to open, or, in fact, anything should happen to the driving-motor that would result in its losing its power, the generator would immediately become a series motor, taking current from the line to which it is connected, and by its nature would reverse in direction of rotation, and increase in speed enormously, and if not disconnected from its circuits in time would result in a complete wreck of the machine. It is always safest to have the generator terminals connected to their line through some automatic cut-out, so arranged that should the shunt break, as suggested, it would actuate the device, and automatically detach the booster from the circuit before harm could be done.

ROTARY CONVERTERS.

A rotary converter is the name given to a machine designed for changing alternating currents into direct currents. If the same machine be used inverted, i. e., for changing direct currents into alternating, it is sometimes known as an *inverted converter.* Again, if the same machine be driven by outside mechanical power, both alternating and direct currents may be taken from it, and it then becomes known as a *double current generator.*

Theoretically the *rotary converter* is a continuous current dynamo with collector rings added, which are connected by leads to certain parts of the armature windings, sometimes at the commutator segments.

In the following figure, which represents in diagram the *single-phase rotary converter*, the collector rings r and r_1 are connected by leads to diametrically opposite segments or coils of the armature at c and c_1. It is obvious that as the armature revolves the greatest difference of potential between the rings, or maximum E.M.F., will be at the instant the segments c and c_1 pass under and coincide with the brushes B and B_1; and this E.M.F. will decrease as the rotation continues, until the lowest E.M.F. will occur when the segments c and c_1 are directly opposite the centre of the pole-pieces P and P_1.



SINGLE PHASE ROTARY CONVERTER

FIG. 46.

The maximum alternating E.M.F. will be equal to the direct-current voltage at the brushes B and B_1, and if the machine be designed to produce a sinusoidal curve of E.M.F., then the alternating E.M.F., that is, the $\sqrt{\text{mean}^2}$ or effective E.M.F., will be,

$$e = \frac{E}{\sqrt{2}} = .707\ E,$$

where $e = \sqrt{\text{mean}^2}$ value of the alternating E.M.F.,
and $E =$ direct-current voltage between brushes.

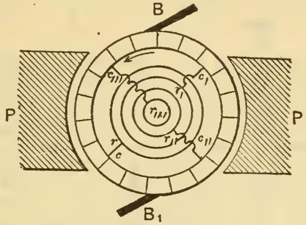
In a bipolar machine the frequency = r.p.s., and in a machine with p poles the frequency will be $\frac{p}{2}$ r.p.s.

Neglecting losses and phase displacement the supply of alternating current to the rings must be $I\sqrt{2} = 1.414\ I$ where I is the direct-current output.

If, as shown in Fig. 47, another pair of rings be added, and connected to points on the winding at right angles to the first, then another and similar

E.M.F. will be produced, but in quadrature to the first. The E.M.F. will be the same for each phase as in the single-phase connection previously shown, and still neglecting phase displacement and losses the current will be for each of the two phases

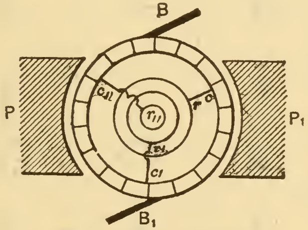
$$\frac{I}{\sqrt{2}} = .707\ I.$$



TWO PHASE, OR QUARTER PHASE ROTARY CONVERTER

FIG. 47.

If three equidistant points on the armature windings be connected to three rings, as shown in the following diagram, a *three-phase* converter is produced.



THREE PHASE ROTARY CONVERTER

FIG. 48.

As the connections of a *three-phase rotary* are always delta, the E.M.F.'s as compared with the continuous current E.M.F. E have the following value:

Voltage between collector ring and neutral point $e = \frac{E}{2\sqrt{2}} = .354\ E.$

Voltage between collector rings $e^1 = \frac{E\sqrt{3}}{2\sqrt{2}} = .612\ E.$

Alternating current input $= i = \frac{I\,E}{3\,e} = \frac{2\,I\sqrt{2}}{3} = .943\ I.$

Steinmetz, in the *Electrical World* of Dec. 17, 1898, gives the following tables of values of the alternating E.M.F. and current in units of direct current.

Value of Alternating-Current Voltage and Current in Terms of Direct Current.

	Continuous Current	Single-phase.	Three-phase.	Two-phase.	Six-phase.	Twelve-phase.	n phase.
Volts between collector ring and neutral point . .	1	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = 354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$
Volts between adjacent collector rings	1	$\frac{1}{\sqrt{2}} = .707$	$\frac{\sqrt{3}}{2\sqrt{2}} = .612$	$\frac{1}{2} = .5$	$\frac{1}{2\sqrt{2}} = .354$	.183	$\frac{\sin\frac{\pi}{n}}{\sqrt{2}}$
Amperes per line .	1	$\sqrt{2} = 1.414$	$\frac{2\sqrt{2}}{3} = .943$	$\frac{1}{\sqrt{2}} = .707$	$\frac{\sqrt{2}}{3} = .472$	.236	$\frac{2\sqrt{2}}{n}$
Amperes between adjacent lines .	1	$\sqrt{2} = 1.414$	$\frac{2\sqrt{2}}{3\sqrt{3}} = .545$	$\frac{1}{2} = .5$	$\frac{\sqrt{2}}{3} = .472$	.455	$\frac{\sqrt{2}\sin\frac{\pi}{n}}{n}$

The values of E.M.F. and of current stated above are theoretical, and are varied in practice by reason of drop in armature conductors and phase displacement. In converting from a.c. to d.c., if the current in the rotary is in phase with the impressed E.M.F., armature self-induction has little effect; but with a *lagging* current, which may be due to under-excitation, the induced d.c. E.M.F. is somewhat reduced; and if the machine be over-excited, thus producing a *leading* current, the induced d.c. E.M.F. will be raised. The same is the case in converting from d.c. to a.c., the a.c. volts being down on a lagging circuit.

The corrections for the theoretical ratios of voltages as shown are, first for drop in the armature; and second, they have to be multiplied by the factors shown above.

Steinmetz says that the current flowing in the armature conductors of a rotary is the difference between the alternating current input and the continuous current output. The armature heating is therefore relatively small, and the practical limit of overload is limited by the commutator, and is usually far higher than in the continuous current generator.

In six-phase rotaries the I^2R losses of the armature are but 29 % of the regular I^2R loss in the armature as used for d.c. dynamo.

Kapp shows that width of pole-face has a bearing on the increase in output of a rotary converter over the same machine used as a continuous current dynamo. He compares the output of two converters, one in which the pole-face is two-thirds the pole distance, and another in which it is one-half the pole distance. In single-phase converters the output is not equal to that of the d.c. dynamo, and two- and three-phase machines are much different.

He gives, in the following table, the percentage of d.c. output of what would be the output of the same machine used as a d.c. dynamo.

		Pole-width.	
		$\frac{2}{3}$	$\frac{1}{2}$
Single-phase	Cos = 1.	88%	95%
	Cos = .9	81	88
	Cos = .8	73	80
	Cos = .7	63	70
Three-phase	Cos = 1.	138	144
	Cos = .9	128	137
	Cos = .8	117	126
Two- or four-phase	Cos = 1.	167	170
	Cos = .9	160	167
	Cos = .8	144	153

To find the voltage required between collector rings on rotary converters, when

T = number of turns in series between collector rings,
Φ = flux from one pole-piece into the armature,
f = cycles per second,
E = required E.M.F.

Then

For single-phase and two-phase machines

$$E = 2.83\ T\ f\ \Phi\ 10^{-8},$$

For three-phase machines

$$E = 3.69\ T\ f\ \Phi\ 10^{-8}.$$

The single-phase *rotary* has to be turned up to synchronous speed by some external power, as it will not start itself.

The polyphase *rotary* will start itself from the a.c. end, but takes a tremendous lagging current, and therefore, where possible, it should be started from its d.c. side.

The starting of rotaries that are connected to lines having lights also connected, should *always* be done from the d.c. side, as the large starting current taken at the moment of closing the switch will surely show in the lamps. Polyphase rotaries are sometimes started, as are induction motors, by use of a "compensator."

In starting a *rotary*, the field circuit must be opened until synchronism is reached, after which it is closed. The d.c. side must also be disconnected from its circuit, as it is obvious that the current produced is alternating until synchronism is reached. Care must be taken to keep the field circuit closed when the d.c. side is connected in parallel with other machines, and the a.c. side open, or the armature will run away and destroy itself.

As the change in excitation of the field of a rotary changes the d.c. voltage but little, and on the other hand produces wattless currents, the regulation of E.M.F. must be accomplished by some other method. This can be done by changing the ratio of the static transformer by cutting in and out turns as its primary, or by the introduction of self-induction coils in the a.c. leads to the *rotary*.

The first introduces a complicated set of connections and contacts, but is unlimited in range.

The second method seems especially suited for the purpose, but is somewhat limited in range. Theoretically the action is as follows: Suppose the excitation to be low enough so that the current lags 90° behind the impressed E.M.F., the E.M.F. of self-induction lags 90° behind the current, and is therefore 180° behind the impressed E.M.F., and therefore in opposition to it. On the other hand, if the excitation is large, and produces a leading current of 90°, the E.M.F. of self-induction is in phase with the impressed E.M.F. and adds itself to it. Therefore, with self-induction introduced in the a.c lines, it is only necessary to vary the excitation in order to change the continuous current E.M.F. A *rotary* can thus be compounded by using shunt and series field, to maintain a constant E.M.F. under changes of load, the compounding taking place, of course, in the a.c. lines and not in the field of the machine, as usual in d.c. dynamos.

In handling the *inverted* converter care must be exercised in starting it under load, as it is apt to run away if not connected in parallel with other alternators. If they are started from the d.c. side, and have lagging currents flowing from a.c. side, this current will tend to demagnetize or weaker the fields, and the speed of the armature is liable to accelerate to the danger limit.

A lagging current taken from an inverted rotary, even after having reached synchronism, will cause an immediate increase in speed, and if enough lagging will cause an approach to the danger point.

Running as a rotary, and converting from a.c. to d.c., the phase of the entering current has no effect on the speed, this being determined by the cycles of the driving generator, nor upon the commutation, simply influencing the heat in the armature and ratio of voltages slightly.

Double-current generators are useful in situations where continuous current can be used for a portion of the day and the current transferred through the a.c. side to some other district for use in another portion of the day, thus keeping the machine under practically constant load.

The size of *double-current generators* is limited by the size of the d.c. generator that can be built with the same number of poles as a good alternator. The heating of the armature depends upon the sum and not the difference of the currents, as in the *rotary*, and the capacity is therefore no greater than a d.c. machine of the same total output.

Automatic compounding of *double-current generators* is scarcely feasible in practice, and the field must be very stable, as the demagnetizing effect of the lagging a.c. currents tends to drop the excitation entirely. Such machines run better separately excited.

CONVERTER ARMATURE WINDINGS.

Two-Circuit Winding for Two-Phase Rotary Transformers.

The following diagram shows the connections of the four rings to the different sections of the armature. The connections are made at the commutator segments at four points, although there are six poles.

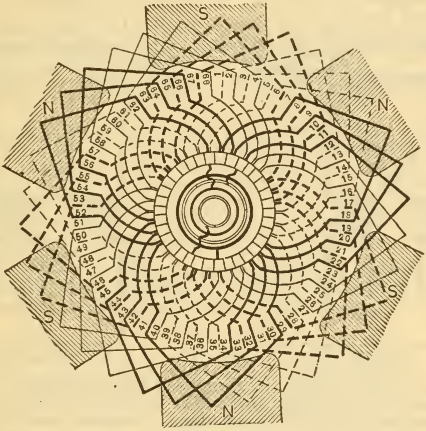


FIG. 49.

Two-Circuit Winding for Three-Phase Rotary Transformers.

The following diagram shows the connections of the three collector rings to the continuous current winding of a six-pole dynamo. As in the last figure, the rings are connected to points on the commutator at nearly equidistant points.

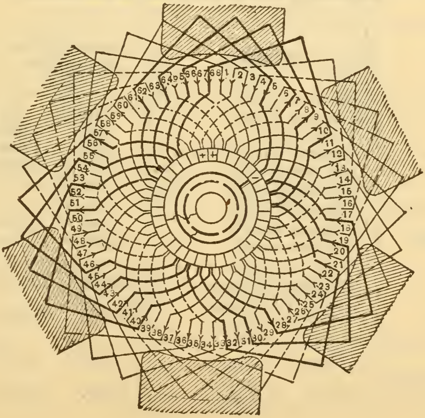


FIG. 50.

Note. — Connection of Transformers and Rotary Converters.

In the use of rotary converters, two or more of these machines are sometimes connected in multiple to the secondary of the transformers, and their direct current leads then conducted in multiple to a common bus-bar circuit, as shown in Fig. 51.

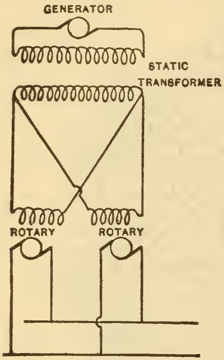


FIG. 51.

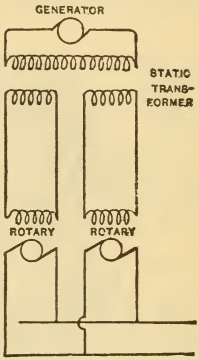


FIG. 52.

With the above connections, currents are often formed in the rotaries that disturb the point of commutation, and it becomes practically impossible to adjust the brushes so they will not spark. Rather than connect across in the above manner, it is better that each rotary have its own transformer, or at least its own secondary on the transformer, as shown in Fig. 52.

Current Densities.

Current leads *from brushes to binding-posts*, must be ample to produce no appreciable drop in voltage. The following table gives current densities, etc., for brush-holders, conductors, bolted joints, and switches.

Average Current Densities for Cross Section and Contact Surface of Various Materials.

	Material.	Square Mils. per Ampere.	Amperes per Square Inch.
Cross section	Copper wire	500 to 800	1,200 to 2,000
	Copper rod	800 " 1,200	800 " 1,200
	Copper-wire cable	600 " 1,000	1,000 " 1,600
	Copper casting	1,400 " 2,000	500 " 700
	Brass casting	2,500 " 3,300	300 " 400
Brush contact	Copper brush	5,700 " 6,700	150 " 175
	Carbon brush	28,500 " 33,500	30 " 35
Switch jaws	Copper — copper	10,000 " 15,000	67 " 100
	Brass < copper, brass	20,000 " 25,090	40 " 50
Screwed contact	Copper — copper	5,000 " 8,000	120 " 200
	Brass < copper, brass	10,000 " 15,000	67 " 100

THE STATIC TRANSFORMER.

REVISED BY W. S. MOODY AND K. C. RANDALL.

THE static transformer is a device used for changing the voltage and current of an alternating circuit in pressure and amount. It consists, essentially, of a pair of mutually inductive circuits, called the primary and secondary coils, and a magnetic circuit interlinked with both the primary and secondary coils. This magnetic circuit is called the core of the transformer.

The primary and secondary coils are so placed that the mutual induction between them is very great. Upon applying an alternating voltage to the primary coil an alternating flux is set up in the iron core, and this alternating flux induces an E.M.F. in the secondary coil in direct proportion to the ratio of the number of turns of the primary and secondary.

Technically, the primary is the coil upon which the E.M.F. from the line or source of supply is impressed, and the secondary is the coil within which an induced E.M.F. is generated.

The magnetic circuit or core in transformers is composed of laminated sheet iron or steel. The following cuts represent sections of several different types of single phase transformers.

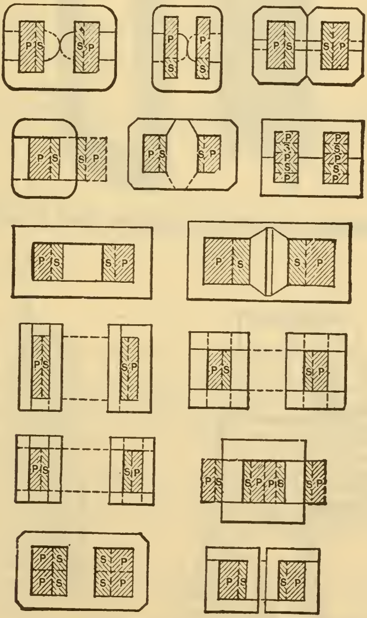


FIG. 1. Cores of some American Transformers.

p = primary winding ; s = secondary winding.

In those showing a double magnetic circuit the iron is built up through and around the coils, and they are usually called the "Shell" type of transformer.

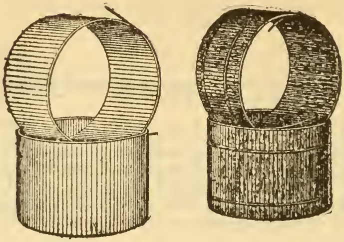


FIG. 2. Unfinished and Finished Coils for Core Type Transformers

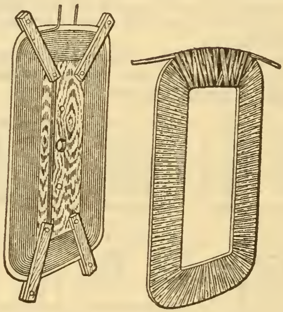


FIG. 3. Unfinished and Finished Coils for Shell Type Transformers

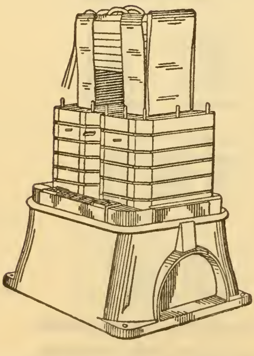


FIG. 4. Shell Type Transformer in Process of Construction.

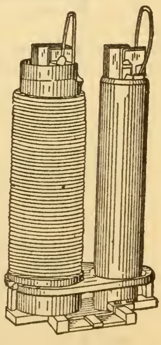


FIG. 5. Core Type Transformer in Process of Construction.

Those having a single magnetic circuit, and having the coils built around the long portions or legs of the core, the short portions or yoke connecting these legs at each end, are called "core" type of transformer.

The duties of a perfect transformer are:

(1) To absorb a certain amount of electrical energy at a given voltage and frequency, and to give out the same amount of energy at the same frequency and any desired voltage.

(2) To keep the primary and secondary coils completely isolated from one another electrically.

(3) To maintain the same ratio between impressed and delivered voltage at all loads.

The commercial transformer, however, is not a perfect converter of energy, although it probably approaches nearer perfection than any form of apparatus used to transform energy. The difference between the energy taken into the transformer and that given out is the sum of its losses. These losses are made up of the copper loss and the core loss.

The core loss is that energy which is absorbed by the transformer when the secondary circuit is open, and is the sum of the hysteresis and eddy current loss in the core, and a slight copper loss in the primary coil, which is generally neglected in the measurements.

The hysteresis loss is caused by the reversals of the magnetism in the iron core, and differs with different qualities of iron With a given quality of iron, this loss varies as the 1.6 power of the voltage with constant frequency.

Steinmetz gives a law or equation for hysteresis as follows:

$$W_H = \eta \mathfrak{B}^{1.6}.$$

W_H = Hysteresis loss per cubic centimeter per cycle, in ergs ($= 10^{-7}$ joules).

η = constant dependent on the quality of iron.

If N = the frequency,
V = the volume of the iron in the core in cubic centimeters,
P = the power in watts consumed in the whole core,

then $P = \eta N V \mathfrak{B}^{1.6} 10^{-7}$,

and $$\eta = \frac{P}{N V \mathfrak{B}^{1.6} 10^{-7}}.$$

In the construction, the core loss depends on the following factors:

(1) Magnetic density,
(2) Weight of iron core,
(3) Frequency,
(4) Quality of iron,
(5) Thickness of iron,
(6) Insulation between the sheets or laminations.

The density and frequency being predetermined the weight or amount of iron is a matter of design. The quality of the iron is very variable, and up to the present time no method has been found to manufacture iron for transformers which gives as great a uniformity of results as to the magnetic losses as could be desired.

On the thickness of the laminations and the insulation between them depend the eddy current losses in the iron. Theoretically[1] the best thickness of iron for minimum combined eddy and hysteresis loss at commercial frequencies is from .010″ to .015″, and common practice is to use iron about .014″ thick.

The copper losses in a transformer are the sum of the I^2R losses of both the primary and secondary coils, and the eddy current loss in the conductors. In any well-designed transformer, however, the eddy current loss in the conductors is negligible, so that the sum of the I^2R losses of primary and secondary can be taken as the actual copper loss in the transformer.

[1] Bedell, Klein, Thomson, Elec. W., Dec. 31. 1898.

TRANSFORMER EQUATIONS.

Practically all successful designs of transformers are determined to greater or less extent by the method of cut and try. Empirical methods are of little value if the designer can obtain data on other successful transformers for the same kind of work, and base the calculations for the new apparatus on the behavior of the old while under test.

For any transformer or reactive coil:

Let $E = \sqrt{\text{mean}^2}$ of the induced E.M.F.
$\Phi =$ total flux.
$\mathfrak{B}'' =$ lines of force per square inch.
$A =$ section of magnetic circuit in square inches.
$N =$ frequency in cycles per second.
$T =$ total turns of wire in series.

$$4.44 = \frac{2\pi}{\sqrt{2}} = \sqrt{2} \times \pi$$

$$\text{Then } E = \frac{4.44\, N \Phi T}{10^8} \qquad (1)$$

This equation is based on the assumption of a sine wave of electromotive force, and is the most important of the formulae used in the design of an alternating current transformer.

By substituting and transposing we can derive an equation for any unknown quantity.

Thus if the volts, frequency, and turns are known, then—

$$\Phi = \frac{E \times 10^8}{4.44 \times N \times T} \qquad (2)$$

$$\text{But } \Phi = \mathfrak{B}'' A \qquad (3)$$

$$\text{Therefore } A = \frac{E \times 10^8}{4.44 \times N \times T \times \mathfrak{B}''} \qquad (4)$$

which equation gives at once the cross section of iron necessary for the magnetic circuit after we have decided on the total primary turns, and the density at which it is desired to work the iron.

Again, if the volts, frequency, cross section of core, and density are known, we have, transposing equation (4),

$$T = \frac{E \times 10^8}{4.44 \times N \times \mathfrak{B}'' \times A}$$

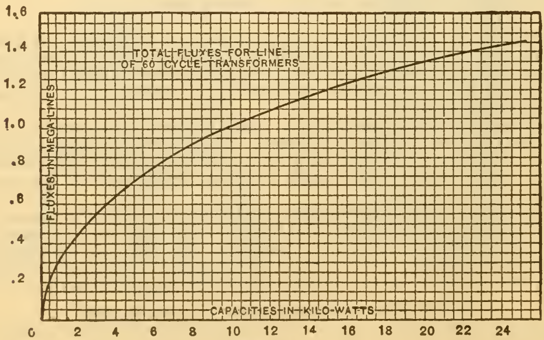


FIG. 6.

Fig. 6 is a curve giving the total fluxes as ordinates and capacities in K.W. as abscissæ. This curve represents approximately common practice for a line of lighting transformers, to be operated at 60 cycles.

For any other frequency or for power work, a curve of total fluxes can be drawn after three or more transformers have been calculated with quite widely differing capacities.

Magnetic densities in the cores of transformers vary considerably with the different frequencies and different designs of various makers. The practical limits of these densities are as follows:

For 25 cycle transformers from 60,000 to 90,000 C.G.S. lines per square inch.

For 60 cycle transformers from 40,000 to 60,000 lines per square inch.

For 125 cycles from 30,000 to 50,000 lines per square inch.

Densities for other frequencies are taken in proportion.

Current Densities. — Current density cannot be determined except in connection with the coil surface exposed for heat radiations, and if, therefore, for any reason, different portions of the winding have relatively different amounts of exposed surface, current densities must be adjusted to give equal heat distribution.

FEATURES OF DESIGN.

In the design of successful transformers the principal features requiring attention are:

(1) Quality of insulation between primary and secondary windings,
(2) Temperature rise,
(3) Regulation,
(4) Efficiencies,
(5) Ageing of iron or increase in core loss,
(6) Power factor and exciting current,
(7) Cost.

Insulation.

No feature of a successful transformer should be given more consideration than the quality and durability of the insulation used to separate the two windings. Good insulation means few burn-outs and interruptions of service, safety of customers, and low maintenance. The failure of the insulation is fatal to the primary function of the transformer.

Not only must the transformer withstand the strain when first installed or tested by the manufacturer, but during years of continued use after being subjected to frequent overloads and probably high temperatures for short periods.

No insulating material has been found which fills the purpose outlined above so well as mica, first, because of its being fire-proof, and second, because of its high dielectric strength. In a construction where there are no sharp corners to insulate, no insulation can surpass mica.

Next in value as insulators are perhaps varnished or oiled cloths. The value of such insulation varies greatly, and depends not only upon the quality of the cloth, but more especially on the qualities of the varnish and oils used in their manufacture. Their particular value over mica is their adaptability for use with coils having sharp or abrupt corners or edges.

Fiber, pressboard, fuller board, or other artificial boards are lowest in the scale of insulations, and are generally used not so much as insulators as for mechanical separation. If treated with oil or varnish, however, their insulating value is greatly increased.

For very high voltages no better insulator is known than mineral oils properly refined. Oil-filled spaces insulating great differences of potential should be sub-divided by partitions to prevent bridging of the space by conducting material.

Temperature.

Statements regarding temperature rise and method of determining the same, mean little unless all the conditions are considered. Measurement of temperature by thermometer is superficial and of little value.

In small transformers in which relatively large coil surface results, the temperature rise is quite uniform, and there is little possibility of any local high temperature in any part of the windings. Temperature measured by the resistance method or thermometer on such transformers is, therefore, not far from the maximum temperature.

On large transformers the only effective method of insuring uniform temperature is to provide liberal ducts between adjacent portions of the winding and between the windings and the core. Such ducts greatly increase the cost of a transformer, but experience has shown their necessity.

Because of the different methods of cooling, transformers are grouped in several classes. There are two classes of self-cooled transformers, namely, natural draft and self-cooled oil-insulated transformers.

Natural Draft Transformers. — The natural draft transformer is one in which the heat is dissipated by the air passing through the transformer, circulation of which is generated by the rise in temperature of the air itself. Such transformers are not suited for out-door installation, and are expensive because of the large surface that must be provided for radiation. This class of transformers is little used in this country, but is very common abroad.

Oil-Cooled Transformers. — The oil-cooled transformer is one in which the heat is dissipated by the oil circulating through the transformer

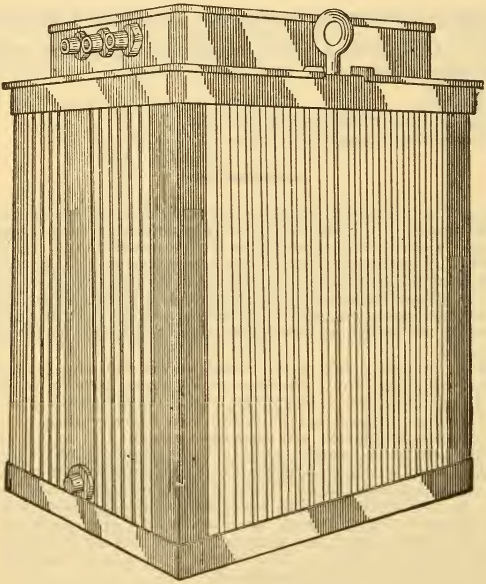


FIG. 7. 175 K.W. Oil-Insulated Self-Cooling Transformer Complete with Case.

structure. In addition to acting as a heat-conducting medium, it also serves to preserve the insulation from oxidation, increasing the breakdown resistance of the insulation, and, in a number of insulators, restores the insulation in case of puncture.

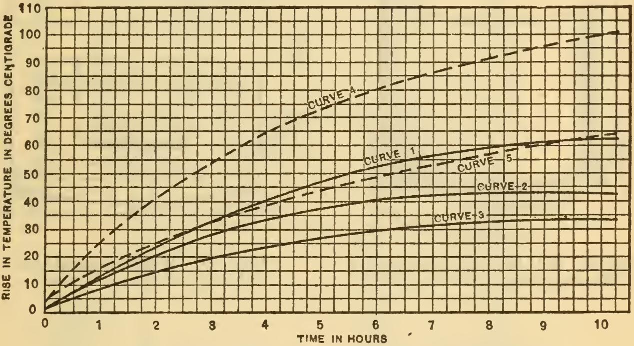
The use of oil in insulating a transformer results in a more rapid conduction between the transformer proper and its case or tank, and the consequent lowering of the temperature increases the life of the transformer.

Again, instances are known when the discharge of "atmospheric electricity," or lightning at a distance, has punctured the insulation of an oil-insulated transformer, in which the oil has flowed in and repaired the rupture, which was too small to cause immediate damage.

This cooling may be effectively increased by making the containing tank with vertical corrugations, thus largely increasing the radiating surface.

The curves in Fig. 8 serve to show the effect on the temperature by the use of oil. Curve 1 represents the temperature rise (by resistance method) of the small transformer without oil; curve 2, the temperature rise of the same transformer with oil; curve 3, the temperature rise of the oil; curve 4, the temperature rise of another transformer run with oil; and curve 5, the highest temperature rise accessible to thermometer, whose actual temperature by resistance is shown in curve 4.

These curves show very forcibly the value or merit of measuring the temperature rise of transformers by resistance method rather than by



CURVES SHOWING RESULTS DUE TO USE OF OIL IN TRANSFORMERS

FIG. 8.

thermometer. The difference of temperature of transformers operated with and without oil as shown in these curves is greatly exaggerated in larger sizes.

When the transformers are of such size that sufficient radiating surface cannot be had in the tank to dissipate the heat, it becomes necessary to provide artificial means for cooling the same. The principal methods employed are the use of a forced blast of air and by the circulation of water through the coils immersed in oil-cooled transformers.

The former are known as air-blast transformers and the latter as water-cooled.

Some special forms of water-cooled transformers have been built, wherein water has been circulated through the conductor itself.

Transformers have been constructed in sizes up to about 4000 K.W., using water circulation for cooling.

An Air-Blast Transformer, or one in which ventilation and radiation of heat is, by means of a blast or current of air, forced through the transformer coils and core, is shown in Figs. 14 and 15. In this transformer, the coils are built up high and thin, and assembled with spaces between them, the air being forced through these spaces. The iron core is also built with numerous openings through which the air is forced for cooling purposes. This style of transformer has been constructed in sizes up to about 2500 K.W.

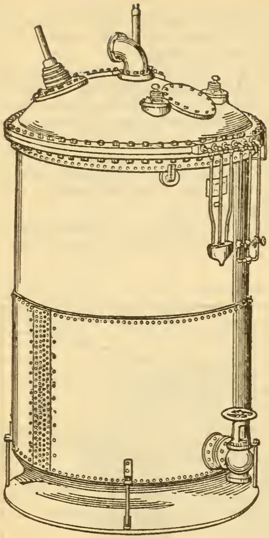


Fig. 9. 300 K.W. Oil-Insulated Water-Cooled Transformer.

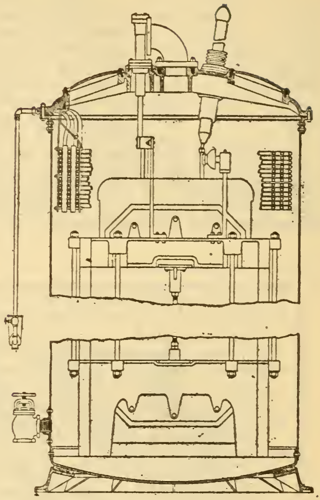


Fig. 10. Water-Cooled Oil-Insulated Transformer.

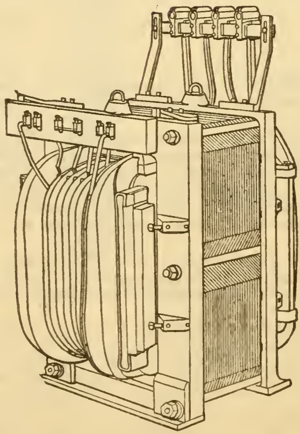


Fig. 11. 200 K.W. 22,000-Volt Oil-Insulated, Self-Cooling Transformer.

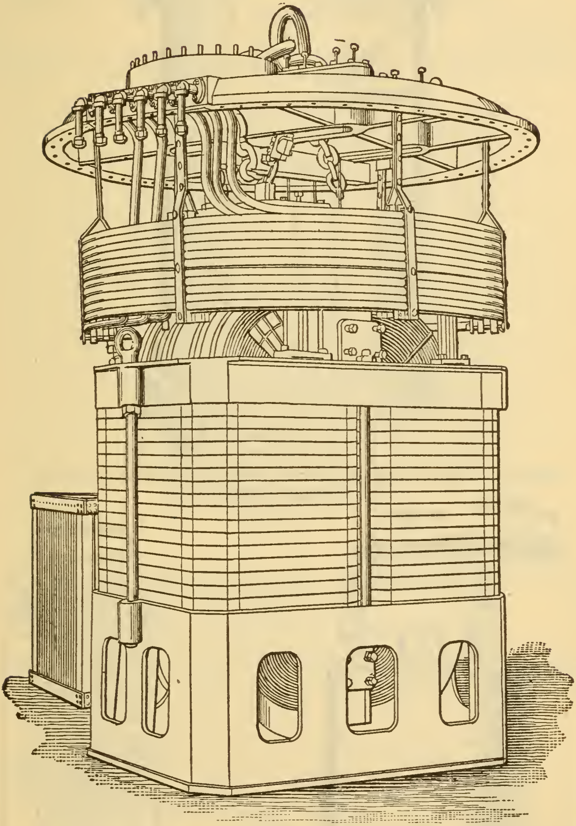


FIG. 12. Water-Cooled Transformer out of Tank.

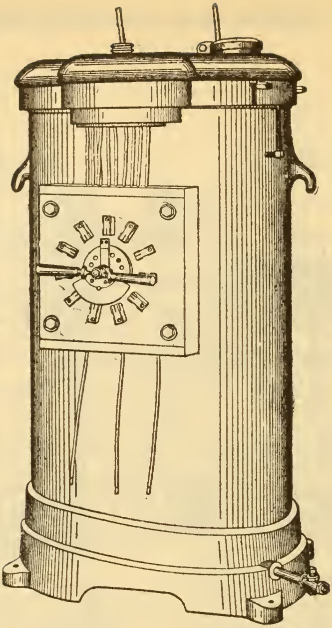


FIG. 13. Water-Cooled Transformer in Tank with Switch for Voltage Regulation.

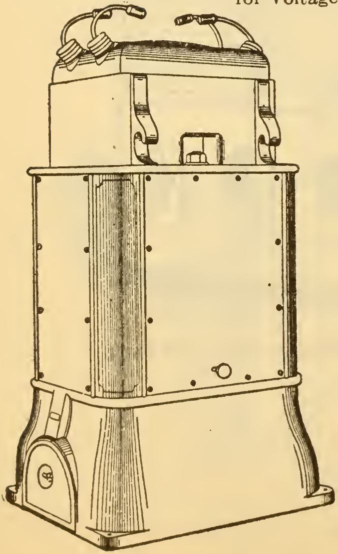


FIG. 14. 250 K.W. Single-Phase Air-Blast Transformer.

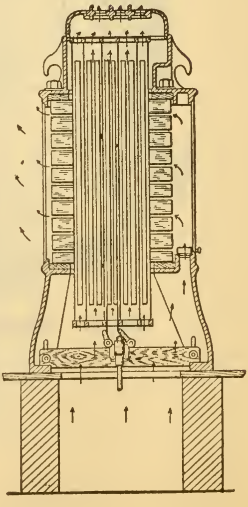


FIG. 15. Section of Air-Blast Transformer.

EFFICIENCIES.

The efficiency of a transformer is the ratio of the output watts to the input watts. Thus

$$\text{Efficiency} = \frac{\text{Output watts}}{\text{Input watts}} = \frac{\text{Output}}{\text{Output + Core loss + Copper loss}}.$$

The core loss, which is made up of the hysteresis loss and eddy current loss, remains constant in a constant potential transformer at all loads

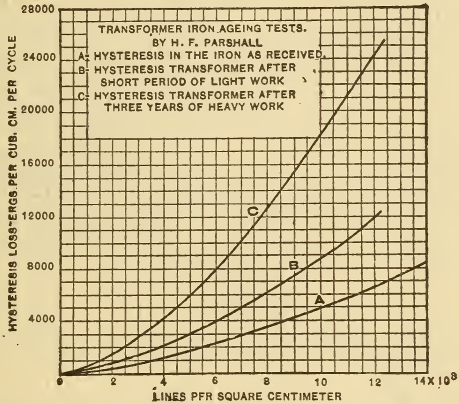


FIG. 16.

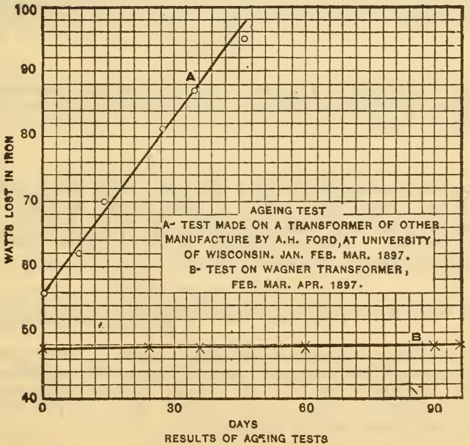


FIG. 17.

while the copper loss, or I^2R loss, varies as the square of the current in the primary and secondary. Methods for determining all the losses are fully described in the chapter on transformer testing.

In a service where a transformer is generally worked at full load while connected to the circuit, as in power work, the average or "all-day" efficiency will be about the same as its full-load efficiency. By "all-day" efficiency is meant the percentage which the energy used by the customer is of the total energy sent into the transformer during twenty-four hours.

In lighting work the transformers are usually connected to the mains or

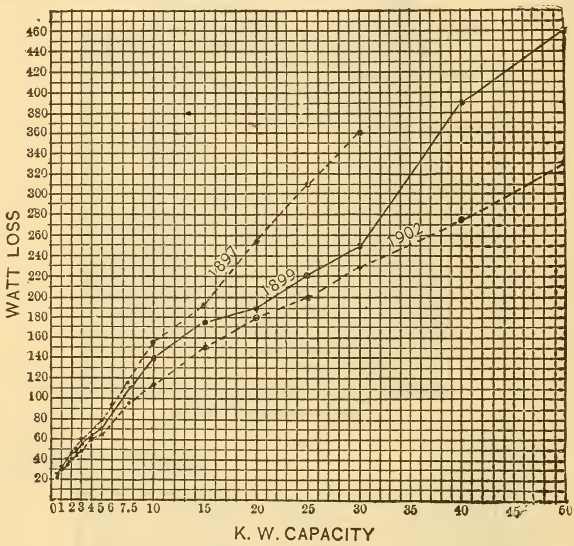


FIG. 18. Comparative Curves of Core Losses and Regulation, Showing the Improvement made in Transformers from 1897 to 1902.

are excited the full twenty-four hours per day, while the customer draws current from them during from three to five hours in the twenty-four. Assuming on an average five hours full load, the losses will be 5 hours I^2R and 24 hours core loss. The calculation of the "all-day" efficiency can, therefore, be made by the following formula:

$$\text{All-day efficiency} = \frac{\text{Full load} \times 5}{\text{Core loss} \times 24 + I^2R \times 5 + \text{Full load} \times 5}.$$

From this it is evident that while for power work or continuous full load the relative amount of the core and copper losses will not affect the "all-day" efficiency seriously, yet in the design of transformers which are worked at full load only a short time, but are always kept excited, a large core loss means a very low "all-day" efficiency.

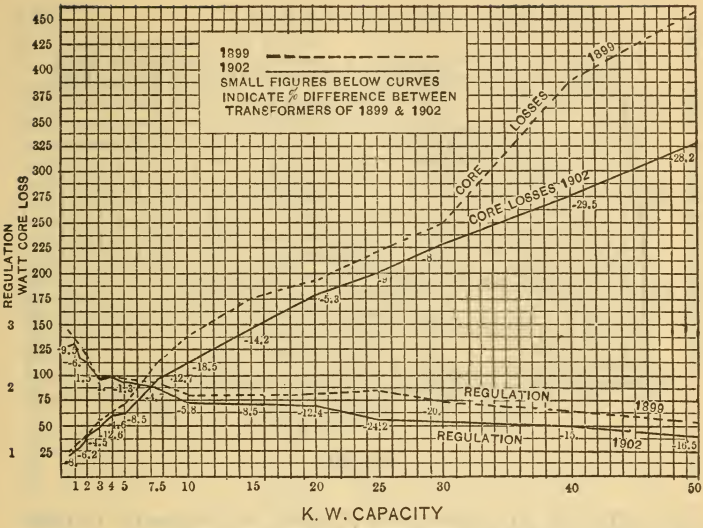


Fig. 19. Reduction in Core Loss, Illustrating the Reduction in Core Loss by the Leading Manufacturers.

MAGNETIC FATIGUE OR AGEING OF IRON AND STEEL.

The subject of ageing is of vast importance. The result of investigations by Professor Goldsborough, Mr. William M. Mordey and Mr. S. R. Rouget, B.A., led to the following conclusions:

First. There is unquestionably such a phenomena as ageing.

Second. A great difference exists in the amount of ageing taking place in different qualities of iron and steel when maintained at the same temperatures.

Third. This increase in the loss in a given body of iron is dependent solely on the temperatures at which it is maintained.

Fourth. Within ordinary limits of temperature the tendency to age is greater the greater the temperature.

Fifth. Soft sheet steel is much less subject to ageing than soft sheet iron.

Sixth. Sheet steel that does not age materially at moderate temperatures (below 75° C.) can be obtained, but almost any iron or steel ages more or less at higher temperatures.

Seventh. The real cause of ageing has not been discovered. Many of the laws governing it have been determined, but there is much room for further study and investigation.

The following curves (Fig. 20) and Table 1 show results of ageing tests on samples of iron from the same sheet of metal heated to different temperatures.

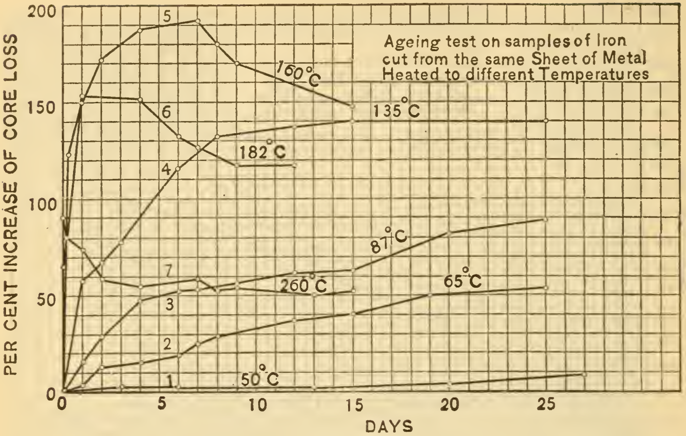


Fig. 20.

The curve (Fig. 21) shows result of ageing tests taken by Professor Goldsborough on a 5 K.W. transformer of prominent make.

"The ageing tests were made at 1100 volts primary pressure and 60 cycles. The core loss was measured at 104 volts secondary pressure.

Full Load Hours	0	115	163	187	221	266	350	494	602	822	Test Discontinued for a period of 8 Months.	822	1403	1858
Watts Core Loss	73.8	73.9	72.2	73.5	73.5	74	73	72.8	73	73.8		75.0	72.6	75.8

Increase in core loss only 2.7%."

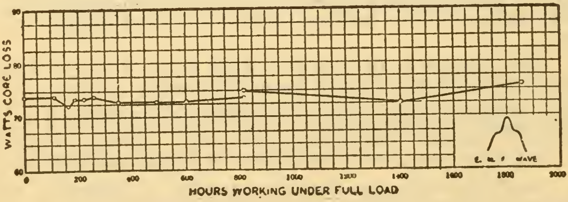


Fig. 21.

The above is the record of an ageing test on a 5000-watt 60-cycle Transformer. The test was made in the electrical laboratory of Purdue University, in May, 1900, the pressure wave of the generator being as indicated.

Table I. — Change of Hysteresis by Prolonged Heating.

Curve No.	1		2		3		4		5		6		7	
Temperature.	50° C.		65° C.		87° C.		135° C.		160° C.		182° C.		260° C.	
Time in days	Hysteresis.		Hysteresis.		Hysteresis.		Hysteresis.		Hysteresis.		Hysteresis.		Hysteresis.	
	Abs. C.G.S.	Increase per cent.	Abs. C.G.S.	Increase per cent.	Abs. C.G.S.	Increase per cent.	Abs. C.G.S.	Increase per cent.	Abs. C.G.S.	Increase per cent.	Abs. C.G.S.	Increase per cent.	Abs. C.G S.	Increase per cent.
0	635	0	620	0	600	0	610	0	590	0	665	0	595	0
1	...	...	635	2	695	16	960	57	1,480	151	1,680	153	1,030	73
2	...	...	695	12	770	29	1,020	67	1,600	172	.....	...	940	58
3	643	1.3	...	..	.....	...	1,090	78	.....	...	.....	...	....	..
4	...	...	710	14	885	48	.....	...	1,700	188	1,670	151	920	55
6	645	1.6	740	19	910	52	1,325	117	.....	...	1,540	132	940	58
7	...	...	775	25	915	53	.....	...	1,720	192	1,515	128	905	52
8	...	...	805	29	.....	..	1,415	132	1,650	180	.....	...	....	..
9	...	...	...	..	930	55	.....	...	1,590	170	1,445	117	910	53
12	...	...	855	37	960	61	1,450	138	.....	..	1 440	116	....	..
13	645	1.6	...	..	.....	..	.....	...	.....	...	.....	...	890	50
15	...	...	875	40	975	63	1,465	140	1 470	149	.....	...	900	51
20	660	4	940	51	1,090	82	....	...						
25	...	...	945	53	1 135	89	1,465	140						
27	690	9												

Regulation.

The most important factor in the life of incandescent lamps is a steady voltage, and a system of distribution in which the regulation of pressure is not maintained to within 2% is liable to considerable reduction in the life and candle-power of its lamps. For this reason it is highly important that the *regulation*, i.e., the change of voltage due wholly to change of load on the secondary of a transformer, be maintained within as close limits as possible.

In the design of a transformer, good regulation and low core loss are in direct opposition to one another when both are desired in the highest degree. For instance, assuming the densities will not be changed in the iron or in the copper, if we cut the section of the core down one-half we decrease the core loss one-half. The turns of wire, however, are doubled, and the reactance of the coils quadrupled, because the resistance changes with the square of the turns in series.

A well-designed transformer, however, should give good results, both as regards core loss and regulation, the relative values depending upon the class of work it is to do, and the size of the transformer.

Comparative Expense of Operating Large and Small Transformers.

It is obvious that the design of the distributing system has quite as much to do with the maintenance of a steady voltage as does the *regulation* of the transformers, and the proper selection of the size of transformers to be used requires skilled judgment.

When transformers were first used it was the custom to supply one for each house, and sometimes two or three where the load was heavy. Experience and tests soon made it evident that the installation of one large transformer in place of several small ones was very much more economical in first cost, running expenses (cost of power to supply loss), and regulation.

Where transformers are supplied one for each house, it is necessary to provide a capacity for 80 % of the lamps wired, and allowing an overload of 25% at times. Where one large transformer is installed for a group of houses, capacity for only 50% of the total wired lamps need be provided. For residence lighting, where the load factor is always very low, it is often best to run a line of secondaries over the region to be served, and connect a few large transformers to them in multiple.

A study of the following curves will show in a measure the results to be expected by careful selection and placing of the transformers. The first curve, Fig. 22, shows the relative cost per lamp or unit of transformers of different capacity, showing how much cheaper large ones are than small ones.

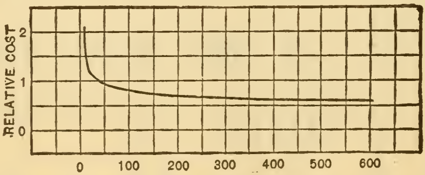


Fig. 22. Relative Cost of Transformers of Different Capacities.

The second set of curves (Fig. 23), shows the power saved at different loads, and using different sizes of transformers.

Power Factor is the ratio of the actual watts in a line to the volt amperes or apparent watts in that line. It is also defined as the cosine of the angle of phase displacement of the current from the voltage in the circuit.

The power factor of most commercial transformers is low at no load, varying from 50% to 70%, while at high loads the power factor is very

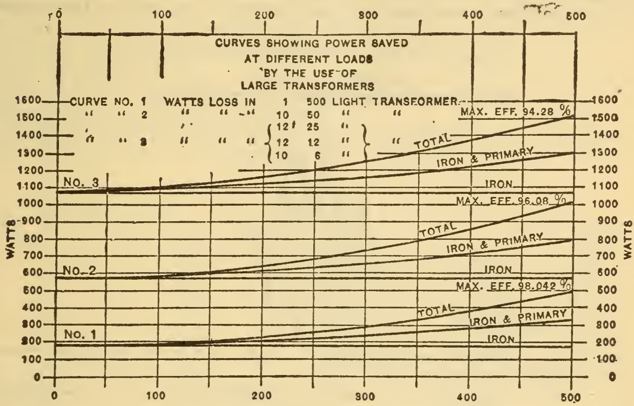


Fig. 23. Relative Efficiency of Large and Small Transformers.

nearly 100%. For this reason it is better to distribute the transformers on the line so that they will carry load enough most of the time to keep the power factor reasonably high.

TESTING TRANSFORMER.

The term testing transformer is a commercial one for describing a transformer used in testing the insulation of cables, transformers and other ap-

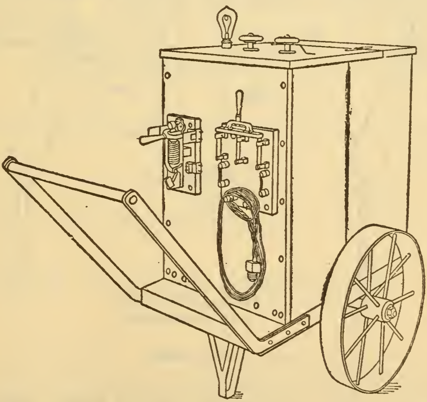


Fig. 24. Shop Testing Set. 0 to 12,000 Volts by 200 Volt Steps.

paratus. Such apparatus is generally tested at a voltage from 2 to 10 times the working pressure. It is necessary, therefore, to build such transformers for very high voltages, some having been made for pressures as high as 500,000.

Because of the severe nature of the service to which they are subjected it is essential that more than ordinary attention be paid to the insulation

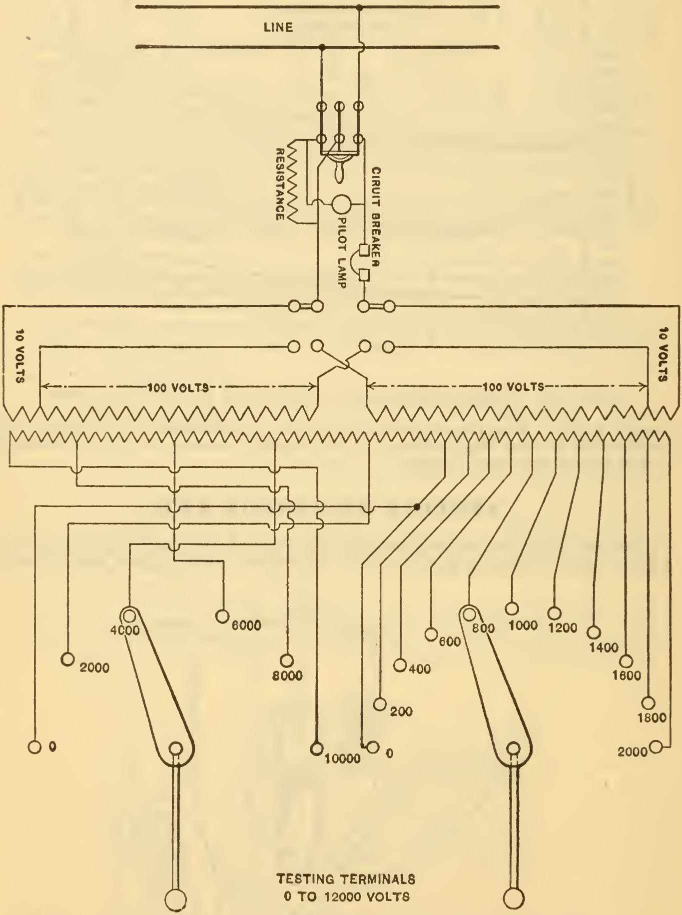


FIG. 25.

of the windings so that a minimum potential strain results between adjacent portions, and that sufficient insulation be provided between the two windings.

These transformers are generally of the core type of design, because the construction of this type of transformer lends itself more readily to the sub-division of the high voltage coils into separate and independent parts of few turns, thus reducing the potential strain within such coils to a very low figure.

Such transformers are almost invariably oil-insulated and the best practice is to place them in metal cases which are connected to the ground to protect the operator against accident from the static induced by the high voltage winding.

Figs. 24 and 26 show two types of this appliance, Figs. 24 and 25 showing a handy shop testing set with diagram of connections, and Fig. 26 showing a set for moderately high voltage.

The only practical way of measuring the high potential generated by these transformers is by spark-gap shunted across the terminals of the

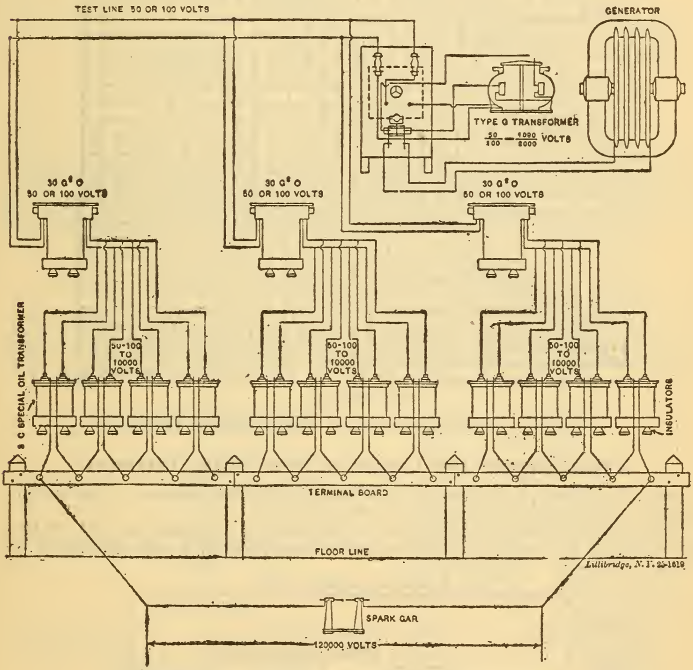


FIG. 26. S. K. C. High Voltage Testing Set.

transformer. Ordinarily the spark-gap is set for the desired voltage by use of a calibration curve or by preliminary calibration by means of a voltmeter connected to the low potential side, the ratio of the transformer being known.

A high resistance should be connected in series with the spark-gap to prevent the flow of an appreciable amount of current should the potential jump across the needle points: this will prevent the accumulation of high frequency voltage which might otherwise result.

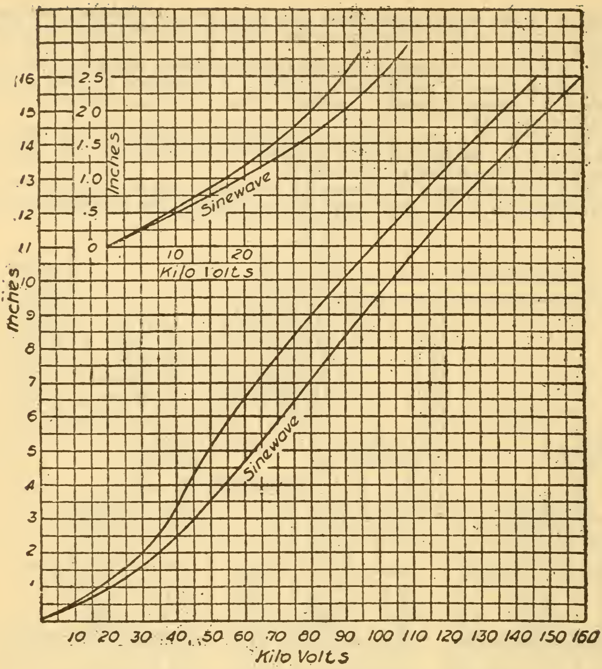


FIG. 27. Sparking Distances Across Needle Points.

Transformer for Constant Secondary Current.

Several methods have been tried with more or less success to obtain constant current at the secondaries of transformers.

The simplest and earliest system for obtaining a constant current in the secondary is by means of transformers whose primaries are connected in

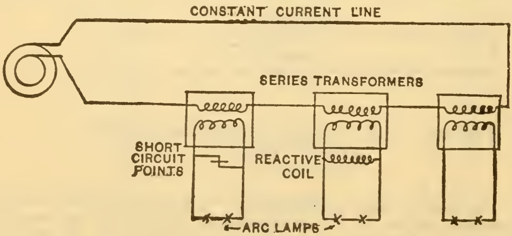


FIG. 28.

series, and a constant current maintained in the primary. This is shown in diagram in Fig. 28. Series transformers for this purpose have never been very successful, due to the trouble caused by the rise of potential in the secondary when opened for any cause. Various devices (Fig. 28), such as short-circuiting points separated by a paraffined paper, or a reactive or choking-coil connected across the secondary terminals, have been introduced to prevent any complete opening of the secondary by reason of any defect in the lamp or other device connected in the circuit.

Reactive coils used as shunt devices have been used under different names; as compensators, choking coils, and economy coils.

A device of this kind has been introduced by the Westinghouse Electric and Mfg. Company, and others, for use in street-lighting by series incandescent lamps. It is shown diagrammatically in Fig. 29. The lamp is

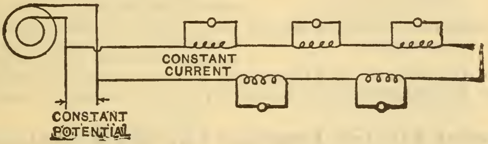


FIG. 29.

placed in shunt to the coil; when the filament breaks, the total current passes through the coil, maintaining a slightly higher pressure between its terminals than when the lamp is burning. It is thus evident that the regulation of the circuit is limited, due to the excessive reactance of the coils when several lamps are taken out of circuit.

Economy Coils or Compensators.

A modification of the above is built by several companies for use on ordinary low potential circuits, where it is desired to run two or three arc lamps. It is a single coil transformer, and is shown in Fig. 30, and diagrammatically in Fig. 31, same page. If any lamp is cut out or open-circuited,

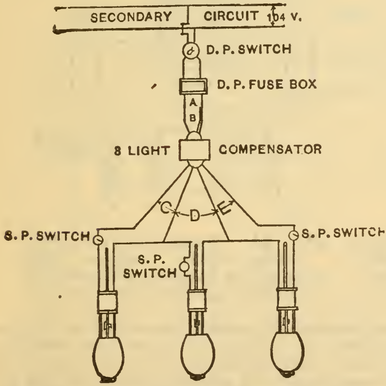


FIG. 30. Arrangement of Apparatus for use of Economy Coil or Compensator.

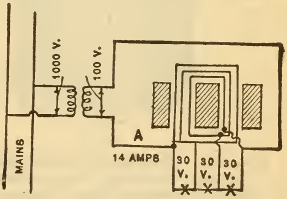


FIG. 31. Westinghouse Economy Coil, for A.C. Arc Lamps.

the current in the main line decreases slightly. As more lamps are cut out the remaining lamps receive less current, and it is necessary to replace the bad lamps in order to obtain normal current through the circuit.

Transformers for Constant Current from Constant Potential.

The transformers represented in Fig. 32 show a design that will give out an approximately constant current when connected to constant potential circuits. The transformer has its core so designed that there is a leakage path for the flux between the primary and secondary. This is shown in the diagram at *a* and *b*. At open secondary circuit there is little or no tendency for the flux to leak across the gap. When current flows through the secondary, thus creating a counter magneto-motive force, there is then a leakage across this path, and if properly proportioned, this leakage will act to regulate the current in the secondary, so that it will be approximately constant.

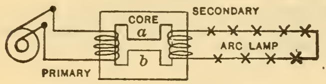


FIG. 32. Constant-Current or Series Transformer.

General Electric Constant Current Transformers.

The transformer thus described has the disadvantage that its regulation is fixed for any transformer and may vary in transformers of the same design without any ready means of adjustment. The transformer also regulates for constant current over but a limited range in the secondary loads.

The General Electric Company constant-current transformer shown in Figs. 35 and 36 is constructed with movable secondary coils, and fixed primary coils.

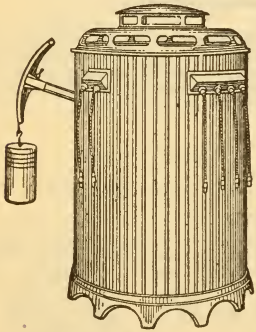


FIG. 33. Constant-Current Transformer showing Counterweight and Primary and Secondary Leads from Winding.

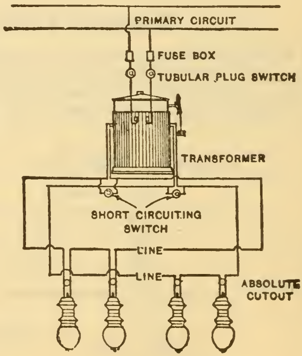


FIG. 34. Connections for Alternating Series Enclosed Arc Lighting System, with 50, 75, or 100 Light Transformer.

The weight of the movable coil is partially counterbalanced, so that at normal full-load current the movable coil or coils lie in contact (see Fig. 35) with the stationary coil, notwithstanding the magnetic repulsion between them. When, however, one or more lamps are out of the circuit, the increasing current increases the repulsion between the coils, and separates them, reducing the current to normal. (See Figs. 35 and 36.) At minimum load, the distance between the coils is maximum. The regulation is thus entirely automatic, and is found to maintain practically constant current, or a departure from constant current if desired. The transformer can be adjusted for practically constant current for positive regulation;

i.e., increasing current from full load to light loads, or for a negative regulation, i.e., decreasing current from full load to light loads. This adjust-

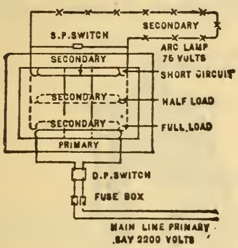


FIG. 35. Diagram of Connections.

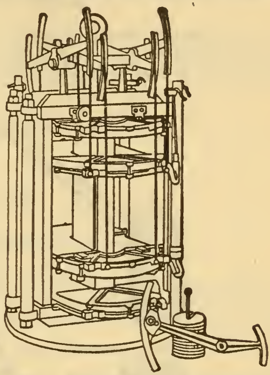


FIG. 36. Mechanism of Oil-Cooled Constant Current Transformer—100 Lamps.

ment is obtained by changing the position of a cam from which the counterweights are suspended. The curves shown in Fig. 37 show the range obtained in a 100-light transformer.

The transformers are enclosed in cast iron or sheet iron tanks filled with transil oil. The oil, in addition to being an insulating and cooling medium, serves to dampen any sudden movement of the secondary coils.

These transformers are connected to the regular constant potential mains,

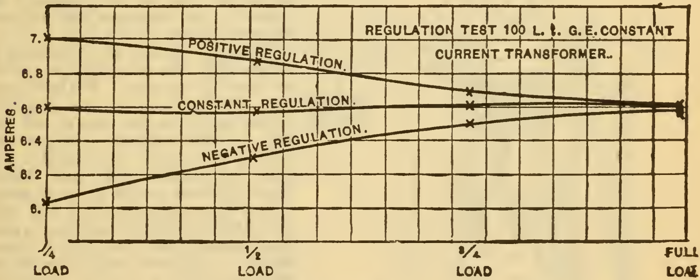


FIG. 37.

and the larger sizes are arranged for multiple circuits in the secondary. After having been started on a run the transformers need no attention, as they are entirely automatic in their action.

In the Westinghouse constant-current transformer the movable coil is partially counter-balanced by a weight or another movable coil, depending upon the size of the regulator. A dashpot is arranged to permit free separation of the coils, but slow approach. This device is important at starting and overcomes the tendency to pump, common to such transformers.

The full-load efficiency of this type is practically the same as that of a constant-potential transformer of the same capacity. The power factor of the system at full load is about 85 per cent, due to the reactance of alternating arc lamps. At fractional loads the power factors necessarily are much lower, and it is therefore not desirable to operate such a system at light load.

REACTANCE FOR ALTERNATING CURRENT ARC CIRCUITS.

For low voltage circuits required on transformers, a modification of the constant-current transformer has been devised in the regulating reactance connected in series with the line. Fig. 38 shows a typical construction

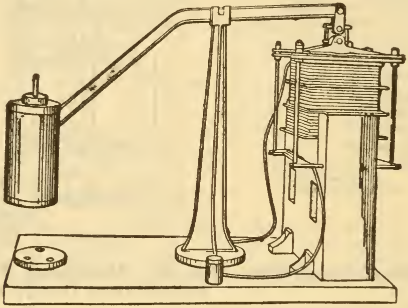


Fig. 38. Regulating Reactance Coil by Manhattan General Construction Co.

adopted by one of the leading manufacturers. It consists of a single coil of insulated wire arranged to inclose more or less of one leg of a "W"-shaped magnet as shown in the following cut. The coil is suspended from one end of a lever and counterbalanced by a weight on the other, and so arranged that at all points of its travel it just balances the varying magnetic pull of the coil.

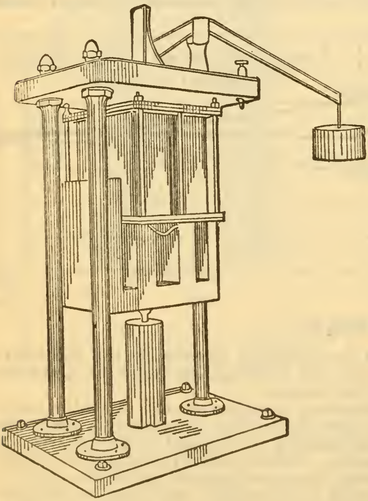


Fig. 39. "G. I." Series A. C. Regulator.

The arc circuit is connected in series with this coil with a switch to open the circuit. Without current flowing, the normal position of the coil is at the top or off the leg of the magnet. When the switch is closed, current flows in the circuit (and coil), and draws the coil down on the leg to a point where the reactance of the coil holds the current strength at a predetermined point; as, say, 6.6 amperes. It is said that this device will maintain a current constant within one-tenth of an ampere.

The losses are the iron losses and I^2R losses in the coil, which, with constant current, are the same under all conditions of load.

As it is not always, or even often, that it is necessary to provide for regulation of an arc circuit to the extent of its full load, the makers have adopted the policy of supplying instruments to care for but that part of the load that is expected to vary, in some cases 10% of the circuit and in others 75%, thus avoiding the need for larger apparatus, or for insulation for the total voltage of the circuits.

They claim another advantage in being able to connect the device in one leg of the series circuit, and allowing the other end of the circuit to be connected to the mains at any such point as may be the nearest at hand.

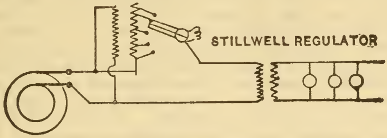


FIG. 40.

Potential Regulators.

An alternating current potential regulator is essentially a transformer having its primary connected across the mains, and its secondary in series with the mains. The secondary is arranged so that the voltage at its terminals can be varied over any particular range.

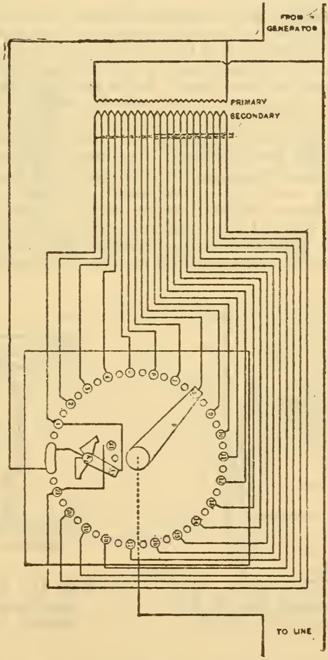


FIG. 41. Diagram of Connections for Single-Phase Potential Regulator, Westinghouse Elec. and Mfg. Co.

The several different styles of feeder regulators have been devised, differing in principle of operation, but all of them have the primary coil connected across the mains, and the secondary coils in series with the mains.

The "Stillwell" regulator, which was designed by Mr. L. B. Stillwell, has the usual primary and secondary coils, and effects the regulation of the circuit by inserting more or less of the secondary coil in series with the line. This secondary coil has several taps brought out to a commutating switch, as shown in Fig. 40. The apparatus is arranged so that the primary can be reversed, and therefore be used to reduce as well as to raise the voltage of the line. It is evident from an observation of the diagram that if two of the segments connected to parts of the coils were to be short-circuited, it would be almost certain to cause a burn-out. To prevent this, the movable arm or switch-blade is split, and the two parts connected by a reactance,

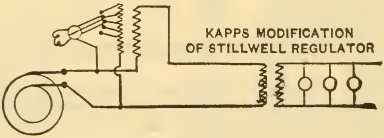


FIG. 42.

this reactance preventing any abnormal local flow of current during the time that the two parts of the switch-blade are connected to adjacent segments. The width of each half of the switch-arm must of necessity be less than that of the space or division between the contacts or segments.

As the whole current of the feeder flows through the secondary of the booster, the style of regulator which effects regulation by commutating the secondary cannot well be designed for very heavy currents because of the destructive arcs which will be formed at the switch-blades. To overcome this difficulty, Mr. Kapp has designed the modification which is shown in Fig. 42. In this regulator the primary is so designed that sections of it can be commutated, thus avoiding an excessive current at the switch. This regulator, however, has a limited range, as the secondary always has an E.M.F. induced in it while the primary is excited; and care must be taken to see that there are sufficient turns between the line and the first contact in order to avoid excessive magnetizing current on short circuit.

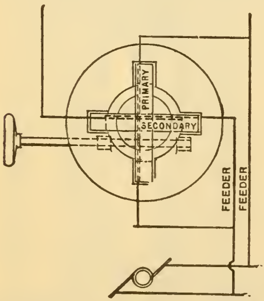


FIG. 43. Connections for M. R. Feeder Regulator of G. E. Co.

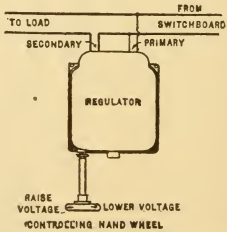


FIG. 44. Diagram of Connections of Feeder Potential Regulator.

The General Electric Company have brought out a feeder regulator, in which there are no moving contacts in either the primary or secondary, and which can be adapted for very heavy currents. This appliance is plainly shown in Figs. 43 and 44. The two coils, primary and secondary, are set at right angles in an annular body of laminated iron, and the central laminated core is arranged so as to be rotated by means of a worm wheel and shaft as shown.

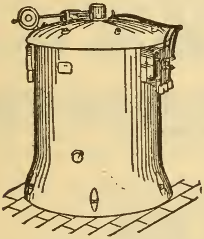
The change in the secondary voltage, while boosting or lowering the line voltage, is continuous, as is also the change from boosting or lowering, or *vice versa*. In this regulator, the change of the secondary voltage is effected by the change in flux through the secondary coil, as the position of the movable core is changed by the turning of the hand wheel and shaft. There are, therefore, no interruptions to the flow of current through either the primary or secondary coils, and the regulator is admirably adapted for incandescent lighting service, where interruptions in the flow of current, however instantaneous, are objectionable.

Separate Circuit Regulators.

Where a number of circuits are run out from the same set of bus bars, regulation of each circuit is provided for by the use of a single coil transformer from various points, on the winding of which leads are brought out to a regulator head, from which any part or all of the transformer may be thrown into service to increase the pressure on the line.

Three-Phase Regulators.

The regulator described above is suitable only for operation on single-phase circuits. The primary is connected in a shunt and the secondary in series with the circuits to be controlled. Two or three-phase regulators of similar design, but having either primary or secondary on the moving



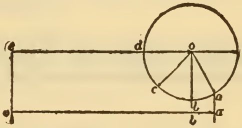


FIG. 45. Three-Phase Induction Potential Regulator.

core, are commonly used. The voltage in such a design is constant in each phase of the secondary winding, but by varying the relative positions of primary and secondary the effective voltage of any phase of the secondary in its circuit is varied from maximum boosting to maximum lowering.

Referring to the diagram which represents graphically the voltage of a single phase of the regulator, *e o* = Generator voltage or the E.M.F. impressed on the primary; *a o* = E.M.F. generated in the secondary coils, and is constant with constant generator E.M.F.; *b′ a′* = Secondary E.M.F. in phase with the generator E.M.F.; *e′ a′* = Line E.M.F. or resultant of the generator E.M.F. and the secondary E.M.F.

The construction of the regulator is such that the secondary voltage *o a* is made to assume any desired phase position relative to the primary E.M.F., as *o f*, *o b*, *o c*, etc.

When its phase relation is as represented by *o f*, which is the position when the north poles and the south poles of the primary and secondary windings are opposite, the secondary voltage is in phase with the primary voltage and is added directly to that of the generator. The regulator is then said to be in the position of maximum "boost," and by rotating the armature with reference to the fields, the phase relation can be changed to any extent between this and directly opposed voltages. When the voltage of the secondary is directly opposed to that of the primary or generator, its phase relation is as represented by *o d* in the diagram, while *o b* represents the phase relation of the secondary when in the neutral position.

THREE-PHASE TRANSFORMERS.

This type of transformer has been commonly used "abroad" for a long time and has recently been introduced into American practice. Such transformers differ little from the single-phase designs and may be built in either core and shell type.

The three-phase shell type transformer consists simply of the single-phase units so united that considerable of the iron in the core becomes unnecessary. This is illustrated by the following cuts.

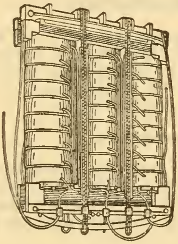


Fig. 46. Three-Phase Core Type Transformer.

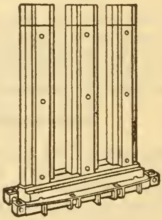


Fig. 47. Core of Three-Phase Core Type Transformer.

A three-phase core type transformer consists of three legs of single-phase core transformer placed side by side and united at either end by a yoke of the same cross section as each single-phase leg.

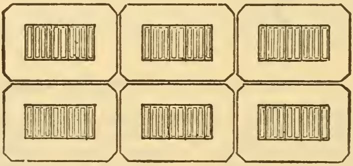


Fig. 48. Cross Section of the Cores and Coils of Three Single-Phase Air-Blast Transformers.

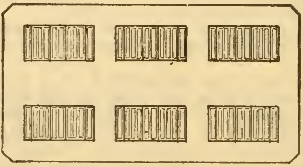


Fig. 49. Cross Section of the Same Coils Combined in One Three-Phase Air-Blast Transformer of a Capacity Equal to the Total Capacity of Those Above.

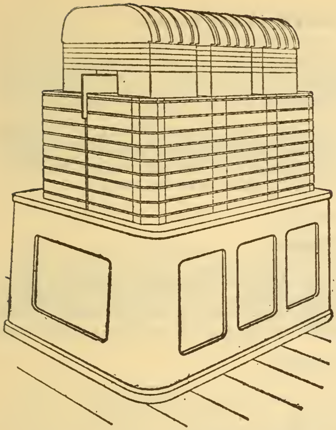


FIG. 50. Three-Phase Air-Blast Transformer in Process of Building.

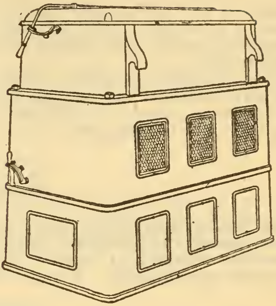


FIG. 51. A Typical Three-Phase Air-Blast Transformer.

RATIO OF TRANSFORMATION IN THREE-PHASE SYSTEMS.

Transformers are usually built with both their primary and secondary coils wound in two or more sections in order to facilitate changes of transformation ratio. This is especially useful where three transformers are used in a three-phase system. Let

n = ratio of transformation from one section of high-tension side to one section of low-tension side, expressed as an integer;
Y = total number of sections in series in each arm of the star, high-tension side;
D = total number of sections in series in each arm of the delta, high-tension side;

y, and d, being the corresponding quantities for the low-tension side.

Then, $$\frac{\text{H.T. line volts}}{\text{L.T. line volts}} = n\,\frac{Y\sqrt{3}+D}{y\sqrt{3}+d}.$$

This formula is applicable to combination stars and deltas as well as to simple stars and deltas.

EXAMPLE. — Fig. 52 shows a combined star and delta for the H.T. side and a simple star for the L.T. side.

$$\text{Ratio} = 10\,\frac{2\sqrt{3}+3}{3\sqrt{3}+0},$$

as $n = 10$,
$Y = 2$, $y = 3$,
$D = 3$, $d = 0$.

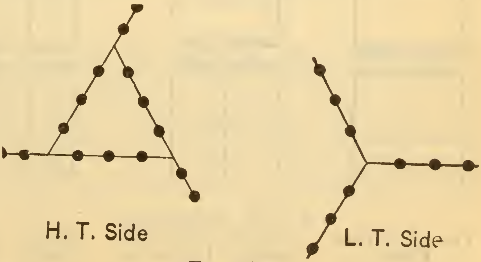


FIG. 52.

TRANSFORMER CONNECTIONS.

Some of the advantages claimed for alternating current systems of distribution over the direct current systems is the facility with which the potential, current, and phases can be changed by different connections of transformers.

On single-phase circuits, transformers can be connected up to change from any potential and current to any other potential and current; but in a multi-phase system, in addition to the changes of potential and current, the phases can be changed to almost any form that may be desired.

Single-Phase.

The connections of the single-phase step-down and step-up transformers, having parallel connections, need no explanation. For residence lighting, a favorite method of supply is through single-phase transformers with three-wire secondaries. A tap is brought out from the middle of the sec-

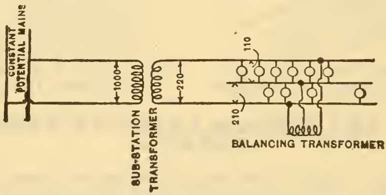


FIG. 53. Arrangement of Balancing Transformer for Three-Wire Secondaries.

ondary winding, this tap connecting to the middle or neutral of the three-wire system. In this way a few large transformers can be connected by three-wire secondaries in a residence or other district, and will take care of a large number of connected lamps.

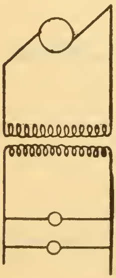


FIG. 54. Single-Phase.

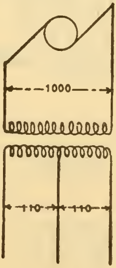


FIG. 55. Single-Phase, with Three-Wire Secondary, Useful for Residence Circuits.

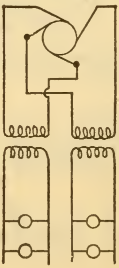


FIG. 56. Two-Phase, Four Wires.

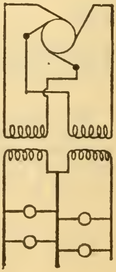


FIG. 57. Three-Wire, Two-Phase.

Kapp shows a modification of the three-wire circuits, in which the outside wires are fed by a single transformer, and the neutral wire is taken care of by a balancing transformer, connected up at or near the center of distribution. The capacity of the balancing transformer need be but half the greatest variation in load between the two sides.

Some makers of transformers have the connection board in their transformers so arranged that the two primary coils may be connected either in series or parallel by mere changes of small copper connecting links, so that the same transformer can be connected up for either 1000- or 2000-volt circuits, and the secondary for either 50 or 100 volts.

Two-Phase.

The plain two-phase or quarter-phase connection (Fig. 56) is simply two single transformers connected to their respective phases, the phases being kept entirely separate. In the three-wire quarter-phase circuit, one of the leads can be used as a common return, as shown in Fig. 57.

Three-Phase.

The three-phase connections shown in diagram 58 are known as the delta connections, and are of great advantage where continuity of service is very important. The removal of any one transformer does not interrupt

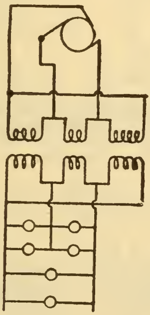


Fig. 58. Three-Phase Delta Connection.

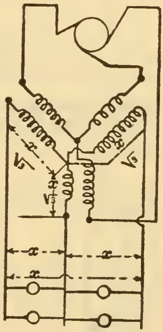


Fig. 59. Three-Phase Star Connection.

the three-phase distribution, and the removal of two transformers still admits of power transmission on a single phase of the circuit.

The Y or star connection, as shown in diagram 59, has one of the terminals of each primary and secondary brought to a common connection, the remaining three terminals being brought to the main line and the distributing lines. The advantage of the star connection over the delta connection is, that for the same transmission voltage each transformer is wound for only 58% of the line voltage. In high-voltage transmission this admits of much smaller transformers being built for high potentials than is possible with the delta connection.

Arrangement of Transformers for Stepping Up and Down for Long Distance Transmission.

Figures 60, 61, and 62 show diagrammatically the connections for adapting three-phase transmission to quarter-phase generators, with interchangeable and non-interchangeable transformers.

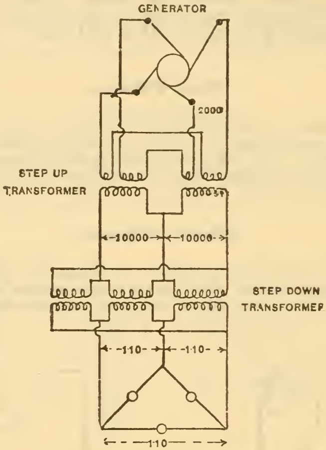


FIG. 60. Changing Quarter-Phase to Three-Phase, Non-Interchangeable Step-up Transformers.

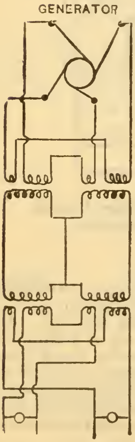


FIG. 61. Changing Quarter-Phase to Three-Phase, and back to Quarter-Phase. All Transformers Interchangeable.

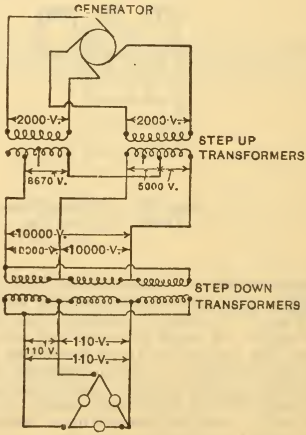
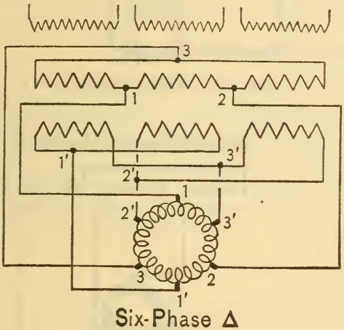


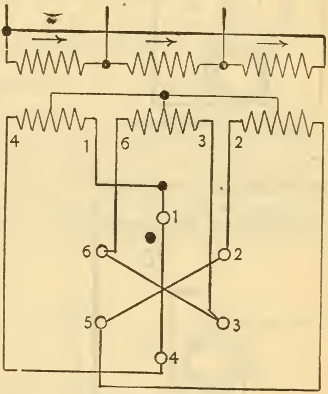
FIG. 62. Changing Quarter-Phase to Three-Phase. All Step-up Transformers Interchangeable.

Three-Phase to Six-Phase Connections.

A rotary converter wound for six-phase has a greater capacity for work than the same machine wound for three-phase. Three-phase transmission, however, is very economical, and in Figs. 63 and 64 is shown a diagram by which six phases can be obtained from three phases by the use of only three transformers.

Each transformer has two secondary coils. One secondary of each transformer is first connected into a delta, then the remaining secondary coils are





FIGS. 63 and 64. Three-Phase to Six-Phase Connection.

connected up into a delta, but in the reverse order of the first delta. This is an equivalent of two deltas, one of which is turned 180° from the other. In the diagram ABC represents one delta, and DEF the other.

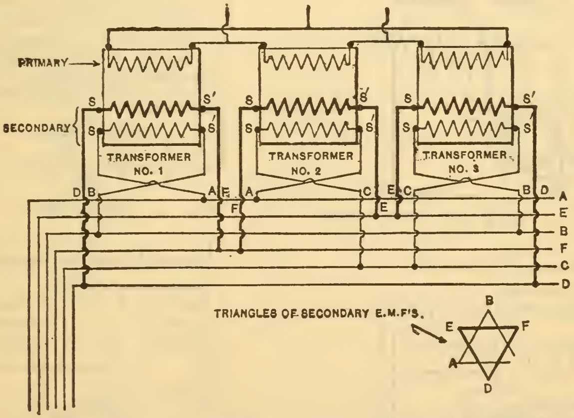


FIG. 65. Diagrams of Connections for Changing from Three-Phase to Six-Phase.

In the same way the two secondaries can be connected up Y, and one Y turned 180° to obtain six phases. The disadvantage of Y connection, however, is that in case one transferrer is burned out, it is not possible to continue running, as can be done with delta connections

Methods of Connecting Transformers to Rotary Converters.

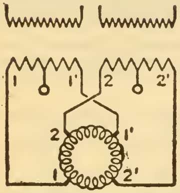


FIG. 66. Two-Phase.

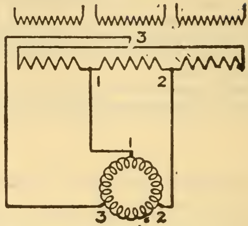


FIG. 67. Three-Phase Δ.

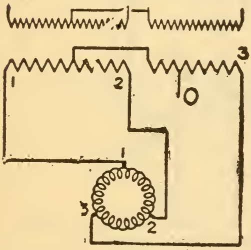


FIG. 68. Three-Phase T.

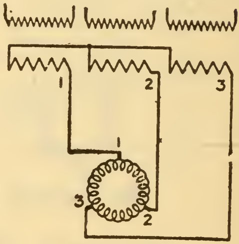


FIG. 69. Three-Phase Y.

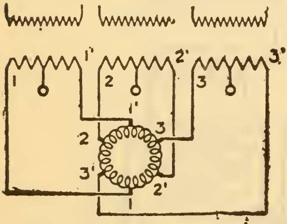


FIG. 70. Six-Phase Diametrical.

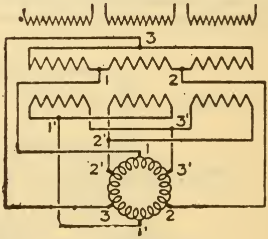


FIG. 71. Six-Phase Δ.

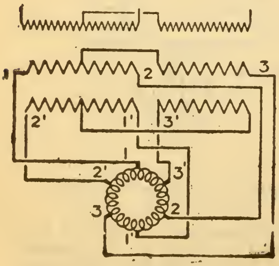


FIG. 72. Six-Phase T.

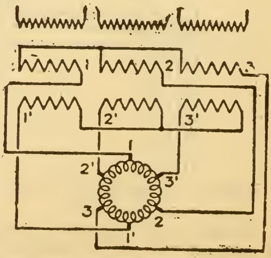


FIG. 73. Six-Phase Y.

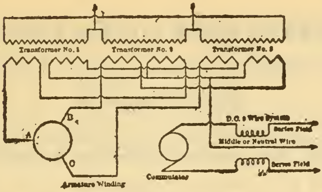


FIG. 74. Three Transformers Arranged in Inter-connected Star, Operating a Three-Phase Rotary Converter on a D. C. Three-Wire System.

Converter and Transformer Connections.

The "Scott" connection is used a great deal in transmissions and distributions (See Fig 75.) One transformer is designated the main, and the other the teaser. Two transformers are required. They are made exactly alike, so that with proper connections either may be used as main or teaser. The winding is provided with a 50% tap and with taps so that 86.6% of the winding may be used. 1–2–3 are three-phase voltage, *A–A′* one-phase, *B–B′* the other of the two-phase circuit. Reference to the small diagram shows the reason for using 86 6% of winding of one transformer; also the necessity for the 50% tap.

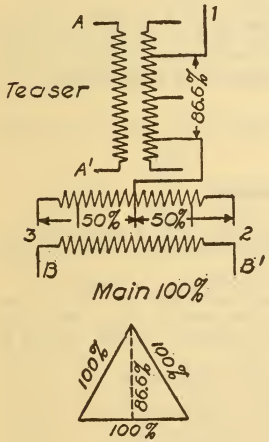


FIG. 75.

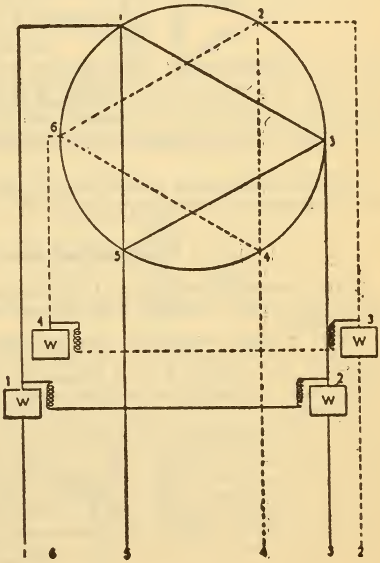


FIG. 76.

MEASURING POWER IN SIX-PHASE CIRCUITS.

Use two pairs of wattmeters, each pair connected to one of the three-phase circuits as shown in Fig. 76. If power factor is less than 60% one meter of each pair will read negative. The algebraical sum of the readings of each of the two pairs will be the result required.

Y OR Δ CONNECTION OF TRANSFORMERS.

(F. O. Blackwell. Trans. A. I. E. E., 1903.)

Transformers.

Assuming that three transformers are to be used for a three-phase power transmission and that the potential of the line is settled, each of the transformers, if connected in Y, must be wound for $\frac{1}{\sqrt{3}}$ or about 58 per cent of the line potential, and for the full line current. If connected in Δ, each transformer must be wound for the line potential and for 58 per cent of the line current. The number of turns in the transformer winding for Y connection is, therefore, but 58 per cent of that required for Δ connection, to avoid eddy current losses that occur when the cross section of the conductor is too large.

The Y connection requires the use of three transformers, and if anything goes wrong with one of them the whole bank is disabled. With the Δ connection, one of the transformers can be cut out and the other two still deliver three-phase power up to 86.6 per cent of their aggregate capacity, or 66.6 per cent of the capacity of the entire bank.

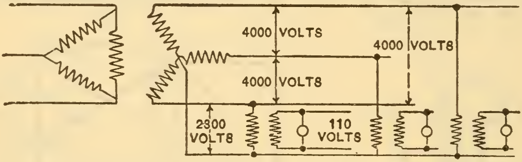


FIG. 77. Step-down Transformer for 4000 Volt Y Distribution.

Combined three-phase transformers are now made of any size and are preferably Y connected on the high potential side.

Grounding the Neutral.

If the common connection of transformers joined in Y is grounded, the potential between windings and the core is limited to 58 per cent of that of the line.

Under normal conditions, the potential between any conductor of a three-phase transmission circuit and the ground is 58 per cent of the line potential, with either Y or Δ connection, but the neutral may drift so as to increase the potential with an ungrounded system. If one branch is

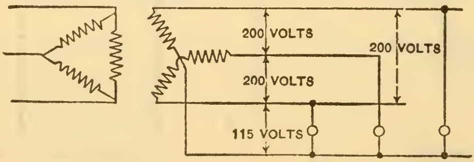


FIG. 78. Step-down Transformer for 200 Volt Y Distribution.

partly or completely grounded, the potential between the other two branches and the ground is, of course, increased and may be the full line potential. With a grounded neutral Y system, a ground is a short circuit of the transformers on the grounded branch, and the transmission becomes inoperative.

From the point of view of safety to life and prevention of fires this is a desirable condition, especially if the low tension distribution is also grounded. If the high tension circuit makes contact with the ground or low potential system, it can be immediately cut out by fuses or automatic circuit breakers.

The difficulty is that a power transmission with grounded neutral is likely to be frequently shut down by temporary grounds, such as would be caused by a tree blowing against one of the wires. Even if the circuit is not opened, the drop in the pressure due to the sudden "short" on the line will cause synchronous apparatus to fall out of step.

Unstable Neutral.

If two transformers are connected in series, there is no certainty that they will divide the potential equally between them. A system in which all the electrical apparatus is connected in Y has somewhat the same characteristics. The neutral may drift out of its proper place and there will be unequal potentials between it and the three conductors of the circuit, due to unequal loading and differences in the transformers or transmission circuits. Such unbalancing would cause unequal heating of the transformers, and if a four-wire three-phase system of distribution were employed, would seriously interfere with the regulation of the voltage. If transformers, therefore, have Y secondaries, it is desirable that the primary should be Δ connected. Two systems in common use with which Δ primary windings should be used, are shown in Figs. 77 and 78.

Rise of Potential.

The high potential windings of transformers are necessarily of high reactance, and if left in series with a circuit of large capacity, as shown in Figs. 79, 80, 81, and 82, the leading charging current flowing over the reactance may set up extraordinarily high pressures. Figs. 79 and 80 represent Y-connected banks of three transformers each connected so as to cause such

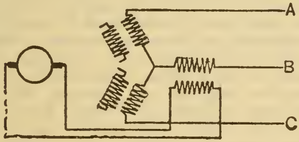


FIG. 79.

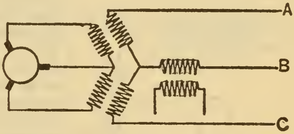


FIG. 80.

a rise of potential. In Fig. 79 the primary of one transformer is excited by a generator, the primary of the other two transformers being open-circuited. In Fig. 80 the primary of one transformer is open-circuited, the other two being connected to the generator. Figs. 81 and 82 show T-connected banks of two transformers, which might be used to transform from either two-phase or three-phase to three-phase or vice versa, and are similar in action to Fig. 79. If in any one of Figs. 79, 80, 81 and 82 the secondaries are connected to a long distance transmission circuit, a pressure of many times the normal potential will be set up between A and B, and between B and C, that between A and C not being affected.

It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches of one or more of the transformers of a bank connected in Y before the secondary switches are used. Actually, the current jumps across the insulation at some point in the system before there can be any such increase in pressure. If there are a number of banks of transformers in parallel, this phenomena cannot occur except when all but one bank are disconnected. This source of trouble could be obviated by employing oil switches on the high potential side which disconnect the line before the low tension switches are used, or by triple pole switches on the primary which open all three branches of the bank of transformers at once.

The selection of Y or Δ connection of transformers for long distance

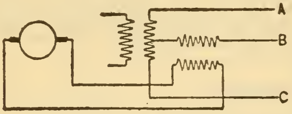


FIG. 81.

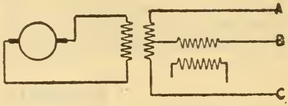


FIG. 82.

transmissions should only be determined after a careful consideration of the conditions in each case.

There is little choice between Y or Δ without a grounded neutral.

NOTE.— For further information on this subject see discussion on this paper in Proceedings of A. I. E. E. for 1903.

GENERAL ELECTRIC COMPANY MERCURY ARC RECTIFIERS.

(By P. D. Wagoner.)

A detailed idea of the operation of the mercury arc rectifier circuit may be obtained from Fig. 83. Assume an instant when the terminal *H* of the supply transformer is positive, the anode *A* is then positive and the arc is free to flow between *A* and *B*, *B* being the mercury cathode. Following the direction of the arrows still further the current passes through the load *J*, through the reactance coil *E* and back to the negative terminal *G* on the transformer. A little later, when the impressed electromotive force falls below a value sufficient to maintain the arc against the counter electromotive force of the arc and load, the reactance *E*, which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly. This serves to maintain the arc in the rectifier until the electromotive force of the supply has passed through zero, reverses and builds up to such a value as to cause *A′* to have a sufficiently positive value to start an arc between it and the mercury cathode *B*. The discharge circuit of the reactance coil *E* is now through the arc *A′B*, instead of through its former circuit. Consequently the arc *A′B* is now supplied with current, partly from the transformer and partly from the reactance coil *E*. The new circuit from the transformer is indicated by the arrows inclosed in circles. The amount of reactance inserted in the circuit reduces the pulsations of the direct current sufficiently for all ordinary commercial purposes. Where it is advisable to still further reduce the amplitude of the pulsations, as, for instance, in telephone work, this is done with very slight reduction in efficiency by means of reactances.

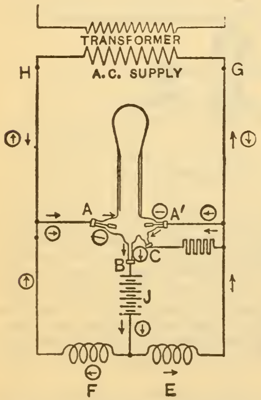
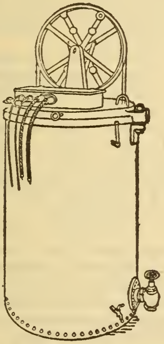


FIG. 83. Rectifier Connections Shown Diagrammatically.

WESTINGHOUSE MERCURY ARC RECTIFIER OUTFITS.

For Arc Lamps.

These outfits are a development of the constant current transformer adapted for use with the mercury rectifier, receiving alternating current at a constant potential, and delivering a constant direct current. By a special



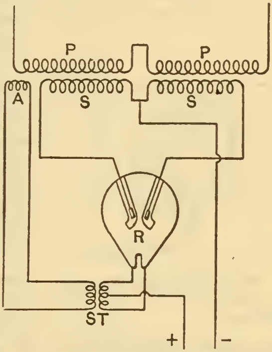


Fig. 84 and Fig. 85. Diagrams of Westinghouse Mercury Arc Rectifier.

arrangement of coils the usual sustaining reactance is omitted, resulting in reduced floor space and an improved efficiency. A boiler iron tank with cast iron cover, two alternating currents and two direct currents leads, describes the simple and rugged appearance of an outfit. (See Fig. 84.)

The connections (Fig. 85) explain the operation. *P–P* and *S–S* are respectively the primary and secondary; *ST* the starting transformer, *R* the rectifier, and *A* the auxiliary coil for exciting the starting transformer.

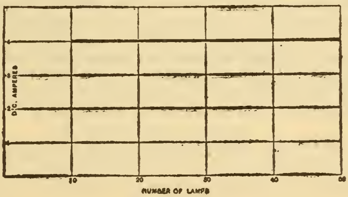


Fig. 86.

The outfit is started by tipping the bulb, causing a spark between the terminals of the starting transformer as the current path through the mercury is interrupted. This breaks down the high resistance of the negative electrode and permits the establishment of the direct current.

The bulb is carried in a box which is easily slid in or out between guides to the bottom of the containing tank, thus making the bulb replacement a matter of but a few moments.

Simple variable weights permit of adjusting the transformer so as to deliver its exact rated direct current (Fig. 86), at all loads.

The power factor at full load averages over 70 per cent and the efficiency well over 90 per cent for all sizes of rectifier outfits. These are regularly built in 25, 35, 50, 75 and 100 light capacities, either 25 or 60 cycles, for 2200 V., 6600 V., 11,000 V., and 13,200 V. circuits.

For Battery Charging.

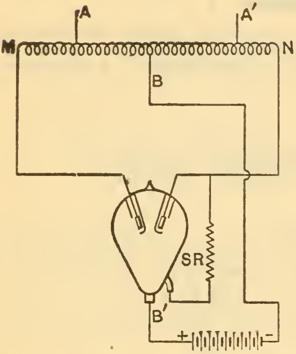


FIG. 87. Westinghouse Mercury Arc Rectifier for Battery Charging.

These outfits are intended to operate from low constant potential circuits and deliver a constant D. C. voltage, varying from 5 to 125 volts, according to design.

Fig. 87 indicates a method of connection which is essentially the same as for the arc lighting outfits. *SR* is a starting resistance, for the rectifier; *MN*, the autotransformer, *BB′* the D. C. terminals, and *AA′* the A. C. terminals.

These outfits are started by tipping the bulb. A spark due to interrupting the current in the starting resistance breaks down the high negative electrode resistance, permitting the direct current to be established. In this outfit, like the arc outfit, a special arrangement of coils permits the omission of the usual sustaining coil. The D. C. voltage is varied by changes in the connection to the autotransformer, or by changes in the A. C. impressed voltage made by an adjustable series reactance. Control panels carrying instruments, control dial, circuit breaker, etc., are furnished. Thirty amperes, 110 volts, is at present the maximum capacity for which these outfits are built, for either 25 or 60 cycle service.

TRANSFORMER TESTING.

Although the standard types of transformers of to-day are made on lines found by long experience to be the best for all purposes, and are subject to careful inspection and test at the factory in most cases, yet the various makers have such different ideas as to the value of the different points, that in order to obtain fair bids on such appliances when purchased, it is always best to prepare specifications, and the buyer should be prepared to conduct or check tests to determine whether the specifications have been fulfilled. Large stations should have a full outfit of apparatus for conducting such tests ; but smaller purchasers can do quite well by having a competent superintendent, or by hiring an outside engineer to witness the tests at the factory. It is not always necessary to put each individual transformer through all the tests, but the break-down test for insulation should be applied to all.

Prof. Jackson gives the following requirements for guaranties of transformers.

Iron loss for 1000-volt transformers and for frequencies over 100 as follows :

Capacity.	Iron Loss.	Exciting Current.
1000 watts	30 watts	.055 amperes.
1500 watts	40 watts	
2000 watts	50 watts	.080 amperes.
2500 watts	60 watts	
4000 watts	80 watts	
6500 watts	100 watts	.150 amperes.
17500 watts	150 watts	.200 amperes.

For frequencies less than 100 it may be advisable to allow 10 % higher loss to avoid excessive cost.

NOTE. — Guaranties for iron loss should cover ageing for at least one year.

Drop in secondary pressure not to exceed 3 % between no load and full load.

Rise of temperature after 10 hours' run under full load, 70° F. (about 40° C.).

NOTE. — This measurement was probably meant by Professor Jackson to be made by thermometer. It is better to take the rise by resistance measurement, in which case the allowable temperature is 50° C.

Disruptive strength of insulation after full-load run, between coils and between primary coil and iron, at least 10 times the primary voltage. Insulation resistance to be not less than 10 megohms, and guaranteed not to deteriorate with reasonable service.

NOTE. — See previous matter as to test voltage.

Exciting current for 1000-volt transformers not to exceed values given in the above table, when the frequency is above 100. The exciting current *increases* as the frequency *decreases*, and varies inversely as the voltage. For intermediate capacities proportional values may be expected.

He further says : "*Transformers which do not meet the insulation and heating guaranties are unsafe to use upon commercial electric lighting and motor circuits, while those which do not meet the iron loss, regulation, and exciting current guaranties waste the company's money.*"

The characteristics of a transformer, to be determined by tests, are as follows :

(1) Insulation strength between different parts.
(2) Core loss and exciting current.
(3) Resistances of primary and secondary and I^2R.
(4) Impedance and copper loss, direct measurement.
(5) Heating and temperature rise.
(6) Ratio of voltages.
(7) Regulation and efficiency, which may be calculated from the results of tests (2), (3), and (4), or may be determined directly by test.
(8) Polarity.

The instruments required to make these tests should be selected for each particular case, and consist of ammeters, voltmeters, and indicating wattmeters.

For central station work, the following instruments will suffice for nearly any case which may come up in ordinary practice.

A. C. Voltmeter, reading to 150 volts, and with multiplier to say 2500 volts.

A. C. Ammeter, reading to 150 amperes, with shunt multiplier if necessary to carry the greatest output.

Indicating wattmeter, reading to 150 or 200 watts.

NOTE. — For full data and examples of transformer testing, see pamphlet No. 8126, "Transformer Testing for Central Station Managers," by General Electric Company, and Westinghouse Pamphlet No. 7035.

Insulation Test.

This is the simplest and most important test to be made, for the reason that one of the principal functions of a transformer is its ability to thoroughly and effectually insulate the secondary circuit from the primary circuit.

Tests of the insulation of practically all high-potential apparatus are now carried out by high pressure, rather than by test of the insulation resistance by galvanometer. Some insulations will show a very high test by galvanometer, but will fail entirely under test with a voltage much exceeding that at which it is to be used. On the other hand, it is not uncommon to find insulation such that, while the galvanometer tests show low resistance, it will not break down at all under the ordinary voltages. For this reason, it is common practice among manufacturers of transformers to apply a moderately high voltage, from two to three times the working voltage, for a short period, usually about one minute.

The Committee on Standardization of the A. I. E. E. has given certain voltages which they recommend to be used in the testing of all electrical apparatus, and the tables and methods of application for the testing of transformers will be found in paragraphs Nos. 217 to 221, both inclusive in the latest revision of the rules of that Committee which will be found elsewhere in the book.

In standard transformers these insulation tests should be (1) between primary and secondary, and between primary and core and frame; (2) between secondary and core and case.

To obviate any induced potential strain, the secondary should be grounded while making the test between the primary and secondary, and between primary and core and case.

In testing between the primary and secondary, or between the primary and core and frame, the secondary must be connected to the core and frame.

It is also important that all primary leads should be connected together as well as all secondary leads, in order to secure throughout the winding a uniform potential strain during the test.

NOTE. — *See index for sparking-gap curve, and use new needles after every discharge.*

From one point of view, the factor of safety of the secondary need not be greater than that of the primary, and if 10,000 volts is considered a sufficient test for a 2000-volt primary, 1000 volts might be sufficient for a 200-volt secondary. But a thin film of insulation may easily withstand a test of 1000 volts, although it is so weak mechanically as to be dangerous. A 200-volt secondary should therefore be tested for at least 2500 volts in order to guarantee it against breakdown due to mechanical weakness.

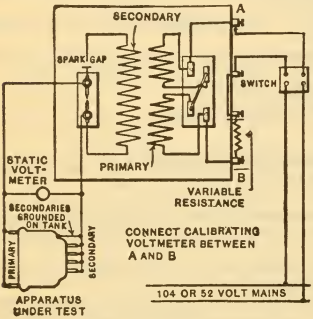


FIG. 88.

The duration of the insulation test may vary somewhat with the magnitude of the voltage applied to the transformer. If the test is a severe one, it should not be long continued; for while the insulation may readily withstand the momentary application of a voltage five or ten times the normal strain, yet continued application of the voltage may injure the insulation and permanently reduce its strength.

Attention has been called to the fact that in testing between the primary and the core or the secondary, the secondary should be grounded. In testing between one winding and the core, for example, an induced potential strain is obtained between the core and the other winding which may be much greater than the strain to which the insulation is subjected under normal working conditions, and greater therefore than it is designed to withstand. In testing between the primary and the core, the induced potential between the secondary and the core may be several thousand volts, and the secondary may thus be broken down by an insulation test applied to the primary under conditions which do not exist in the natural use of the transformer.

Attention is further called to the fact that during the test all primary leads as well as all secondary leads should be connected together. If only one terminal of the transformer winding is connected to the high potential transformer, the potential strain to which it is subjected may vary throughout the winding, and may even be very much greater at some point than at the terminals to which the voltage is applied. Under such conditions the reading of the static voltmeter affords no indication of the strain to which the winding is subjected.

Indications which are best learned by experience reveal to the operator the character of the insulation under test. The transformer in test requires a charging current varying in magnitude with its size and design. From the reading of the ammeter, placed in the low potential circuit of the testing transformer, the charging current may be ascertained. It will increase as the voltage applied to the insulation is increased.

If the insulation under test be good there will be no difficulty in bringing the potential up to the desired point by varying the rheostat. If the insulation be weak or defective, it will be impossible to obtain a high voltage across it, and an excessive charging current will be indicated by the ammeter.

Inability to obtain the desired potential across the insulation may be the result merely of large electrostatic capacity of the insulation and the consequent high charging current required, so that the high potential transformer may not be large enough to supply this current at the voltage desired.

A breakdown in the insulation will result in a drop in voltage indicated by the electrostatic voltmeter, an excessive charging current, and the burning of the insulation if the discharge be continued for any length of time.

Core Loss and Exciting Current.

In taking measurements of core loss and exciting current, the instruments required are a wattmeter, voltmeter, and ammeter.

One of the two following described methods for connecting up the instruments is usually employed, although several others might be shown. These methods differ only in the way of connecting up the instruments, and are as follows:

Method 1. — The voltmeter and pressure coil of the wattmeter are connected directly to the terminals of the test transformer. When the pressure of the voltmeter is at the standard voltage the reading of the wattmeter will be the core loss in watts. It is evident from an inspection of diagram 89 that the wattmeter will indicate, in addition to the watts consumed by the test transformer, the I^2R or copper loss in both the pressure coil of the wattmeter and voltmeter. This error, however, being constant for any pressure, is easily corrected. This method is very good for accurate results, and where the quantities to be measured are small it is most desirable.

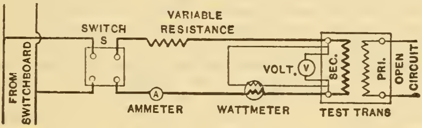


FIG. 89. Core Loss (Method 1).

Method 2. — The current coils of the wattmeter are inserted between a terminal of the test transformer and the terminal of the voltmeter and pressure coil of the wattmeter (see diagram 90). In this method the error introduced is the I^2R loss in the current coil of the voltmeter. This is a very much smaller error than in Method 1, but does not allow of an easy or accurate correction, and the results obtained by it must, therefore, be taken without correction. For this reason Method 2 is more convenient, and for the measurement of large core losses, and for commercial purposes, it is sufficiently accurate.

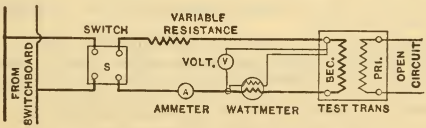


FIG. 90. Core Loss (Method 2).

Core losses and exciting current should be measured from the low-potential side of the transformer to avoid the introduction of high voltage in the test.

Notes on Core Loss and Excitation Current.

In an ordinary commercial transformer, a given core loss at 60 cycles may consist of 70 per cent hysteresis and 30 per cent eddy current loss, while at 125 cycles the same transformer may have 55 per cent hysteresis loss and 45 per cent eddy current loss.

The core loss is also dependent upon the wave form of the impressed E.M.F., a peaked wave giving somewhat lower core losses than a flat wave. It is not uncommon to find alternators having such a peaked wave form that the core loss obtained, if the transformer is tested with current from them, will be 5 per cent to 10 per cent less than that obtained if the transformer is tested from a generator giving a sine wave. On the other hand, generators are sometimes obtained which have a very flat wave form, so that the core loss obtained will be greater than that obtained from the use of a sine wave.

The magnitude of the core loss depends also upon the temperature of the iron. Both the hysteresis and eddy current losses decrease slightly as the temperature of the iron increases. It is well known that if the temperature be increased sufficiently, the hysteresis loss disappears almost entirely, and since the resistance of iron increases with the temperature the eddy current losses necessarily decrease. In commercial transformers, an increase in temperature of 40° C. will cause a decrease in core loss of from 5 per cent to 10 per cent. An accurate statement of core loss thus necessitates that the temperature and wave form be specified.

If, in the measurement of core loss, the product of impressed volts and excitation current exceeds twice the measured watts, there is reason to suspect poorly constructed magnetic joints or higher iron densities than are allowable in a well-designed transformer.

Measurement of Resistance.

Resistance of the coils can be measured by either the Wheatstone Bridge or Fall of Potential Method.

For resistances below one or two ohms it is generally more accurate to use the Fall of Potential Method.

Resistances should always be corrected for temperature, common practice being to correct to 20° centigrade. For pure soft-drawn copper this correction is .4 % per degree centigrade. Readings should be taken at several different current values, and the average value of all the readings will be the one to use. (See Index for correction for rise of temperature.)

Having obtained the resistance of the primary and secondary coils, the I^2R of both primary and secondary can be calculated; the sum of the two being (very nearly) equal to the copper loss of the transformer. If it is preferred to measure the copper loss directly by wattmeter, then we must make test No. 4.

The fall of potential method is subject to the following sources of error:

(1) With the connections as ordinarily made the ammeter reading includes the current in the voltmeter, and in order to prevent appreciable error the resistance of the voltmeter must be much greater than that of the resistance to be measured. If the resistance of the voltmeter be 1000 times greater, an error of $\frac{1}{10}$ of 1 per cent will be introduced, while a voltmeter resistance 100 times the coil's resistance will mean the introduction of an error of 1 per cent. Correction of the ammeter reading obtained in (3) may thus become necessary, but whether or not it be essential will depend upon the accuracy desired. (See example below.)

(2) The resistance of the voltmeter leads must not be sufficient to affect the reading of the voltmeter.

(3) Since the resistance of copper changes rapidly with the temperature, the current used in the measurement should be small compared with the carrying capacity of the resistance, in order that the temperature may not change appreciably during the test. If a large current is necessary, readings must be taken quickly in order to obtain satisfactory results. If a gradual increase in drop across the resistance can be detected within the length of time taken for the test, it is evident that the current flowing through the resistance is heating it rapidly, and is too large to enable accurate measurement of resistance to be secured.

It is quite possible to use a current of sufficient strength to heat the winding so rapidly as to cause it to reach a constant hot resistance before the measurement is taken, thus introducing a large error in the results. Great care should be taken, therefore, in measuring resistance to avoid the use of more current than the resistance will carry without appreciable heating.

(4) Considerable care is necessary to determine the temperature of the winding of the transformer. A thermometer placed on the outside of the winding indicates only the temperature of the exterior. The transformer

should be kept in a room of constant temperature for many hours in order that the windings may reach a uniform temperature throughout. The surface temperature may then be taken as indicative of that of the interior.

Impedance and Copper-Loss Test.

Method 1. — In this method, which was first described by Dr. Sumpner, the secondary coil is short-circuited through an ammeter. A wattmeter and a voltmeter are connected up in the primary circuit in a manner similar to either of the two methods described for the core-loss test. An adjustable resistance or other means for varying the impressed voltage is placed in series with the primary circuit.

To make the test, the voltage is raised gradually until the ammeter shows that normal full-load current is flowing through the secondary circuit. Readings are then taken on the wattmeter and voltmeter.

This method of measuring the impedance and copper loss of a transformer is now seldom used, on account of the liability to error due to the insertion of the ammeter in the secondary. In addition to being inaccurate, it usually requires an ammeter capable of measuring a very heavy current.

Method 2. — This method differs from Method 1 only in that the secondary is short-circuited directly on itself, an ammeter being inserted in the primary circuit. The diagram of connections is shown in Fig. 91. In connecting up the voltmeter and the potential coil of the wattmeter, the same corrections hold as in the measurement of core loss and exciting current, and connections made according to whether accuracy of results or simplicity of test is the more imporant.

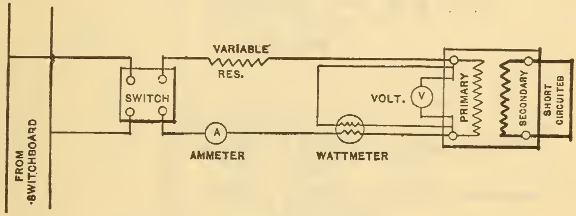


FIG. 91. Impedance Test with Wattmeter.

Having the readings of amperes, volts, and watts, we obtain from the first two the impedance of the transformer. This impedance is the geometrical sum of the resistance and reactance, and is expressed algebraically as follows:

$$z = \sqrt{R^2 + (2\pi n L)^2},$$

where z = Impedance,
R = Resistance,
L = Coefficient of self-induction,
I = Current in amperes,
n = Frequency in cycles per second,
$2\pi n L$ = reactance of the circuit.

In a test on a transformer with secondary short-circuited as in Fig. 91 above, and primary connected to 2000 volts, the impedance volts were 97 at full-load primary current of 2.5 amperes, then

$$\text{Impedance} = \frac{97}{2.5} = 38.8 \text{ ohms},$$

and

$$\text{Impedance drop} = \frac{97 \times 100}{2000} = 4.85 \text{ per cent.}$$

The reading on the wattmeter indicates the combined I^2R of the primary and secondary coils, and in addition includes a very small core loss, which can be neglected, and an eddy current loss in the conductors.

In standard lighting transformers, the impedance voltage varies from 2 per cent to 8 per cent. In making this test, careful record of the frequency should be made, as the impedance voltage will vary very nearly with the frequency.

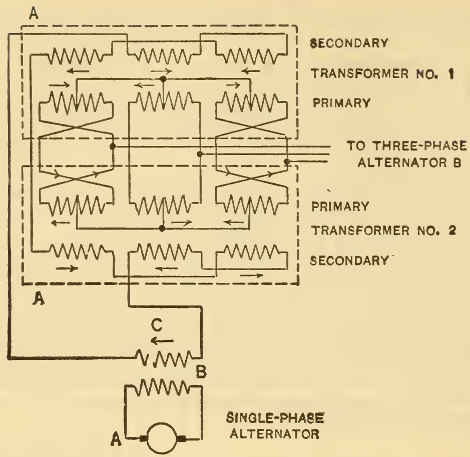


FIG. 92.

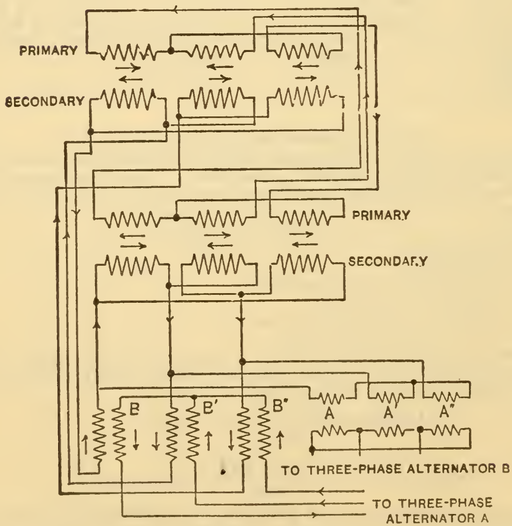


FIG. 93.

Figures 92 and 93 show a method of loading three-phase transformers for heat test.

Heat Tests.

To test the transformer for its temperature rise, it is necessary to run it at full excitation and full-load current for a certain length of time. An eight-hour run at full load will usually raise the temperature to its highest point, and in the case of lighting transformers a full-load run very seldom continues longer than eight hours in practice. If it is desired to find just what is the final temperature rise under full load (as is often the case with transformers for power work) the transformer can be operated for two or three hours at an overload of about 25 %, after which the load should be reduced to normal, and the run continued as long as may be necessary.

There are several methods for making heat runs of transformers, and all of them approximate the condition of the transformer in actual service.

Heat Test, Method 1. —The primary is connected to a circuit of the proper voltage and frequency, and the secondary loaded with lamps or resistance until full-load current is obtained. The temperature of all accessible parts should be obtained by thermometer, and the temperature rise of the coils determined by increase of resistance. Frequent readings should be taken during the run to see to what extent the transformer is heating.

Heat Test, Method 2. —Where the transformer is of large size, or sufficient load is not obtainable, the motor generator method of heat test is preferable. Two transformers of the same voltage, capacity and frequency are required, and are connected up as shown in Fig. 94.

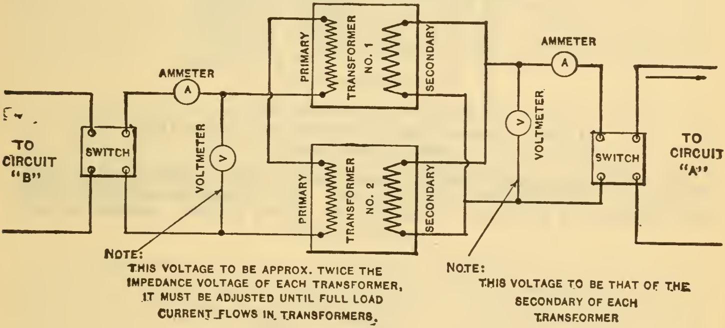


FIG. 94.

The two secondaries are connected in parallel, and excited from circuit A at the proper voltage and frequency. The two primaries are connected in series in such a way as to oppose each other.

The resultant voltage at B will be zero, however, because the voltage of the two primaries is equal and opposite. Any voltage impressed at B will thus cause a current to flow independent of the exciting voltages at the transformer terminals, and approximately twice the impedance voltage of one transformer will cause full-load current to flow through the primaries and secondaries of both transformers.

The total energy thus required to run two transformers at full load is merely the losses in the iron and copper. Circuit A supplies the exciting current and core losses, and circuit B the full-load current and copper losses.

Heat Test, Method 3. —When only one transformer is to be tested, and this transformer is of large capacity, a modification of the motor generator method can be used as described below:

This method was first used in testing an 830 k.w. 25-cycle transformer made for the Carborundum Company of Niagara Falls. The connections are shown in Fig. 95.

Both primary and secondary windings are divided into two parts, the primary coils x and y being connected in multiple to the dynamo circuit, but an auxiliary transformer capable of adding a few per cent E.M.F. to that half of the primary is connected as shown in the y half.

By this means the primary coils are properly magnetized, and full-load currents can be passed through them by varying the auxiliary E.M.F.

The two halves of the secondary coils are connected in series in opposition to each other, and are subject to an auxiliary E.M.F. from the same generator, but reduced to the proper voltage by the auxiliary transformer B.

The currents were measured in all three transformer circuits, and the E.M.F. of one-half the secondary was measured.

The method is accurate enough for large units, and is quite handy where no large dynamo can be gotten for supplying full-load currents, as in this case current is required only for the transformer losses and for supplying the auxiliary transformers.

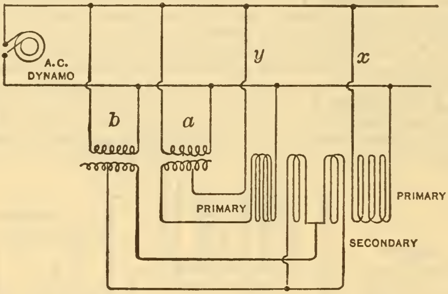


FIG. 95. General Electric Method of Testing One Large Transformer.

Fig. 96 shows connections for heat-run on three single-phase transformers, or one three-phase transformer. The primaries and secondaries are connected in delta, and in one corner of the primary impedance vol-

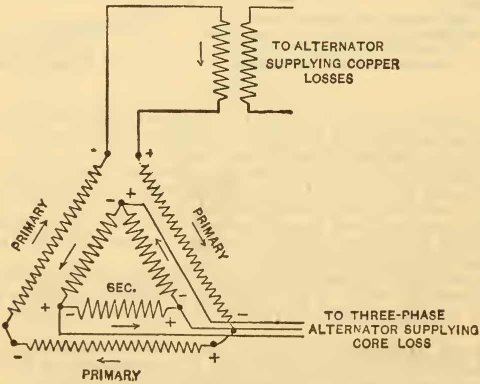


FIG. 96.

tage for the three transformers connected in series is impressed. The current circulates in the delta connections and is entirely independent of the secondary voltage. The method outlined above requires only power enough to supply the losses.

Temperature Rise.

To ascertain the temperature rise of the different parts of a transformer, thermometers are placed on the various parts, and readings taken at frequent intervals. These readings, however, indicate only the surface temperature of a body and not the actual internal temperature.

The average rise of temperature of the windings can be more accurately determined by means of the increase of resistance of the conductor, and is determined by knowing the resistances hot and cold.

Let R_c = resistance of one coil, cold.
R_h = resistance of one coil, hot.
T_c = temperature of one coil in cent. degrees, cold.
T_h = temperature of one coil in cent. degrees, hot.
K = temperature of coefficient of copper .004.

$$T_h = \frac{R_h\,(1 + .004\,T_c) - R_c}{.004\,R_c}.$$

This equation is based on the assumption that the resistance of pure copper increases .4 % of its value at zero for every degree centigrade rise in temperature.

If it be desired to know the temperature rise of both primary and secondary coils, their hot and cold resistances must be determined separately; but it is customary to determine the temperature rise by resistance of only one coil, usually the primary, and comparing the secondary temperatures by the thermometer measurements. The method for taking these measurements is described in the paragraph in this section on measurement of resistance.

Ratio.

As a check against possible mistakes in winding the coils and connecting up, a test should be made for ratio of voltages.

The ratio test is made at a fractional part of the full voltage at no-load current, and should not be substituted for a regulation test. An error of one or two per cent is quite admissible in making this test, because of its being taken at partial voltages.

Regulation.

The regulation of a transformer can be determined either by direct measurement or by calculation from the measurements of resistance and reactance in the transformer. Since the regulation of any commercial transformer is at the most but a few per cent of the impressed voltage, and as errors of observation are very liable to be fully one per cent, the direct method of measuring regulation is not at all reliable.

Regulation by Direct Measurements.

Connect up the transformer with a fully loaded secondary, as in Fig. 97. If the primary voltage is very steady, voltmeter No. 2 only will be necessary, but it is better to use one on the primary circuit also as shown. A

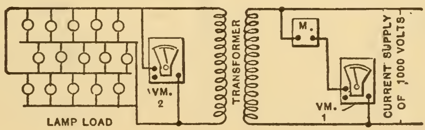


FIG. 97. Test for Regulation of Transformer.

reading of voltmeter No. 2 is taken with no load, and again with load, the difference in the two readings being the drop in voltage on the secondary.

We, therefore, have,

$$\%\ \text{Regulation} = 100 - \left(\frac{100 \times \text{Reading at full load}}{\text{Reading at no load}}\right).$$

Regulation by Calculation.

Several methods of calculating the regulation of transformers from the measurements of resistance and reactive drop have been devised.

Below is a method of Mr. A. R. Everest, which has been found to answer the requirements of daily use.

Let IR = Total resistance drop in transformer expressed as per cent of rated voltage.

IX = Reactive drop, similarly expressed.

P = Proportion of energy current in load or power factor of load. For non-inductive load $P = 1$.

W = Wattless factor of primary current.
(With non-inductive load, W = Magnetizing current expressed as a fraction of full-load current. With inductive load, W = Wattless component of load, plus magnetizing current.)

Then if volts at secondary terminals = 100%,

Primary voltage —

For Non-Inductive Load:

$$E = \sqrt{(100 + PIR + WIX)^2 + (IX)^2}.$$

For Inductive Load:

$$E = \sqrt{(100 + PIR + WIX)^2 + (PIX - WIR)^2}.$$

In each of these equations the last expression within parentheses represents the drop "in quadrature."

$$\text{The magnetizing current} = \sqrt{\left(\text{Exciting current}\right)^2 - \left(\frac{\text{Core loss}}{\text{Voltage}}\right)^2}.$$

For frequencies of 60 cycles or higher, magnetizing current may be taken as 75 per cent of the exciting current.

Extracting the square root in the expression for regulation may be avoided in the use of the following table:

Quadrature Drop.	Increase in Primary Voltage.
2.5 per cent.	.025 per cent.
3 " "	.04 " "
3.5 " "	.06 " "
4 " "	.08 " "
4.5 " "	.10 " "
5 " "	.13 " "
5.5 " "	.15 " "
6 " "	.18 " "
6.5 " "	.21 " "
7 " "	.24 " "
7.5 " "	.27 " "
8 " "	.31 " "
8.5 " "	.35 " "
9 " "	.39 " "
9.5 " "	.45 " "
10 " "	.50 " "

As an example, take a 2 k.w. transformer having the following losses:

$$IR \text{ drop} = 2\%.$$
$$IX \text{ drop} = 3.5\%.$$

Exciting current = 4% or .04; then magnetizing current = 75% of this, or .03.

1. Non-Inductive Load.—Secondary voltage = 100%.
Primary voltage in phase = 100 + 2% + (.03 × 3.5%) = 102.1%.
Quadrature drop = 3.5%; this from table adds .06% of total primary voltage = 102.16%.

The drop is 2.16% of secondary voltage, or $\frac{2.16}{102.16}$ = 2.11% of primary voltage, which is the true regulation drop.

2. Inductive Load.—With a power factor of .86, wattless factor of load = .5, and adding magnetizing current (which in most cases might be neglected on inductive load), W becomes .52.
The primary voltage in phase is now 100% + (2% × .86) + (3.5 × .52) = 103.54%.
The quadrature drop is (.86 × 3.5%) − (.52 × 2%) = 1.97.
From the table 1.97% adds .02% to primary voltage or

$$103.54 + .02\% = 103.56.$$

Primary voltage = 103.56

Regulation drop = $\frac{3.56}{103.56}$ = 3.43% of primary voltage. Regulation drop should always be expressed finally in terms of primary voltage.
The above-described methods of transformer testing are in use by one of the large manufacturers, and present average American shop practice.
The following matter is largely from the important paper by Mr. Ford and presents the commonest theoretical test methods.

EFFICIENCY.

The efficiency of a transformer is the ratio of its net power output to its gross power input, the output being measured with non-inductive load. The power input includes the output together with the losses which are as follows:
(1) The core loss, which is determined by test at the rated frequency and voltage.
(2) The I^2R loss of the primary and the secondary calculated from their resistances.

Example.

Transformer, Type H, 60 Cycles, 5 k.w., 1000–2000 Volts Prim., 100–200 Volts Sec.

AMPERES.	
Primary, at 2000 volts	2.5
Secondary, at 200 volts	25

RESISTANCE.	OHMS AT 20° C.
Primary	10.1
Secondary	0.067

At Full Load.

LOSSES.	WATTS.
Primary I^2R	63
Secondary I^2R	42
Total I^2R	105
Core Loss	70
Total Loss	175
Output at Full Load	5000
Input " " "	5175
Efficiency	5000/5175 or 96.6%

At Half Load.

Losses.	Watts.
Total $I^2 R$	26
Core Loss	70
Total Loss	96
Output	2500
Input	2596
Efficiency	2500/2596 or 96.2%

The all-day efficiency of a transformer is the ratio of the output to the input during 24 hours. The usual conditions of practice will be met if the calculation is based on 5 hours at full load, and 19 hours at no load.

Output.	Watt Hrs.
5 Hours at Full Load	25000
19 Hours at No Load	0
Total, 24 Hours	25000
Input.	
5 Hours at Full Load	25875
19 Hours at No Load (Neglecting I^2R Loss due to Excitation Current)	1330
Total, 24 Hours	27205
All-day Efficiency	25000/27205 or 91.9%

In calculating the efficiencies in both of the above examples, the copper loss due to excitation current of the transformer has been neglected. This current, in the example given above, is less than 3%, and its effect on the loss of the transformer is thus negligible. Even at no load the total $I^2 R$ loss introduced by it is less than one watt. It is quite necessary, however, that the loss introduced by the excitation current should be checked in all cases. In some transformers, for example, the excitation current may reach 30% of the full-load current, and thus its effect is noticeable at large loads, while at ¼ load the loss in the primary winding due to excitation current is greater than the loss due to the load current.

Inasmuch as the losses in the transformer are affected by the temperature and the wave form of the E.M.F., the efficiency can be accurately specified only by reference to some definite temperature, such as 25° C., and by stating whether the E.M.F. is sine or otherwise.

The foregoing method of calculating the efficiency neglects what are known as "load losses," *i.e.*, the eddy current losses in the iron and the conductors caused by the current in the transformer windings. The watts measured in the impedance test include "load losses" and $I^2 R$ losses together with a small core loss. Considering the core loss as negligible, the "load losses" are obtained by subtracting from the measured watts the I^2R loss calculated from the resistance of the transformer. It is sometimes assumed that the "load losses" in a transformer when it is working under full-load conditions are the same as those obtained with short-circuited secondary, and it is stated that these losses should enter into the calculation of efficiency. Many tests have been made to determine whether or not the above assumption is correct, and while the results cannot be considered as conclusive, they indicate in every case that, under full-load conditions, the "load losses" are considerably less than those measured with short-circuited secondary. Inasmuch as these losses, in general, form a small percentage of the total loss in a transformer, and in view of the difficulty in determining them with accuracy, they may be neglected in the calculation of efficiency for commercial purposes. The measurement of watts in the impedance test is, however, useful as a check on excessive eddy current losses in a poorly designed transformer.

POLARITY.

For lighting and other small uses, transformers are generally designed so that the instantaneous direction of flow of the current in certain selected leads is the same in all transformers of the same type. For example, referring to Fig. 98, the transformer there shown is designed so that the current at any instant flows into the primary at "A" and into the secondary at "C." This is the system adopted for small transformers by the majority of manufacturers.

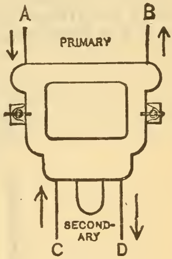


FIG. 98.

The polarity test should be unnecessary when banking transformers of the same type and design. When, however, transformers manufactured by different companies are to be run in parallel, it is necessary to test them in order to avoid the possibility of connecting them in such a way as to short circuit the one on the other. Their polarity may be determined by one of the following methods:

In Fig. 98, Primary lead "A" is of opposite polarity to the Secondary lead "C." Connect the primary lead "A" to the Secondary lead "C." Apply one hundred volts, say to the primary "A-B" of the transformer. The voltage measured from "A" to "D" will be greater than the applied voltage. In other words, a transformer connected as shown will act as a booster to the voltage. If the leads "A" and "B" are of the same polarity, voltage measured from "A" to "D" will be less than that applied at "A-B."

If a standard transformer known to have correct polarity and the same ratio as the test transformer is available, the simplest method for testing the polarity is to connect the primaries and secondaries of the transformers in parallel, placing a fuse in series with the secondaries. On applying voltage to the primaries of the transformers if they are of the same polarity and ratio no current should flow in the secondary circuit and the fuse will remain intact. If the transformers are of opposite polarity the connection will short circuit the one transformer on the other, and the fuse selected should therefore be small enough to blow before the transformers are injured. In nearly all transformers there will be a slight current in the secondaries when connected as above. This current is known as the "exchange current" and should be less than 1 per cent of the normal full load current of the transformer.

Transformers of large capacity and higher voltage for central station work usually have a polarity opposite that shown in Fig. 98. There is, however, no standard for these transformers.

DATA TO BE DETERMINED BY TESTS.

Partly from a paper by Arthur Hillyer Ford, B. S.

I. Copper loss, to determine the efficiency.

II. Iron-core loss, hot and cold, to determine the efficiency: to separate the hysteresis from the foucault current loss.

If
$W =$ watts output,
$I =$ watts iron-core loss,
$C =$ watts copper loss,

then the

$$\text{Efficiency} = 100 - \left(\frac{W}{W+I+C} \times 100\right)$$

Foucault currents loss should decrease with an increase in temperature.

Hysteresis loss is supposed to be constant regardless of heat.

III. Open circuit or exciting current.

IV. Regulation, to determine the magnetic leakage.

V. Rise in temperature in case and out of case, for no load and full load; with and without oil.

VI. Insulation.

Methods.

Opposition Method of Ayrton and Sumpner.—This method is especially valuable where the transformers to be tested are of large capacity, and a source of power great enough to put them under full load in the ordinary way is unavailable. A supply of current of an amount somewhat greater than the total losses of both transformers is all that is necessary. Following is a diagram of the connections, by which it will be seen that the transformers are so connected that one feeds the other, or they work in opposition.

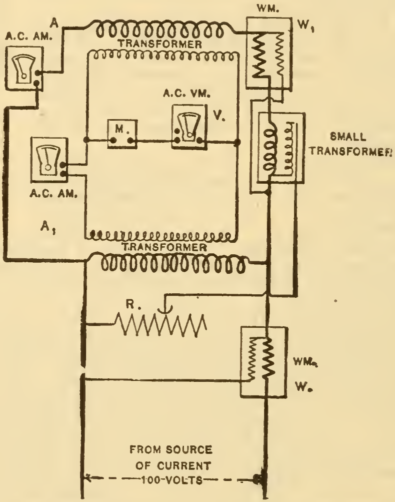


Fig. 99. Diagrams of Connections for Ayrton and Sumpner Opposition Method of Testing Transformers.

In making the test, current is turned on and the resistance R adjusted until full-load current flows in the secondary, as shown by the ammeter A, and the primary current and voltage in A and V is up to standard. Then the watts read on W are equal to all the losses in both transformers, and W_1 the losses in the copper of the transformers plus the copper loss in the leads and in the current coils of W_1 and A.

The iron loss in both transformers is $= W - W_1 - A$, where A is the loss in the leads and instruments which may be calculated by I^2R.

Method of Dr. Sumpner. Iron Loss.—The following diagram shows the connections for Dr. Sumpner's test for iron losses. The low-

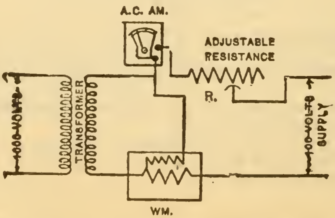


Fig. 100. Dr. Sumpner's Test for Iron Losses

pressure side is connected to a source of current of the same pressure at which the transformer is expected to work, thus producing the same primary voltage in the high-pressure side at which it is expected to work. With the primary circuit open, the iron losses in the transformer are read directly in watts on the wattmeter.

Copper Loss. — The next diagram shows the connections for determining the copper losses. The low-pressure side is short-circuited through an ammeter, the high-pressure side being connected to the 100-volt supply-mains. The resistance R is then adjusted to obtain full-load or any other desired current in the secondary, as shown by the ammeter. The reading of the wattmeter will then show the total copper losses in the transformer and in the ammeter plus a very small and entirely negligible iron loss. The ammeter losses and that in the leads may be calculated by I^2R. The small iron loss can be separated or determined by disconnecting the ammeter and

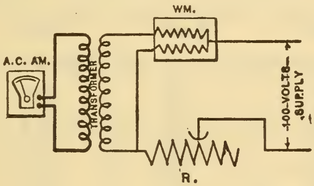


FIG. 101. Dr. Sumpner's Test for Copper Losses.

adjusting R until the pressure on the primary is the same as in the copper loss test; the wattmeter will then show the small iron loss.

The iron loss is proportional to $\mathfrak{B}^{1.6}$ and $\mathfrak{B}$ the magnetic density is proportional to the pressure at the terminals of the transformer, therefore the iron loss is equal to $K.\mathfrak{B}^{1.6}$ where K is a constant and $\mathfrak{B}$ the voltage. In the iron-loss test the $\mathfrak{B} = 1000$ and in the copper loss test

$$\mathfrak{B} = 100.$$

$$K \times 1000^{1.6} = 63{,}000\ K$$

$$K \times 100^{1.6} = 1{,}600\ K = 2.5\% \text{ of total iron loss.}$$

Heating. — Tests should be made at no load, at full load, and at intermediate loads for rise of temperature of the transformers out of their cases, in their cases, without oil and with oil, if full data is wanted. If a strictly commercial test is all that is necessary, a test with the transformer at full load and set up in the condition it is to be run, will be sufficient.

Surface temperatures can be taken by thermometers laid on and covered with cotton waste. In oil-insulated transformers, the temperature of the oil should be taken in two places, — inside the coil, and between the coil and case.

Leakage Drop. — The drop in the secondary due to magnetic leakage can be found by deducting from the measured total drop in the I^2R drop due to the resistance of the coil.

SPECIFICATIONS FOR TRANSFORMERS.

It is almost impossible to enumerate the features to be included in specifications covering transformers, because of the wide range of operation and service to which they may be put, necessitating different characteristics for the transformers intended for different kinds of services.

For transformers operating from a fairly expensive source of supply, the leading manufacturers have decided on characteristics which, in general, will be covered in the following tabulation.

This gives average characteristics of transformers designed for operation on 60-cycle circuits, and the figures given are based on operation of 2000 volts and sine wave alternator.

Capacity.	Core Loss Watts.	Copper Loss Watts.	Exciting Current %.	Regulation %
1	35	30	9.0	2.8
2	45	50	7.0	2.5
3	55	70	3.0	2.3
5	70	105	2.5	2.2
7.5	100	150	2.3	2.2
10	120	180	2.3	2.0
15	155	275	2.2	1.8
20	185	300	1.5	1.7
30	235	475	1.2	1.5
50	335	675	1.0	1.3

AGEING.

Guarantees against serious ageing of iron should cover a period of at least one year.

RISE OF TEMPERATURE.

The rise of temperature should be referred to the standard conditions of a room-temperature of 25° C., a barometric pressure of 760 mm. and normal conditions of ventilation; that is, the apparatus under test should neither be exposed to draught nor inclosed, except where expressly specified.

If the room temperature during the test differs from 25° C. the observed rise of temperature should be corrected by ½ per cent for each° C. Thus with a room temperature of 35° C. the observed rise of temperature has to be decreased by 5 per cent, and with a room temperature of 15° C. the observed rise of temperature must be increased by 5 per cent. The thermometer indicating the room temperature should be screened from thermal radiation emitted by heated bodies, or from draughts of air. When it is impracticable to secure normal conditions of ventilation on account of adjacent engine or other sources of heat, the thermometer for measuring the air temperature should be placed so as fairly to indicate the temperature which the machine would have if it were idle, in order that the rise of temperature determined shall be that caused by the operation of the machine.

The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from six to eighteen hours according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

In electrical conductors, the rise of temperature should be determined by the increase of their resistance where practicable. For this purpose the resistance may be measured either by galvanometer test, or by drop of potential method. A temperature coefficient of 0.42 per cent per degree C. from and at 0° C. may be assumed for copper, by the formula:

$$R_t = R_0 (1 + 0.0042\, t) \text{ and } R_{t+0} = R_0 [1 - 0.0042 (t + 0)]$$

where R_t = the initial resistance at room temperature t° C.
T_{t+0} = the final resistance at temperature elevation 0° C.
R_0 = the inferred resistance at 0° C.

These combine into the formula:

$$0 = (238.1 + t) \left(\frac{T_{t+0} - 1}{T_t} \right) °\text{C}.$$

For insulation test see report of Committee on Standardization of A. I. E. E., page 514.

LOCATION OF TRANSFORMERS.

1. Where practicable, the transformers should be placed in a boiler iron case, capable of withstanding an internal pressure of 50 lbs. per square inch, the case to be suitably vented.

2. Where a sheet iron construction is necessary, the case should be made practically air tight and provided with a very large safety valve, so that an internal explosion cannot burst the case.

3. Provision should be made for rapidly drawing off the oil in case it becomes necessary to do so.

4. Individual transformer units, or groups of units, should be located in fireproof compartments, such compartments to be suitably drained so that in case the oil escapes from the cases, it can flow out where it can do no harm.

5. Adequate means should be provided for extinguishing fire, and the station attendants should be trained to know what to do in case of emergency.

An oil should be selected which has a flash point not lower than, say, 175° C. Such an oil, if properly made, will have practically no evaporation whatever at 100° C., this temperature being higher than will be found except under the most extreme conditions of temporary overload.

Too high a flash test oil is undesirable on account of the viscosity being so great that the power to carry heat from the transformer to the cooler case is greatly reduced, and on account of it being very unpleasant to handle.

Where rubber-covered leads are used, the rubber should be heavy (not less than ¼″ wall per 10,000 volts) and of high quality, and a fireproof covering should be used. Extra flexible cable is usually preferable. Rubber may be tested for dielectric strength, insulation resistance, etc., but its qualification for important uses is best judged by its mechanical properties. To examine these, remove the braid from the wire for several inches, but without cutting the rubber except at the ends of the space. Here it should be cut (at both ends) down to the wire. It will be found in many makes that there are two joints in the rubber running parallel to the wire. A longitudinal cut along the wire, and down to it, should be made midway between the joints. This will make it possible to easily remove the rubber from the wire. First, test each of the joints by bending them over backwards. The best joints will show some tendency to open, and for this reason a double layer of rubber, with joints staggered, is desirable. In many (so called) first class wires it will be found that the joints are just slightly stuck together, or break open on the slightest provocation. Such insulation is worthless. The quality of the rubber may be judged by cutting long strips, about ¼″ wide, or less, and bending it double and as short as possible. It should show no signs of cracking. Pure rubber is very elastic and strong, and it loses these properties in proportion as it is adulterated.

SPECIFICATIONS FOR TRANSFORMER OIL.

(C. E. Skinner.)

In the following will be found a brief specification for a transformer oil.

(1) The oil should be a pure mineral oil obtained by fractional distillation of petroleum unmixed with any other substances and without subsequent chemical treatment.

(2) The flash test of the oil should not be less than 180° C. (356° F.), and the burning test should not be less than 200° C. (392° F.).

(3) The oil must not contain moisture, acid, alkali, or sulphur compounds.

(4) The oil should not show an evaporation of more than 0.2% when heated at 100° C. for eight hours.

(5) It is desirable that the oil be as fluid as possible and that the color be as light as can be obtained in an untreated oil.

The method of making tests to determine the above qualities should be distinctly specified so that there can be no misunderstanding on account of results being obtained by different methods of test.

The specification for flash test given above is intended to be low enough so that there will be some leeway to allow for slight variations in the oil and for variations obtained by different observers. It is expected that an oil to fulfill this specification will run something higher than 180° flash test.

STANDARDIZATION RULES OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

(*Approved by the Board of Directors, June 27, 1911.*)

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STANDARDIZATION RULES OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

(*As Approved June* 27, 1911.)

I. DEFINITIONS AND TECHNICAL DATA.

1. Note. The following definitions and classifications are intended to be practically descriptive and not scientifically rigid.

A. DEFINITIONS. CURRENTS AND E.M.F.'S.

2. A Direct Current is an unidirectional current.
3. A Continuous Current is a steady, or non-pulsating, direct current.
4. A Pulsating Current is a current equivalent to the superposition of an alternating current upon a continuous current.
5. An Alternating Current or E.M.F. is a current or E.M.F. which, when plotted against time in rectangular coördinates, consists of half-waves of equal area in successively opposite directions from the zero line.

5*a*. Cycle. Two immediately succeeding half-waves constitute a cycle.

5*b*. Period. The time required for the execution of a cycle is called a period.

5*c*. Frequency. The number of cycles per second is called the frequency.

5*d*. Wave-Form. The shape of the curve of E.M.F. or current plotted against time in rectangular coördinates is ordinarily referred to as the wave-form or wave-shape. Two alternating quantities are said to have the same wave-shape if their corresponding phase ordinates bear a constant ratio. The wave-shape, as ordinarily understood, is thus independent of the scales to which the curve is plotted.

5*e*. Simple Alternating Wave. Unless otherwise specified an alternating current or E.M.F. is assumed to be sinusoidal, and the wave a sinusoid, sine-wave or curve of sines. On this account a complete cycle is taken as 360 degrees, and any portion of a cycle may be expressed in degrees from any convenient reference point, such as the ascending zero-point.

5*f*. A Complex Alternating Wave is a non-sinusoidal wave. A complex alternating wave is capable of being resolved into a single sine wave of fundamental frequency, with superposed odd-frequency harmonic waves, or ripples, of 3, 5, 7 . . . $(2n + 1)$ times the fundamental frequency, each harmonic having constant amplitude, and a definite starting phase-relation to the fundamental sine-wave. It is customary when analyzing a complex wave to neglect harmonics higher than the 11th; *i.e.*, of frequency higher than 11 times the fundamental. In special cases, however, frequencies still higher may have to be considered. In certain exceptional cases even harmonics are present.

5*g*. Root-Mean-Square Value (sometimes called the Virtual or Effective Value). Unless otherwise specified, the rating of an alternating-current or E.M.F., in amperes or volts, is assumed to be the square root of the mean square value taken throughout one or more complete cycles. This is sometimes abbreviated to r.m.s. The term root-mean-square is to be preferred to the terms virtual or effective. The root-mean-square value is indicated by all properly calibrated alternating-current voltmeters and ammeters. In the case of a sine-wave, the ratio of the maximum to the r.m.s. value is $\sqrt{2}$.

5*h*. Form-Factor of an Alternating Wave. The ratio of the root-mean-square to the arithmetical mean ordinate of a wave, taken without regard to sign, is called its form-factor. The form-factor for a purely rectangular wave is the minimum, 1.0; for a sine-wave it is 1.11, and for a wave more peaked than a sine-wave it is greater than 1.11.

5*i*. The Equivalent Sine-Wave is a sine-wave having the same frequency and the same r.m.s. value as the actual wave.

5*j*. The Deviation of wave-form from the sinusoidal is determined by superposing upon the actual wave (as determined by oscillograph), the equivalent sine-wave of equal length, in such a manner as to give the least difference, and then dividing the maximum difference between corresponding ordinates by the maximum value or the equivalent sine-wave.

5*k*. Phase Difference. When corresponding cyclic values of two sinusoidal alternating quantities such as two alternating currents or E.M.F.'s or of a current and an E.M.F., of the same frequency, occur at different instants, the two alternating quantities are said to differ in phase, their phase difference being the time interval, expressed in degrees or as a fraction of a cycle, between the occurrence of their corresponding values; *e.g.*, their ascending zeros or their positive maxima.

5*l*. EQUIVALENT PHASE DIFFERENCE. If two alternating quantities are non-sinusoidal, and of different wave shapes, the preceding definition of phase-difference is inapplicable, and phase-difference ceases to have exact significance. However, when the two complex alternating quantities are the voltage E and current I in a given circuit, the effective power P of which is known, it is customary to define the equivalent phase difference by the angle whose cosine is the power-factor, P/EI, of the circuit. See Sections 54 and 324.

5*m*. SINGLE-PHASE. A term characterizing a simple alternating-current circuit energized by a single alternating E.M.F. Such a circuit is usually supplied through two wires. The currents in these two wires counted positively outwards from the source, differ in phase by 180 degrees or half a cycle.

5*n*. THREE-PHASE. A term characterizing the combination of three circuits energized by alternating E.M.F.'s which differ in phase by one-third of a cycle; *i.e.*, 120°.

5*o*. QUARTER-PHASE, also called TWO-PHASE. A term characterizing the combination of two circuits energized by alternating E.M.F.'s which differ in phase by a quarter of a cycle; *i.e.*, 90°.

5*p*. SIX-PHASE. A term characterizing the combination of six circuits energized by alternating E.M.F.'s which differ in phase by one-sixth of a cycle; *i.e.*, 60°.

5*q*. Polyphase is the general term applied to any alternating system with more than a single phase.

6. An Oscillating Current is a current alternating in direction, and of decreasing amplitude.

B. DEFINITIONS. ROTATING MACHINES.

7. A Generator transforms mechanical power into electrical power.

8. A Direct-Current Generator produces a direct current that may or may not be continuous.

9. An Alternator is an alternating-current generator, either single-phase or polyphase.

9*a*. A Synchronous Alternator comprises a constant magnetic field and an armature delivering either single-phase or polyphase current in synchronism with the rotation of the machine.

10. A Polyphase Generator produces currents differing symmetrically in phase; such as quarter-phase currents, in which the terminal voltages of the two circuits differ in phase by 90 degrees: or three-phase currents, in which the terminal voltages of the three circuits differ in phase by 120 degrees.

11. A Double-Current Generator supplies both direct and alternating currents from the same armature winding.

11*a*. An Inductor Alternator is an alternator in which both field and armature windings are stationary.

11*b*. An Induction Generator is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

12. A Motor transforms electrical power into mechanical power.

12*a*. A Direct-Current Motor transforms direct-current power into mechanical power.

12*b*. An Alternating-Current Motor transforms alternating-current power into mechanical power.

12*c*. A Synchronous Motor is a machine structurally identical with a synchronous alternator, but operated as a motor.

12*d*. A Synchronous Phase Modifier, sometimes called a Synchronous Condenser, is a synchronous motor, running either idle or under load, whose field excitation may be varied so as to modify the power-factor of the circuit, or through such modification to influence the voltage of the circuit.

12*e*. An Induction Motor is an alternating-current motor, either single-phase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding has no conductive connection with the supply circuit.

12*f*. A Repulsion Motor is an induction motor, usually single phase, in which the magnetic axis of the secondary (a closed coil winding mounted on the rotor) is maintained at a certain fixed angle with respect to the stationary primary coil by means of a multisegmental commutator and short-circuiting brushes.

12*g*. A Single-Phase Series Commutator Motor is structurally similar to a series direct-current motor, except that it is usually provided in addition with a series compensating winding distributed around the outer air-gap periphery and supported in slots in the pole faces, for the purpose of diminishing the armature leakage reactance.

13. A Booster is a machine inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

14. A Motor-Generator is a transforming device consisting of a motor mechanically connected to one or more generators.

15. A Dynamotor is a transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

16. A Converter is a machine employing mechanical rotation in changing electrical energy from one form into another. A converter may belong to either of several types, as follows:

17. *a*. A Direct-Current Converter converts from a direct current to a direct current, usually with a change of voltage.

18. *b*. A Synchronous Converter (commonly called a rotary converter) converts from an alternating to a direct current, or *vice versa*.

19. *c*. A Motor-Converter is a combination of an induction motor with a synchronous converter, the secondary of the former feeding the armature of the latter with current at some frequency other than the impressed frequency; *i.e.*, it is a synchronous converter concatenated with an induction motor.

20. *d*. A Frequency Changer converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases or in the voltage.

21. *e*. A Rotary Phase Converter converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

21*a*. Equalizing Connections are low resistance connections between equipotential points of multiple-wound closed-coil armatures to equalize the induced voltage between brushes.

C. DEFINITIONS. STATIONARY INDUCTION APPARATUS.

22. Stationary Induction Apparatus changes electric energy to electric energy through the medium of magnetic energy. It comprises several forms, distinguished as follows:

23. *a*. Transformers, in which the primary and secondary windings are insulated from one another.

23*a*. A Primary Winding is that winding of a transformer, or of an induction motor, which receives power from an external source.

23*b*. A Secondary Winding is that winding of a transformer, or of an induction motor, which receives power from the primary by induction.

NOTE. The terms "High-voltage winding" and "Low-voltage winding" are suitable for distinguishing between the windings of a transformer, where the relations of the apparatus to the source of power are not involved.

24. *b*. Auto-Transformers, also called compensators, in which a part of the primary winding is used as a secondary winding, or conversely.

25. *c*. Potential Regulators, in which one coil is in shunt and one in series with the circuit, so arranged that the ratio of transformation between them is variable at will. They are of the following three classes:

26. (1) Contact Voltage Regulators, also called Compensator Regulators, in which the number of turns in use of one of the coils is adjustable.

27. (2) Induction Potential Regulators in which the relative positions of the primary and secondary coils are adjustable.

28. (3) Magneto Potential Regulators in which the direction of the magnetic flux with respect to the coils is adjustable.

29. *d*. Reactors or Reactance Coils, also called choke coils, are a form of stationary induction apparatus used to supply reactance or to produce phase displacement.

29*a*. *e*. An Induction Starter is a device used in starting induction motors, converters, etc., by voltage control, consisting of an auto-transformer combined with a suitable switching device.

29*b*. A Leakage Reactance or Series Reactance is a portion of the reactance of any induction apparatus which is due to stray or purely self-inductive flux.

D. GENERAL CLASSIFICATION OF APPARATUS.

30. Commutating Machines. Under this head may be classed the following: Direct-current generators; direct-current motors; direct-current boosters; motor-generators; dynamotors; converters; compensators or balancers; closed-coil arc machines, and alternating-current commutating motors.

31. Commutating machines may be further classified as follows:

32. *a.* Direct-Current Commutating Machines, which comprise a magnetic field of constant polarity, a closed-coil armature, and a multisegmental commutator connected therewith.

33. *b.* Alternating-Current Commutating Machines, which comprise a magnetic field of alternating polarity, a closed-coil armature, and a multisegmental commutator connected therewith.

34. *c.* Synchronous Commutating Machines, which comprise synchronous converters, motor-converters and double-current generators.

35. Synchronous Machines comprise a constant magnetic field and an armature receiving or delivering alternating-currents in synchronism with the motion of the machine; *i.e.*, having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

36. Stationary Induction Apparatus include transformers, auto-transformers, potential regulators, and reactors or reactance coils.

37. Rotary Induction Apparatus, or Induction Machines, include apparatus wherein the primary and secondary windings rotate with respect to each other; *i.e.*, induction motors, induction generators, frequency converters, and rotary phase converters.

38. Unipolar or Acyclic Machines, direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

39. Rectifying Apparatus, Pulsating-Current Generators.

40. Electrostatic Apparatus, such as condensers, etc.

41. Electrochemical Apparatus, such as batteries, etc.

42. Electrothermal Apparatus, such as heaters, etc.

42*a*. Regulating Apparatus, such as rheostats, etc.

42*b*. Switching Apparatus.

43. Protective Apparatus, such as fuses, circuit-breakers, lightning arresters, etc.

44. Luminous Sources.

E. MOTORS. SPEED CLASSIFICATION.

45. Motors may, for convenience, be classified with reference to their speed characteristics as follows:

46. *a.* Constant-Speed Motors, in which the speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

47. *b.* Multispeed Motors (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as motors with two armature windings, or induction motors with controllers for changing the number of poles.

48. *c.* Adjustable-Speed Motors, in which the speed can be varied gradually over a considerable range; but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of field variation.

49. *d.* Varying-Speed Motors, or motors in which the speed varies with the load, decreasing when the load increases; such as series motors.

F. DEFINITIONS. INSTRUMENTS.

49*a*. An Ammeter is a current-measuring instrument, indicating in amperes.

49*b*. A Voltmeter is a voltage-measuring instrument, indicating in volts.

49*c*. A Wattmeter is an instrument for measuring electrical power, and indicating in watts.

49*d*. Recording Ammeters, Voltmeters, Wattmeters, etc., are instruments which record graphically upon a time-chart the values of the quantities they measure.

49*e*. A Watt-Hour Meter is an instrument for registering total watt-hours. This term is to be preferred to the term "integrating wattmeter."

49*f*. A Voltmeter Compensator is a device in connection with a voltmeter, which causes the latter to indicate the voltage at some other point of the circuit.

49*g*. A Synchroscope is a synchronizing device which, in addition to indicating synchronism, shows whether the machine to be synchronized is fast or slow.

G. DEFINITION AND EXPLANATION OF TERMS.

(I) *Load Factor.*

50. The Load Factor of a machine, plant or system is the ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day or a year, and the maximum is taken over a short interval of the maximum load within that period.

51. In each case the interval of maximum load should be definitely specified. The proper interval is usually dependent upon local conditions and upon the purpose for which the load factor is to be determined.

(II) *Diversity Factor.*

51*a*. Diversity Factor is the ratio of the sum of the maximum power demands of the subdivisions of any system or part of a system to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

(III) *Demand Factor.*

51*b*. Demand Factor is the ratio of the maximum power demand of any system or part of a system to the total connected load of the system or of the part of the system under consideration.

(IV) *Non-Inductive Load and Inductive Load.*

52. A non-inductive load is a load in which the current is in phase with the voltage across the load.

53. An inductive load is a load in which the current lags behind the voltage across the load. A load in which the current leads the voltage across the load is sometimes called a condensive or anti-inductive load.

53*a*. When voltage and current waves are sinusoidal but not in phase, the voltage may be resolved into two components, one in phase with the current and the other in quadrature therewith. The former is called the effective component (sometimes the energy component), and the latter the reactive component of the voltage. The current may be similarly subdivided with respect to the voltage, and the two components similarly named.

(V) *Power-Factor and Reactive Factor.*

54. The Power-Factor in alternating-current circuits or apparatus is the ratio of the effective (*i.e.*, the cyclic average) power in watts to the apparent power in volt-amperes. It may be expressed as follows:

$$\frac{\text{effective power}}{\text{apparent power}} = \frac{\text{effective watts}}{\text{total volt-amperes}} = \frac{\text{effective current}}{\text{total current}} = \frac{\text{effective voltage}}{\text{total voltage}}.$$

55. The Reactive-Factor is the ratio of the reactive volt-amperes (*i.e.*, the product of the reactive component of current by voltage, or reactive component of voltage by current) to the total volt-amperes. It may be expressed as follows:

$$\frac{\text{reactive power}}{\text{apparent power}} = \frac{\text{reactive watts}}{\text{total volt-amperes}} = \frac{\text{reactive current}}{\text{total current}} = \frac{\text{reactive voltage}}{\text{total voltage}}.$$

56. Power-Factor and Reactive-Factor are related as follows:

If p = power-factor and q = reactive-factor, then with sine-waves of voltage and current,

$$p^2 + q^2 = 1.$$

With distorted waves of voltage and current, q ceases to have definite significance.

(VI) *Saturation-Factor.*

57. The Saturation-Factor of a machine is the ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. The saturation-factor is, therefore, a criterion of the degree of saturation attained in the magnetic circuit at any excitation selected. Unless otherwise specified, however, the saturation-factor of a machine refers to

the excitation existing at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

58. The Percentage of Saturation of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is independent of the scale selected for excitation and voltage. This ratio is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity. Thus, if f be the saturation-factor and p the percentage of saturation,

$$p = 1 - \frac{1}{f}.$$

(VII) *Variation and Pulsation.*

59. The Variation in Prime Movers which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360°.

60. The Pulsation in Prime Movers is the ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

61. The Variation in Alternators or alternating-current circuits in general is the maximum difference in phase of the generated voltage wave from a wave of absolutely constant frequency of the same average value, expressed in electrical degrees (one cycle equals 360°) and may be due to the variation of the prime mover.

62. The Pulsation in Alternators or alternating-current circuits, in general, is the ratio of the difference between maximum and minimum frequency during an engine cycle to the average frequency.

63. Relation of Variation in prime mover and alternator. If p = number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and pn times the variation of the prime mover if rigidly connected thereto in the velocity ratio n; so that the speed of the alternator is n times that of the prime mover.

II. PERFORMANCE SPECIFICATIONS AND TESTS.

A. RATING.

65. Rating by Output. All electrical apparatus should be rated by output and not by input. Generators, transformers, etc., should be rated by electrical output: motors by mechanical output, and preferably in kilowatts.

65*a*. The following four classes of rating are recognized and recommended: they do not cover the rating of railway motors, which is treated in Appendix B, and there are other large though less definitely definable classes of service in which each case must be treated by itself. Some of these may be later reduced to fairly simple terms and introduced into these Rules.

65*b*. (1) Continuous Rating in which under load there is the attainment of approximately stationary temperature, and no other limit of capacity is exceeded.

65*c*. (2) Intermittent Rating in which one minute periods of load and rest alternate until the attainment of approximately stationary temperature and no other limit of capacity is exceeded.

65*d*. Note. Since the temperature depends upon the losses and the capacity of the apparatus to emit them, a constant load may be substituted for the intermittent load in determining the temperature, provided the losses are equivalent.

65*e*. (3) Minute Rating in which under load for one minute, no mechanical, thermal, magnetic, or electrical limit of capacity is exceeded and no permanent change is wrought in the apparatus.

65*f*. (4) Variable Service Rating. It is desirable here to recognize this class of rating which is intended to cover the rating of motors for machine-tool and similar service, in which the thermal absorptive capacity plays a part. The specifications for this rating have not been fully determined at the time that this edition of the Rules goes to press.

66. Rating in Kilowatts. Electrical power should be expressed in kilowatts, except when otherwise specified.

67. Apparent Power, Kilovolt-Amperes. Apparent power in alternating-current circuits should be expressed in kilovolt-amperes as distinguished from effective power in kilowatts. When the power-factor is 100 per cent, the apparent power in kilovolt-amperes is equal to the kilowatts.

68. The Rated (Full-Load) Current is that current which, with the rated terminal voltage, gives the rated kilowatts, or the rated kilovolt-amperes. In machines in which the rated voltage differs from the no-load voltage, the rated current should refer to the former.

69. Determination of Rated Current. The rated current may be determined as follows: If P = rating in watts, or volt-amperes if the power-factor be other than 100 per cent, and E = full-load terminal voltage, the rated current per terminal is:

70. $I = \frac{P}{E}$ amperes, in a direct-current machine or single-phase alternator.

71. $I = \frac{1}{\sqrt{3}} \frac{P}{E}$ amperes, in a three-phase alternator.

72. $I = \frac{1}{2} \frac{P}{E}$ amperes, in a quarter-phase alternator.

73. Normal Conditions. The rating of machines or apparatus should be based upon certain normal conditions to be assumed as standard, or to be specified. These conditions include voltage, current, power-factor, frequency, wave shape and speed; or such of them as may apply in each particular case. Performance tests should be made under these standard conditions unless otherwise specified.

74. *a*. Power-Factor. Since the inherent capacity of alternating-current generators, synchronous motors, and transformers, depends upon their voltage and their current, they should be rated in kilovolt-amperes. If the apparatus is rated in kilowatts without specification as to the power-factor, a power-factor of 100 per cent shall be understood.

If rated in kilowatts and a power-factor other than 100 per cent be specified, this should be understood as defining only the nature of the load, and not as implying an increase in the ampere rating of the apparatus, which should be based upon the kilowatt rating at 100 per cent power-factor.

75. *b*. Wave Shape. In determining the rating of alternating-current machines or apparatus, a sine-wave shape of alternating current and voltage is assumed, except where a distorted wave shape is inherent to the apparatus. See Secs. 79–80.

76. Fuses. The rating of a fuse should be the maximum current which it will continuously carry.

77. Circuit-Breakers. The rating of a circuit-breaker should be the maximum current which it is designed to carry continuously.

77*a*. Note. In addition thereto, the maximum current and voltage at which a fuse or a circuit-breaker will open the circuit should be specified. It is to be noted that the behavior of fuses and of circuit-breakers is much influenced by the amount of electric power available on the circuit.

78. Indicating Meters should be rated according to their full-scale reading of volts, amperes, or watts. In wattmeters the rated volts and rated amperes should also be included; *i.e.*, the volts and amperes which can be safely and continuously carried by the voltage and current coils respectively.

78*a*. Watt-Hour Meters should be rated in volts and amperes.

B. WAVE SHAPE.

79. The Sine Wave should be considered as standard, except where a deviation therefrom is inherent in the operation of the apparatus.

80. A Maximum Deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified. See Secs. 5*j*, 81, 82, 83. See Secs. 5*e* to 5*l*.

C. EFFICIENCY.

(I) *Definitions.*

84. The Efficiency of an apparatus is the ratio of its output to its input. The output and input may be in terms of watt-hours, watts, volt-amperes, amperes, or any other quantity of interest, thus respectively defining energy-

efficiency, power-efficiency, apparent power-efficiency, current efficiency, etc. Unless otherwise specified, however, the term is ordinarily assumed to refer to power-efficiency. An exception should be noted in the case of luminous sources (see Sec. 346).

86. Apparent Efficiency. In apparatus in which a phase displacement is inherent to their operation, apparent efficiency should be understood as the ratio of net power output to volt-ampere input.

87. *a.* Note. Such apparatus comprises induction motors, synchronous phase modifiers, synchronous converters controlling the voltage of an alternating-current system, potential regulators, open magnetic circuit transformers, etc.

88. *b.* Note. Since the apparent efficiency of apparatus delivering electric power depends upon the power-factor of the load, the apparent efficiency, unless otherwise specified, should be referred to a load power-factor of unity.

(II) *Measurement of Efficiency.*

89. Methods. Efficiency may be determined by either of two methods, *viz.*: by measurement of input and output or by measurement of losses.

90. *a.* Method of Input and Output. The input and output may both be measured directly. The ratio of the latter to the former is the efficiency.

91. *b.* Method by Losses. The losses may be measured either collectively or individually. The total losses may be added to the output to derive the input, or subtracted from the input to derive the output.

92. Comparison of Methods. The output and input method is preferable with small machines. When, however, as in the case of large machines, it is impracticable to measure the output and input, or when the percentage of power loss is small and the efficiency is nearly unity, the method of determining efficiency by measuring the losses should be followed.

93. Electric Power should be measured at the terminals of the apparatus. In tests of polyphase machines, the measurement of power should not be confined to a single circuit but should be extended to all the circuits in order to avoid errors of unbalanced loading.

94. Mechanical Power in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered, with constant speed, as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of separating them from those of the prime mover.

95. In Auxiliary Apparatus, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the principal machine, but to the plant consisting of principal machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

96. Normal Conditions. Efficiency tests should be made under normal conditions herein set forth, which are to be assumed as standard. These conditions include voltage, current, power-factor, frequency, wave shape, speed, temperature and barometric pressure, or such of them as may apply in each particular case. Performance tests should be made under these standard conditions unless otherwise specified. See Secs. 73–75.

97. *a.* Temperature. The efficiency of all apparatus, except such as may be intended for intermittent service, should be either measured at, or reduced to, the temperature which the apparatus assumes under continuous operation at rated load, referred to a room temperature of 25° C. See Secs. 267–292.

98. With apparatus intended for intermittent service, the efficiency should be determined at the temperature assumed under specified conditions.

99. *b.* Power-Factor. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the voltage, unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, induction generators, frequency converters, etc.

100. *c.* Wave Shape. In determining the efficiency of alternating-current apparatus, the sine-wave should be considered as standard, except where a difference in the wave form from the sinusoidal is inherent in the operation of the apparatus. See Sec. 80.

(III) *Measurement of Losses.*

101. Losses. The usual sources of losses in electrical apparatus and the methods of determining these losses are as follows:

(*A*) Bearing Friction and Windage.

102. The magnitude of bearing friction and windage (which may be considered as independent of the load) is conveniently measured by driving the machine from an independent motor, the output of which may be suitably determined. See Sec. 94.

(*B*) Commutator Brush Friction.

103. The magnitude of the commutator brush friction (which may be considered as independent of the load) is determined by measuring the difference in power required for driving the machine with brushes on and with brushes off (the field being unexcited).

(*C*) Collector-Ring Brush Friction.

104. Collector-ring brush friction may be determined in the same manner as commutator brush friction. It is usually negligible.

(*D*) Molecular Magnetic Friction and Eddy Currents.

105. These losses include those due to molecular magnetic friction and eddy currents in iron and copper and other metallic parts, also the losses due to currents in the cross-connections of cross-connected armatures.

106. In Machines these losses should be determined on open circuit and at a voltage equal to the rated voltage $+ Ir$ in a generator, and $- Ir$ in a motor, where I denotes the current strength and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

107. Note. The Total Losses in bearing friction and windage, brush friction, magnetic friction and eddy currents can, in general, be determined by a single measurement by driving the machine with the field excited, either as a motor, or by means of an independent motor.

108. Retardation Method. The no-load iron, friction, and windage losses may be segregated by the Retardation Method. The generator should be brought up to full speed (or, if possible, to about 10 per cent above full speed) as a motor, and, after cutting off the driving power and excitation, frequent readings should be taken of speed and time, as the machine slows down, from which a speed-time curve can be plotted. A second curve should be taken in the same manner, but with full field excitation; from the second curve the iron losses may be found by subtracting the losses found in the first curve.

109. The speed-time curves can be plotted automatically by belting a small separately excited generator (say $\frac{1}{10}$ kw.) to the generator shaft and connecting it to a recording voltmeter.

(*E*) Armature-Resistance Loss.

110. This loss may be expressed by pI^2r; where r = resistance of one armature circuit or branch, I = the current in such armature circuit or branch, and p = the number of armature circuits or branches.

(*F*) Commutator, Brush and Brush-Contact Resistance Loss.

111. It is desirable to point out that with carbon brushes these losses may be considerable in low-voltage machines.

(*G*) Collector-Ring and Brush-Contact Resistance Loss.

112. This loss is usually negligible, except in machines of extremely low voltage or in unipolar machines.

(*H*) Field-Excitation Loss.

113. With separately excited field, the loss of power in the resistance of the field coils alone should be considered. With either shunt- or series-field windings, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

(I) Load Losses.

114. The load losses may be considered as the difference between the total losses under load and the sum of the losses as above specified and determined

115. *a.* In Commutating Machines of small field distortion, the load losses are usually trivial and may, therefore, be neglected. When, however, the field distortion is large as in commutating-pole machines, or, as is shown, for instance, by the necessity for shifting the brushes between no load and full load on non-commutating pole machines, these load losses may be considerable, and should be taken into account. In this case the efficiency may be determined either by input and output measurements, or the load losses may be estimated by the method of Sec. 116.

116. *b.* Estimation of Load Losses. While the load losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short-circuit and at full-load current, that is, by determining what may be called the "short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

117. One-third of the short-circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

(IV) *Efficiency of Different Types of Apparatus.*

(*A*) Direct-Current Commutating Machines.

118. In Direct-Current Commutating Machines the losses are:

119. *a.* Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

120. *b.* Molecular Magnetic Friction and Eddy Currents. See Meas. of Losses (*D*), Sec. 105.

121. *c.* Armature Resistance Losses. See Meas. of Losses (*E*), Sec. 110.

122. *d.* Commutator Brush Friction. See Meas. of Losses (*B*), Sec. 103.

123. *e.* Commutator, Brush and Brush-Contact Resistance. See Meas. of Losses (*F*), Sec. 111.

124. *f.* Field-Excitation Loss. See Meas. of Losses (*H*), Sec. 113.

125. *g.* Load Losses. See Meas. of Losses (*I*), Sec. 114.

126. Note. *b* and *c* are losses in the armature or "armature losses"; *d* and *e* "commutator losses"; *f* "field losses."

(*B*) Alternating-Current Commutating Machines.

127. In Alternating-Current Commutating Machines, the losses are:

128. *a.* Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

129. *b.* Rotation Loss, measured with the machine at open circuit, the brushes on the commutator, and the field excited by alternating current when driving the machine by a motor.

130. This loss includes molecular magnetic friction and eddy currents, caused by rotation through the magnetic field, I^2r losses in cross-connections of cross-connected armatures, I^2r and other losses in armature-coils and armature-leads which are short-circuited by the brushes as far as these losses are due to rotation.

131. *c.* Alternating or Transformer Loss. These losses are measured by wattmeter in the field circuit, under the conditions of test *b*. They include molecular magnetic friction and eddy currents due to the alternation of the magnetic field, I^2r losses in cross-connections of cross-connected armatures, I^2r and other losses in armature coil and commutator leads which are short-circuited by the brushes, as far as these losses are due to the alternation of the magnetic flux.

132. The losses in armature-coils and commutator leads short-circuited by the brushes can be separated in *b* and *c* from the other losses by running the machine with and without brushes on the commutator.

133. *d.* I^2R Loss, other load losses in armature and compensating winding and I^2r loss of brushes, may be measured by a wattmeter connected across the armature and compensating winding.

134. *e.* Field-Excitation Loss. See Meas. of Losses (*H*), Sec. 113.

135. *f.* Commutator Brush-Friction. See Meas. of Losses (*B*), Sec. 103.

(*C*) Synchronous Commutating Machines.

136. 1. In Double-Current Generators, the efficiency of the machine should be determined as a direct-current generator, and also as an alternating-current generator. The two values of efficiency may be different, and should be clearly distinguished.

137. 2. In Converters the losses should be determined when driving the machine by a motor. These losses are:

138. *a.* Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

139. *b.* Molecular Magnetic Friction and Eddy Currents. See Meas. of Losses (*D*), Sec. 105.

140. *c.* Armature-Resistance Loss. This loss in the armature is qI^2r, where I = direct current in armature, r = armature resistance, and q, a factor which is equal to 1.47 in single-circuit single-phase, 1.15 in double-circuit single-phase, 0.59 in three-phase, 0.39 in two-phase, and 0.27 in six-phase converters.

141. *d.* Commutator-Brush Friction. See Meas. of Losses (*B*), Sec. 103.

142. *e.* Collector-Ring Brush Friction. See Meas. of Losses (*C*), Sec. 104.

143. *f.* Commutator, Brush and Brush-Contact Resistance Loss. See Meas. of Losses (*F*), Sec. 111.

144. *g.* Collector-Ring Brush-Contact Resistance Loss. See Meas. of Losses (*G*), Sec. 112.

145. *h.* Field-Excitation Loss. See Meas. of Losses (*H*), Sec. 109.

146. *i.* Load Losses. These can generally be neglected, owing to the absence of field distortion.

147. 3. The Efficiency of Two Similar Converters may be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct-current input and the direct-current output. This process may be modified by returning the output of the second machine through two boosters into the first machine and measuring the losses. Another modification is to supply the losses by an alternator between the two machines, using potential regulators.

(*D*) Synchronous Machines.

148. In Synchronous Machines, the losses are:

149. *a.* Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

150. *b.* Molecular Magnetic Friction and Eddy Currents. See Meas. of Losses (*D*), Sec. 105.

151. *c.* Armature-Resistance Loss. See Meas. of Losses (*E*), Sec. 110.

152. *d.* Collector-Ring Brush Friction. See Meas. of Losses (*C*), Sec. 104.

153. *e.* Collector-Ring Brush-Contact Resistance Loss. See Meas. of Losses (*G*), Sec. 112.

154. *f.* Field-Excitation Loss. See Meas. of Losses (*H*), Sec. 113.

155. *g.* Load Losses. See Meas. of Losses (*I*), Sec. 114.

(*E*) Stationary Induction Apparatus.

156. In Stationary Induction Apparatus, the losses are:

157. *a.* Molecular Magnetic Friction and Eddy Currents measured at open secondary circuit, rated frequency, and at rated voltage $- Ir$, where I = rated current, r = resistance of primary circuit.

158. *b.* Resistance Losses, the sum of the I^2r losses in the primary and in the secondary windings of a transformer, or in the two sections of the coil in a compensator or auto-transformer, where I = rated current in the coil or section of coil, and r = resistance.

159. *c.* Load Losses, *i.e.*, eddy currents in the iron and especially in the copper conductors, caused by the current at rated load. For practical purposes they may be determined by short-circuiting the secondary of the transformer and impressing upon the primary a voltage sufficient to send rated-load current through the transformer. The loss in the transformer under these conditions, measured by wattmeter, gives the load losses $+ I^2r$ losses in both primary and secondary coils.

160. In Closed Magnetic Circuit Transformers, either of the two circuits may be used as primary when determining the efficiency.

161. In Potential Regulators, the efficiency should be taken at the maximum voltage for which the apparatus is designed, and with noninductive load, unless otherwise specified.

(*F*) Rotary Induction Apparatus or Induction Machines.

162. In Rotary Induction Apparatus, the losses are:

163. *a.* Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

164. *b.* Molecular Magnetic Friction and Eddy Currents in iron, copper and other metallic parts; also I^2r losses which may exist in multiple-circuit windings. *a* and *b* together are determined by running the motor without load at rated voltage, and measuring the power input.

165. *c.* Primary I^2R Loss, which may be determined by measurement of the current and the resistance.

166. *d*. Secondary I^2R Loss, which may be determined as in the primary when feasible; otherwise, as in squirrel-cage secondaries, this loss is measured as part of *e*.

167. *e*. Load Losses; *i.e.*, molecular magnetic friction, and eddy currents in iron, copper, etc., caused by the stray field of primary and secondary currents, and secondary I^2R loss when undeterminable under (*d*). These losses may for practical purposes be determined by measuring the total power, with the rotor short-circuited at standstill and a current in the primary circuit equal to the primary energy current at full load. The loss in the motor under these conditions may be assumed to be equal to the load losses + I^2r losses in both primary and secondary coils.

(*G*) Unipolar or Acyclic Machines.

168. In Unipolar Machines, the losses are:

169. (*a*) Bearing Friction and Windage. See Meas. of Losses (*A*), Sec. 102.

170. (*b*) Molecular Magnetic Friction and Eddy Currents. See Meas. of Losses (*E*), Sec. 106.

171. (*c*) Armature-Resistance Losses. See Meas. of Losses (*E*), Sec. 110.

172. (*d*) Collector-Brush Friction. See Meas. of Losses (*C*), Sec. 104.

173. (*e*) Collector Brush-Contact Resistance. See Meas. of Losses (*G*), Sec. 112.

174. (*f*) Field-Excitation. See Meas. of Losses (*H*), Sec. 113.

175. (*g*) Load Losses. See Meas. of Losses (*I*), Sec. 114.

(*H*) Rectifying Apparatus, Pulsating-Current Generators.

176. This division includes: open-coil arc machines and mechanical and other rectifiers.

177. In Rectifiers the most satisfactory method of determining the efficiency is to measure both electric input and electric output by wattmeter. The input is usually inductive, owing to phase displacement and to wave distortion. For this reason the power-factor and the apparent efficiency should also be considered, since the latter may be much lower than the true efficiency. The power consumed by auxiliary devices, such as the synchronous motor or cooling devices, should be included in the electric input.

178. In Constant-Current Rectifiers, transforming from constant potential alternating to constant direct current, by means of constant-current transforming devices and rectifying devices, the losses in the transforming devices are to be included in determining the efficiency and have to be measured when operating the rectifier, since in this case the losses may be greater than when feeding an alternating secondary circuit. In constant-current transforming devices, the load losses may be considerable, and, therefore, should not be neglected.

179. In Open-Coil Arc Machines, the losses are essentially the same as in direct-current (closed coil) commutating machines. In this case, however, the load losses are usually greater, and the efficiency should preferably be measured by input- and output-test, using wattmeters for measuring the output.

179*a*. In alternating-current rectifiers, the output should, in general, be measured by wattmeter and not by voltmeter and ammeter, since, owing to pulsation of current and voltage, a considerable discrepancy may exist between watts and volt-amperes. If, however, a direct-current and an alternating-current meter in the rectified circuit (either a voltmeter or an ammeter) give the same reading, the output may be measured by direct-current voltmeter and ammeter. The type of alternating-current instrument here referred to should indicate the effective or root-of-mean-square value and the type of direct-current instrument the arithmetical mean value, which would be zero on an alternating-current circuit.

(*I*) Transmission Lines.

180. The efficiency of transmission lines should be measured with non-inductive load at the receiving end, with the rated receiving voltage and frequency, also with sinusoidal impressed wave form, except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the ends of the line.

(*J*) Phase-Displacing Apparatus.

183. In Synchronous Phase-Modifiers and exciters of induction generators, the determination of losses is the same as in other synchronous machines.

184. In Reactors, the losses are molecular magnetic friction, eddy losses and I^2r loss. They should be measured by wattmeter. The losses of reactors should be determined with a sine wave of impressed voltage except where expressly specified otherwise.

185. In Condensers, the losses are due to dielectric hysteresis and leakage, and should be determined by wattmeter with a sine wave of voltage or by an alternating-current bridge method.

186. In Polarization Cells, the losses are those due to electric resistivity and a loss in the electrolyte of the nature of chemical hysteresis. These losses may be considerable. They depend upon the frequency, voltage and temperature, and should be determined with a sine wave of impressed voltage, except where expressly specified otherwise.

D. REGULATION.

(I) *Definitions.*

187. The Regulation of a machine or apparatus in regard to some characteristic quantity (such as terminal voltage, current or speed) is the ratio of the deviation of that quantity from its normal value at rated load to that normal value. The term "regulation," therefore, has the same meaning as the term "inherent regulation," occasionally used.

188. Constant Standard. If the characteristic quantity is intended to remain constant (*e.g.*, constant voltage, constant speed, etc.) between rated load and no load, the regulation is the ratio of the maximum variation from the rated-load value to the no-load value.

189. Varying Standard. If the characteristic quantity is intended to vary in a definite manner between rated load and no load, the regulation is the ratio of the maximum variation from the specified condition to the normal rated-load value.

190. (*a*) Note. If the law of the variation (in voltage, current, speed, etc.) between rated load and no load is not specified, it should be assumed to be a simple linear relation; *i.e.*, one undergoing uniform variation between rated load and no load.

191. (*b*) Note. The regulation of an apparatus may, therefore, differ according to its qualification for use. Thus, the regulation of a compound-wound generator specified as a constant-potential generator will be different from that which it possesses when specified as an over-compounded generator.

192. In Constant-Potential Machines, the regulation is the ratio of the maximum difference of terminal voltage from the rated-load value (occurring within the range from rated load to open circuit) to the rated-load terminal voltage.

193. In Constant-Current Machines, the regulation is the ratio of the maximum difference of current from the rated-load value (occurring within the range from rated-load to short-circuit, or minimum limit of operation) to the rated-load current.

194. In Constant-Power Apparatus, the regulation is the ratio of maximum difference of power from the rated-load value (occurring within the range of operation specified) to the rated power.

195. In Constant-Speed Direct-Current Motors and Induction Motors, the regulation is the ratio of the maximum variation of speed from its rated-load value (occurring within the range from rated load to no load) to the rated-load speed.

196. The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism to the synchronous speed.

197. In Constant-Potential Transformers, the regulation is the ratio of the rise of secondary terminal voltage from rated non-inductive load to no load (at constant primary impressed terminal voltage) to the secondary terminal voltage at rated load.

198. In Over-Compounded Machines, the regulation is the ratio of the maximum difference in voltage from a straight line connecting the no-load and rated-load values of terminal voltage as function of the load current to the rated-load terminal voltage.

199. In Converters, Dynamotors, Motor-Generators and Frequency Converters, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated-load voltage to the rated-load voltage on the output side.

200. In Transmission Lines, Feeders, etc., the regulation is the ratio of the

maximum voltage difference at the receiving end, between rated non-inductive load and no load, to the rated-load voltage at the receiving end (with constant voltage impressed upon the sending end).

201. In Steam Engines, the regulation is the ratio of the maximum variation of speed in passing slowly from rated load to no load (with constant steam pressure at the throttle) to the rated-load speed. For variation and pulsation see Secs. 59–64.

202. In a Hydraulic Turbine or Other Water-Motor, the regulation is the ratio of the maximum variation of speed in passing slowly from rated load to no load (at constant head of water; *i.e.*, at constant difference of level between tail race and head race) to the rated-load speed. For variation and pulsation see Secs. 59–64.

203. In a Generator-Unit, consisting of a generator united with a prime-mover, the regulation should be determined at constant conditions of the prime-mover; *i.e.*, constant steam pressure, head, etc. It includes the inherent speed variations of the prime-mover. For this reason the regulation of a generator-unit is to be distinguished from the regulation of either the prime-mover, or of the generator contained in it, when taken separately.

(II) *Conditions for and Tests of Regulation.*

204. Speed. The Regulation of Generators is to be determined at constant speed, and of alternating apparatus at constant impressed frequency.

205. Non-Inductive Load. In apparatus generating, transforming or transmitting alternating currents, regulation should be understood to refer to non-inductive load, that is, to a load in which the current is in phase with the E.M.F. at the output side of the apparatus, except where expressly specified otherwise.

206. Wave Form. In alternating apparatus receiving electric power, regulation should refer to a sine wave of E.M.F., except where expressly specified otherwise.

207. Excitation. In commutating machines, rectifying machines, and synchronous machines, such as direct-current generators and motors, alternating-current and polyphase generators, the regulation is to be determined under the following conditions:

(1) At constant excitation in separately excited fields.
(2) With constant resistance in shunt-field circuits, and
(3) With constant resistance shunting series-field circuits; *i.e.*, the field adjustment should remain constant, and should be so chosen as to give the required rated-load voltage at rated-load current.

208. Impedance Ratio. In alternating-current apparatus, in addition to the non-inductive regulation, the impedance ratio of the apparatus should be specified; *i.e.*, the ratio of the voltage consumed by the total internal impedance of the apparatus at rated-load current to its rated-load voltage. As far as possible, a sinusoidal current should be used.

209. Computation of Regulation. In synchronous machines, the open-circuit exciting ampere-turns corresponding to terminal voltage plus armature-resistance-drop and the exciting ampere-turns at short-circuit for rated-load current should be combined vectorially to obtain the resultant ampere-turns, and the corresponding internal E.M.F. should be taken from the saturation curve.

E. INSULATION.

(I) *Insulation Resistance.*

210. Insulation Resistance is the ohmic resistance offered by an insulating coating, cover, material or support to an impressed voltage, tending to produce a leakage of current through the same.

211. Ohmic Resistance and Dielectric Strength. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage. Since the ohmic resistance of the insulation can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

212. Recommended Value of Resistance. The insulation resistance of completed apparatus should be such that the rated terminal voltage of the apparatus will not send more than $\frac{1}{1,000,000}$ of the rated-load current through

the insulation. Where the value found in this way exceeds one megohm, it is usually sufficient.

213. Insulation Resistance Tests should, if possible, be made at the pressure for which the apparatus is designed.

(II) *Dielectric Strength.*

(*A*) Test Voltages.

214. Definition. The dielectric strength of an insulating wall, coating, cover or path is measured by the voltage which must be applied to it in order to effect a disruptive discharge through the same.

215. Basis for Determining Test Voltages. The test voltage which should be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the apparatus, and its normal operating voltage upon the nature of the service in which it is to be used and the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended have been determined as reasonable and proper for the great majority of cases and are proposed for general adoption, except when specific reasons make a modification desirable.

216. Condition of Apparatus to be Tested. Commercial tests should, in general, be made with the completely assembled apparatus and not with individual parts. The apparatus should be in good condition and high-voltage tests, unless otherwise specified, should be applied before the machine is put into commercial service, and should not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests should, in general, be made at the temperature assumed under normal operation. High-voltage tests considerably in excess of the normal voltages to determine whether specifications are fulfilled are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine should be understood as being made at the factory.

217. Points of Application of Voltage. The test voltage should be successively applied between each electric circuit and all other electric circuits including conducting material in the apparatus.

218. The Frequency of the alternating-current test voltage is, in general, immaterial within commercial ranges. When, however, the frequency has an appreciable effect, as in alternating-current apparatus of high voltage and considerable capacity, the rated frequency of the apparatus should be used.

219. Table of Testing Voltages. The following voltages are recommended for testing all apparatus, lines and cables, by a continued application for one minute. The test should be with alternating voltage having a virtual value (or root mean square referred to a sine wave of voltage) given in the table, and preferably for tests of alternating apparatus at the normal frequency of the apparatus.

220. Rated Terminal Voltage of Circuit.	Rated Output.	Testing Voltage.
Not exceeding 400 volts	Under 10 kw.	1,000 volts
" " " "	10 kw. and over	1,500 "
400 and over, but less than 800 volts	Under 10 kw.	1,500 "
" " " " " "	10 kw. and over	2,000 "
800 " " " 1,200 "	Any	3,500 "
1,200 " " " 2,500 "	Any	5,000 "
2,500 " "	Any	Double the normal rated voltages.

221. Exception. — Transformers. Transformers having primary pressures of from 550 to 5,000 volts, the secondaries of which are directly connected to consumption circuits, should have a testing voltage of 10,000 volts, to be applied between the primary and secondary windings, and also between the primary winding and the core.

222. Exception. — Field Windings. The tests for field windings should be based on the rated voltage of the exciter and the rated output of the machine of which the coils are a part. Field windings of synchronous motors and converters, which are to be started by applying alternating current to the armature when the field is not excited and when a high voltage is induced in the field windings, should be tested at 5,000 volts.

223. Rated Terminal Voltage. — Definition. The rated terminal voltage of circuit in the above table means the voltage between the conductors of the circuit to which the apparatus to be tested is to be connected; for instance, in three-phase circuits the delta voltage should be taken. In the

following specific cases, the rated terminal voltage of the circuit is to be determined as specified in ascertaining the testing voltage:

224. (*a*) Transformers. The test of the insulation between the primary and secondary windings of transformers is to be the same as that between the high-voltage windings and core, and both tests should be made simultaneously by connecting the low-voltage winding and core together during the test. If a voltage equal to the specified testing voltage be induced in the high-voltage winding of a transformer it may be used for insulation tests instead of an independently induced voltage. These tests should be made first with one end and then with the other end of the high-tension winding connected to the low-tension winding and to the core.

225. (*b*) Constant-Current Apparatus. The testing voltage is to be based upon a rated terminal voltage equal to the maximum voltage which may exist at open or closed circuit.

226. (*c*) Apparatus in Series. For tests of machines or apparatus to be operated in series, so as to employ the sum of their separate voltages, the testing voltage is to be based upon a rated terminal voltage equal to the sum of the separate voltages except where the frames of the machines are separately insulated, both from the ground and from each other, in which case the test for insulation between machines should be based upon the voltage of one machine, and the test between each machine and ground to be based upon the total voltage of the series.

(*B*) Methods of Testing.

227. Classes of Tests. Tests for dielectric strength cover such a wide range in voltage that the apparatus, methods and precautions which are essential in certain cases do not apply to others. For convenience, the tests will be separated into two classes:

228. Class 1. This class includes all apparatus for which the test voltage does not exceed 10 kilovolts, unless the apparatus is of very large static capacity, *e.g.*, a large cable system. This class also includes all apparatus of small static capacity, such as line insulators, switches and the like. for all test voltages.

229. Method of Test for Class 1. The test voltage is to be continuously applied for the prescribed interval (one minute, unless otherwise specified). The test voltage may be taken from a constant-potential source and applied directly to the apparatus to be tested, or it may be raised gradually as specified for tests under Class 2.

230. Class 2. This class includes all apparatus not included in Class 1.

231. Method of Test for Class 2. The test voltage is to be raised to the required value smoothly and without sudden large increments and is then to be continuously applied for the prescribed interval (one minute, unless otherwise specified), and then gradually decreased.

232. Conditions and Precautions for Class 1 and Class 2. The following apply to all tests:

233. The Wave Shape should be approximately sinusoidal and the apparatus in the testing circuits should not materially distort this wave.

234. The Supply Circuit should have ample current-supply capacity so that the charging current which may be taken by the apparatus under test will not materially alter the wave form nor materially affect the test voltage. The circuit should be free from accidental interruptions.

235. Resistance or Inductance in series with the primary of a raising transformer for the purpose of controlling its voltage is liable seriously to affect the wave form, thereby causing the maximum value of the voltage to bear a different and unknown ratio to the root mean square value. This method of voltage adjustment is, therefore, in general, undesirable. It may be noted that if a resistance or inductance is employed to limit the current when burning out a fault, such resistance or inductance should be short-circuited during the regular voltage test.

236. The Insulation under test should be in normal condition as to dryness and the temperature should, when possible, be that reached in normal service.

237. Additional Conditions and Precautions for Class 2. The following conditions and precautions, in addition to the foregoing, apply to tests of apparatus included in Class 2.

238. Sudden Increment of Testing Voltage on the apparatus under test should be avoided, particularly at high voltages and with apparatus having considerable capacity, as a momentarily excessive rise in testing voltage will result.

239. Sudden Variations in Testing Voltage of the circuit supplying the voltage during the test should be avoided as they are likely to set up injurious oscillation.

240. Good Connections in the circuits supplying the test voltage are essential in order to prevent injurious high frequency disturbances from being set up. When a heavy current is carried by a small water rheostat, arcing may occur, causing high-frequency disturbances which should be carefully avoided.

241. Transformer Coils. In high-voltage transformers, the low-voltage coil should preferably be connected to the core and to the ground when the high-voltage test is being made, in order to avoid the stress from low-voltage coil to core, which would otherwise result through condenser action. The various terminals of each winding of the high-tension transformer under test should be connected together during the test in order to prevent undue stress on the insulation between turns or sections of the winding in case the high-voltage test causes a breakdown.

(*C*) Methods for Measuring the Test Voltage.

242. For Measuring the Test Voltage, two instruments are in common use, (1) the spark gap and (2) the voltmeter.

243. 1. The Spark Gap is ordinarily adjusted so that it will break down with a certain predetermined voltage, and is connected in parallel with the insulation under test. It ensures that the voltage applied to the insulation is not greater than the breakdown voltage of the spark gap. A given setting of the spark gap is a measure of one definite voltage, and, as its operation depends upon the maximum value of the voltage wave, it is independent of wave form and is a limit on the maximum stress to which the insulation is subjected. The spark gap is not conveniently adapted for comparatively low voltages.

244. In Spark-Gap Measurements, the spark gap may be set for the required voltage and the auxiliary apparatus adjusted to give a voltage at which this spark gap just breaks down. The spark gap should then be adjusted for, say, 10 per cent higher voltage, and the auxiliary apparatus again adjusted to give the voltage of the former breakdown, which is to be the assumed voltage for the test. This voltage is to be maintained for the required interval.

245. The Spark Points should consist of new sewing needles, supported axially at the ends of linear conductors which are each at least twice the length of the gap. There should be no extraneous body near the gap within a radius of twice its length. A table of approximate striking distances is given in Appendix D. This table should be used in connection with tests made by the spark-gap methods.

246. A Non-Inductive Resistance of about one-half ohm per volt should be inserted in series with each terminal of the gap so as to keep the discharge current between the limits of one-quarter ampere and 2 amperes. The purpose of the resistance is to limit the current in order to prevent the surges which might otherwise occur at the time of breakdown.

247. 2. The Voltmeter gives a direct reading, and the different values of the voltage can be read during the application and duration of the test. It is suitable for all voltages, and does not introduce disturbances into the test circuit.

248. In Voltmeter Measurements, the voltmeter should, in general, derive its voltage from the high-tension testing circuit either directly or through an auxiliary ratio transformer. It is permissible, however, to measure the voltage at other places, for example, on the primary of the transformer, provided the ratio of transformation does not materially vary during the test; or that proper account is taken thereof.

249. Spark Gap and Voltmeter. The spark gap may be employed as a check upon the voltmeter used in high-tension tests in order to determine the transformation ratio of the transformer, the variation from the sine wave form and the like. It is also useful in conjunction with voltmeter measurements to limit the stress applied to the insulating material.

(*D*) Apparatus for Supplying Test Voltage.

250. The Generator or Circuit supplying voltage for the test should have ample current carrying capacity, so that the current which may be taken for charging the apparatus to be tested will not materially alter the wave form nor otherwise materially change the voltage.

The Testing Transformer should be such that its ratio of transformation does not vary more than 10 per cent when delivering the charging current required by the apparatus under test. (This may be determined by short-circuiting the secondary or high-voltage winding of the testing transformer and supplying $\frac{1}{10}$ of the primary voltage to the primary under this condition. The primary current that flows under this condition is the maximum which should be permitted in regular dielectric test.)

251. The Voltage Control may be secured in either of several ways, which, in order of preference, are as follows:

252. 1. By generator field circuit.

253. 2. By magnetic commutation.

254. 3. By change in transformer ratio.

255. 4. By resistance or choke coils.

256. In Generator Voltage Control, the voltage of the generator should preferably be about its approximate normal rated-load value when the full testing voltage is attained, which requires that the ratio of the raising transformer be such that the full testing voltage is reached when the generator voltage is normal. This avoids the instability in the generator which may occur if a considerable leading current is taken from it when it has low voltage and low field current.

257. In Magnetic Commutation, the control is effected by shunting the magnetic flux through a secondary coil so as to vary the induction through the coil and the voltage induced in it. The shunting should be effected smoothly, thus avoiding sudden changes in the induced voltage.

258. In Transformer Voltage Control, by change of ratio, it is necessary that the transition from one step to another be made without interruption of the test voltage, and by steps sufficiently small to prevent surges in the testing circuit. The necessity of this precaution is greater as the inductance or the static capacity of the apparatus in the testing circuit under test is greater.

259. When Resistance Coils or Reactors are used for voltage control, it is desirable that the testing voltage should be secured when the controlling resistance or reactance is very nearly or entirely out of circuit in order that the disturbing effect upon the wave form which results may be negligible at the highest voltage.

F. CONDUCTIVITY.

260. Copper. The conductivity of copper in annealed wires and in electric cables should not be less than 98 per cent of the Annealed Copper Standard, and the conductivity of hard-drawn copper wires should not be less than 95 per cent of the Annealed Copper Standard. The Annealed Copper Standard represents a mass-resistivity of 0.153022 ohm per metergram at 20° C. or 873.75 ohms per mile-pound at 20° C.; or using a density of 8.89, a volume-resistivity of 1.72128 microhm-cm., or microhms in a cm. cube, at 20° C., or 0.67767 microhm-inch at 20° C.

G. RISE OF TEMPERATURE.

(I) *Measurement of Temperature.*

(*A*) Methods.

261. There are two methods in common use for determining the rise in temperature, *viz.:* (1) by thermometer, and (2) by increase in resistance of an electric circuit.

262. 1. By Thermometer. The following precautions should be observed in the use of thermometers:

263. *a.* Protection. The thermometers indicating the room temperature should be protected from thermal radiation emitted by heated bodies, or from draughts of air or from temporary fluctuations of temperature. Several room thermometers should be used. In using the thermometer by applying it to a heated part, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

264. *b.* Bulb. When a thermometer is applied to the free surface of a machine, it is desirable that the bulb of the thermometer should be covered by a pad of definite area. A convenient pad may be formed of cotton waste in a shallow circular box about one and a half inches in diameter, through a slot in the side in which the thermometer bulb is inserted. An unduly large pad over the thermometer tends to interfere with the natural liberation of heat from the surface to which the thermometer is applied.

265. 2. By Increase in Resistance. The resistance may be measured either by the Wheatstone bridge, the Thomson or Kelvin double bridge, the potentiometer method, or the ammeter and voltmeter method. If a temperature coefficient must be assumed, its value for copper may be taken to be 0.00394 per degree C. from and at 20° C. or 0.00428 per degree C. from and at

0° C. This value holds for average commercial *annealed* copper. If the copper wire is hard-drawn, or if the conductivity is known, a different value of temperature coefficient should be taken, according to the explanation and discussion of the temperature coefficient in Appendix E.

The temperature rise may be determined either (1) by dividing the per cent increase of initial resistance by the temperature coefficient for the initial temperature expressed in per cent; or (2) by multiplying the increase in per cent of the initial resistance by T plus the initial temperature in degrees C., and then dividing the product by 100. ($-T$ is the "inferred absolute zero temperature of resistance" and is given in the last column of the table in Appendix E. For average commercial *annealed* copper it is 233.8.)

266. 3. Comparison of Methods. In electrical conductors, the rise of temperature should be determined by their increase of resistance where practicable. Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers. In very low-resistance circuits, thermometer measurements are frequently more reliable than measurements by the resistance method. Where a thermometer applied to a coil or winding indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted.

(*B*) Normal Conditions for Tests.

267. 1. Duration of Tests. The temperature should be measured after a run of sufficient duration for the apparatus to reach a practically constant temperature. This is usually from 6 to 18 hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

268. 2. Room Temperature. The rise of temperature should be referred to the standard condition of a room temperature of 25° C.

269. Temperature Correction. If the room temperature during the test differs from 25° C., correction on account of difference in resistance should be made by changing the observed rise of temperature by one-half per cent for each degree Centigrade. Thus with a room temperature of 35° C., the observed rise of temperature has to be decreased by 5 per cent, and with a room temperature of 15° C., the observed rise of temperature has to be increased by 5 per cent. In certain cases, such as shunt-field circuits without rheostat, the current strength will be changed by a change of room temperature. The heat-production and dissipation may be thereby affected. Correction for this should be made by changing the observed rise in temperature in proportion as the I^2R loss in the resistance of the apparatus is altered owing to the difference in room temperature.

270. 3. Barometric Pressure. Ventilation. A barometric pressure of 760 mm. and normal conditions of ventilation should be considered as standard, and the apparatus under test should neither be exposed to draught nor enclosed, except where expressly specified. The barometric pressure needs to be considered only when differing greatly from 760 mm.

271. Barometric Pressure Correction. When the barometric pressure differs greatly from the standard pressure of 760 mm. of mercury, as at high altitudes, a correction should be applied. In the absence of more nearly accurate data, a correction of one per cent of the observed rise in temperature for each 10 mm. deviation from the 760-mm. standard is recommended. For example at a barometric pressure of 680 mm. the observed rise of temperature is to be reduced by $\frac{760-680}{10} = 8$ per cent.

(II) *Limiting Temperature Rise.*

272. General. The temperature of electrical machinery under regular service conditions should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

273. Limits Recommended. It is recommended that the following maximum values of temperature elevation, referred to a standard room temperature of 25° C., at rated load under normal conditions of ventilation or cooling, should not be exceeded.

(*A*) Machines in General.

274. In commutating machines, rectifying machines, pulsating-current generators, synchronous machines, synchronous commutating machines and

unipolar machines, the temperature rise in the parts specified should not exceed the following:

275. Field and armature, 50° C.
276. Commutator and brushes, by thermometer, 55° C.
277. Collector rings, 65° C.
278. Bearings and other parts of machine, by thermometer, 40° C.
279. (*B*) Rotary Induction Apparatus. The temperature rise should not exceed the following:
280. Electric circuits, 50° C., by resistance.
281. Bearings and other parts of the machine, 40° C., by thermometer.
282. In squirrel-cage or short-circuited armatures, 55° C., by thermometer, may be allowed.

(*C*) Stationary Induction Apparatus.

283. *a*. Transformers for Continuous Service. The temperature rise should not exceed 50° C. in electric circuits, by resistance; and in other parts, by thermometer.

284. *b*. Transformers for Intermittent Service. In the case of transformers intended for intermittent service, or not operating continuously at rated load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air-temperature should not exceed 50° C., by resistance in electric circuits and by thermometer in other parts, after the period corresponding to the term of rated load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the rated-load test may be taken as three hours, unless otherwise specified.

285. *c*. Reactors, Induction- and Magneto-Regulators. Electric circuits by resistance and other parts by thermometer, 50° C.

286. *d*. Large Apparatus. Large generators, motors, transformers, or other apparatus in which reliability and reserve overload capacity are important, are frequently specified not to rise in temperature more than 40° C. under rated load and 55° C. at rated overload. It is, however, ordinarily undesirable to specify lower temperature elevations than 40° C. at rated load, measured as above.

(*D*) Rheostats.

287. In Rheostats, Heaters and other electrothermal apparatus, no combustible or inflammable part or material, or portion liable to come in contact with such material, should rise more than 50° C. above the surrounding air under the service conditions for which it is designed.

288. *a*. Parts of Rheostats. Parts of rheostats and similar apparatus rising in temperature, under the specified service conditions, more than 50° C., should not contain any combustible material, and should be arranged or installed in such a manner that neither they, nor the hot air issuing from them, can come in contact with combustible material.

(*E*) Limits Recommended in Special Cases.

289. *a*. Heat-Resisting Insulation. With apparatus in which the insulating materials have special heat-resisting qualities, a higher temperature elevation is permissible.

290. *b*. High Air Temperature. In apparatus intended for service in places of abnormally high temperature, a lower temperature elevation should be specified.

291. *c*. Apparatus Subject to Overload. In apparatus which by the nature of its service may be exposed to overload, or is to be used in very high voltage circuits, a smaller rise of temperature is desirable than in apparatus not liable to overloads or in low-voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

292. *d*. Apparatus for Intermittent Service. In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of rated load should not exceed the values specified for machines in general. In such apparatus, including railway motors, the temperature elevation should be measured after operation, under as nearly as possible the conditions of service for which the apparatus is intended, and the conditions of the test should be specified.

H. OVERLOAD CAPACITIES.

293. Performance with Overload. All apparatus should be able to carry the overload hereinafter specified without serious injury by heating, sparking, mechanical weakness, etc., and with an additional temperature rise not exceeding 15° C., above those specified for rated loads, the overload being applied after the apparatus has acquired the temperature corresponding to rated-load continuous operation. Rheostats to which no temperature rise limits are attached are naturally exempt from this additional temperature rise of 15° C. under overload specified in these rules.

294. Normal Conditions. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

295. Overload Capacities Recommended. The following overload capacities are recommended:

296. *a*. Generators. Direct-current generators and alternating-current generators, 25 per cent for two hours.

297. *b*. Motors. Direct-current motors, induction motors and synchronous motors, not including railway and other motors intended for intermittent service, 25 per cent for two hours, and 50 per cent for one minute.

298. *c*. Converters. Synchronous converters, 25 per cent for two hours, 50 per cent for one-half hour.

299. *d*. Transformers and Rectifiers. Constant-potential transformers and rectifiers, 25 per cent for two hours; except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

300. *e*. Exciters. Exciters of alternators and other synchronous machines, 10 per cent more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time. All exciters of alternating-current, single-phase or polyphase generators, should be able to give at their rated speed, sufficient voltage and current to excite their alternators, at the rated speed, to the full-load terminal voltage, at the rated output in kilovolt-amperes and with 50 per cent power-factor.

301. *f*. A Continuous-Service Rheostat, such as an armature- or field-regulating rheostat, should be capable of carrying without injury for two hours a current 25 per cent greater than that at which it is rated. It should also be capable of carrying for one minute a current 50 per cent greater than its rated-load current, without injury. This excess of capacity is intended for testing purposes only, and this margin of capacity should not be relied upon in the selection of the rheostat.

302. *g*. An Intermittent Service or Motor-Starting Rheostat is used for starting a motor from rest and accelerating it to rated speed. Under ordinary conditions of service, and unless expressly stated otherwise, a motor is assumed to start in fifteen seconds and with 150 per cent of rated current strength. A motor-starter should be capable of starting the motor under these conditions once every four minutes for one hour.

303. (*a*) This test may be carried out either by starting the motor at four-minute intervals, or by placing the starter at normal temperature across the maximum voltage for which it is marked, and moving the lever uniformly and gradually from the first to the last position during a period of fifteen seconds, the current being maintained substantially constant at said 50 per cent excess, by introducing resistance in series or by other suitable means.

304. (*b*) Other Rheostats for Intermittent-Service are employed under such special and varied conditions that no general rules are applicable to them.

III. VOLTAGES AND FREQUENCIES.

A. VOLTAGES.

305. Direct-Current Generators. In direct-current, low-voltage generators, the following average terminal voltages are in general use and are recommended:

125 volts. 250 volts. 600 volts

306. Low-Voltage Circuits. In direct-current low-voltage circuits, the following terminal voltages are in general use and are recommended:

115 volts. 230 volts. 550 volts.

In alternating-current low-voltage circuits, the following terminal voltages are in general use and are recommended:

110 volts. 220 volts. 440 volts. 550 volts.

307. Primary Distribution Circuits. In alternating-current, constant-potential, primary-distribution circuits, an average voltage of 2,200 volts, with step-down transformer ratios $\frac{1}{10}$ and $\frac{1}{20}$, is in general use, and is recommended.

308. Transmission Circuits. In alternating-current constant-potential transmission circuits, the following impressed voltages are recommended:

6,600 11,000 22,000 33,000 44,000 66,000 88,000 110,000

309. Transformer Ratio. It is recommended that the standard transformer ratios should be such as to transform between the standard voltages above named. The ratio will, therefore, usually be an exact multiple of 5 or 10, *e.g.*, 2,200 to 11,000; 2,200 to 44,000.

310. Range in Voltage. In alternating-current generators, or generating systems, a range of terminal voltage should be provided from rated voltage at no load to 10 per cent in excess thereof, to cover drop in transmission. If a greater range than ten per cent is specified, the generator should be considered as special.

B. FREQUENCIES.

311. In Alternating-Current Circuits, the following frequencies are standard:

25 cycles. 60 cycles.

312. These frequencies are already in extensive use and it is deemed advisable to adhere to them as closely as possible.

IV. GENERAL RECOMMENDATIONS.

313. Name Plates. All electrical apparatus should be provided with a name plate giving the manufacturers' name, the voltage and the current in amperes for which it is designed. Where practicable, the kilowatt capacity, character of current, speed, frequency, type, designation and serial number should be added.

314. Diagrams of Connections. All electrical apparatus when leaving the factory should be accompanied by a diagram showing the electrical connections and the relation of the different parts in sufficient detail to give the necessary information for proper installation.

315. Rheostat Data. Every rheostat should be clearly and permanently marked with the voltage and amperes, or range of amperes, for which it is designed.

316. Colored Indicating Lights. When using colored indicating lights on switch-boards, red should denote danger, such as "switch closed" or "circuit alive"; green should denote safety, such as "switch open" or "circuit dead."

317. When white lights are used, a light turned on should denote danger, such as "switch closed" or "circuit alive"; while the light out should denote safety, such as "switch open" or "circuit dead." Low-efficiency lamps should be used on account of their lesser liability to accidental burn-out.

318. The use of colored lights is recommended, as safer than white lights.

319. Grounding Metal Work. It is desirable that all metal work near high potential circuits be grounded.

320. Circuit Opening Devices. The following definitions are recommended.

321. *a*. A Circuit-Breaker is an apparatus for breaking a circuit at the highest current which it may be called upon to carry.

322. *b*. A Disconnecting Switch is an apparatus designed to open a circuit only when carrying little or no current.

323. *c*. An Automatic Circuit-Breaker is an apparatus for breaking a circuit automatically under an excessive strength of current. It should be capable of breaking the circuit repeatedly at rated voltage and at the maximum current which it may be called upon to carry.

V. APPENDICES AND TABULAR DATA.

APPENDIX A. NOTATION.

The following notation is recommended:

	Name of Quantity.	Symbol.	Unit.
324.	Voltage, E.M.F., potential difference	E, e,	volt
	Current	I, i,	ampere
	Resistance	R, r,	ohm
	Reactance	X, x,	"
	Impedance	Z, z,	"
	Admittance	Y, y,	mho
	Conductance	G, g,	"
	Susceptance	B, b,	"
	Power	P, p,	watt
	Capacity	C, c,	farad
	Inductance	$\mathfrak{L}$, L,	henry
	Magnetic flux	Φ	maxwell
	Magnetic density	$\mathfrak{B}$,	gauss
	Magnetic force	H,	gilbert per cm.
	Length	L, l,	cm. or inch
	Mass	M, m,	gm. or lb.
	Time	T, t,	second or hour

Em, *Im* and *Bm* should preferably be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see Sec. 5g) and P for the average value or effective power. These distinctions are not necessary in dealing with continuous-current circuits. Vector quantities are preferably represented by bold face capitals.

APPENDIX B. RAILWAY MOTORS.

(I) *Rating.*

325. Introductory Note on Rating. Railway motors usually operate in a service in which both the speed and the torque developed by the motor are varying almost continually. The average requirements, however, during successive hours in a given class of service are fairly uniform. On account of the wide variation of the instantaneous loads, it is impracticable to assign any simple and definite rating to a motor which will indicate accurately the absolute capacity of a given motor or the relative capacity of different motors under service conditions. It is also impracticable to select a motor for a particular service without much fuller data with regard both to the motor and to the service than is required, for example, in the case of stationary motors which run at constant speeds.

326. Scope of Nominal Rating. It is common usage to give railway motors a nominal rating in horse power on the basis of a one-hour test. As above explained, a simple rating of this kind is not a proper measure of service capacity. This nominal rating, however, indicates approximately the maximum output which the motor should ordinarily be called upon to develop during acceleration. Methods of determining the continuous capacity of a railway motor for service requirements are given under a subsequent heading.

327. The Nominal Rating of a railway motor is the horse-power output at the car-axle, that is, including gear and other transmission losses, which gives a rise of temperature above the surrounding air (referred to a room temperature of 25° C.) not exceeding 90° C. at the commutator and 75° C. at any other part after one hour's continuous run at its rated voltage (and frequency, in the case of an alternating-current motor) on a stand, with the motor-covers removed, and with natural ventilation. The rise in temperature is to be determined by thermometer, but the resistance of no electrical circuit in the motor shall increase more than 40 per cent during the test.

(II) *Selection of Motor for Specified Service.*

328. General Requirements. The suitability of a railway motor for a specified service depends upon the following considerations:

329. *a.* Mechanical ability to develop the requisite torque and speeds as given by its speed-torque curve.

330. *b.* Ability to commutate successfully the current demanded.

331. *c.* Ability to operate in service without occasioning a temperature rise in any part which will endanger the life of the insulation.

332. Operating Conditions, Typical Run. The operating conditions

which are important in the selection of a motor include the weight of load, the schedule speed, the distance between stops, the duration of stops, the rate of acceleration and of braking retardation, the grades and the curves; with these data at hand, the outputs which are required of the motor may be determined, provided the service requirements are within the limits of the speed-torque curve of the motor. These outputs may be expressed in the form of curves giving the instantaneous values of current and of voltage which must be applied to the motor. Such curves may be laid out for the entire line, but they are usually constructed only for a certain average or typical run, which is fairly representative of the conditions of service. To determine whether the motor has sufficient capacity to perform the service safely, further tests or investigations must be made.

333. Capacity Test of Railway Motor in Service. The capacity of a railway motor to deliver the necessary output may be determined by measurement of its temperature after it has reached a maximum in service. If a running test cannot be made under the actual conditions of service, an equivalent test may be made in a typical run back and forth, under such conditions of schedule speed, length of run, rate of acceleration, etc., that the test cycle of motor losses and conditions of ventilation are essentially the same as would be obtained in the specified service.

334. Methods of Comparing Motor Capacity with Service Requirements. Where it is not convenient to test motors under actual service conditions or in an equivalent typical run, recourse may be had to one of the two following methods of determining temperature rise now in general use:

335. 1. Method by Losses and Thermal Capacity Curves. The heat developed in a railway motor is carried partly by conduction through the several parts and partly by convection through the air to the motor-frame whence it is distributed to the outside air. As the temperature of the several parts is thus dependent not only upon their own internal losses but also upon the temperature of neighboring parts, it becomes necessary to determine accurately the actual value and distribution of losses in a railway motor for a given service and reproduce them in an equivalent test-run. The results of a series of typical runs expressed in the form of thermal capacity curves will give the relation between degrees rise per watt loss in the armature and in the field for all ratios of losses between them met with in the commercial application of a given motor.

336. This method consists, therefore, in calculating the several internal motor losses in a specified service and determining the temperature rise with these losses from thermal capacity curves giving the degrees rise per watt loss as obtained in experimental track tests made under the same conditions of ventilation.

337. The following motor losses cause its heating and should be carefully determined for a given service: I^2R in the field; I^2R in the armature; I^2R in the brush contacts, core loss and brush friction.

338. The loss in the bearings (in the case of geared motors) also adds somewhat to the motor-heating, but owing to the variable nature of such losses they are generally neglected in making calculations.

339. 2. Method by Continuous Capacity of Motor. The essential losses in the motor, as found in the typical run, are in most cases those in the motor windings and in the core. The mean service conditions may be expressed in terms of the current which would produce the same losses in the motor windings and the voltage which, with that current, would produce the same core losses as the average in service. The continuous capacity of the motor is given in terms of the amperes which it will carry when run on a testing stand — with covers on or off, as specified — at different voltages, say, 40, 60, 80 and 100 per cent of the rated voltage — with a temperature rise not exceeding 90° C. at the commutator and 75° C. at any other part, provided the resistance of no electric circuit in the motor increases more than 40 per cent. A comparison of the equivalent service conditions with the continuous capacity of the motor will determine whether the service requirements are within the safe capacity of the motor.

340. This method affords a ready means of determining whether a specified service is within the capacity of a given motor and it is also a convenient approximate method for comparing the service capacities of different motors.

APPENDIX C. PHOTOMETRY AND LAMPS.

341. Candle-Power. The luminous intensity of sources of light is expressed in candle-power. The unit of candle-power is the international candle

maintained by the Bureau of Standards at Washington, D. C. The Hefner unit is 0.90 of the international candle.

342. Lumen. The total flux of light from a source is equal to its mean spherical intensity multiplied by 4 π. The unit of flux is called the lumen. A lumen is the $\frac{1}{4\pi}$ th part of the total flux of light emitted by a source having a mean spherical intensity of one candle-power.

344. Illumination. The fundamental physical unit of illumination is the centimeter-candle, or lumen per square centimeter of incident surface. This is a very intense illumination. It is, therefore, convenient to express illumination practically in thousandths of the fundamental unit; *i.e.*, in millilumens per sq. cm. In English-speaking countries, the unit of illumination commonly employed is the foot-candle or lumen per square foot. A foot-candle is nearly the same illumination as a millilumen per sq. cm. and is actually the more intense in the ratio 1.0764, so that n foot-candles = 1.0764 $\times$ n millilumens per sq. cm. A meter candle, or lumen per square meter, is called a "lux." A foot-candle is 10.764 lux, and a millilumen per sq. cm. is exactly 10 lux.

346. The Efficiency of Electric Lamps is properly stated in terms of lumens per watt at lamp terminals. This use of the term efficiency is to be considered as special, and not to be confused with the generally accepted definition of efficiency in Sec. 84.

347. *a.* Efficiency, Auxiliary Devices. In illuminants requiring auxiliary power-consuming devices outside of the luminous body, such as steadying resistances in constant potential arc lamps, a distinction should be made between the net efficiency and the gross efficiency of the lamp. This distinction should always be stated. The gross efficiency should include the power consumed in the auxiliary resistance, etc. The net efficiency should, however, include the power consumed in the controlling mechanism of the lamp itself. Comparison between such sources of light should be made on the basis of gross efficiency, since the power consumed in the auxiliary device is essential to the operation.

348. A Standard Circuit Voltage of 110 volts, or a multiple thereof, may be assumed, except where expressly stated otherwise.

349. Watts per Candle. The specific consumption of an electric lamp is its watt consumption per mean spherical candle-power. "Watts per candle" is the term used commercially in connection with incandescent lamps, and denotes watts per mean horizontal candle-power.

350. Photometric Tests in which the results are stated in candle-power should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made at shorter distances, as for example in the measurement of lamps with reflectors, the results should always be given as "apparent candle-power" at the distance employed, which distance should always be specifically stated.

351. Basis for Comparison. Either the total flux of light in lumens, or the mean spherical candle-power, should always be used as the basis for comparing various luminous sources with each other, unless there is a clear understanding or statement to the contrary.

352. Incandescent Lamps, Rating. It is customary to rate incandescent lamps on the basis of their mean horizontal candle-power; but in comparing incandescent lamps in which the relative distribution of luminous intensity differs, the comparison should be based on their total flux of light measured in lumens, or on their mean spherical candle-power.

352*a*. Life Tests. Similar filaments may be assumed to operate at the same temperature only when their lumens per watt consumed are the same. Life tests are comparable only when conducted under similar conditions as to filament temperatures.

353. The Spherical Reduction-Factor of a lamp

$$= \frac{\text{mean spherical candle-power}}{\text{mean horizontal candle-power}}.$$

354. The Total Flux of light in lumens emitted by a lamp = 4 π $\times$ mean horizontal candle-power $\times$ spherical reduction-factor.

355. The Spherical Reduction-Factor should only be used when properly determined for the particular type and characteristics of each lamp. The spherical reduction-factor permits of substantially accurate comparisons being made between the total lumens, or mean spherical candle-powers of different

types of incandescent lamps, and may be used in the absence of proper facilities for direct measurement of the total lumens, or mean spherical candle-power.

356. "READING DISTANCE." Where standard photometric measurements are impracticable, approximate measurements of illuminants such as street lamps, may be made by comparing their "reading distances"; *i.e.*, by determining alternately the distances at which an ordinary size of reading print can just be read, by the same person or persons, when all other light is screened. The angle below the horizontal at which the measurement is made should be specified when it exceeds 15°. Reading distance methods usually involve the comparison of very faint illuminations and hence the results may be seriously affected by the Purkinje effect.

357. In Comparing Different Luminous Sources not only should their candle-power be compared, but also their relative form, brightness, distribution of illumination and character of light.

357*a*. The following symbols are recommended in connection with photometry:

Photometric magnitude.	Symbol.	Unit.
Intensity of light.	I	International candle.
Luminous flux.	F	Lumen.
Illumination.	E	Lumen/cm.^{2}, foot-candle.
Specific radiation.	R	Foot-candle.
Brightness.	b	Candle/cm.^{2}
Quantity.	Q	Candle.
Lighting.	L	Lumen-second, lumen-hour.

APPENDIX D. SPARKING DISTANCES.

358. Table of Sparking Distances in Air between Opposed Sharp Needle-Points, for Various Root-Mean-Square Sinusoidal Voltages, in inches and in centimeters. The table applies to the conditions specified in Secs. 240–246.

359.

Kilovolts R.M.S.	Distance. Inches.	Cm.	Kilovolts R.M.S.	Distance. Inches.	Cm.
5	0.225	0.57	140	13.95	35.4
10	0.47	1.19	150	15.0	38.1
15	0.725	1.84	160	16.05	40.7
20	1.0	2.54	170	17.10	43.4
25	1.3	3.3	180	18.15	46.1
30	1.625	4.1	190	19.20	48.8
35	2.0	5.1	200	20.25	51.4
40	2.45	6.2	210	21.30	54.1
45	2.95	7.5	220	22.35	56.8
50	3.55	9.0	230	23.40	59.4
60	4.65	11.8	240	24.45	62.1
70	5.85	14.9	250	25.50	64.7
80	7.1	18.0	260	26.50	67.3
90	8.35	21.2	270	27.50	69.8
100	9.6	24.4	280	28.50	72.4
110	10.75	27.3	290	29.50	74.9
120	11.85	30.1	300	30.50	77.4
130	12.90	32.8			

APPENDIX E. TEMPERATURE COEFFICIENT OF COPPER.

360. The fundamental relation between the rise of temperature and the increase of resistance of copper may be expressed thus:

$$R_t = R_{t_1}(1 + \alpha_{t_1}[t - t_1]),$$

where R_t is the resistance at any temperature t° C.; R_{t_1} is the resistance at any "initial temperature" (or "temperature of reference") t_1° C.; and α_{t_1} is the temperature coefficient from and at the initial temperature t_1° C. Obviously the temperature coefficient is different for different initial temperatures, and this variation is shown in the horizontal rows of the table below. Furthermore, it has been shown that the temperature coefficient is different for different conductivities, and that the temperature coefficient is substantially proportional to the conductivity. The results of this simple law are shown by the vertical columns of the table below.

TEMPERATURE COEFFICIENTS OF COPPER FOR DIFFERENT INITIAL TEMPERATURES AND DIFFERENT CONDUCTIVITIES.

Ohms per meter-gram at 20° C.	Per cent conductivity.	α_0	α_{15}	α_{20}	α_{25}	α_{30}	α_{50}	$-T$ "Inferred absolute zero."
0.16108	95	0.00405	0.00381	0.00374	0.00367	0.00361	0.00336	−247.2
0.15940	96	0.00409	0.00386	0.00378	0.00371	0.00364	0.00340	−244.4
0.15776	97	0.00414	0.00390	0.00382	0.00375	0.00368	0.00343	−241.7
0.15727	97.3	0.00415	0.00391	0.00383	0.00376	0.00369	0.00344	−240.9
0.15614	98	0.00418	0.00394	0.00386	0.00379	0.00372	0.00346	−239.0
0.15457	99	0.00423	0.00398	0.00390	0.00383	0.00375	0.00349	−236.4
0.153022	100	0.00428	0.00402	0.00394	0.00386	0.00379	0.00352	−233.8
0.15151	101	0.00432	0.00406	0.00398	0.00390	0.00383	0.00355	−231.3

The quantity ($-T$) given in the last column of the above table is the calculated temperature on the centigrade scale at which copper of the particular conductivity concerned would have zero electrical resistance *provided* the temperature coefficient between 0° C. and 100° C. applied continuously down to the absolute zero. The usefulness of this "inferred absolute zero temperature of resistance" in calculating temperature rise is evident from the following formula:

$$t - t_1 = \frac{R_{t_1} - R_{t_1}}{R_{t_1}}(T + t_1).$$

The presentation of the above table is intended to emphasize the desirability of determining the temperature coefficient rather than assuming it. Actual experimental determination is facilitated by the proportional relation between the temperature coefficient and the conductivity; a measurement of either quantity gives both. However, if a temperature coefficient *must* be assumed, the best value to take for average commercial *annealed* copper wire is that given in the table for 100 per cent conductivity, *viz.*,

$$\alpha_0 = 0.00428, \ \alpha_{20} = 0.00394, \ \alpha_{25} = 0.00386.$$

This is the value recommended for wire wound on instruments and machines, since they are generally wound with annealed wire and experiments have shown that the distortions due to the winding of the wire do not appreciably affect the temperature coefficient.

If a value must be assumed for *hard-drawn* copper wire, the value recommended is that given in the table for 97.3 per cent conductivity, *viz.*,

$$\alpha_0 = 0.00415, \ \alpha_{20} = 0.00383, \ \alpha_{25} = 0.00376.$$

The temperature coefficients in Fahrenheit degrees are given by dividing any α above by 1.8. Thus, the 20° C. or 68° F. temperature coefficient for copper of 100 per cent conductivity is 0.00394 per degree C., or 0.00219 per degree F.

APPENDIX F. HORSE POWER.

361. In view of the fact that a horse power defined as 550 foot-pounds per second represents a power which varies slightly with the latitude and altitude (from 743.3 to 747.6 watts) and also in view of the fact that different authorities differ as to the precise value of the horse power in watts, *the Standards Committee has adopted* 746 *watts as the value of the horse power.* The number of foot-pounds per second to be taken as one horse power is therefore such a value at any given place as is equivalent to 746 watts; the number varies from 552 to 549 foot-pounds per second, being 550 at 50° latitude (London), and 550.5 at Washington. The Standards Committee, however, recommends that the kilowatt instead of the horse power be used generally as the unit of power.

ELECTRIC LIGHTING.

REVISED BY DR. C. H. SHARP.

LIGHT.

VELOCITY of light 300,000 kilometers per second, or 186,000 miles per second.

Composition of Sunlight.

Violet produces the maximum chemical effect.
Indigo. Blue. Green.
Yellow, the maximum light effect.
Orange.
Red produces the maximum heat effect.

The most luminous part of the spectrum is the yellowish green.

Colors.

Primary.	Red.	Yellow.	Blue.
Secondary.	Orange.	Purple.	Green.

Laws of Radiation of a Black Body.

Stefan-Boltzmann law. The total energy radiated by a black body is proportional to the fourth power of its absolute temperature.

$$S = \sigma\theta^4.$$

Wien's displacement law. The product of the wave-length of the maximum of radiation and the absolute temperature of the radiating body is a constant.

$$\lambda_m\theta = \text{const.} = A.$$

The quotient of the maximum radiation by the fifth power of the absolute temperature is a constant.

$$E_m\theta^{-5} = \text{const.} = B.$$

Applying these laws the temperature of radiating bodies can be determined with a degree of accuracy which depends chiefly on the degree to which the body approaches a black body in its characteristics. Lummer and Pringsheim have found that for polished platinum $\lambda_m\theta = 2630$, while for a black body $\lambda_m\theta = 2940$. Hence the temperatures of other radiating bodies such as carbon must lie between the limits set by the two equations

$$\theta = \frac{2630}{\lambda_m} \text{ and } \theta = \frac{2940}{\lambda_m}.$$

The Intensity of a Source of light is measured by comparison with a source of unit intensity. The unit of luminous intensity commonly employed is the *candle-power*.

Intensity of Illumination produced on a surface by a source of light concentrated at a point is inversely as the square of the distance between the surface and the source of light,

or

$$\text{Intensity of illumination} = \frac{\text{Intensity of source}}{\text{distance}^2} \times \cos i,$$

where i is the angle of incidence of the rays.

Units of illumination are the foot-candle and the meter-candle or candle lumen (A. I. E. E.) The foot-candle is the illumination produced on the surface one foot distant by a source of one candle-power, the rays falling normally on the surface.

The meter-candle or candle lumen is similarly defined, the meter being substituted for the foot.

The unit of **luminous flux** is defined as follows: A unit flux is that flux sent by a source of unit intensity (candle-power) through a unit solid angle. This unit is called the lumen or candle lumen (standardization rules of A. I. E. E.) From a source of 1 c.p. the total flux is 4π lumens. The symbol for flux is ϕ.

Flux and intensity of illumination are connected by the following relation:

$$\text{Illumination} = \frac{\text{Flux}}{\text{Surface}} \text{ or } E = \frac{\phi}{S}.$$

Mean horizontal intensity is the average intensity in all directions in the horizontal plane passing through the source. In case of an incandescent lamp this plane is taken perpendicular to the axis of the lamp.

Mean spherical candle-power is the average candle-power in all directions in space. It bears the following relation to the total luminous flux from the source,

$$I_{ms} = \frac{\phi}{4\pi}.$$

Mean hemispherical candle-power is defined as the average candle-power in all directions in a hemisphere having the source of light at its center.

The spherical reduction factor is the ratio of the mean spherical candle-power to the mean horizontal candle-power.

Trotter gives in the following table the intrinsic brightness of different sources of light.

Intrinsic Brightness of Different Sources of Light.

(Trotter.)

	C.P. per Sq. In.		C.P. per Sq. Cm.	
	Red.	Green.	Red.	Green.
Platinum (Violle standard)	120	120	18.5	18.5
Sun's disk	487,000	1,000,000	75.500	155,000
Sky, near sun	120	120	18.5	18.5
Albo carbon on edge	73.5	60.7	11.4	9.4
White paper, horizontal, exposed to summer sky, noon	16.5	35.2	2.56	5.45
White paper, sun 60° high, paper facing sun	8.25	17.2	1.28	2.67
Albo carbon, flat	10.5	8.7	1.63	1.35
Argand	6.8	5.29	1.05	0.82
Black velvet, summer sky, noon	0.0333	0.07	0.0052	0.0109
White paper, reading without straining	0.0018	0.0024	0.00028	0.00037

	White.	White.
Sperm candle	2	0.31
Moon, 35° above horizon	2	0.31
Moon, high	3	0.46
Batswing (whole flame)	2.26	0.35
Methven standard	4.3	0.666
Incandescent carbon filament (glow lamp)	120	18.5
Crater of electric arc	45,000	7,000

Units and Standards of Light.

The Intensity of a Source of Light is expressed in terms of that of some specified unit or standard of reference.

No very satisfactory standard for all purposes has as yet been produced, but those listed below are among the best in use or proposed.

a. The British standard candle, a spermaceti candle seven-eighths of an inch in diameter, weighing one-sixth pound, and burning at the rate of 120 grains per hour. In case the rate of burning of the candle does not equal 120 grains per hour but falls within the limits of 114 to 126 grains per hour, the value of the light is to be determined by simple proportion assuming that the intensity of the candle light varies in proportion to the rate of consumption of sperm. This standard, in spite of many defects, is still in extensive use and is legalized in many states. It nominally furnishes the unit of measurement in this country.

b. Harcourt 10 *candle pentane standard.* This lamp, which is one of the best of modern standards, is shown in Figs. 1 and 2 in the form in which it is constructed by the American Meter Co. Its fuel is a gas composed of a mixture of pentane vapor and air. The pentane is a light distillate of petroleum passing over at a temperature between 25° and 40° C. The pentane is contained in the vaporizer at the top of the lamp, from which it flows by its own weight down through the small tube to the base of an Argand burner, where it forms a flame inside a metal chimney. The base of the chimney is adjusted accurately to a height of 47 mm. above the top of the burner, and it is only the portion of the flame which comes between the burner and the base of the chimney which falls on the photometer. All the light from the ragged upper portions of the flame is cut off. The flame is adjusted to a definite height by observing it through a mica window in the chimney. The exposed portion of the flame is protected from draughts by a conical shield open on one side. The lamp should be used in a well-ventilated room free from avoidable draughts. According to Paterson of the National Physical Laboratory the candle-power of the lamp is expressed by the equation:

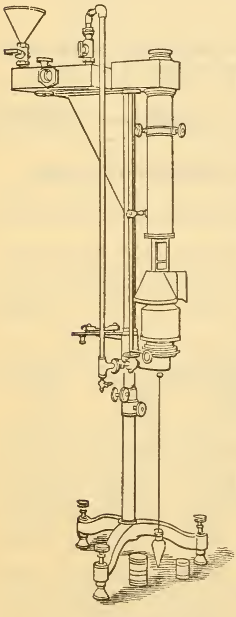


Fig. 1.

$$\text{c.p.} = 10 + 0.066\ (10 - \epsilon) - 0.008\ (760 - b),$$

in which ϵ is the number of liters of moisture per cubic meter of dry air, and b is the barometric height in millimeters. The quantity ϵ is found from the equation $\epsilon = \frac{e}{b - e - e_1} \times 1000$, in which e equals the vapor pressure of the water and e_1 the vapor pressure of the CO_2 present. The constant 10 represents the average hygrometric condition in London for a period of three years.

c. The Carcel lamp, the principal French standard, burns 42 grams of purified colza oil per hour, the flame being 40 mm. high. MM. Regnault and Dumas have proven by experiments that when the consumption of colza is at a rate between 40 and 44 grams per hour, the light emitted by this standard is proportional to the weight of colza burned. Following is a table showing the proper dimensions of this standard.

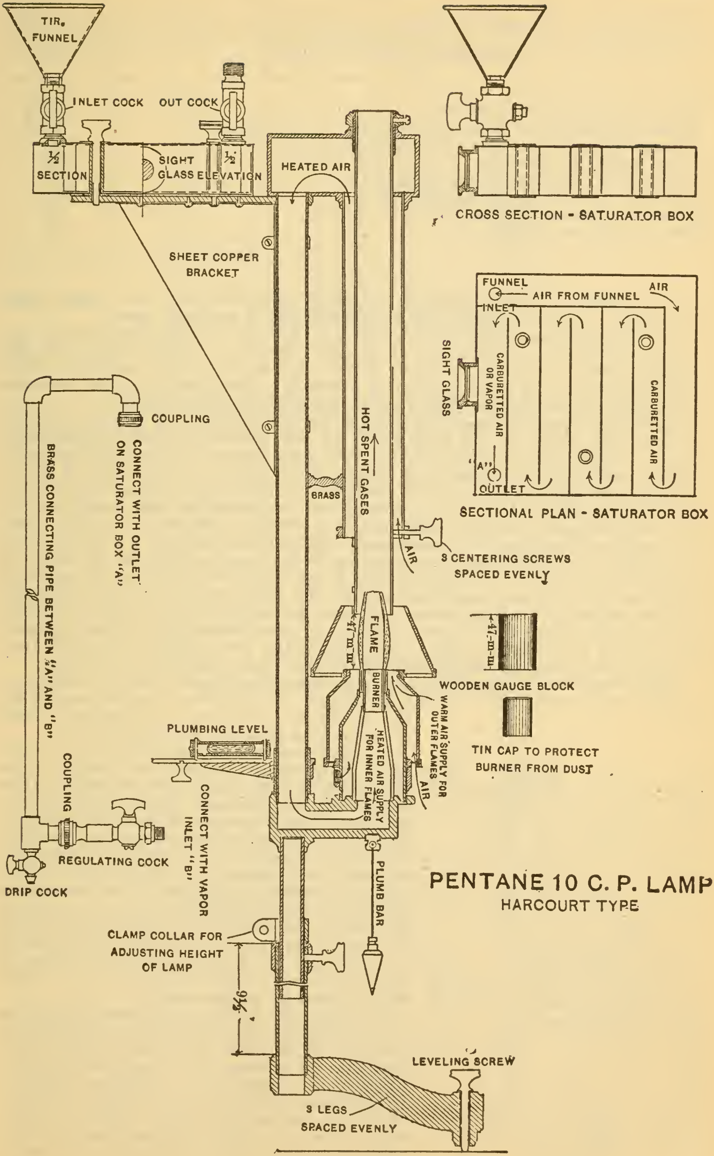

TIR. FUNNEL
INLET COCK
OUT COCK
½ SECTION
SIGHT GLASS ELEVATION
½
HEATED AIR
CROSS SECTION - SATURATOR BOX
SHEET COPPER BRACKET
FUNNEL
AIR FROM FUNNEL
AIR
INLET
SIGHT GLASS
CARBURETTED AIR OR VAPOR
CARBURETTED AIR
"A"
OUTLET
SECTIONAL PLAN - SATURATOR BOX
COUPLING
CONNECT WITH OUTLET ON SATURATOR BOX "A"
BRASS CONNECTING PIPE BETWEEN "A" AND "B"
HOT SPENT GASES
BRASS
AIR
3 CENTERING SCREWS SPACED EVENLY
FLAME
47 m m
47 m m
WOODEN GAUGE BLOCK
BURNER
WARM AIR SUPPLY FOR OUTER FLAMES
TIN CAP TO PROTECT BURNER FROM DUST
PLUMBING LEVEL
HEATED AIR SUPPLY FOR INNER FLAMES
AIR
COUPLING
CONNECT WITH VAPOR INLET "B"
REGULATING COCK
DRIP COCK
PLUMB BAR
PENTANE 10 C. P. LAMP
HARCOURT TYPE
CLAMP COLLAR FOR ADJUSTING HEIGHT OF LAMP
9½"
LEVELING SCREW
3 LEGS SPACED EVENLY

FIG. 2.

Dimensions of Carcel Lamp.	mm.
External diameter of burner	23.5
Interior diameter of inner air current	17.0
Interior diameter of outer air current	45.5
Total height of chimney	290
Distance from elbow to base of glass	61
Exterior diameter at level of bend	47
Interior diameter of glass at top of chimney	34
Mean thickness of glass	2

Use lighthouse wick weighing 3.6 grams per decimeter and woven with 75 strands. This standard is quite satisfactory if carefully used.

d. The platinum standard proposed by Violle is the light emitted by one square centimeter of platinum at its melting-point. Violle shows that the light emitted by this unit is equivalent to 19½ to 19¾ British candles. This standard has never been reduced to practice. The French bougie décimale is supposed to equal the 20th part of the Violle platinum unit.

e. Hefner Amyl Lamp. The legal standard in Germany is the so-called *Hefner unit*, which is the light given by the Hefner-Alteneck amylacetate lamp. This lamp has been exhaustively investigated by the Reichsanstalt, which certifies to the accuracy of lamps submitted to it; its intensity is about 10 per cent less than that of the English candle, and its normal flame is 40 millimeters high. It is very uniform and reproducible, and owing to the fact that lamps of certified value can be so readily obtained it is widely used, not only in Germany, but elsewhere. Careful instructions are issued with each lamp, and when used in accordance with these instructions the errors of measurement are not more than half those met with in the use of standard candles. The color is somewhat against this unit, being a distinctly reddish orange, which is a rather serious objection when used as a working standard in measurements of Welsbach burners or incandescent and Nernst lamps. Even with its faults though, it is probably the best primary standard that we have, as it can be reproduced accurately to a most unusual degree.

This lamp has of late come into very general use as a reliable, moderate-priced and easily reproducible standard. It has been recommended by the American Institute of Electrical Engineers and the German Reichsanstalt.

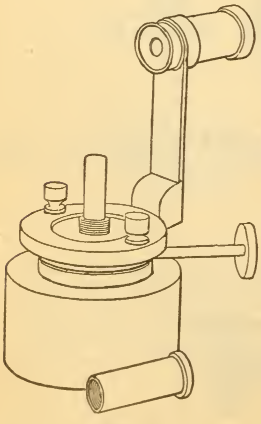
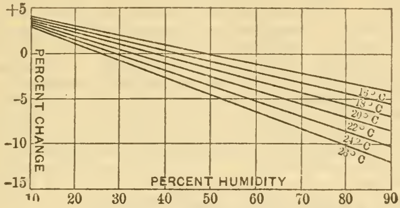


FIG. 3.

A cylindrical base contains the amyl acetate, which is drawn up through a wick tube of German silver in a specially prepared wick. The height of this German silver tube and the height of the flame are of vital importance. To secure the proper adjustment at the time the lamp is used, an optical flame gauge is provided, consisting of a small camera with lens, and ground glass plate. On this ground glass plate a horizontal line determines exactly the point at which the top of the flame should be kept. An error of 0.2 of a millimeter in the height of the flame produces an error of ½ of 1 per cent in the candle-power, so their setting must be made closely.

In using this lamp special care should be taken that fresh air in abundance is supplied, but the room must be perfectly free from draughts or air currents, and it should be watched by a person at a distance from it. If the flame does not burn steadily the wick should be carefully trimmed, making it somewhat crowned. Never char the wick by burning it too high; after continued use it should appear to be only slightly browned.

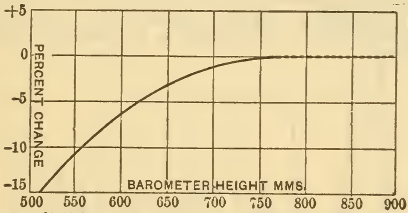
With a little experience it will be found that the flame can be kept accurately on the line of the optical flame gauge and quite steady. The variations of temperature, humidity and barometer height affect the candle-power of the



CHANGE IN INTENSITY FROM HUMIDITY AT DIFFERENT TEMPERATURES

FIG. 4.

lamp to a certain extent, but these fluctuations have been investigated fully, and corrections are given in the accompanying diagrams (Figs. 4 and 5).



CHANGE IN INTENSITY WITH BAROMETER HEIGHT

FIG. 5.

Incandescent Lamps as Secondary Standards. Carbon filament lamps which have been seasoned by burning them a few hours until their initial period of rise of candle-power at constant voltage has been passed, furnish secondary standards of light of remarkable constancy. It should be understood, however, that no single lamp can be relied on absolutely, but rather the average value given by a group of such lamps. The uniformity of results which is obtained in the photometry of incandescent lamps in present practice in this country is due in no small measure to the fact that incandescent lamp standards, practically all of which emanate from the same laboratory, are in nearly universal use. These sub-standards have been standardized not by direct reference to a primary standard, none of which is entirely constant, but by reference to a series of incandescent lamp secondary standards, whereby a constant value for the unit is obtained. An invariable unit of luminous intensity has been maintained by such a series of lamps by the Electrical Testing Laboratories in New York for upwards of ten years. The standardization value for these lamps was derived from a similar series in the possession of the Edison Lamp Works, which were in turn standardized originally by reference to lamps standardized in the Reichsanstalt. The basis of this original standardization was the assumption that the Hefner unit equals 0.88 candle-power. This ratio has since received the sanction of the A. I. E. E., and more recently the Bureau of Standards in Washington has established its unit of luminous intensity on the same basis. Thus it has come about that photometric measurements in this country which are nominally based on the British candle as a unit are actually, as far as electrical measurements are concerned, based on an invariable unit representing one of the values which the variable candle may assume, which is maintained by standardized incandescent lamps, and which is reproducible only through the intermediary of the Hefner standard lamp. Standardized lamps are furnished by the Electrical Testing Laboratories in New York of any required candle-power and voltage and for use either stationary or rotating. A special type of lamp has been developed for use in making stationary standards. These lamps have two horse-shoe shaped filaments in the same plane, one inside the other. The standard direction in these lamps is at right angles to the plane of the filaments, as indicated by vertical lines etched in the glass. Lamps are also standardized and certified by the Bureau of Standards.

On account of the adoption of the Harcourt 10 candle pentane lamp as the official standard by the Metropolitan Board of Gas Referees of London and the introduction of this standard into practice in this country, chiefly in the photometry of illuminating gas, a discrepancy has arisen between the candle of the electric industry and the candle of the gas industry. Recent international determinations of the ratio between the Hefner unit and the pentane unit have shown that the Hefner equals 0.915 candle-power, the candle being defined as the one-tenth part of the intensity of the pentane unit. As has been said, the value of the Hefner in terms of the candle of the electrical industry and of the Bureau of Standards is 0.88. The matter of this discrepancy is now (Dec., 1907) under advisement by a joint committee of the Illuminating Engineering Society, the American Institute of Electrical Engineers, and the American Gas Institute.

The following is a table giving the values of the various standards and units in terms of each other. This table is compiled from the most recent data on the subject.

	Hefner.	10 C.P. Pentane.	Carcel.	Bougie décimale.	Candle U. S. A.	Unit N. P. L. London.	Unit L. C. E. Paris.
Hefner unit	1	0.0915	0.093	...	0.88	...	...
10 c.p. pentane	10.95	1	1.02	...	...	...	...
Carcel	10.75	0.980	1	9.6	...	...	...
Bougie décimale	...	...	0.1042	1	...	...	...
Candle unit. U. S. A.	...	...	...	...	1	1.018	1.020
Unit National Physical Laboratory. London	...	...	...	...	0.984	...	...
Unit Laboratoire Central d'Eléctricité. Paris	...	...	...	...	0.982	...	...

PHOTOMETERS.

A photometer is an apparatus for measuring the intensity of a source of light or of an illumination in terms of a standard. In case the apparatus is intended for the latter purpose only, it is sometimes called an "illuminometer." All photometric measurements are made by a visual comparison of the source to be measured with some standard. The eye cannot tell us how many times brighter one light is than another. It can say only that one illuminated field is just as bright as another. A photometer consists, then, of two essential parts: first, an arrangement whereby two fields are obtained in juxtaposition to each other, one of them being illuminated by the standard light, and the other by the light which is to be measured; second, of an arrangement whereby the brightness of one or both the fields can be varied continuously according to a known law, from which the relative intensities of the sources can be computed as soon as the conditions have been discovered under which the fields are equal in illumination. In an illuminometer a further part must be provided; namely, a standard plate for the reception of the illumination which is to be measured.

The law of variation which is most commonly employed is that which states that illumination from a punctiform source of light varies inversely as the square of the distance to the source. A common form of photometer is as shown in Fig. 6. The light to be measured and the standard light are set up at opposite ends of a bar on which the sight-box containing a photometric screen or disk for testing the equality of illumination can be moved. When a setting has been made, the intensities of the two sources

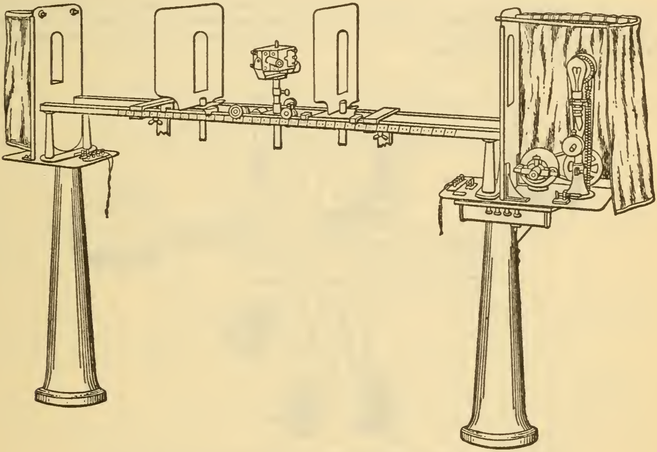


FIG. 6. Photometer, *Queen & Co.*

of light are directly proportional to the squares of their respective distances from the photometric screen in the sight-box.

The forms of sight-box which are most commonly employed are the Bunsen and the Lummer-Brodhun. The latter is unexcelled by any other photometric device when the lights to be compared are of the same color. When color differences are present, the Bunsen is to be recommended, especially so when it is equipped with the Leeson star disk.

In **Bunsen's** photometer a piece of white paper — certain kinds of draughting paper are good — with a grease spot in its center is placed between the two lights with its surface at right angles to the rays. Behind the paper in the sight-box are placed two mirrors at an angle of about 140 degrees with each other so that both sides of the disk can be viewed simultaneously. The box is moved along the bar between the lights until the grease spot is seen with equal distinctness on both sides. This indicates an equality of illumination, and the general law given above is used to compute the relative intensities of the lights. The Leeson star disk is in some respects superior to the grease spot disk, and is made as follows: A star-shaped figure is cut out of a piece of moderately heavy paper, and the latter is pressed between two pieces of tissue paper of the proper degree of transparency. The outside pieces may be pasted fast to the middle piece.

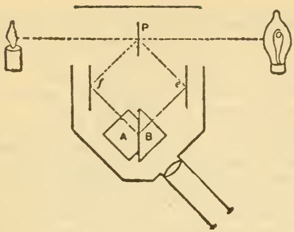


FIG. 7. Diagram of Lummer-Brodhun Photometer.

In the **Lummer-Brodhun** photometer, diagram and cut of the carriage of which are shown below, the rays of light from the two sources under comparison enter at the sides so as to strike the surfaces of the opaque gypsum screen. Diffused light from these white surfaces reaches two parallel mirrors (inside) at an angle of 45°, and is reflected to right-angled prisms which have the outer portions of their hypothenuse surfaces cut away and coated with asphalt varnish to secure complete absorption. Light entering the prisms from the mirrors is either transmitted or totally reflected at their surface of contact, so that an observer at the telescope tube sees a circular disk of light from one side of the gypsum screen surrounded by an annular ring of light from the other side, the boundary line between the two being sharply defined.

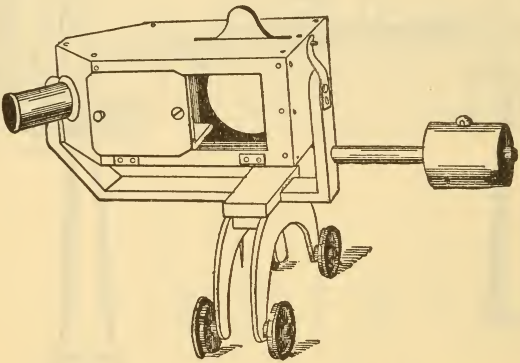


FIG. 8. Lummer-Brodhun Photometer Carriage.

Rumford's photometer compares the shadows of an opaque rod thrown on a white screen by two lights.

When the shadows are of equal density,

$$\frac{i}{i_1} = \frac{d^2}{d_1^2}.$$

In **Ritchie's** photometer two equal white surfaces are placed at an angle with each other, and with the line of light and their brightness compared, moving back and forth on the line of light until both surfaces are alike in illumination; the relative intensities of the lights are then the same as with the *Bunsen* instrument.

In **Joly's** photometer, two slabs of paraffin wax, or translucent glass about 3″ × 2″ × ½″, are fastened together back to back by Canada balsam, a sheet of paper or silver foil being first interposed, after which the edges and surfaces are ground smooth.

This slab is placed between the two lights, with the plane of the joint at right angles to the line between the lights, and moved back and forth on that line until the observer looking at the edge of the slab finds both sides equally illuminated, when the relative intensities are as before. By reversing the slab, a check can be had on the observation.

***The Test Plate.** — *Preston S. Millar.* In general work the intensity of the light incident upon a given surface is the only quantity which it is practicable or even desirable to measure. This is not proportional necessarily to the illuminating effect, which varies as well with the point from which the surface is viewed, with the color of the light and with the color and character of the surface.

The criterion by which the light intensity is judged must be strictly proportional to the light incident upon the test plate, and must be independent of each of the other improper variables just mentioned, if the results of the observation are to show the intensity of the light incident upon the surface.

Whether or not the light falling upon the photometric device varies only with that incident upon the test plate, depends upon the design and location of that plate.

The requirements for a theoretically correct test plate are:

First, a plain white surface which, when viewed from the point of photometric observation, obeys Lambert's law of the cosines with reference to intensity of illumination produced by light incident upon its surface at any inclination and from any direction.

Second, a material which will not introduce errors due to color differences.

Third, a plate which may be placed at any angle.

Fourth, a location such that neither the body of the observer nor instrument parts shall obstruct light which would otherwise fall upon the plate.

It is, of course, desirable to measure all of the light which would be incident upon an object at the point to be considered. In all interior lighting systems there is more or less diffused light, all of which has some illuminating value. In order to measure all of the effective light, there must be no objective interference with light incident upon the plate at any angle. This means that all instrument parts, as well as the observer, must be beneath or behind the surface of the test plate. This is possible only when transmitted light, instead of reflected light, is measured.

The only color which is practicable is white, of as great purity as may be obtainable, and as free as possible from selective absorption. With such a test plate, lights of different colors are credited with approximately their true intensities, when the test plate is viewed from the photometric device.

Prof. L. Weber has invented a photometer, as follows:

The apparatus consists of a tube, *A*, about 30 cm. long, which can be moved up and down and swung in a horizontal plane on the upright, *c*. The standard light, *S*, a benzine lamp, is contained in a lantern fastened to the right end of the tube, *A*. Within the tube, *A*, a circular plate of opal glass can be moved from or towards the light, *S*; its distance from *E* is read in centimeters on the scale, *s*, by means of an index fastened to the pinion, *P*. At right angles to tube, *A*, a second tube, *B*, is fastened. This tube can be rotated in a vertical plane, and its position in reference to the horizontal is read on the graduated circle, *C*. A Lummer-Brodhun prism contained in tube *B* in its axis of rotation receives light from the opal glass plate in tube *A*, and reflects this light towards the eye-piece, *O*, so that the outer half of the field of vision is illuminated by this light; the inner half is illuminated by the light entering the tube, *B*, through *g*.

In making measurements, the tube *B* is pointed toward the source of light to be measured. The light has to pass through a square box, *g*, in which may be inserted one or more opal glass plates, in order to diminish the intensity of the light, and thus to make it comparable with the standard light. The apparatus permits the measurement of light in the shape of a flame, as well as the measurement of diffused light.

Since the measurement of diffused light interests us most at present, a short description of the method will not be out of place.

A white screen, the surface of which is absolutely without luster, furnished as part of the apparatus, is placed in a convenient position, either horizontal or vertical, or at any desired inclination, toward the source of light.

The photometer having been located at a convenient distance from the screen, the tube *B* is pointed to the center of the screen. The distance of the photometer from the screen can be varied within very wide limits, the only restrictions being that the field of vision receives no other light than

* Trans. Illuminating Engineering Society, October, 1907.

that emanating from the screen. The necessary precautions for adjustment having been observed, the opal glass plate in the tube *A* is moved until both halves of the field of vision appear equally illuminated. The distance, *r*, of this glass plate from the standard light at the moment of equal illumina-

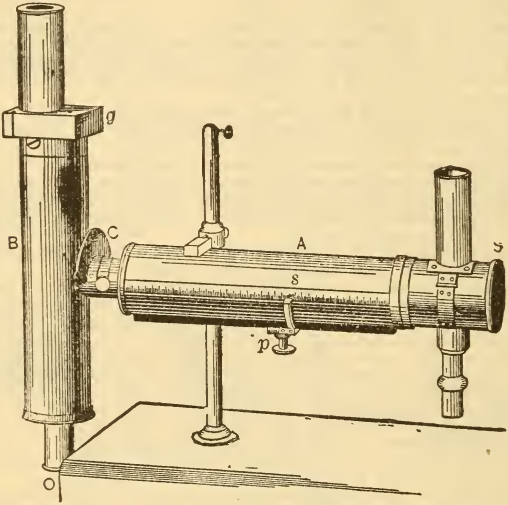


FIG. 9. Prof. L. Weber's Portable Photometer.

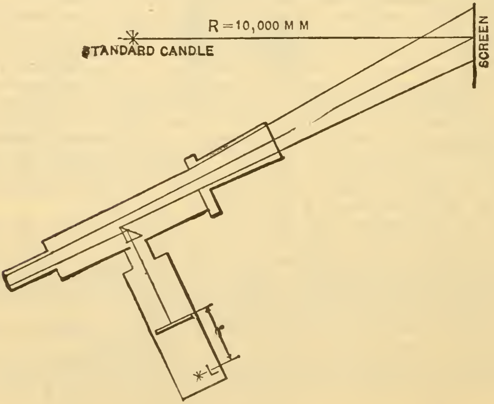


FIG. 10.

tion is read on the scale on tube *A* in millimeters, and the intensity of illumination on the white screen is calculated from the formula,

$$I = \frac{10{,}000}{r^2} K.$$

The constant K is previously determined as follows:

A standard candle or its equivalent is placed exactly one meter distant from the white screen, and the tube, B, of the photometer is pointed towards the screen, so that the center of the screen, which is marked by a cross, is seen in the center of the field of vision. As indicated in Fig. 6, the photometer must be so placed that the eye, looking through the eye-piece, sees nothing but the white screen. The angle of inclination under which the screen is observed may be varied within wide limits without influencing the result; it should, however, not exceed 60 degrees from the normal to the screen.

Equal illumination of both halves of the field of vision having been obtained by means of adjusting the opal glass plate in tube A, the constant, K, is found by calculation:

$$K = \frac{r^2}{R^2}.$$

Since r is read in millimeters, and R is made 1 meter or 1000 millimeters, 1000 instead of 1 must be taken in the formula for calculating the intensity of illuminating in meter-candles.

A second method permits of measurements of diffused light without the intervention of a screen; but for further details the reader is referred to the description of the apparatus by Professor Weber, *Elektrotechnische Zeitschrift*, vol. v., p. 166.

The whole apparatus can easily be taken apart, and packed in a box about 24 × 8 × 12 in hes. In some cases the benzine lamp might well be replaced by a small incandescent lamp, provided this lamp is standardized before and after each set of experiments. Such miniature lamps have been found very convenient, and quite sufficiently constant in candle-power for several hundred observations.

Sharp-Millar Universal Portable Photometer. — This instrument is designed for making all the various measurements of candle-power

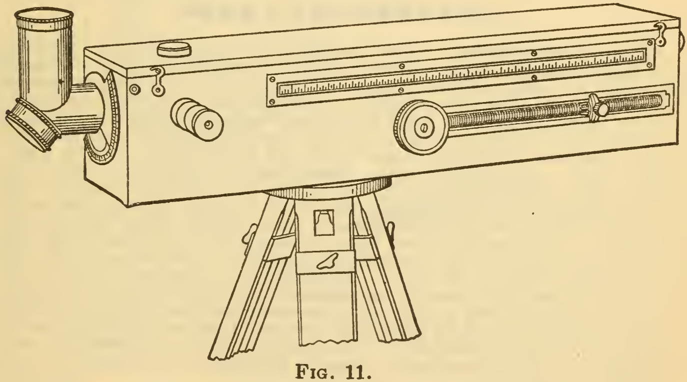


FIG. 11.

and illumination which the Weber is fitted for, while it is more portable, convenient, and accurate than the latter instrument, and less complicated and expensive. The instrument is illustrated in Fig. 11.*

Integrating Photometers. — Photometers can be constructed, so that they will measure directly the mean spherical candle-power of lamps. Such photometers have been designed by Professor Matthews both for arc and incandescent lamps. (Trans. A. I. E. E.)

* See *Electrical World*, LI. p. 181, Jan. 25, '08. *Electrical Review*, LII. p. 141, Jan. 25, '08. *Electrician* (London), LX. p. 562, Jan. 24, '08.

A simple form of this type of photometer is the Ulbricht sphere photometer. This consists of a large sphere coated on the inside with dull white paint and furnished with a small window of diffusing glass. The lamp is introduced into the interior and a screen is so placed that the direct rays of the lamp cannot fall on the window, which is consequently illuminated by reflected rays alone. The theory shows that the intensity of such illumination is proportional to the total luminous flux, or the mean spherical candle-power of the source within, so that it is necessary only to photometer the light issuing from the window to have a measure of these quantities. The sphere must be calibrated by the "substitution method," using an incandescent lamp standardized for mean spherical candle-power.

Rating of Illuminants. — Illuminants are rated according to their candle-power and their volts, amperes or watts. Differences occur in practice as to what is meant by the candle-power, that is, in what direction the candle-power is to be measured. In the earliest days incandescent lamps were rated by their maximum candle-power; now, however, the most common practice is to use the *mean horizontal candle-power.* In comparing lamps having differently shaped filaments this is in general not a fair basis, since two lamps might give the same total flux of light and yet one of them might have a much smaller mean horizontal candle-power than the other. These differences are recognized by the differences in the spherical reduction factors of the two. A small difference in spherical reduction factor may have a very large influence on the results obtained in a life-test. The fair way is to use the total flux of light or the *mean spherical candle-power* as the basis for comparing lamps or illuminants of different types. The American Nernst lamp is usually rated by its maximum candle-power, that is, the candle-power immediately below it. The intensity in this direction is increased considerably by the light reflected from the heater coils and other parts of the lamp. No standard method for candle-power rating of arc lamps has ever been adopted in America. In Germany the mean lower hemispherical intensity is chosen for this purpose.

INCANDESCENT LAMPS.

Watts per candle. — The condition of operation of an incandescent lamp is usually specified by the watts per candle, meaning, ordinarily, the watts per mean horizontal candle. The efficiency of a lamp is inversely proportional to its watts per candle. The life history of a carbon filament lamp is characterized by a small initial increase in candle-power lasting for about 50 hours in the case of a 3.1 watt per candle-lamp and then by a unform decrease in candle-power until the lamp fails. This is accompanied by a regularly increasing blackening of the bulb. It has been shown (Sharp, *Electrical World*, Vol. 48, p. 18), that the age of a lamp may be estimated by an examination of the degree of bulb blackening. The light from frosted lamps decreases more rapidly than that from unfrosted ones, an effect which has been shown (Millar, *Electrical World*, April 20, 1907) to be due to the increased absorption of that portion of the light which suffers multiple reflections. Any lamp may be operated at any watts per candle simply by raising or lowering the impressed voltage, but the life of a lamp decreases very rapidly with decreased watts per candle. In operation it is necessary to strike a balance between increased efficiency and increased cost of lamp renewals. The standards are 3.1, 3.5 and 4.0 watts per candle. Closely regulated voltage is essential to successful 3.1 watts per candle operation.

After a lamp has reached a certain point in its decline in candle-power and efficiency, it is more economical to replace it with a new one than to consume energy in a wasteful device. The period of the life at which this condition is reached is called the "*smashing point,*" of the lamp. The smashing point may be computed, but it is found in practice that it is most satisfactory to assume uniformly that its point has been reached when the candle-power has decreased 20 per cent from the initial value. This constitutes by common consent the close of the "useful life" of a carbon filament lamp.

Spherical Candle-power and Distribution Curves. — A lamp filament giving a certain total flux of light may be made to give a greater or a smaller proportion of this in the horizontal direction. Therefore the mean horizontal candle-power is not a true basis for comparing the performance of lamps of different types. The "spherical reduction factor," or ratio of mean spherical to mean horizontal candle-power must be taken into consideration. The following curves and table give values for this factor for different types of lamps and the axial distribution of candle-power about the same types. The curves show also the Rousseau diagrams for the lamps, that is, curves the area enclosed by which is proportional to the mean spherical candle-power. The data were obtained at the Electrical Testing Laboratories.

Lamp Type.	Description.
1	Double loop.
2	Oval.
3	Small spiral; single turn.
4	Large spiral; single turn.
5	Medium spiral; single turn.
6	Short-legged spiral; double turn.
7	Elliptical spiral, double turn, axis of ellipse horizontal.

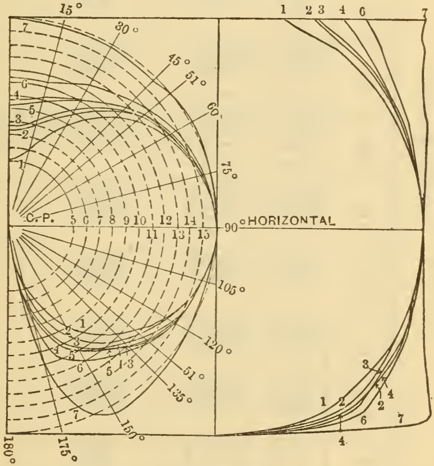


Fig. 12.

Table I.

Lamp Type. Watts.	1 49.6	2 49.6	3 63.5	4 56.6	5 53.8	6 59.3	7 64.74
End-on c.p.	5.06	7.3	7.7	9.6	9.31	11.4	15.9
Mean horizontal c.p.	16.00	16.0	16.C	16.0	16.0	16.0	16.0
Mean spherical c.p.	12.82	13.19	13.42	13.63	13.78	14.07	15.72
Ratio: $\frac{\text{Mean spherical c.p.}}{\text{Mean horizontal c.p.}}$	0.802	0.825	0.840	0.854	0.862	0.880	0.983
Ratio: $\frac{\text{Mean spherical c.p.}}{\text{End-on c.p.}}$	2.54	1.81	1.74	1.42	1.48	1.23	0.864
Ratio: $\frac{\text{End-on c.p.}}{\text{Mean horizontal c.p.}}$	0.316	0.456	0.481	0.602	0.582	0.712	0.992
Watts per mean spherical	3.88	3.76	4.73	4.15	3.91	4.22	4.09
Watts per mean horizontal	3.10	3.10	3.97	3.52	3.36	3.70	4.02
Watts per end-on	9.8	6.78	8.26	5.90	5.78	5.20	4.04

Table II. Showing Current taken by Lamps of Various Candle-powers, Efficiencies and Voltages.

From a Pamphlet by the National Electric Lamp Association.

Volts.	Nom. W.P.C.	Candle-Power.																
		2	3	4	5	6	8	10	12½	16	20	24	25	32	40	50	75	100
50	3.1	...	...	...	...	...	.496	.620	.775	.997	1.217	1.488	...	1.984	...	3.100	...	...
	3.5	...	...	...	...	.448	.571	.715	.908	1.120	1.392	1.790	1.816	2.286	...	3.630	...	...
	4.0	...	...	...	.417	.515	.658	.835	1.023	1.280	1.669	2.057	2.086	2.629	...	...	...	...
	4.5	.193	.289	.386	...	...	...	...	...	...	...	...	...	...	...	...	...	...
55	3.1	...	...	...	...	...	.451	.564	.705	.907	1.106	1.352	...	1.805	...	2.820	...	...
	3.5	...	...	...	...	.408	.520	.650	.826	1.018	1.267	1.627	1.650	2.080	...	3.300	...	...
	4.0	...	...	...	.379	.468	.598	.760	.930	1.164	1.517	1.871	1.896	2.390	...	...	...	...
	4.5	.176	.263	.351	...	...	...	...	...	...	...	...	...	...	...	...	...	...
100	2.5	...	...	...	...	...	...	...	...	...	.500	...	...	...	1.000	1.250	1.875	2.500
	3.1	...	...	...	...	...	.248	.310	.388	.496	.608	.744	...	.992	...	1.550	...	...
	3.5	...	...	...	...	.224	.286	.357	.454	.560	.696	.895	.908	1.142	...	1.815	...	...
	4.0	...	...	...	.208	.257	.329	.417	.511	.640	.834	1.030	1.042	1.315	...	...	...	...
	4.5	...	.145	.193	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	6.0	.125	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
105	2.0	...	...	...	...	...	...	...	...	...	.390	...	...	...	...	...	...	...
	2.5	...	...	...	...	...	...	...	...	...	.476	...	...	...	.953	1.190	1.785	2.380
	3.1	...	...	...	...	...	.236	.295	.370	.473	.579	.709	...	.945	...	1.476	...	...
	3.5	...	...	...	...	.213	.273	.340	.433	.534	.664	.853	.865	1.089	...	1.729	...	...
	4.0	...	...	...	.198	.245	.313	.397	.487	.610	.794	.982	.993	1.252	...	...	...	...
	4.5	...	.138	.184	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	6.0	.119	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

110	2.0	...	...	...	...	...	...	...	...	...	.373	...	...	...	...	...	...	...
	2.5	...	...	...	...	...	...	...	...	...	.455	...	...	...	.910	1.137	1.705	2.270
	3.1	...	...	...	...	...	.226	.282	.353	.451	.554	.676	...	.902	...	1.410	...	...
	3.5	...	...	...	...	.204	.260	.325	.413	.509	.633	.814	.826	1.039	...	1.650	...	...
	4.0	...	...	...	.189	.234	.299	.379	.465	.582	.758	.937	.949	1.195	...	...	...	...
	4.5	...	.132	.176	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	6.0	.114	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
115	2.0	...	...	...	...	...	...	...	...	...	.374	...	...	...	...	...	...	...
	2.5	...	...	...	...	...	...	...	...	...	.435	...	...	...	.870	1.088	1.680	2.180
	3.1	...	...	...	...	...	.216	.270	.338	.432	.529	.647	...	.804	...	1.348	...	...
	3.5	...	...	...	...	.195	.249	.310	.395	.487	.606	.779	.790	.994	...	1.580	...	...
	4.0	...	...	...	.181	.224	.286	.363	.445	.567	.725	.895	.907	1.143	...	...	...	...
	4.5	...	.126	.168	...	...	...	...	...	...	..	...	...	...	...	...	...	...
	6.0	.109	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
120	2.0	...	...	...	...	...	...	...	...	...	.375	...	...	...	...	...	...	...
	2.5	...	...	...	...	...	...	...	...	...	.517	...	...	...	.825	1.042	1.563	2.085
	3.1	...	...	...	...	...	.207	.258	.324	.414	.507	.620	...	.827	...	1.292	...	...
	3.5	...	...	...	...	.177	.238	.298	.378	.458	.581	.746	.757	.953	...	1.512	...	...
	4.0	...	...	...	.173	.214	.274	.348	.426	.534	.695	.859	.870	1.096	...	...	...	...
	4.5	...	.121	.161	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	6.0	.104	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
220	3.8	...	...	...	...	...	...	...	...	.276	.346	.415	...	.553	...	.864	...	1.728
	4.25	...	...	...	...	...	...	.193	...	...	...	...	...	...	...	...	...	...
	4.38	...	...	...	...	...	.159	...	...	...	...	...	...	...	...	...	...	...
	5.5	...	...	...	.133	...	...	...	...	...	...	...	...	...	...	...	...	...

The Proper Use of Incandescent Lamps.

(From a Circular of the General Electric Company.)

A lamp to give satisfaction must not only be properly made, but it must also be properly used. A lamp of the highest quality may be so misused as to give only a small fraction of its rated light capacity. Proper use, producing a maximum of light at a minimum expense, requires:

That the lamps be burned at marked voltage.
That the voltage be kept constant.
That lamps be replaced whenever they get dim.

The last requirement is not considered economical by many users who prize lamps that have long life, and insist on using them as long as they will burn. Let us see by an example if extremely long life is desirable.

As the cost of current varies greatly, we will assume an average cost of one-half cent per lamp hour. If a rated 16-candle-power lamp, burned for 1000 hours, be burned an additional 1000 hours, it takes practically the same current during the last period, but gives an average light of only about 8 candles. The cost of current for the 2000 hours is $10.00. A new lamp costs 20 to 25 cents; and had three lamps, with a life of about 700 hours each, been used during the entire period, the average light would have been fully doubled, at an added expense of not more than 50 cents, or 5 % of cost of current. In other words, by adding 5 % to operating expense (representing the cost of the two renewal lamps) the customer would add 100 % to the light given. One new lamp gives a light equal to two old ones at half the cost of current. If the old lamps gave light enough, the new lamps would halve the number of lamps in use, and produce the same light with half the current.

It is important to note that the above example is based on results obtained with the highest grade of lamps. With an inferior quality of lamp the argument against extremely long life would be still stronger and the necessity of frequent renewals of lamps much greater.

Thus, from any point of view, it is false economy to select lamps with a sole regard for long life. Lamps should be renewed when dim, for in no other way can light be produced economically.

The points to be remembered are as follows:

Do not run pressure above the voltage of the lamps. Increased pressure means extra power; and although the old lamps may thus give more light for a while, every new lamp that does not break from the excessive pressure will deteriorate very rapidly and give greatly diminished light.

Do not treat incandescent lamps like lamp chimneys, and use them until they break. They should be renewed whenever they get dim.

Life and Candle-power of Lamps.

Since the prime function of an incandescent lamp is to give light, the best lamp is that which gives maximum light at minimum cost. This is an exceedingly simple axiom, and yet few users of lamps follow it out in practice. Lamps are repeatedly selected for long life, irrespective of good, uniform candle-power. Lamps are often continued in use long after their candle-power has seriously diminished.

An examination of the characteristics of an incandescent lamp will give a clear understanding of the principles applying to their selection and use. A theoretically perfect lamp would maintain its normal candle-power indefinitely, or until the lamp was broken. In practice the deterioration of the lamp filament causes a steady loss of candle-power.

Regarding Loss in Candle-power. — The drop in candle-power is a characteristic of an incandescent lamp always to be borne in mind. The relative drop or loss of candle-power, other things being equal, determines the comparative value of different lamps. We may have a lamp that loses 50 per cent in candle-power inside of 200 hours on a 3-watt basis. Considered from the standpoint of life only, such lamps are excellent, because their filaments deteriorate to such a degree that it is practically impossible to supply enough current to brighten them up to the breaking point, but no discerning station manager would want such dim lamps, even with unlimited life. As in the selection of incandescent lamps so in their use — the exclusive consideration of life leads to poor results Loss of candle-power in a lamp sooner or later makes it uneconomical to continue in use.

A customer cares little how efficiently a station is operated, but is much concerned about the quality of light furnished. Some means of keeping the average life below 600 hours should be adopted by every lighting company that has any regard for the economical production of light, or the satisfaction of their customers.

A simple method is to fix the average life at 600 hours or less, and then determine from the station record how many lamps should be renewed each month to keep the average life within this limit. The required number of lamps should be renewed each month.

If, for example, a station decides on an average life not to exceed 600 hours and the station records show that on the average 60,000 lamp hours of current are supplied monthly, then it would be necessary to renew $\frac{60,000}{600}$ or 100 lamps a month.

The Importance of Good Regulation.

Proper Selection and Use of Transformers. — Poor regulation of voltage probably results in more trouble with customers than any other fault in electric lighting service.

Some central station managers act on the theory that so long as the life of the lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased; and if the station is on a meter basis, it increases the amount of the customers' bills.

Evils of Excessive Voltage. — Excessive voltage is thus a double error — it decreases the total light of the lamps, and increases the power consumed. The loss of light displeases the customers and discredits the service. If light is sold by meter, the increased power consumption dissatisfies the customers; if light is sold by contract, the additional power is a dead loss to the station. If increased light is needed, 20 candle-power lamps should be installed, instead of raising the pressure. Their first cost is the same as 16 candle-power lamps; they take but little more current than 16 candle-power lamps operated at high voltage, and give greater average light.

Increased pressure also decreases the commercial life of the lamp; and this decrease is at a far more rapid rate than the increase of pressure, as shown in the following table. This table shows the decrease in life of standard 3.1 watt lamps, due to increase of normal voltage.

Per Cent of Normal Voltage.	Life Factor.
100	1.000
101	0.795
102	.615
103	.49
104	.40
105	.34
106	.29

From this table it is seen that 3% increase of voltage halves the life of a lamp, while 6% increase reduces the life by two-thirds.

Irregular pressure, therefore, necessarily results in the use of lamps in which the power consumption per candle is greater than a well-regulated pressure would allow. The result is reduced capacity of station, and reduced station efficiency.

These remarks apply with special force to alternating-current stations, since we have here two sources of possible irregularity in voltage — the generator and the transformer. Poor regulation is most apt to occur in the transformers, and the utmost care should, therefore, be taken in their selection and use. The efficiency of the average lamp on alternating systems is nearly 4 watts per candle. With good regulation obtained by the intelligent use of modern transformers, the use of lamps of an efficiency of 3.1 watts per candle becomes practicable. It is thus possible to save 25 % in power consumption at the lamps, and increase the capacity of the station and transformers by the same amount.

The general adoption of higher voltage secondaries gives smaller loss in wires, and permits the use of larger transformer units, thus greatly improving the regulation. On this account 50-volt lamps are gradually going out of use. The replacement of a number of small transformers by one large unit, and of old, inefficient transformers by modern types, has also been of immense advantage to stations. A large number of stations, however, still retain these old transformers, and load their circuits with large numbers of small units. Such stations necessarily suffer from loss of power, bad regulation, and a generally deteriorated lighting service. Simply as a return on the investment, it would pay all such stations to scrap their old transformers and replace them with large and modern units.

Proper care in the selection of transformers considers the quality and the size. Quality is the essential consideration, and should have preference over first cost. No make of transformer should be permitted on a station's circuit that does not maintain its voltage well within 3 per cent from full load to no load. The simple rule regarding size is to use as large units as possible, and thus reduce the number of units as far as the distribution of service permits. Every alternating station should aim to so improve regulation as to permit the satisfactory use of 3.1-watt lamps.

Good regulation is eminently important to preserve the average life and light of the lamps, to prevent the increase of power consumed by the lamps, and to permit the use of lamps of lower power consumption, so that both the efficiency and capacity of the station may be increased.

Constant voltage at the lamps can be maintained only by constant use of reliable portable instruments. No switchboard instrument should be relied on, without frequent checking by some reliable standard. Owing to the varying drop at different loads, constant voltage at the station is not what is wanted. Pressure readings should be taken at customers' lamps at numerous points, the readings being made at times of maximum, average and minimum load. Not less than five to ten readings should be made at each point visited, the volt-meter being left in circuit for four or five minutes, and readings being taken every fifteen seconds. The average of all the readings gives the average voltage of the circuits. Lamps should be ordered for this voltage, or if desired, the voltage of the circuits can be reduced or increased to suit the lamps in use. The practical points are to determine the average voltage at frequent periods with a portable voltmeter at various points of the circuits, and then to arrange the voltage of the lamps and circuits so that they agree.

Candle-Hours — The Regulation of Lamp Value.

The amount of light given by lamps of the same efficiency is the only proper measure of their value. The amount of light given, expressed in candle-hours, is the product of the average candle-power for a given period by the length of the period in hours.

Many of the best central station managers consider that a lamp has passed its useful life when it has lost 20 % of its initial candle-power. In the case of a 16 candle-power lamp, the limit would be 12.8 candle-power. The period of time a lamp burns until it loses 20 % of its candle-power may therefore be accepted as its useful life. The product of this period in hours by the average candle-power gives the "candle-hours" of light for any given lamp.

The better a lamp maintains its candle-power under equal conditions of comparison the greater will be the period of "useful life," and therefore the greater will be the "candle-hours." This measure is, therefore, the only proper one with which to compare lamps and determine their quality.

The practical method of comparison is as follows: Lamps of similar candle-power and voltage are burned at the same initial efficiency of 3.1 watts per candle on circuits whose voltage is maintained exactly normal. At periods of 50, 75, or 100 hours the lamps are removed from the circuits and candle-power readings taken, the lamps being replaced in circuit at the end of each reading. Readings are thus continued until the candle-power drops to 80 % of normal. The results obtained are then plotted in curves, and the areas under these curves give the "candle-hours" and the relative value of the different lamps.

Variation in Candle-power and Efficiency.

In the following table is shown the variation in candle-power and efficiency of standard 3.1 watt-lamps due to variation of normal voltage.

Per Cent of Normal Voltage.	Per Cent of Normal Candle-power.	Watts per Candle.
90	53	4.68
91	57	4.46
92	61	4.26
93	65	4.1
94	69½	3.92
95	74	3.76
96	79	3.6
97	84	3.45
98	89	3.34
99	94½	3.22
100	100	3.1
101	106	2.99
102	112	2.9
103	118	2.8
104	124½	2.7
105	131½	2.62
106	138½	2.54

Example: Lamps of 16 candle-power, 105 volts, and 3.1 watts, if burned at 98 % of normal voltage, or 103 volts, will give 89 % of 16 candle-power, or 14¼ candle-power, and the efficiency will be 4.34 watts per candle.

Lamp Renewals.

The importance and necessity of proper lamp renewals applies forcibly to all stations, regardless of the cost of power, and whether lamp renewals are charged for or furnished free. The policy of free-lamp renewals at the present low price of lamps is, however, preferable for both station and customer. Free lamp renewals give a station that full and complete control of their lighting service so requisite to perfect results.

Points to be Remembered.

That a constant pressure at the lamps must be maintained.

That the lamps are not to be used to the point of breakage — they should be renewed when they become dim.

That satisfaction to customers, and the success of electric lighting, are dependent upon good, full, and clear light, which old, black, and dim lamps cannot give.

That to furnish a good, full, and clear light is as much a part of the lighting company's business as to supply current to light the lamps.

That a company should always endeavor to keep the average life of lamps within 600 hours.

That to renew dim lamps properly on the free renewal system, inspectors should examine the circuits regularly when the lamps are burning. If lamp renewals are charged to customers, induce them to exchange their dim lamps.

Luminosity of Incandescent Lamps.

As showing the quality of incandescent light, we present here a curve showing the relative luminosity of an incandescent lamp at different regions of the visible spectrum.

On this subject Prof. E. L. Nichols states the following:

"The most important wave-lengths, so far as light-giving power is concerned, are those which form the yellow of the spectrum, and the relative

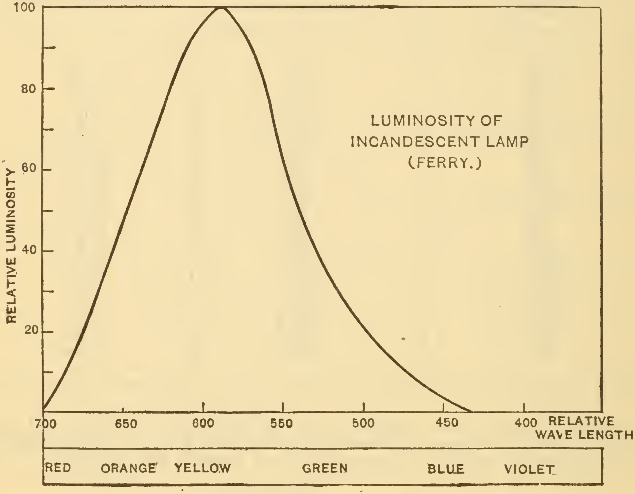


FIG. 13. Regions of Spectrum.

luminosity falls off rapidly both toward the red and the violet. The longer waves have, however, much more influence upon the candle-power than the more refrangible rays.

"Luminosity is the factor which we must take into account in seeking a complete expression for the efficiency of any source of illumination, and the method to be pursued in the determination of luminosity must depend upon the use to which the light is applied. If we estimate light by its power of bringing out the colors of natural objects, the value which we place upon the blue and violet rays must be very different from that which would be ascribed to them if we consider merely their power of illumination as applied to black and white. In a picture gallery, for instance, or upon the stage, the value of an illuminant increases with the temperature of the incandescent material out of all proportion to the candle-power, whereas candle-power affords an excellent measure of the light to be used in a reading room.

Metallized Carbon or Gem Lamps. — The so-called "metallizing" process as applied to carbon filaments consists in heating the filaments to an enormously high temperature both before and after flashing, using a carbon tube electric furnace for the purpose. The term "metallized" is applied on account of the positive temperature coefficient which the filaments acquire in the process. The useful life of the metallized filament lamps at 2.5 w.p.c. is said to be the same as that of the ordinary carbon lamp at 3.1 w. p. c.

Label Rating of Gem Lamps.

The style of label employed for Gem Lamps is as here shown. These labels are printed for all the voltages from 100 to 130 and for the various sizes of lamps.

As shown in the cut of label, only the total wattage of lamp and the volts are printed. Candle-power values are not given, as these values vary with the different forms of reflectors. (See candle-power distribution curves.) The voltage markings are arranged to show three voltages in steps two volts apart, and this provides a ready method of varying the efficiency and life of lamps to suit different conditions. The values at each of the three voltages are shown in the following table:

Lamps should, of course, be ordered at the "Top" or first voltage (V1) whenever possible, so as to secure the full lighting value and maximum efficiency and brilliancy.

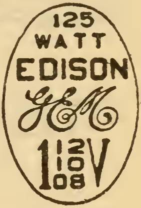


FIG. 14.

Table of Values at 1st, 2nd and 3rd Voltages.

Voltage of Circuit.	Per cent Total Watts.	Per cent of c. p. Values.	Eff. in w. p. c. (mean horizontal c. p.)	Useful Life in hours.
Same as "Top" or 1st Voltage (V1)	100%	100%	2.5	500
Same as "Middle" or 2nd Voltage (V2)	95%	90%	2.65	700
Same as "Bottom" or 3rd Voltage (V3)	90%	80%	2.8	1,000

TANTALUM LAMP.

The filament of this lamp is a fine wire of metallic tantalum. The high melting point and low vapor pressure of this metal make it possible to operate the lamps at 2.0 w.p.c. with a life comparable with that of the ordinary lamp at 3.1 w. p. c. The life on alternating current is much shorter than on direct current and is a function of the frequency. Fig. 15 shows free-hand drawings of microscopic views of the tantalum filament as affected by rise on alternating and direct current. The vertical distribution of intensity changes during the life of the lamp, the horizontal intensity diminishing more rapidly than the spherical, due chiefly to more rapid bulb blackening in the horizontal zone. On this account the spherical reduction factor also changes. (See Fig. 16.) Characteristic life curves of tantalum lamps manufactured in Germany in about 1904, are shown in Figs 17 and 18. These tests were made in the Electrical Testing Laboratories. (See Sharp, *New Types of Incandescent Lamps.* Proc. A. I. E. E., 1905, p. 809.)

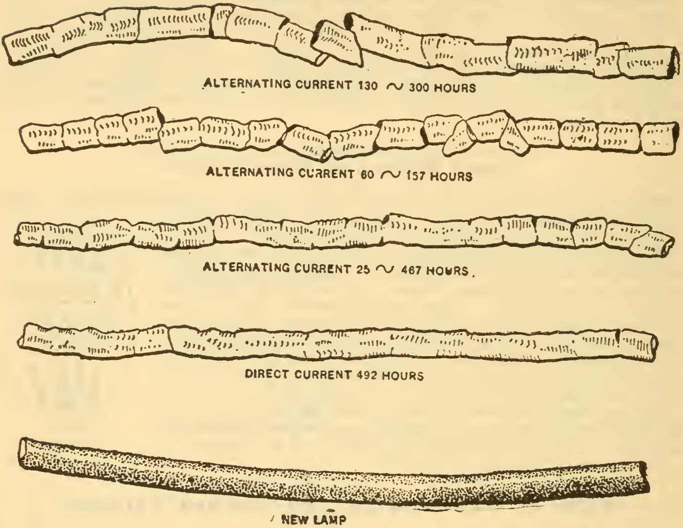


FIG. 15. Microscopic Views of the Tantalum Filament.

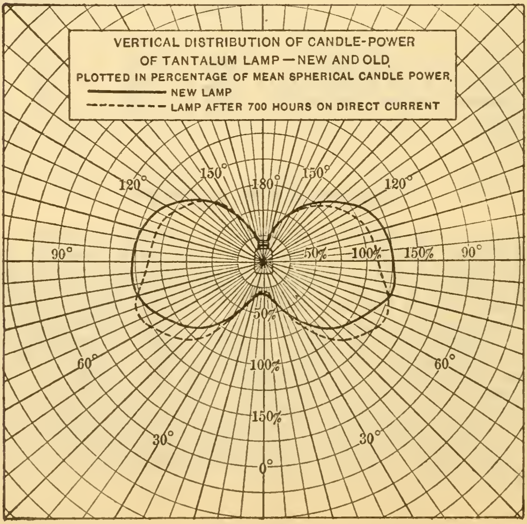


FIG. 16.

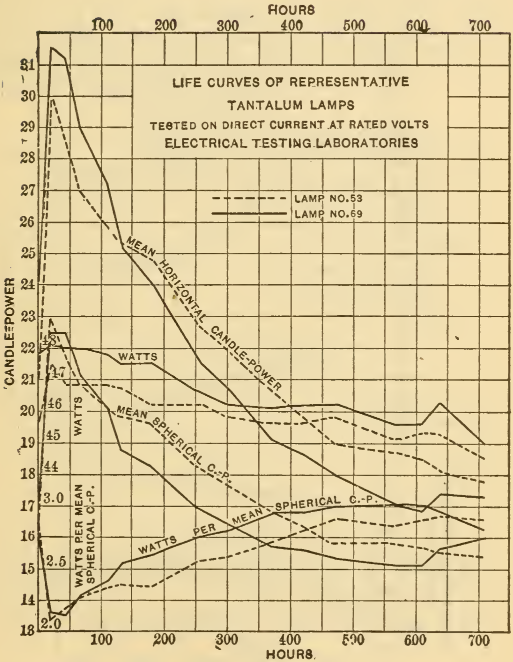

HOURS
LIFE CURVES OF REPRESENTATIVE
TANTALUM LAMPS
TESTED ON DIRECT CURRENT AT RATED VOLTS
ELECTRICAL TESTING LABORATORIES
LAMP NO.53
LAMP NO.69
MEAN HORIZONTAL CANDLE-POWER
WATTS
MEAN SPHERICAL C.-P.
WATTS PER MEAN SPHERICAL C.-P.
CANDLE-POWER
HOURS

FIG. 17.

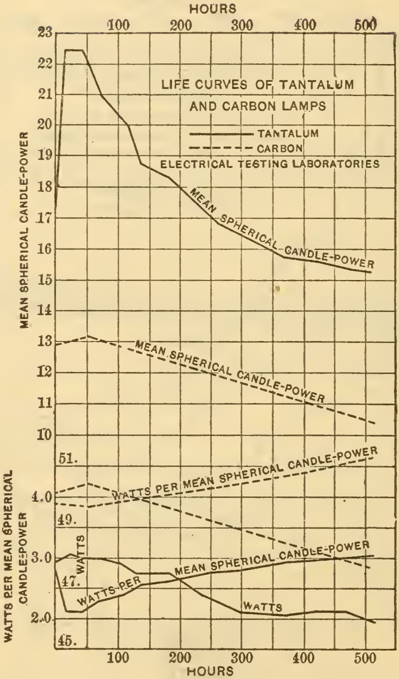


FIG. 18. Curves of Tantalum and Carbon Lamps

TUNGSTEN LAMP.

The metal tungsten has such a high melting point (about 3200° C., according to Waidner and Burgess) that when it has been worked into lamp filaments by special processes, the lamps so produced can be operated at very high efficiencies. The most favorable condition of operation is at about 1.25 watts per candle, which is the point most commonly selected by makers in this country. Even at this low value the rate of deterioration in candle-power and efficiency is very slow until near the end of the life when it may become very rapid. Because of the high conductivity of the metal it has as yet been found impracticable to make 100-volt lamps of lower candle-power than 25, but tungsten lends itself admirably to the construction of heavy current, low-voltage lamps for use in series on constant current street-lighting circuits. Life curves of six German-made tungsten lamps (Osram lamps) are shown in Fig. 19.

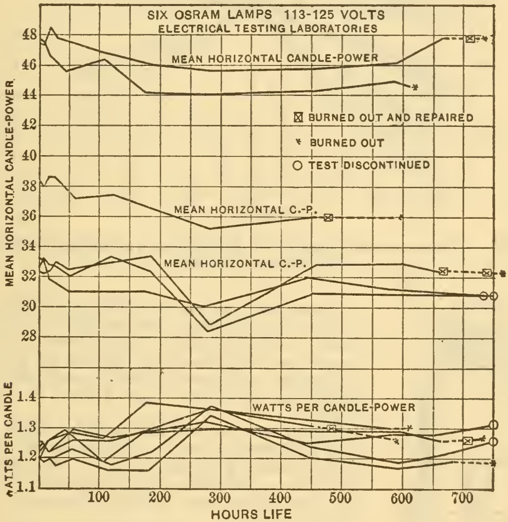


FIG. 19. Tests of Six Tungsten Lamps.

Effect of Changes in Voltage.

Change with 5 per cent increase in voltage above normal.

	Candle-power.	Watts per Candle
Carbon	+30%	−15%
Metallized	+27%	−13%
Tantalum	+22%	−11%
Tungsten	+20%	−10%

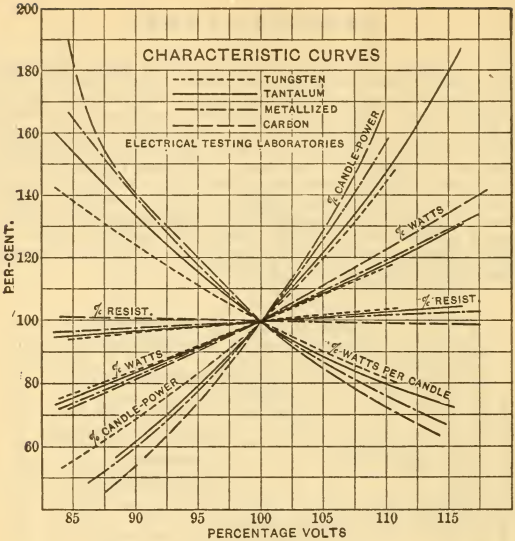


FIG. 20. Characteristic Curves of Tungsten, Tantalum, Metallized and Carbon Lamps.

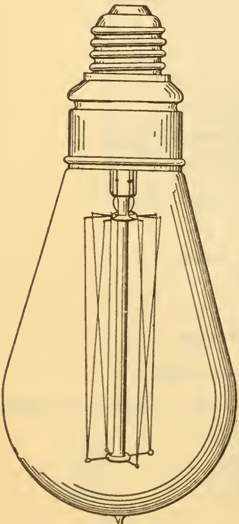


FIG. 21. Tungsten 60-Watt Lamp.

These data show that Tungsten lamps are less affected by voltage fluctuation than are other lamps. The operating temperature of the Tungsten is so high that the light is of peculiar and agreeable whiteness, much better fitted for the matching of colors than is that of the carbon lamp.

Lamps are now on the market rated at 100, 60, and 40 watts for use on circuits of 100 to 125 volts. Series burning lamps for street lighting are also available. The life of a Tungsten multiple lamp at 1.25 watts per candle is said to be 800 hours.

The following statement and table are from a Bulletin of the Engineering Department of the National Electric Lamp Association.

Operating Cost.—Table 5 shows the total cost of operating various lamps on various costs of power. The combined cost of power and lamp renewals, for a period of 1000 hours, shows the saving effected by the use of high efficiency lamps, when the cost of power is high.

At costs of power greater than two cents per kilowatt hour the Tungsten lamp is the cheapest, considering both the first cost of the lamp and the cost of power, excepting only the higher candle-power Tantalum lamp. The latter is cheaper than the Tungsten at costs of power below two and one half cents per kilowatt hour on 60-cycle alternating and four cents per kilowatt hour on direct current.

WHEN AND HOW INCANDESCENT LAMPS ARE USED.

By Mortimer Norden.

The following data have been collated to show the yearly consumption of current per 16 c.p. lamp on the circuits of a large central station company, giving the yearly average of current used in kw.-hours. The data represent ten plants all operated by the one company:

Totals of Average Consumption, Showing Yearly Consumption per 16-c.p. Lamp Connected.

		Lights.	Kw.-hours.
1	Green house	54	1.33
24	Colleges and schools	2,863	5.70
127	Churches	11,616	7.75
3	Parks	416	9.24
1343	Residences	40,095	10.73
64	Dentists' and physicians' offices	1,066	15.10
344	Factories	21,936	15.53
8	Signs	365	18.48
14	Public halls	1,781	18.81
6	Dressmakers	111	20.24
1	Grain elevator	24	20.75
102	Municipal buildings, hospitals, armories and city halls	14,654	24.79
104	Clubs and lodge rooms	7,391	24.82
147	Nine o'clock stores	4,433	26.35
401	Seven o'clock stores	17,623	26.55
449	Eight o'clock stores	13,228	27.10
137	Livery stables and stables	1,775	29.56
26	Eleven o'clock stores	624	30.01
287	Office buildings and offices	7,363	30.65
10	Theaters	10,581	32.13
9	Road houses	305	32.70
45	Banks and insurance companies	3,322	33.80
11	Ten o'clock stores	339	38.34
2	Cold storage companies	158	40.82
4	R. R. terminals and docks	854	42.14
180	Drug, confectionery and cigar stores	4,370	42.44
640	Saloons, restaurants and concert halls	17,592	43.62
327	Six o'clock stores	23,584	45.61
22	Wholesale butchers	1,012	46.92
25	Commission dealers	518	48.06
8	Twelve o'clock stores	170	52.44
3	Steamship docks	2,293	61.71
5	Hotels	1,099	65.
23	Railroad stations	909	118.98
2	All night stores	410	218.06
4904	customers,	214,934	
		Grand average	27.28

Table III.

The list prices and discounts in this table are given solely to assist in calculation. They are correct at this date but are liable to change without notice. Line 8 shows the cost of lamps to consumers using 10,000 lamps per year, and when used in connection with line 44 enables one to calculate what it costs him to light with any costs of lamps and power.

Designation . . .	1	Carbon.				Gem.					Tantalum. Direct Current.		Tantalum. 60 ~ Alternating.		Tungsten.	
C. P.	2	16	16	32	32	20	40	50	75	100	20	40	20	40	32	48
Nominal W. P. C.	3	3.1	3.5	3.1	3.5	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.25	1.25
Actual W. P. C. .	4	3.1	3.5	3.1	3.57	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.C	1.25	1.25
Total Watts . .	5	49.6	56.0	99.2	114.24	50.0	100.0	125.0	187.5	250.	40.	80.	40.	80.	40.	60.
Hours Total Life .	6	587.5	1162.5	593.75	1200.	560.	575.	560.	560.	560.	1400.	1600.	600.	900.	1000.	1000.
K. W. H. Consumed during life . .	7	29.14	65.10	153.4	137.09	28.0	57.5	70.0	105.0	140.0	56.	128.0	24.0	72.0	40.	60.
Cost of Lamp . .	8	.16	.16	.24	.24	.20	.28	.36	.52	.64	.48	.68	.48	.68	1.20	1.40
Cost of Renewals per 1000 hours .	9	.272	.138	.404	.200	.357	.487	.643	.929	1.143	.343	.425	.80	.756	1.20	1.40
Cost of Power per Kilowatt Hour. — Table of Combined Cost of Power and Lamp Renewals for 1000 Hours.																
.006	10	.570	.474	.999	.885	.657	1.087	1.393	2.054	2.643	.583	.905	1.040	1.236	1.44	1.76
.008	11	.669	.586	1.198	1.114	.757	1.287	1.643	2.429	3.143	.663	1.065	1.120	1.396	1.52	1.88
.010	12	.768	.696	1.396	1.342	.857	1.487	1.893	2.804	3.643	.743	1.225	1.200	1.556	1.60	2.00
.012	13	.867	.810	1.594	1.571	.957	1.687	2.143	3.179	4.143	.823	1.385	1.280	1.716	1.68	2.12
.014	14	.966	.922	1.793	1.799	1.057	1.887	2.393	3.554	4.643	.903	1.545	1.360	1.876	1.76	2.24
.016	15	1.066	1.034	1.991	2.028	1.157	2.087	2.643	3.929	5.143	.983	1.705	1.440	2.036	1.84	2.36
.018	16	1.165	1.146	2.190	2.256	1.257	2.287	2.893	4.304	5.643	1.063	1.865	1.520	2.196	1.92	2.48
.020	17	1.264	1.258	2.388	2.485	1.357	2.487	3.143	4.679	6.143	1.143	2.025	1.600	2.356	2.00	2.60
.022	18	1.363	1.370	2.586	2.713	1.457	2.687	3.393	5.054	6.643	1.223	2.185	1.680	2.516	2.08	2.72
.024	19	1.462	1.482	2.785	2.942	1.557	2.887	3.643	5.429	7.143	1.303	2.345	1.760	2.676	2.16	2.84
.026	20	1.562	1.594	2.983	3.170	1.657	3.087	3.893	5.804	7.643	1.383	2.505	1.840	2.836	2.24	2.96
.028	21	1.661	1.706	3.182	3.399	1.757	3.287	4.143	6.179	8.143	1.463	2.665	1.920	2.996	2.32	3.08
.030	22	1.760	1.818	3.380	3.627	1.857	3.487	4.393	6.554	8.643	1.543	2.825	2.000	3.156	2.40	3.20
.032	23	1.859	1.930	3.578	3.856	1.957	3.687	4.643	6.929	9.143	1.623	2.985	2.080	3.316	2.48	3.32
.034	24	1.958	2.042	3.777	4.084	2.057	3.887	4.893	7.304	9.643	1.703	3.145	2.160	3.476	2.56	3.44

Cost of Power per Kilowatt Hour.	Table of Comb'ned Cost of Power and Lamp Renewals for 1000 Hours.															
.036	25	2.058	2.154	3.975	4.313	2.157	4.087	5.143	7.679	10.143	1.783	3.305	2.240	3.636	2.64	3.56
.038	26	2.157	2.266	4.174	4.541	2.257	4.287	5.393	8.054	10.643	1.863	3.465	2.320	3.796	2.72	3.68
.040	27	2.256	2.378	4.372	4.770	2.357	4.487	5.643	8.429	11.143	1.943	3.625	2.400	3.956	2.80	3.80
.045	28	2.504	2.658	4.868	5.341	2.607	4.987	6.268	9.366	12.393	2.143	4.025	2.600	4.356	3.00	4.10
.050	29	2.752	2.938	5.364	5.912	2.857	5.487	6.893	10.304	13.643	2.343	4.425	2.800	4.756	3.20	4.40
.055	30	3.000	3.218	5.860	6.483	3.107	5.987	7.518	11.242	14.893	2.543	4.825	3.000	5.156	3.40	4.70
.060	31	3.248	3.498	6.356	7.054	3.357	6.487	8.143	12.179	16.143	2.743	5.225	3.200	5.556	3.60	5.00
.065	32	3.496	3.778	6.852	7.626	3.607	6.987	8.768	13.117	17.393	2.943	5.625	3.400	5.956	3.80	5.30
.070	33	3.744	4.058	7.348	8.197	3.857	7.487	9.393	14.054	18.643	3.143	6.025	3.600	6.356	4.00	5.60
.075	34	3.992	4.338	7.844	8.768	4.107	7.987	10.018	14.992	19.893	3.343	6.425	3.800	6.756	4.20	5.90
.080	35	4.240	4.618	8.340	9.339	4.357	8.487	10.643	15.929	21.143	3.543	6.825	4.000	7.156	4.40	6.20
.085	36	4.488	4.898	8.836	9.910	4.607	8.987	11.268	16.867	22.393	3.743	7.225	4.200	7.556	4.60	6.50
.090	37	4.736	5.178	9.332	10.482	4.857	9.487	11.893	17.804	23.643	3.943	7.625	4.400	7.956	4.80	6.80
.095	38	4.984	5.458	9.828	11.053	5.107	9.987	12.518	18.742	24.893	4.143	8.025	4.600	8.356	5.00	7.10
.100	39	5.232	5.738	10.324	11.624	5.357	10.487	13.143	19.679	26.143	4.343	8.425	4.800	8.756	5.20	7.40
.105	40	5.480	6.018	10.820	12.195	5.607	10.987	13.768	20.617	27.393	4.543	8.825	5.000	9.156	5.40	7.70
.110	41	5.728	6.298	11.316	12.766	5.857	11.487	14.393	21.554	28.643	4.743	9.225	5.200	9.556	5.60	8.00
.115	42	5.976	6.578	11.812	13.338	6.107	11.987	15.018	22.492	29.893	4.943	9.625	5.400	9.956	5.80	8.30
.120	43	6.224	6.858	12.308	13.909	6.357	12.487	15.643	23.429	31.143	5.143	10.025	5.600	10.356	6.00	8.60
For each one cent difference in cost, add or subtract.	44	.0170	.0086	.0168	.0083	.0179	.0174	.0179	.0179	.0179	.0071	.0062	.0167	.0111	.01	.01
Cost of Renewals per 1000 K.W.H.	45	$5.49	$2.46	$4.50	$1.75	$7.14	$4.87	$5.14	$4.95	$4.57	$8.57	$5.31	$20.00	$9.44	$30.00	$23.33

COOPER-HEWITT MERCURY VAPOR LAMP.

Characteristics.—This lamp is an arc lamp rather than an incandescent lamp, the arc having a mercury cathode and passing through vapor of mercury at low vapor tension. The light probably results from the electro-luminescence of the mercury vapor and not from any very high temperature produced either at the anode, the cathode or in the arc stream. Being produced in this way, the light shows not a continuous spectrum of all the colors, but a discontinuous or line spectrum characteristic of mercury. The percentage of the electrical energy which is converted into light is relatively high, and the lamp is very efficient. It would constitute for many purposes an almost ideal source of light were it not for the unfortunate fact that in the spectrum of mercury red is almost entirely lacking. The result is that the light of this lamp has a tint which to most people is very distasteful, namely a strongly greenish hue. Red objects look black or purple in it, and all colors containing red are falsely rendered. When this characteristic is not objectionable the Cooper-Hewitt lamp may be used to good advantage. It is asserted that the light is very favorable for the eyes, causing little fatigue. It has been used in draughting rooms to some extent. Its actinic powers are high, due to the presence of bright violet lines in its spectrum, hence it is a desirable source of light for night photography, for copying, blue-printing, etc.

Photometry. — The photometry of the Cooper-Hewitt lamp is attended with considerable difficulties due to the large linear dimensions of the lamp, and to the wide divergence of the color of its light from that of other sources.

As a result of its large linear dimensions it is necessary to place the lamp at a considerable distance from the photometer. For distances which are small in comparison with the length of the lamp, the intensity of the light does not diminish as the square of the distance. The difficulties due to the color of the light are two-fold. In the first place photometer settings are difficult and uncertain to make unless a flicker photometer is used, and the personal equation of the operator is a large one. In the second place what is known as the *Purkinje Phenomenon* plays an important part in the results. This is a physiological effect, according to which if a reddish and a greenish or a bluish light appear equally bright when the intensity of each is high, the reddish light appears much fainter than the other when the intensity is greatly diminished. It follows from this that the apparent candle-power of the Cooper-Hewitt lamp when photometered against an ordinary standard, such as an incandescent lamp, is higher the farther the lamps are removed from the photometer or the dimmer the illumination on the photometer disk. In order to get even approximately accurate results in the photometry of this lamp a standard illumination on the photometer disk must be chosen and adhered to. No such standard illumination has as yet been designated and established.

The following matter is condensed from an article in the *Electrical Age.*

The Cooper-Hewitt lamp consists essentially of a glass tube, from which all the air has been exhausted, but which contains a small amount of liquid mercury and is filled with mercury vapor. At the ends of the tube are means for introducing the electric current. At the positive end the tube swells out, forming a chamber, which is called the condensing chamber. A platinum wire is sealed into each end of the lamp. At the positive end the wire connects either with a small puddle of mercury or a piece of iron, according to the type of electrode used, and this constitutes the positive electrode, or anode. At the negative end the wire connects with a small puddle of mercury constituting the negative electrode, or cathode.

The lamp may be made of such dimensions as to make it suitable for a direct-current line of any assigned voltage. Most lamps are designed to run at a pressure of about 115 volts. A lamp about 4 feet in length and 1 inch in diameter would be suitable for this voltage and would work best on a current of about 3 amperes.

Before being started, the electrical resistance of a mercury vapor lamp is very high.

This negative electrode resistance to starting may be almost totally destroyed in various ways. One method consists simply in tilting the lamp until the two electrodes are brought into connection by a thin stream of liquid mercury along the length of the tube; then, upon tilting back, an arc is started which prevents the high cathode resistance from making its appearance, and the lamp continues to operate until the current is turned off. Another method of starting is to send a small, momentary high-tension current from an inductance coil through the lamp, which at the same time is connected with the low-voltage mains. This high-tension current penetrates the high cathode resistance, and the current from the low-voltage mains follows, and if this latter current be great enough the high cathode resistance does not again make its appearance until the current is turned off; and if it is desired to relight the lamp the same procedure has to be repeated. To facilitate the starting of the lamp by this method the so-called "starting band" is employed. This is simply a narrow, thin, metallic band attached to the outside surface of the lamp in the neighborhood of the cathode, and connected by a wire to the positive terminal of the lamp.

In the latest model of automatic lamps this operation is accomplished by the use of a "shifter." This consists of an evacuated glass bulb containing mercury which is shifted by the action of an electromagnet when the circuit is closed and which interrupts the current. Thereby a high potential is induced which starts the lamp.

A view of this lamp is shown in Fig. 22, of the interior of the auxiliary box in Fig. 23, and a diagram of connections in Fig. 26.

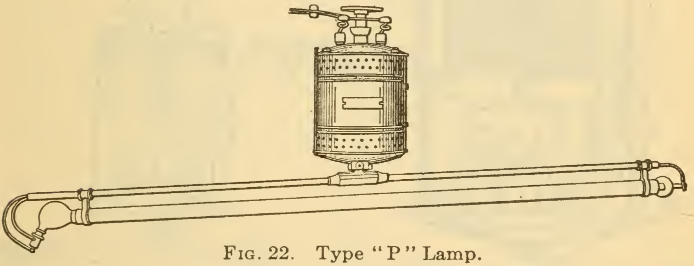


Fig. 22. Type "P" Lamp.

The resistance which a mercury arc offers to the passage of electric current may be separated into three distinct parts: — First, the resistance encountered by the current in passing from the anode into the vapor; second, the resistance of the vapor column itself; and third, the resistance encountered by the current in passing from the vapor into the cathode.

In the commercial lamp the potential drop over the anode is about eight volts and is approximately independent of the magnitude of the current flowing and the diameter of the tube. The anode resistance, then, varies inversely with the current. The potential drop over the cathode is about five volts and is approximately independent of the diameter of the tube and of the magnitude of the current flowing, provided that the current is above a certain minimum value, depending upon the inductance and resistance in series with the lamp. If the current falls below this minimum value, the cathode resistance immediately becomes enormous and the lamp is extinguished. A certain amount of inductance and resistance is usually placed in series with the lamp, as this has a beneficial effect, causing the lamp to operate more steadily.

In fixing the resistance of the vapor to the passage of the current, four quantities predominate, namely, the length of the tube, the diameter of the tube, the magnitude of the current, and the density of the vapor.

The results can be roughly expressed as follows: — The resistance of a lamp increases directly with its length; it decreases with increase of its diameter and at a greater rate when the current and diameter are small and the vapor density large; it decreases with increase of the current and at a greater rate when the current and diameter are small and the vapor density large; it increases with increase of the vapor density and almost directly, although at a certain value of the density (varying with different currents and different diameters), the rate of increase changes somewhat abruptly and is less for values of the density greater than this value than it is for lesser values.

When the vapor density is quite high, say for values greater than those corresponding to a pressure of three millimeters of mercury, the luminous column no longer fills the tube; and when the density is very high it is of very small cross section and passes along the axis of the tube. The vapor

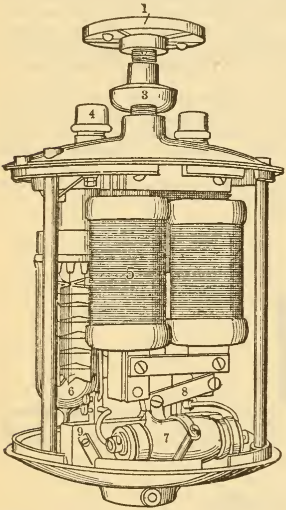


FIG. 23. Auxiliary for "P" Lamp (casing removed). 1. Ceiling Plate. 2. Nipple. 3. Insulating Joint. 4. Binding Post for Main. 5. Inductance Coil. 6. Ballast. 7. Shifter. 8. Actuating Armature. 9. Terminal Block.

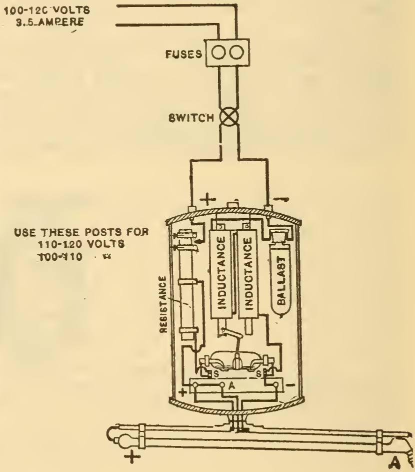


FIG. 24. Wiring Diagram. Type "P" Lamp.

pressure of a lamp operating under normal conditions is in the neighborhood of one millimeter of mercury.

It has been observed by Dr. Hewitt that there is a value of the vapor density at which the light efficiency of a lamp is greatest, and lamps are designed to run at this density when they are to be operated under commercial conditions. In order to maintain the density at the proper point the condensing chamber mentioned at the beginning of this article is employed. This chamber usually, though not necessarily, surrounds the positive electrode at the upper end of the lamp. By virtue of its size it has a considerable radiating surface exposed to the air, and consequently the temperature within it, except in that portion of it which is quite close to the electrode, is low, compared with that in the other parts of the lamp. In consequence of this the pressure also is low in this region, and the mercury vapor from the main part of the tube rushes into the chamber and condenses there. The effect of all this is to keep the vapor density in the conducting column at a lower value than it would otherwise assume.

By making the condensing chamber of the proper dimensions, the vapor density can easily be made that corresponding to the greatest light efficiency. In connection with all this, it should be remembered that the mercury at the cathode is continually vaporizing, owing to the heat produced by the current. After condensing in the condensing chamber the mercury falls back into the cathode end, and after a while again takes its turn at being vaporized.

The efficiency is said to be somewhat higher than that of the arc lamp, and much higher than that of the incandescent light.

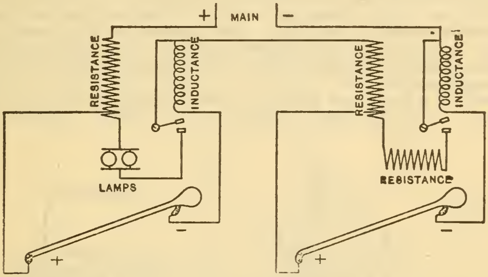


FIG. 26. Diagram Illustrating the Method of Operating Lamps in Series.

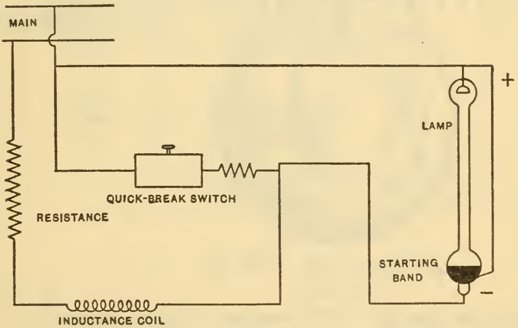


FIG. 27. Diagram illustrating the method of starting by high-tension discharge. To light the lamp, the main switch, which is mounted on a small panel board, is closed, and then the lever handle on the quick-break switch is pressed down, thus completing a circuit through the series resistances and inductances, charging the coil. On releasing the handle the quick-break switch automatically opens the circuit and the discharge of the coil passes through the lamp, breaking down its resistance and establishing a path for the main current.

THE NERNST LAMP.

Early in 1898 Dr. Walther Nernst exhibited in this country his new type of incandescent electric lamp. Mr. Westinghouse purchased the patents and placed at work upon it a staff of engineers, who have developed it into the present commercial form in this country.

The light-emitting element of the lamp as developed by the Nernst Lamp Company of Pittsburgh, is termed a "glower." It is made by pressing through a die, a dough composed of the oxides of the rare earths mixed with a suitable binding material. The porcelain-like string thus formed is cut, after drying, into convenient lengths. It is then baked, and terminals are attached, by means of which a current of electricity may be passed through the glower.

The glower of a standard 220-volt Nernst lamp is about 1″ long by $\frac{1}{32}$″ in diameter. It is an oxide incapable of further oxidation, therefore

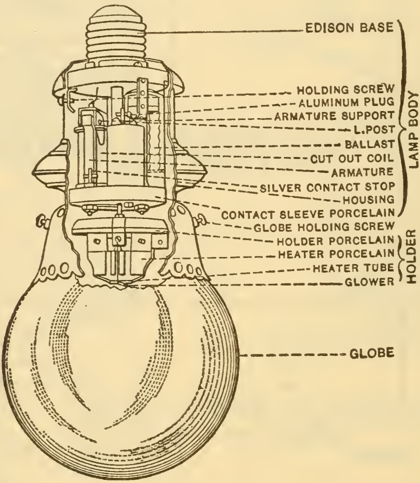


Fig. 28.

operative in the open air. The presence of oxygen is essential. Glowers are insulators when cold, but become conductors when hot, hence they must be heated before they will conduct electricity sufficiently well to maintain themselves at a light-emitting temperature.

The characteristic of the glower with reference to voltage is as follows:— As the current traversing the glower is increased, the voltage across its terminals rises, at first rapidly and then more and more slowly to a maximum; it then drops off with increasing rapidity as the current through the glower and the resulting temperature continues to increase. The glower is operated on the ascending part of the curve at a point just preceding that of maximum pressure. Beyond this point the rapid decrease in the resistance of the glower makes the current difficult of control without a steadying resistance in series with it. This ballasting is accomplished by means of a fine iron wire mounted in a small glass tube filled with hydrogen. The diameter of this wire in a 0.4 ampere ballast is about .045 mm. Iron wire possesses, on reaching its so-called critical temperature, the property of increasing its resistance with great rapidity with rising temperature.

The negative resistance temperature coefficient of a glower may thus be more than counter-balanced by the temperature coefficient of the iron wire ballast placed in series with it. For a 10% rise in current the resistance in the ballast increases 150%, so that a glower thus protected at once becomes operative through a wide range of voltage.

The construction of a commercial lamp requires a device to heat the glower in starting.

The heaters consist of thin porcelain tubes wound with fine platinum wire which in turn is held in place and protected from the intense heat of the glowers by a refractory paste.

The automatic lamp is constructed with a cut-out to disconnect the heater from the circuit as soon as the glowers light.

A general idea of the construction of the lamp and of its principal parts together with an understanding of its electrical connections may be gained from a study of Figs. 28, 29, and 30.

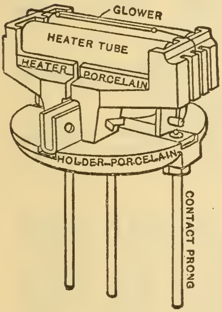
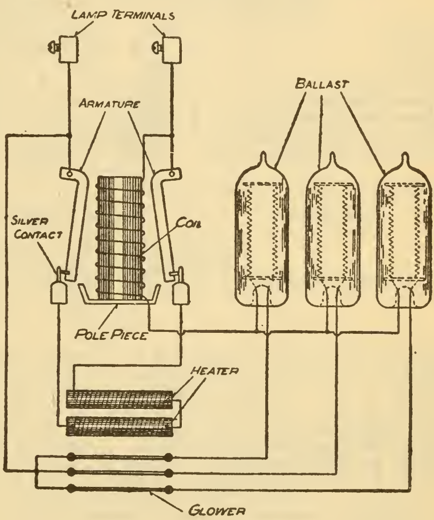


FIG. 29.



3 GLOWER LAMP
FIG. 30.

The action of a Nernst lamp when the switch is turned on is as follows:

(1) The current passes through the heater, bringing it to a white heat; (2) the proximity of the glower to the heater results in the glower becoming a conductor, through which the current then passes; when the current through the glower has reached a predetermined amount; (3) the cut-out coil becomes energized by virtue of the glower current passing through it; (4) the armature of the cut-out which had heretofore closed the heater circuit is attracted; and (5) this opens the heater circuit, leaving only the glowers in operation until the next time the lamp is turned on. Opening the switch which controls the lamp circuit allows the cut-out armature to fall into place again, thus connecting the heaters ready for starting.

Efficiency. — It may be noticed that the efficiency of the Nernst lamp increases as the number of glowers increases. This is due to the fact that the glowers in the multiple glower lamps are operated in a highly heated atmosphere by virtue of the mutual heating effect of the several glowers. This causes the glowers to have a much lower voltage at the normal current in the multiple glower lamp than is the case when they are operated in the open air, this difference amounting to about 16 volts in the six-glower lamp.

Photometric Tests of Various Illuminants by National Electric Light Association.

Illuminants.	Multiple D.C. Arc.	Multiple A.C. Arc.	Nernst 6-Glower.		
Globes and Shades.	Opal. Inner. Clear Outer.	Opal. Inner. Clear Outer.	Clear Globe.	Opal. Globe.	Clear H. C. Opal. Shade.
E.M.F.	110	110	226	226.5	226
Current	4.9	6.29	2.4	2.4	2.4
Watts	529	417	542	543	542
Power Factor	1	.6	1	1	1
Mean Spherical c.p.	182	140	163.9	168.6	155.8
Mean Hemispherical c.p.	239	167	289	258.6	264.2
Watts per Spherical c.p.	2.90	3.02	3.30	3.22	3.48
Watts per Hemispher. c.p.	2.25	2.53	1.88	2.10	2.05

Illuminants.	Nernst 3-Glower.			Nernst 1-Glower.	
Globes and Shades.	Clear Globe.	Sand Blasted Globe.	Clear H. C. Opal. Shade.	Clear Globe.	Sand Blasted Globe.
E.M.F.	218.8	219.5	220	223.7	220.5
Current	1.2	1.2	1.2	0.4	0.4
Watts	262	263	264	89	88
Power Factor	1	1	1	1	1
Mean Spherical c.p.	65.1	61.5	68.5	21.8	20.5
Mean Hemispherical c.p.	112.6	96.9	118.3	38.7	31.8
Watts per Spherical c.p.	4.04	4.28	3.86	4.11	4.3
Watts per Hemispher. c.p.	2.33	2.72	2.23	2.31	2.78

The British unit of c.p. used in above.

The arc lamp figures were taken from the Report of the Committee for Investigating the Photometric Values of Arc Lamps, read before the National Electric Light Association in May, 1900. The Nernst lamp data were obtained from the report of the same committee which was presented at the Twenty-Sixth Convention in May, 1903.

Maintenance. — The frame and connections of the Nernst lamp form a permanent structure having an indefinite life, but its perishable parts have from time to time to be renewed. Of these, the ballast has a life averaging 25,000 hours. The heater has a life averaging about 8 months in ordinary use. The glower, however, like the incandescent lamp filament, has a practically definite term of use at the end of which it would be advisable to replace it whether burnt out or not. 800 hours are given by the company as the guaranteed life on 60 cycles.

Behavior on Alternating and Direct Current. — Unlike the carbon incandescent lamp the life of glowers is not the same on direct current as on alternating current, and is affected even by the frequency of the latter. The American glower was constructed originally for use on alternating current only, while in Europe direct current lamps predominated. The direct current lamp in this country is a comparatively recent development and its glower life is shorter than that of the glower used with alternating current.

THE MOORE VACUUM TUBE LIGHT.

The Moore Vacuum Tube Lighting System, invented by D. McFarlan Moore, has been in commercial service since 1903 and consists essentially of a glass tube about $1\frac{3}{4}$ inch diameter and of any form or length desired up to 200 feet. The tube is attached to the ceiling or walls by supporting

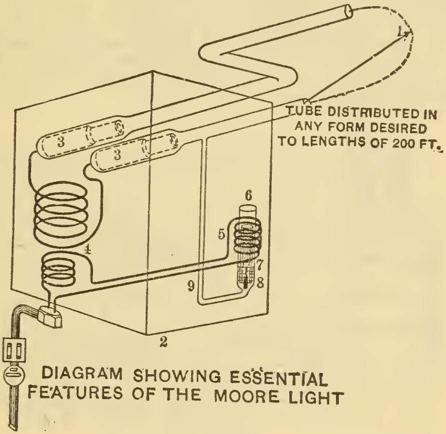
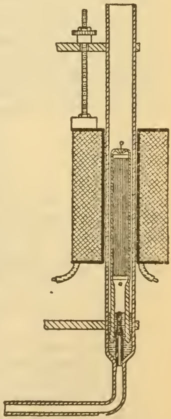


FIG. 31.

fixtures at intervals of about 8 feet. A graphite electrode (3, Fig. 31) is sealed into each end of tube and the two electrodes enclosed within a steel terminal box (2) which also contains a static transformer (4) and regulating device (6) called a feeder valve (see Fig. 32). The completed tube is exhausted to a pressure of about 1/10 mm. of mercury. The feeder valve performs the important service of feeding the tube some pure gas to take the place of that which is used up by the passage of the electric current through the tube. All vacuum tubes or bulbs through which current passes tend to attain a higher vacuum due to solidification or combination of the residual gases. There is a critical pressure, about 0.08 mm. of mercury, at which the conductivity is a maximum and the greatest current will flow. The pressure of maximum light efficiency is, however, slightly higher, i.e., 0.1 to 0.12 mm., hence the feeder valve is adjusted to maintain the pressure at this point which it does as follows:

A carbon plug (8, Fig. 31) is cemented into the mouth of the small bore tube (9) which connects to the lighting tube. This plug is normally covered by mercury the level of which is varied by the glass displacer (7) which also carries the iron core of the solenoid coil (5) which is connected in series with the transformer (4). As the pressure in the lighting tube falls the conductivity and therefore the current increases, and the plunger rises, allowing the surface of the mercury to fall and expose the tip of the carbon plug. A minute quantity of air or whatever gas is supplied to the feeder valve, filters through the porous carbon plug and finds its way to the lighting tube, the action continuing until the pressure is brought back to



FEEDER VALVE

FIG. 32.

normal. The device is capable of very close adjustment. The transformer is usually supplied with alternating current at 220 volts and raises the voltage to 2000 volts or more, depending on the length of the tube.

The tube is self-starting and responds at full brilliancy instantly upon closing the switch.

The intensity may be made anything desired from 5 to 50 candle-power per lineal foot, the normal commercial brilliancy being 12 candle-power per foot, the radiation being uniform in all directions in planes perpendicular to the axis of the tube. The efficiency is said to vary from 1.4 to 2 watts per candle-power depending upon the length of tube, the light intensity, etc., and is not affected by variation of supply voltage. See Fig. 33.

In practice, tubes are said to have a life of from 3000 to 5000 hours and then can be renewed at small cost. The efficiency is said to remain constant after the first 50 hours' run.

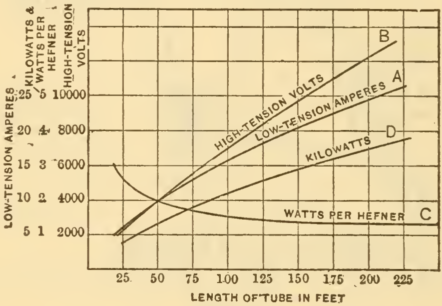


FIG. 33.

The color depends upon the gas supplied to the feeder valve. It is exactly the same shade of white *diffused daylight* when fed with pure nitrogen, and orange-pink when fed with air.

The intrinsic brilliancy is claimed to be the lowest of any known illuminant and therefore is extremely soft and agreeable to the eyes and does not require to be shaded or diffused to avoid glare but may be reflected to obtain any distribution desired. An intensity of 0.66 candle-power per square inch corresponds with 12 candle-power per lineal foot.

Efficiency of Moore Tube.

Early in 1907, Sharp & Millar conducted a series of tests on a Moore tube that had been installed in Assembly Room, No. 7, of the United Engineering Societies Building, and reported the following results.

The tube was 176 feet long and approximately $1\frac{7}{8}$ inches diameter. It was fed with nitrogen gas, and operated as a 60-cycle system.

Total watts consumed by tube system	3451
Line volts	220.3
Amperes	21.5
Volt-amperes (apparent watts)	4736
Power factor	73%
Total lumens produced	17,400
Efficiency as light producer — lumens per watt	5.5
Lumens per apparent watt	3.68
Watts per equivalent mean spherical candle-power	2.49
Apparent watts per equivalent mean spherical candle-power	3.41

This installation of Moore Tube was compared with three installations of incandescent carbon filament lamps in the same room; they were as follows:

Installation No. 1.—Moore Tube, 176 feet long, running around the room close to the cove.
Moore Tube.

Installation No. 2.—One hundred 16-c.p. lamps placed horizontally 5 inches beneath the tube, and equally spaced.
Lamps under Tube.

Installation No. 3.—Eighty-four 16-candle-power lamps bare, arranged in equal rectangles, 15 feet, 4 inches, above the floor.
Lamps in Rectangles.

Installation No. 4.—Same as No. 3, except that the lamps were equipped with Holophane distributing reflectors No. 7381.
Lamps with Reflectors.

Results of the Comparative Tests.

Installation Number.	Number of Lamps.	Mean Horizontal c.p.	Mean Spherical c.p.	Watts per Horizontal c.p.	Watts per Spherical c.p.	Total Watts.
		(per ft.)	(per ft.)			
1	1	8.1	7.9	2.39	2.48	3451
2	100	13.82	11.41	3.48	4.21	4810
3	84	11.31	9.33	4.26	5.16	4040
4	84	11.11	9.16	4.32	5.23	4027

Installation, Number.	Illumination Values Foot Candles.				Efficiency Values.		
					Lamp.	Gross.	Net.
	Maximum.	Minimum.	Mean.	Variation.	Lumens per Watt.	Lumens Effective per Watt.	Lumens Effective per Lumen Generated.
1	4.38	3.18	3.69	16.2%	5.05	2.08	41.2%
2	3.27	2.28	2.69	18.4	2.98	1.08	36.2
3	2.10	1.16	1.71	27.5	2.44	0.82	33.6
4	2.51	1.26	1.97	31.7	2.40	0.95	39.6

The above table shows that, with regard to the uniformity of the distribution of illumination, the Moore Tube performance was very good, but that the performance of the incandescent lamps arranged beneath the tube was practically the same.

A disadvantage from which the Moore Tube suffers is that it flickers in unison with the alternating current which feeds it. On 60-cycle current this flickering is not noticeable, except when the eye is moved rapidly or when an object is moved rapidly before the eye. It then becomes noticeable, and for certain work is very objectionable. It, however, has the great advantage of throwing a very soft light of low intrinsic brilliancy, which does not need to be diminished by diffusing glasses in order to make it entirely bearable for the eye. The test shows that its efficiency, while not equalling that of the tungsten lamp, is about equal to that of the tantalum lamp, and greater than that of any other incandescent lamp.

ARC LAMPS AND ARC LIGHTING.

REVISED BY J. H. HALLBERG, *Consulting Engineer*

THE arc lamp is an electrical apparatus in which an electric arc is struck and maintained between two or more electrodes, giving a brilliant illumination, the color and intensity of which depends upon the composition and diameter of the electrodes, the kind of current supplied and the watts consumed.

Owing to the extremely high temperature of the electric arc (varying between 2500 and 4000° C.) the electrodes must have a high volatilization point in order to obtain sufficient life from one set of them to make the lamp practical. Carbon has been found to be the most suitable material for the purpose. A pair of carbon electrodes of proper diameter to maintain a steady arc with a given current strength and voltage drop, will consume at the approximate rate of 1.25 inches per hour in open arc lamps, and .16 inch per hour in those of the enclosed type. If cross section of the carbon be too large, the arc crater will cover a comparatively small part of the carbon point. The shifting of the arc moves the crater to a cooler point, which makes a considerable change in the resistance of the arc. This change is so rapid that the lamp mechanism cannot compensate for it as quickly as required, hence a variation in the candle-power of the lamp which makes the use of carbons of large diameter impractical. With carbons of too small cross section, the candle-power is greater, and the arc is very steady, but the life of the electrodes is too short for practical purposes.

In Europe, the practice is to use carbons of comparatively small diameter, of extra length, or to trim often in order to secure perfectly steady illumination at maximum efficiency. In the United States, the practice has been to use carbons of larger diameter, giving longer life with one trim and limiting the length of the carbon to about twelve inches, thereby reducing the cost of the carbons and labor required, but sacrificing steadiness of illumination and efficiency.

Developments have been made in the manufacture of carbons for the flaming arc for open arc lamps, which have more than doubled their efficiency, and give four times the efficiency of the enclosed arc. The introduction of arc lamps with electrodes placed points downward at an angle to each other (instead of one above the other as in the old style of lamp) makes it possible to use carbons over twenty-four inches long, if necessary, without making the lamp impracticably long.

The metallic oxide electrode has also been successfully developed, and open arc lamps commonly known as "magnetite" lamps have been put on the market and show a marked increase in efficiency over that of the enclosed arc.

There are seven governing factors to be considered by the designer of arc lamps:

1. Steadiness of the light.
2. Watt consumption per useful candle-power.
3. Maximum practical length of the electrodes.
4. Length of life with one trim.
5. Cost of the electrodes.
6. Cost and reliability of the lamp.
7. Adaptability of lamp to the several systems of electrical distribution in general use.

CLASSIFICATION OF ARC LAMPS.

Open Arcs, Direct Current:

Ordinary open arc lamp with carbon electrodes. Series or multiple, 6 to 10 amperes, 45 to 50 volts at terminals for constant current series; 50 to 60 volts at terminals for constant potential multiple or multiple series operation. Life of carbons, 10 to 14 hours, approximately .6 watt per candle-power, clear globe.

"Magnetite" arc lamp with metallic oxide electrodes in series only on constant current, 4 amperes, 75 to 80 volts at terminals. Life of electrodes, 150 hours, approximately .3 watt per candle-power, clear globe.

"Flaming" arc lamp, carbon electrodes with chemical core filling. Series or multiple, 8 to 12 amperes, 45 to 50 volts at terminals for constant current series; 50 to 60 volts at terminals for constant potential multiple or multiple series operation. Life of carbons, 10 to 18 hours, approximately .22 watt per candle-power yellow flame, approximately .3 watt per candle-power, white flame, clear globe.

Open Arcs, Alternating Current:

Ordinary open arc lamp with carbon electrodes in multiple only, 10 to 16 amperes, 40 volts at terminals — minimum practical frequency — 60 cycles. Life of carbons 7½ to 12 hours, approximately .75 watt per candle-power, clear globe.

"Flaming" arc lamp carbon electrodes with chemical core filling. Series or multiple, 10 to 14 amperes, 40 to 45 volts at terminals for constant current series; 50 to 60 volts at terminals for constant potential multiple or multiple series operation; minimum practical frequency, 25 cycles. Life of carbons, 10 to 16 hours, approximately .25 watt per candle-power, yellow flame; approximately .33 watt per candle-power, white flame with clear globe.

Enclosed Arcs, Direct Current:

Ordinary enclosed arc lamp with carbon electrodes. Series or multiple, 3 to 7½ amperes, 75 to 85 volts at terminals for constant current series; 100 to 250 volts at terminals for constant potential multiple or multiple series operation. Life of carbons, 75 to 150 hours, approximately 1 watt per candle-power, clear globes.

Enclosed arc lamp with inclined electrodes of pure carbon. Multiple operation, 8 to 10 amperes, 100 to 120 volts at terminals. Life of carbons, 30 hours, approximately .45 watt per candle-power, clear globe.

Enclosed Arcs, Alternating Current:

Ordinary enclosed arc lamp with carbon electrodes. Series or multiple, 4 to 7½ amperes, 75 to 85 volts at terminals for constant current series; 100 to 120 volts at terminals for constant potential multiple, or multiple series operation; minimum practical frequency, 40 cycles. Life of carbons, 70 to 100 hours, approximately 1.33 watts per candle-power, clear globes.

Enclosed arc lamp with inclined electrodes of pure carbon. Multiple operation, 10 amperes, 100 to 120 volts at terminals; minimum practical frequency, 40 cycles. Life of carbons, 20 to 25 hours, approximately .6 watt per candle-power, clear globe.

OPEN ARC LAMPS.

Low-Tension Lamp requires for most successful results high-grade carbons, cored positive and solid or cored negative. Lamps with either shunt or differential carbon feed-control, operate 2 in series on 100 to 125 volts, direct-current circuits with any current adjustment between 6 and 12 amperes. The arc should be set for an average of 42 volts, and sufficient resistance must be introduced in series with each pair of lamps to make up the difference between the required lamp voltage and the voltage of the supply circuit. Attempts have been made to operate from 4 to 10 lamps in series on constant potential circuits of 200 to 600 volts, but with only partial success.

On alternating current the low-tension open-arc lamp requires a very high grade of carbon both cored and of the same diameter and length.

The following are the best dimensions for the carbons:

Ten amperes, 9½ × ½ inches; 14 to 16 amperes, 9½ × ⅝″ inches giving about 10 to 12 hours' life.

The alternating current, open arc lamp requires about 30 volts at the arc with 35 to 40 volts at the terminals. The carbon feed is controlled by a simple magnet connected in series with the arc. The lamp is, therefore, a strictly multiple, 35 to 40-volt lamp, and requires special means for providing this pressure. For large installations a special transformer reducing to about 35 volts is used. Where only a few lamps are required a small ("economy") single-coil transformer with taps for one, two, or three lamps is used.

The illumination from the open arc, alternating current lamp has never been altogether satisfactory, mostly on account of low candle-power, excessive amount of violet rays, and noise.

The low-tension, open arc lamp has not been in general use in the United States since 1900, having been superseded by that of the enclosed type. In Europe, however, this form of lamp has been in use until quite recently, as the enclosed arc was never very generally adopted there. The flaming arc lamp is now, however, replacing many of the other forms of open arc lamps.

High-Tension Lamp requires ordinary grade carbons, both of which may be solid, although in some cases it is of advantage to use a cored positive. The usual carbon dimensions are, for 6 to 7 amperes, $12 \times \frac{7}{16}$ inch upper and $7 \times \frac{7}{16}$ inch lower; and for 9 to 10 amperes, $12 \times \frac{1}{2}$ inch upper and $7 \times \frac{1}{2}$ inch lower. This is a strictly constant current series lamp operating any number in series up to the capacity of the generator. Constant current series arc generators have been built for single circuits of 175 to 200 lamps, requiring as much as 10,000 volts. Later practice is to build generators for 100 to 150 lamps, but bringing out leads for several circuits, thus reducing the maximum potential of the system and still securing the benefits due to the use of fewer and larger generators of higher efficiency. The brush multi-circuit arc generators, as built by the General Electric Company, represent the latest development in large arc-lighting units for direct current series lighting.

The high-tension lamp has either shunt or differential carbon feel and is built for 6.8 amperes with 42 to 45 volts at the arc, usually rated at 1200 nominal candle-power; and for 9.6 amperes with 45 to 50 volts at the arc, rated at 2000 nominal candle-power. The high-tension series open arc lamp, operating on direct-current arc generators was the standard for street lighting in the United States until about 1900, since which time many of them have been replaced by enclosed arc lamps.

The "Magnetite" Arc Lamp is of the high-tension, direct-current, open-arc type metallic oxide electrodes. It is especially designed for outdoor lighting, to which it is limited on account of the fumes and heavy deposit from the electrodes. The positive electrode is made of pure copper, or from copper in combination with small non-conducting particles. Another form of positive electrode for this lamp is made of convoluted strips of laminated copper and iron, and is 1 inch long by $\frac{1}{2}$ inch diameter. The negative electrode consists of a steel tube, tightly packed with a fine powder, the principal ingredients of which are: oxide of iron (magnetite), oxide of titanium and oxide of chromium. The steel tube serves as a conductor for the current to the crater and is also the holder of the oxide powder, making a binder unnecessary. The oxide of iron gives conductivity to the fused mixture when cold, the other oxides being conductors only when hot. The titanium oxide has the property of rendering the arc luminous. The oxide of chromium prevents too rapid consumption, thus giving long life to the electrode.

Unlike all other arc lamps the maximum illumination in the "Magnetite" lamp comes from the negative end of the arc. The General Electric Company have designed their "Magnetite" lamp with the negative electrode below the positive, while the Westinghouse Electric & Manufacturing Company place the negative electrode above in their metallic oxide lamp. Advantages are claimed for both forms of construction. An electrode having 12 inches to burn will last about 150 to 175 hours. The positive electrode, of copper, although only one inch long, is generally renewed but once a year.

The metallic arc electrodes, being chiefly composed of oxides of iron titanium and chromium, do not burn away to an invisible gas, as does a carbon stick, but are volatilized bodily, and the vapors instantly condense on leaving the arc to a fluffy reddish soot. This soot if allowed to come in contact with the reflectors or globes will smudge them badly in a few minutes. It will also condense and settle on the electrodes, hiding the light, so special means are introduced for carrying it off. Air currents are caused to circulate past the arc, under the reflector and within the globe in such a manner that all soot deposit is carried up through a chimney in the center of the lamp and out in the open air. The success of the "Magnetite" lamp depends to a large extent upon the creation of air currents

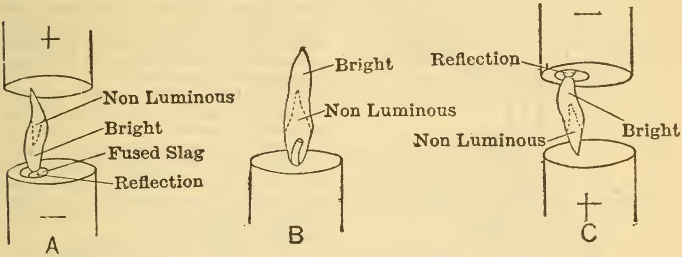


FIG. 34. A. Metallic Arc, with negative below. B. Candle flame. C. Metallic Arc, with negative above.

within the globe, and it has been a great problem to get sufficient natural circulation and to control it with the short chimney permissible in an arc lamp.

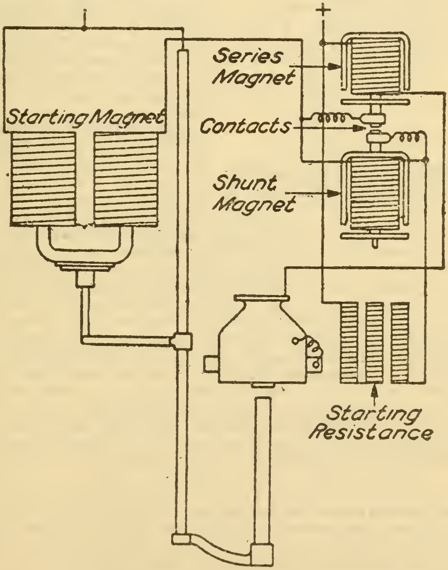


FIG. 35. General Electric Co.'s Magnetite Arc Lamp.

The "Magnetite" lamp has a white dazzling arc of great intensity, but rather small volume. The candle-power is greatest at 10 degrees to 20 degrees below the center line of the arc. This fact makes it especially valuable for street lighting. For this purpose the "Magnetite" lamp is built for 4 amperes and adjusted for about 78 volts at the arc. The electrode is fed intermittently by a shunt cut-out coil which causes the mechanism to restrike the arc. This form of feed is practical for a constant current series system, but will not perform properly on constant potential circuits. The efficiency of the lamp is about 98 per cent.

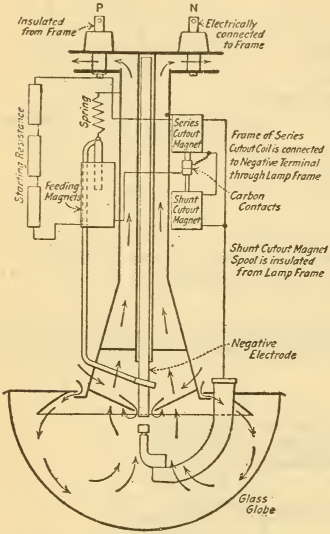


FIG. 36. Westinghouse Elec. & Mfg. Co.'s Metallic Oxide Arc Lamp.

The "Magnetite" lamp may be operated in series on constant direct current, derived from a constant current arc generator or from the mercury arc rectifier in conjunction with a constant current transformer or automatic reactive coil supplied from constant potential alternating current generators.

The cost of the "Magnetite" system (1907), including C. C. Transformer, mercury rectifier with starting transformer, switch panel and lamps is about $53 per lamp.

The cost of the negative electrode is $50 per M.

The positive electrode in the General Electric lamp lasts 4000 hours and costs 45 cents each.

The full load efficiency of the entire system, taken at the primary of the constant current transformer, is 85 to 90 per cent, and the power factor is about 65 per cent.

Flaming Arc Lamps.— From time to time since 1890 it has been proposed to impregnate carbon electrodes for arc lamps, so as to add metallic vapors to the arc, thereby greatly increasing its size and brilliancy. Several methods of combining metallic salts with the carbon have been tried, but great difficulty has been experienced in securing a uniform mixture, which would consume evenly without the formation of slag which would eventually interrupt the service of the lamp. Hugo Bremer of Neheim, Germany, has secured a number of patents on special electrodes for arc lamps, composed of "an intimate mixture" of carbon and metallic salts or metalloids, as calcium, magnesium, glass, fluor-spar, or the like. Mr. Bremer has also developed a line of arc lamps for his special electrodes. It has been found by experience that the Bremer electrodes are difficult to operate, and the lamp rather complicated in order to remove the insulating slag formation and insure good contact between the electrodes when cold. The carbon manufacturers appreciating the great commercial value and efficiency of the flaming arc have developed a line of cored carbons, the shell of which consists of carbon, the core being made up of a mixture of powdered carbon, mineral salts and a suitable binder. This electrode has absolutely removed the difficulty from the slag formation with the Bremer electrode, allowing the use of very simple arc lamps arranged to feed the electrodes with points downward at an angle towards each other. Careful tests prove the watt efficiency of the flaming arc to be about eighteen times that of the ordinary incandescent lamp, three times that of the ordinary open arc, and six times that of the enclosed arc. The intrinsic brilliancy of the arc flame is about one-third that of its positive and negative craters. The candle-power distribution in the flaming arc is approximately as follows: Positive crater, 20 per cent; negative crater, 5 per cent; and the arc flame, 75 per cent.

By placing the carbon points downward, maximum illumination is obtained from the craters without interference and shadows. If the arc voltage is maintained too high, which means a large carbon separation, the mist around the arc flame will be excessive and interfere somewhat with the light from the craters. The flaming arc becomes unsteady at voltages above 40 on alternating current, and 45 on direct current. By reason of the fact that the arc is at the lower end of the two electrodes, with points downward, it becomes necessary to provide means for maintaining it at the extremity of the points, as otherwise the heat of the flame will induce an upward draft which will carry the arc up between the electrodes, soon hiding the craters and preventing proper combustion. It is well known that the electric arc may be controlled by magnetic lines of force. This

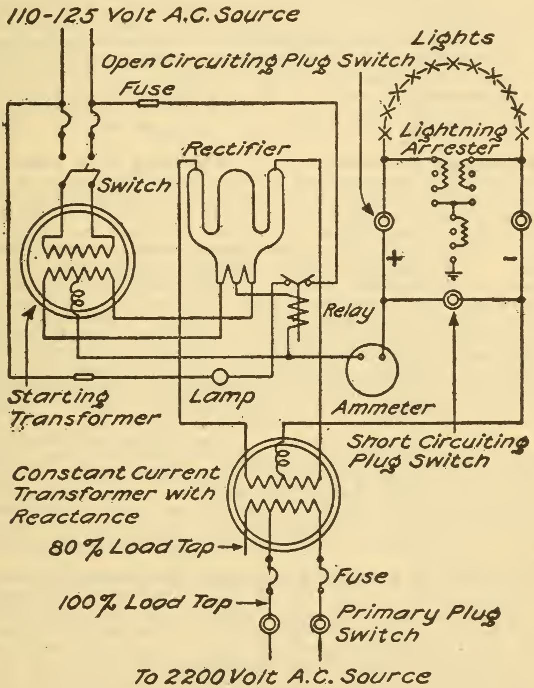


FIG. 37. Diagram Connections G. E. Magnetite Arc Lighting System.

principle has been taken advantage of in the flaming arc lamp, which is provided with a "blow-down coil" having the iron circuit so arranged that the arc flame is forced downward, as if held in a downward draft of air. The magnetic control of the flame makes the arc self-regulating, which makes it unnecessary to use complicated mechanisms for maintaining the current constant. A fixed carbon separation, with some means for feeding the carbons and maintaining the arc length constant, is all that is required.

The large arc flame having an area of about $\frac{3}{4}$ inches square, furnishes 75 per cent of the illumination. This great tongue of light is forced down towards the center of the globe, which is preferably made of light alabaster glass, illuminating it at a high intensity and without shadows. The illumination from the flaming arc lamp with light alabaster globe is practically uniform in all directions, beginning about 10 degrees above the horizontal center line of the arc. The downward illumination is slighty greater, due to the light from the craters, but as the flame throws the greater part of its light in the horizontal direction, the practical result is uniform illumination of the entire globe. Flaming arc lamps should be hung high, 20 to 60 feet above the floor or street level, excepting for advertising purposes where they may be hung lower. If the lamps are placed 50 feet above the floor and 100 feet apart, a practically constant and uniform illumination of great intensity will be the result.

The Constant Potential D. C. Flaming Arc Lamp requires 50 to 60 volts at the terminals and is adjusted for 45 volts at the arc. One lamp operates in multiple on 50 to 60 volts, two lamps in series on 100 to 125 volts, four on 250 volts, ten on 500 volts, twelve on 600 volts, and fifteen on 750 volts. When more than two lamps are to operate in series, an external automatic cut-out with equalizing resistance must be put in multiple with each lamp to protect it against excessive voltage. The standard amperage is 10 to 12; the positive carbon is 10, and the negative 9 mm. in diameter. A pair of carbons 500 mm. long give 12 hours' life outdoors and 13 to 14 hours indoors; the 600 mm. carbons give 16 hours outdoors and 18 hours indoors.

The Constant Potential A. C. Flaming Arc Lamp requires 50 to 60 volts at the terminals and is adjusted for 38 to 40 volts at the arc. One lamp operates in multiple on 50 to 60 volts, or two in series on 100 to 120 volt circuits. When one lamp is to operate in multiple on 100 to 120-volt circuit, a small auto-transformer is required to reduce the voltage to 50 or 55. Similar auto-coils should be used when lamps operate on 200 to 460-volt systems. When a large number of lamps are to be used a regular three-wire system can be installed with 55 volts between each outside wire and the center wire. One large transformer reducing from the primary potential to 110 — 55 volt three-wire system — should be installed, allowing the flaming arc lamp to operate in multiple on 55 volts without loss and extra expense for separate auto-transformers or other compensators. The flaming arc lamp will operate successfully on any frequency from 25 to 140 cycles. Below 40 cycles, lamps should always be operated in multiple on 55 volts. The standard current adjustment is 12 amperes. The carbons are both 9 mm. in diameter. The 500 mm. carbon gives 10 to 11 hours outdoors and 11 to 12 hours indoors. Carbons 600 mm. long give 13 to 15 hours outdoors and 14 to 16 hours indoors. The alternating current lamp is practically noiseless and gives a very steady illumination. The efficiency of the alternating current flaming arc lamp on constant potential is about 80 per cent and the power factor about 90 per cent. The efficiency and quality of the illumination compares favorably with that of the direct current lamp, which is an important point in favor of the flaming arc lamp for alternating current circuits.

The Constant D. C. Series Flaming Arc Lamp requires 45 volts at its terminals and is adjusted for 43 volts at the arc. The lamp is identical in construction with the direct current constant potential lamp, but requires no resistance in series with the arc. An automatic cut-out is used with each lamp to shunt the current in case the carbons should stick or be prematurely consumed. The lamp can be operated in series on the regular 9.6 ampere arc dynamos used for the ordinary high-tension open arc lamps. The mercury arc rectifiers with constant current transformers can also be used to supply current for the direct current flaming arc lamp. As a matter of fact, it may be operated in series with the old style, high-tension, open arc lamp. The size and life of the carbons is the same as for the direct current constant potential lamp.

The Constant A. C. Series Flaming Arc Lamp requires 40 volts at the terminals and is adjusted for 38 volts at the arc. The constant current lamp is practically the same as that for constant potential, but is provided with an automatic cut-out to shunt the current. The lamp operates with 10 to 12 amperes in series on constant current circuits controlled by constant current transformers or automatic reactive coils. As present alternating current series circuits for street lighting carry only 4 to 7½ amperes, it is necessary to install with each lamp on such circuits a small series transformer or series auto-coil which will deliver from its secondary 10 to 12 amperes at 40 volts to the lamp. In conjunction with series Tungsten lamps, operating on the same circuit, the entire street lighting field can be covered, furnishing both large and small units from the same wires. The size and life of the carbon is the same as for the constant potential alternating current lamp.

The 500 to 600 watt direct current flaming arc lamp, with yellow flame carbons, gives approximately 2700 mean spherical candle-power; white flame carbons give about 2000 candle-power.

The candle-power of the alternating current flaming arc lamp is about 10 per cent less than that given for the direct current lamp of the same watt consumption.

Searchlight Projectors and focusing lamps for theatrical use and for photo-engraving, etc., take large and varied quantities of current, as they are always connected across the terminals of constant potential circuits, with a regulating resistance in series with the lamp. The General Electric Company state in one of their bulletins the following as being the approximate currents taken by the different sizes of searchlights:

Diam. of Projector.	Amperes.
12 inch	18 to 20
18 "	30 " 35
24 "	50 " 60
30 "	75 " 90
36 "	90 " 100
60 "	125 " 150

ENCLOSED ARC LAMPS.

It has been found that by enclosing the arc in a small globe, more or less approaching air-tight conditions, combustion of the carbons is practically complete, leaving no dust, and takes place at a slow rate, burning with a 12 × ½-inch carbon 75 to 100 hours without attention. The enclosed arc cannot be properly maintained below 65 volts, and 70 to 75 volts is the usual arc potential for alternating current lamps, and 75 to 85 for the direct current lamp. The minimum current is 3 and the maximum for enclosed arcs is 7½ amperes.

The long arc, low amperage and enclosing globe all tend to lower the illuminating efficiency of the enclosed arc lamp, but notwithstanding this it has superseded most of the open arc lamps for general illumination. The long life of the carbon has greatly reduced the cost of trimming and the cost of carbon renewals. It permits the use of very simple mechanism, actuating a clutch which operates directly on the carbon. Enclosed arc lamps are made for all commercial circuits.

Constant Potential D. C. Enclosed Arc Lamp requires 100 to 250 volts at the terminals with 75 to 160 volts at the arc. The minimum amperage is 2½ and the maximum is 6. The 2½ to 4-ampere lamps use $\frac{5}{16}$ to ⅜-inch carbons. The 5 to 6-ampere lamps use $\frac{7}{16}$ to ½-inch carbons, 12 inches long, giving 75 to 150 hours life. Each lamp is fitted with a resistance coil, and is a complete unit for multiple connection on 100 to 125 volts with 75 to 85 volts at the arc, or on 200 to 250 volts with 140 to 160 volts at the arc. The constant potential lamp is controlled by a series magnet. If the lamp is provided with differential clutch controlling magnet, automatic cut-out and equalizing resistance, it can be connected in series on constant potential circuits, as follows: 2 on 220 volts, 5 on 500 volts, and 6 on 600 volts.

Constant Potential A. C. Enclosed Arc Lamp requires 100 to 125 volts at the terminals, and is adjusted for 70 to 80 volts at the arc. The amperage may be anywhere between 4 and 7½. The alternating current constant potential lamp is not operated in series. The power factor of the lamp is about 70 per cent. The minimum frequency giving satisfactory illumination, is 50 cycles; and the maximum frequency, in general use, for which this style of lamp is built, is 140 cycles. The carbons are usually 10 inches long × ⅜ to ½ inch in diameter and give from 65 to 100 hours' life.

When alternating current constant potential lamps are to operate on voltages above 125, an auto-transformer or other converter for reducing the voltage should be used. A reactive coil is also put in the top of the alternating current lamp.

Constant D. C. Series Enclosed Arc Lamp requires 75 to 80 volts at the terminals. The arc is set for 73 to 78 volts. The amperage is between 5 and 7, depending upon the candle-power desired. The lamp has differential feed and is provided with automatic cut-out to shunt the current, if the carbon sticks or is consumed. The lamps operate in series on any constant current source of supply. The carbon is 12 × ½ inch and lasts about 100 hours.

Constant A. C. Series Enclosed Arc Lamp requires 75 to 80 volts at the terminals. The arc is set for 72 to 77 volts. The minimum amperage is 4 and the maximum is 7½. The feed control may be either shunt or differential. The carbon is 10 × ½ inch and lasts 75 to 100 hours. Each lamp has an automatic cut-out. The lamps operate in series on constant current circuits, usually controlled by constant current transformers or automatic reactive coils. The efficiency of a complete system, including transformer and lamps, is about 85 per cent, and the power factor is between 70 and 80 per cent at full load. The system operates on any frequency from 50 to 140 cycles.

Methods of Regulation in Arc Lamps may be classified as follows:

Carbons lifted or separated by direct or main magnet; shunt magnet acting on a variable resistance to cut out the main magnet in feeding.

Carbons lifted by main magnet as before, and shunt acting to put the main magnet (made movable) into position for feeding.

Carbons separated by main magnet armature; shunt circuiting magnet acting to divert or shunt the magnetism of the main magnet from its armature.

Carbons separated by main magnet and shunt acting to free the carbon-holder, independently of the support given by the main magnet.

Carbons separated by a spring allowed to act by the main magnet lifting a weight which otherwise holds the spring from acting; shunt magnet acts against the spring, to feed and regulate the length of arc.

One carbon, generally the lower, separated by main magnet, while the other holder is released for feeding only, such feeding being under the control either of a differential system or a shunt magnet only.

Carbons separated by main magnet, which lifts the shunt and its armature together, while the shunt magnet armature, acting on the feeding mechanism, controls the arc and feed of the carbons.

Carbon feeding mechanism independently attached to main magnet armature and to shunt armature so as to receive opposite movements of separation, and feed from each respectively.

Carbons separated by a feeding mechanism moved by the main magnet, and fed by a further movement of said mechanism, causing release or return of same under the accumulated force of both shunt and main magnets, acting in the same direction.

Differential clock gear for separation and feed of carbons under control of the regulating magnet system, either simple or differential. Some of the older clock-work lamps embodied this principle.

Carbons controlled by armature of a small electric motor under control of a differential field which turns the armature in one direction for separating and in the other or reversed direction for feeding the carbons.

Carbons controlled by a motor running at a certain speed when the arc is of normal length, and varying in speed when the arc is too short or too long, combined with a centrifugal governor on the shaft of the motor, acting on variations of speed to gear motor shaft to screw carbons together or apart, as needed to maintain the normal arc. This mechanism has been applied to large arc lamps, such as naval searchlights, and has the advantage of great positiveness, and an ability to handle heavy mechanism.

There are also a considerable number of modifications of these principles.

Tests for Arc Light Carbons.

For Open Arcs.

The satisfactory working of arc lamps is largely dependent upon the quality of the carbons used. If carbons are made of impure materials, they will jump and flame badly. If not baked properly, they may cause annoyance by excessive hissing or flaming, or become too hot because of high resistance. If the material of which they are made has not been properly prepared in its preliminary stages, the carbons will have either too short a life, through giving a good quantity and quality of light, or will have good life, but will burn with an excessive amount of violet rays, hence with poor illumination.

For indoor use a free-burning, uncoated carbon of medium life should be used, so as to give a good quality and quantity of light. If longer life is desired they may be lightly coated with copper without materially interfering with the light. (About 1½ lbs. to 2 lbs. of copper per thousand, $\frac{7}{16}''$ x 12″ carbons, and a half pound more for ½″ x 12″ carbons will give good results, increasing the life from an hour to an hour and a half.)

For out-door use a more refractory burning carbon may be used to advantage, giving a longer life, as the quality of the light is not so important. Copper-coated carbons are also usually employed, and may have about four pounds of copper per thousand for $\frac{7}{16}''$ x 12″ carbons, and five pounds for ½″ x 12″. Other sizes in proportion.

All plain molded carbons, and most of the forced carbons, deposit dust when burned in the open arc. Those depositing the most dust give out the most light, but have the least life. Those depositing the least dust usually have the longest life, but the light is of inferior quality on account of the increase in the proportion of violet rays.

The quality of any carbon may be very quickly tested in any station by using the following method, which has been largely employed by carbon manufacturers.

The important points to be determined are the **range**, including the *hissing, jumping*, and *flaming* points, the **resistance**, and the **life.**

The **Range** is found by trimming a lamp with the carbons to be tested, allowing them to burn to good points and the lamps to become thoroughly heated; then connect a voltmeter across the lamp terminals, and very slowly and steadily depress the upper carbon until the lamp hisses, when the voltage will make a sudden drop. This is called the **Hissing-Point,** and varies according to the temper of the carbon. It should be between 40 and 45 volts—preferably 42 volts. Then lengthen the arc somewhat, and allow it to become longer by the burning away of the carbons. Presently the arc will make small jumps or sputters out of the crater in the upper carbon. This is the **Jumping-Point,** and should be not less than 58 or 60 volts. Let the arc still increase in length, carefully watching the voltage, and in most carbons there will soon be a decided flaming. This is the **Flaming-Point.** This should not be less than 62 to 65 volts. Very impure carbons will commence to jump and flame almost as soon as the voltage is raised above the hissing-point, and even the hissing-point in such cases is very irregular and difficult to find. The *Range* is important as being a practical test of the purity of the material used in the manufacture of the carbon, an increase of a quarter of one per cent of impurity making a very decided reduction in the extent of the Range. The hissing-point should be 4 or 5 volts below the normal adjustment of the lamp to insure steady burning.

Resistance.—The resistance is measured on an ordinary Wheatstone bridge. Care must be taken that the contact points go slightly into the carbon. A $\frac{7}{16}''$ x 12″ plain carbon should have a resistance of between .16 and .22 ohms, and ½″ x 12″ between .14 and .18 ohms. $\frac{7}{16}''$ x 12″ carbons coated with three pounds of copper per thousand, have a resistance between .05 and .06 ohms, and ½″ x 12″ with four pounds of copper between .04 and .05 ohms.

Life.—The life of a carbon is most easily tested by consuming it entirely in the lamp, observing, of course, the current and average voltage during the entire time. A very quick and accurate comparative test of different carbons can be made, however, by burning the carbons to good points, then weighing them, and let them burn one hour, then weigh them again. The amount burned by both upper and lower carbons shows the *rate* of consumption which will accurately indicate the comparative merits of the carbons tested as to life.

To calculate the life from a burning test of one hour, both carbons should be first weighed, the upper carbon broken off to a 7-inch length, in order to make the test at the average point of burning, and with the lower carbon, burned to good points, weighed again, and after burning one hour in a lamp that has already been warmed up, taken out and weighed. The amount of two carbons 12 inches long consumed in a complete life-test is 63 per cent of the combined weight of both upper and lower carbons. Therefore 63 per cent of the weight of the two carbons, divided by the rate per hour obtained as above, will give the life approximately.

Dust. — The dust from burning carbons can be collected in the globe, or better, in a paper bag suspended below the lamp. In an ordinary plain molded carbon this dust amounts to 4 per cent of the weight of the upper carbon. A variation below this amount will indicate good life, but inferior light. An excessive amount of dust would show a short life, but usually a good quantity and quality of light. Coating a carbon with copper eliminates this deposit of dust entirely.

Enclosed Arc Carbons.

Carbons for enclosed arcs can be very conveniently tested as to their relative values in an open arc lamp as described above. As their diameters regulate the admission of air to the inclosing globe, thus greatly affecting their life, they should be carefully measured with micrometer calipers. A greater variation than .005 inch from the required diameter should not be permitted. The deposit on the inside of the inclosing globe is caused by impurities, principally in the core. The relative injurious amount of this deposit can be measured by carefully taking the globes off the lamps after burning, and measuring the amount of light absorbed by them with an ordinary photometer, using an incandescent lamp as a source of light, and cutting the light down by means of a hole in a screen so that it will pass through the part of the globe to be measured. Twice the light so measured through the globe, divided by the amount coming through the unobstructed hole, will give the per cent of the light transmitted through the globe from the arc. That carbon whose globe absorbs the least amount of light is, of course, the most desirable.

The resistance of forced carbons, whether cored or solid, used in inclosed arc lamps, is very important. Carbons of high resistance are difficult to volatilize, and hence there is trouble in establishing the arc where small currents are used, and in case of any interruption in reëstablishing it afterwards. This is especially true of carbons used in alternating arcs, and of cored carbons. The resistance of forced carbons is usually much higher than that of molded, ranging from two to four times as much. This will undoubtedly be corrected when the manufacturers become more familiar with the requirements. The lower the resistance the better the quality of the light and the operation of the lamp.

Sizes of Carbons for Arc Lamps.

Open Arcs.	Continuous Current.	
	Upper.	Lower.
6.8 amperes	12 in. × $\frac{7}{16}$ in.	7 in. × $\frac{7}{16}$ in.
9.6 "	12 " × $\frac{1}{2}$ "	7 " × $\frac{1}{2}$ "
9.6 "	12 " × $\frac{5}{8}$ "	7 " × $\frac{5}{8}$ "
9.6 amperes *	12 in. × $\frac{7}{16}$ in. × $\frac{7}{8}$ in.	$6\frac{3}{4}$ in. × $\frac{7}{16}$ in. × $\frac{7}{8}$ in.
9.6 "	$11\frac{3}{4}$ " × $\frac{1}{2}$ " × 1 "	$7\frac{1}{4}$ " × $\frac{1}{2}$ " × 1 "
	Alternating Current.	
15 amperes	$9\frac{1}{2}$ in. × $\frac{5}{8}$ in.	$9\frac{1}{2}$ in. × $\frac{5}{8}$ in.
Enclosed Arcs.	Continuous Current.	
5 amperes	12 in. × $\frac{1}{2}$ in.	$5\frac{1}{2}$ in. × $\frac{1}{2}$ in.
3 amperes	12 " × $\frac{3}{8}$ "	6 " × $\frac{3}{8}$ "

* These are elliptical in cross section, for higher candle-power and longer burning.

Carbons Recommended for Searchlight Projectors.

(Columbia or Hardtmuth or Schmeltzer.)

Size of Lamp.	Positive. Cored.	Negative. Cored or Solid.
9 inch	$5\frac{1}{2}$ in. × $\frac{1}{2}$ in.	$3\frac{1}{2}$ in. × $\frac{7}{16}$ in.
13 "	6 " × $\frac{5}{8}$ "	$4\frac{1}{2}$ " × $\frac{1}{2}$ "
18 "	$8\frac{1}{2}$ " × $\frac{13}{16}$ "	5 " × $\frac{5}{8}$ "
24 "	12 " × 1 "	7 " × $\frac{3}{4}$ "
30 "	12 " × $1\frac{1}{8}$ "	7 " × $\frac{7}{8}$ "
36 "	12 " × $1\frac{1}{4}$ "	7 " × 1 "
48 "	15 " × $1\frac{11}{16}$ "	12 " × $1\frac{5}{16}$ "
60 "	15 " × 2 "	12 " × $1\frac{3}{8}$ "

Carbons Recommended for Automatic and Hand-Feed Focusing Lamps.

Continuous Current.		
Amperes.	Positive. Cored.	Negative. Solid.
5 to 10	6 in. × $\frac{7}{16}$ in.	6 in. × $\frac{7}{16}$ in.
10 " 18	6 " × $\frac{1}{2}$ "	6 " × $\frac{1}{2}$ "
18 " 20	6 " × $\frac{5}{8}$ "	6 " × $\frac{5}{8}$ "
25 " 30	6 " × $\frac{3}{4}$ "	6 " × $\frac{3}{4}$ "
Alternating Current.		
5 to 10	6 in. × $\frac{7}{16}$ in.	Same as for Positive.
10 " 18	6 " × $\frac{1}{2}$ "	
18 " 20	6 " × $\frac{5}{8}$ "	
25 " 30	6 " × $\frac{3}{4}$ "	

Candle-power of Arc Lamps.

The candle-power of an arc lamp is one of the most troublesome things to determine in all electrical engineering; the variations being great the arc unsteady, and the implements for use in such determination being so liable to error. Again, what is the candle-power of an arc lamp, or rather, what is the meaning of the term?

When the lamp was first put forward, for some reason, now in great obscurity, the regular 9.6 ampere lamp was called 2000 candle-power, and it has always since been so called, although the word "nominal" has been tacked on to the candle-power to indicate that it is a rating, and not an actual measurement.

The candle-power of the arc varies with the angle to the horizon on which the measurement is made; in continuous current arcs the maximum candle-power is at a point about 45 degrees below the horizontal if the upper carbon is the positive, and of course above the horizontal if the negative carbon is above.

In alternating current lamps there are two points of maximum light, one about 60 degrees above the horizontal, and the other about the same angle below the line, and the mean horizontal intensity also bears a greater ratio to the mean spherical intensity than in the direct current arc. In the alternating current arc much of the light is above the horizontal plane, and it is necessary to arrange a reflector above the arc to throw that portion of the light downward.

Mean Spherical Candle-power is the mean of the candle-power measured all over the surface of a sphere of which the arc is the center, usually about one-third of the maximum candle-power. In practice the spherical candle-power is seldom fully determined, but a fair approximation may be had by the following formula:

Let $S =$ mean spherical candle-power,
$H =$ horizontal candle-power,
$M =$ candle-power at the maximum.

Then $S = \frac{H}{2} + \frac{M}{4}$.

In a test of arc lamps in November, 1889, for the New York City Bureau of Gas, Captain John Millis found the following results in his trial of the Thomson-Houston lamps.

The same lamp was used, but connected to the different street circuits, all measurements were made at 40 degrees below the horizontal, and $\frac{9}{16}$-inch copper-plated carbons were used.

Ten readings were taken on each of four sides of the lamp when connected to each circuit, with the following results:

	Candle-power.	Watts.
Circuit No. 1.	2072.7	482.88
" " 2.	1981.0	485.10
" " 3.	2048.5	493.22
" " 4.	2000.2	494.40
" " 5.	2067.0	495.36
Means	2033.9	490.19

Mean current, amperes 10.36
Mean volts 47.32

The results of tests of candle-power of arc lamps at the Antwerp Exposition, shown in the table below, would tend to verify the above trials.

Amperes.	Volts.	Maximum C. P.	Horizontal C.P.	Upper Hemisphere Mean C. P.	Lower Hemisphere. Mean C.P.	Mean C.P.	Watts.
4	37.2	390	74	17	119	136	157
6	46.2	1090	168	63	298	361	259
6.8	46	1240	240	65	320	385	313
8	46	1550	334	70	385	454	350
10	45.5	2070	421	102	640	750	491

Arc Light Efficiency. — The light efficiency of an arc lamp is the ratio of its mean spherical candle-power to the watts consumed between the lamp terminals. Some energy is used up in the lamp-controlling mechanism, in the carbons themselves, and the remainder is used on the arc. Arc lamp efficiency is sometimes described as the ratio of the watts used in the arc to the watts used between the lamp terminals. This is true of the lamp as a machine; but the first statement is the correct one, as it is light that is turned out, and not watts consumed in the arc that is the object of the lamp, and the two depend so much on quality and adjustment of carbons, even with the same consumption of current, as to make the latter method erroneous.

Heat and Temperature Developed by the Electric Arc.

The temperature of the crater, or light-emitting surface of the arc, is the same as the point of volatilization of carbon, and therefore constant under constant atmospheric pressure. This temperature is variously stated by different investigators: Dewar gives it as 6000° C.; Rosetti, the positive as 3200° C., and the negative 2500° C.

The carbon in the crater is in a plastic condition during burning; and with the same adjustment of carbons, as to length of arc, the light per unit of power increases with the current.

Hissing, flaming, and rotating of the arc are some of the defects. Hissing is due to a short arc, and was a constant accompaniment of the low potential, high current arc so prevalent during the earlier days of arc lighting.

Flaming and rotating in open arc lamps are due to long arcs and to impure carbons, or carbons not properly baked.

With good carbons the length of arc, or distance between carbon tips for open arcs direct current, continuous current lamps, should be, for 6.8 ampere lamp, $\frac{3}{64}$ inch; and for 9.6 or 10 ampere lamps, $\frac{1}{16}$ to $\frac{3}{32}$ inch.

Balancing Resistance for Arc Lamps on Constant Potential Circuit.

As the ordinary arc lamp takes but 45 to 50 volts, when used on constant potential circuits of more than 50 volts, it is necessary to introduce a certain resistance in series, in order, first, to take up part of the voltage, and second, to act in a steadying capacity to the arc; in fact, until the dead resistance was introduced in series with the arc lamp on constant potential circuits, such lamps were entirely unsuccessful.

Prof. Elihu Thomson says, "a certain line voltage as a minimum is absolutely necessary in working arc lamps on constant potential lines, whether they be open arcs or enclosed arcs. Thus two 45-volt arcs in series, with uncored carbons like the brand known as 'National,' cannot be safely worked below 110 volts on the line without resistance in series with them. More than 100 volts should, of course, be maintained for safety of the service.

"The tests show, also, that with a cored upper carbon, the limit is lowered several volts on the average, and it is known that the voltage of the arcs may be safely reduced somewhat when cored positives are used.

"It is also shown that a 75 to 80-volt enclosed arc, run upon a constant potential line, is stable at a considerably less line voltage than the open arc. It would appear, also, that with either open or enclosed arcs at ordinary current strengths of from 5 to 10 amperes, the steadying resistance in the branch is required to cause a drop of about 15 to 20 volts, or waste energy at the rate in watts of 15 to 20, multiplied by the amperes of current used in the lamp."

Let E = E.M.F. or difference of potential between the circuit leads.
e = E.M.F. required at arc lamp terminals.
i = current required by the arc lamp.
R = dead resistance to be put in series.
r = resistance of the arc lamp burning.
r' = total resistance of dead resistance + lamp.

Then

$$r = \frac{e}{i} \tag{1}$$

$$r_{\prime} = \frac{E}{i} \tag{2}$$

$$R = r_{\prime} - r. \tag{3}$$

As the E.M.F. of most of the circuits on which lamps of this type are used is more than 100 volts, it is customary, and in fact economically necessary, to place two arc lamps in series, and the formula (3) then becomes,

$$R = r_{\prime} - 2r.$$

Street Lighting by Arc Lamps.

For good illumination, distance apart of arc lamps should not exceed six times height of arc from ground.

For railroad yards, 10 ampere arc lamps 30 feet from the ground and about 200 feet apart are found to give good results.

The following table shows some arrangements of arc lamps in foreign cities:

Arc Lamps in Foreign Cities.	Amperes per Arc.	Distance Apart in Ft.	Height of Arc in Ft.
City of London Streets	10	115	17.6
Glasgow Streets	10	160	18.0
Hastings Streets	10	300	18.0
Berlin Streets	15	137	26.7
Milan Streets	...	80 to 100	25.0
Charing Cross Railroad Station	10	90	18.0
Cannon Street Railroad Station	15	180	35.0
St. Pancras Railroad Station	10	60 to 80	14.0
Central Station, Glasgow	10	75	19.5
St. Enoch's Station, Glasgow	10	90	...
Edinburgh Exhibition, 1886	10	33	12.0
Edinburgh Exhibition, 1886	15	41	18.0

Light Cut off by Globes.

Dr. Bell.

With respect to porcelain and glass, the following table gives the general results obtained by several experimenters on the absorption of various kinds of globes, especially with reference to arc lights.

	Per cent.
Clear glass	10
Alabaster glass	15
Opalescent glass	20 to 40
Ground glass	25 to 30
Opal glass	25 to 60
Milky glass	30 to 60

Too much importance should not be attached to this large absorption, since it has already been shown that in most cases, so far as useful effect is concerned, diffusion and the resulting lessening of the intrinsic brilliancy is cheaply bought, even at the cost of pretty heavy loss in total luminous radiation.

The classes of shades commonly used for incandescent lamps and gas lights have been investigated with considerable care by Mr. W. L. Smith.

The experiments covered more than twenty varieties of shades and reflectors, and both the absorption and their distribution of light were investigated. One group of results obtained from 6-inch spherical globes, intended to diffuse the light somewhat without changing its distribution, was as follows, giving figures comparable with those just quoted:

	Per cent.
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opalescent glass	23.0

The prismatic globe in question was of clear glass, but with prismatic longitudinal grooves, while the opal and opalescent globes were of medium density only.

Etched glass has considerably more absorption than any of the above, the etching being optivally equivalent to coarse and dense grinding. Their diffusion is less homogeneous than that given by ordinary grinding, so that they may fairly be said to be undesirable where efficiency has to be seriously considered.

Trimming Arc Lamps.

One trimmer can handle the following number of lamps per day:

	Walking.	Riding.
Regular open double carbon street arcs	80	100 to 120
Magnetite lamps	80	100 " 120
Flaming arcs	80	100 " 120
Enclosed arcs	50	100

The number of commercial lamps which one man can trim depends so much upon local conditions that it is not possible to give any general figure.

ILLUMINATING ENGINEERING.

Revised by Dr. C. H. Sharp.

The problem of the illuminating engineer may be stated in general terms as follows: to obtain the illuminating effect desired in any case with the maximum economy, having due regard to the protection of the eyes from disagreeable or harmful effects and to architectural and æsthetic considerations.

Illumination may be *direct*, coming straight from the lamps which then are visible, or *indirect*, as when the lamps are hidden from view by a cornice and the illumination is due to the light reflected from a cove above.

Measurements of candle-power values are horizontal, vertical and normal illuminations, according to the position of the plane of reference, horizontal, vertical or normal to the light rays.

Curves of illumination have as their abscissas distances from the source of light measured along a horizontal line and as their ordinates intensities of illumination. If the vertical distribution curve of the source of light is known the corresponding illumination curves can be computed according to the following equations, in which E is the illumination, h the height of the lamp above the plane of reference, l the distance from the point in question to the point immediately beneath the lamp, and I_θ the intensity of the lamp at an angle θ with the vertical

$$E_n = \frac{I_\theta}{h^2 + l^2}$$

$$E_h = \frac{I_\theta \cos\theta}{h^2 + l^2} = \frac{I_\theta\, h}{(h^2 + l^2)^{\frac{3}{2}}} = \frac{I_\theta \cos^3\theta}{h^2}$$

$$E_v = \frac{I_\theta \sin\theta}{h^2 + l^2} = \frac{I_\theta\, l}{(h^2 + l^2)^{\frac{3}{2}}} = \frac{I_\theta \sin^3\theta}{h^2}. \quad *$$

In considering the availability of any source of light due regard must be given to the proper selection of shades, reflectors, etc., which may be used in connection with it. These appurtenances serve the following purposes: to direct the light most advantageously; to diffuse the light, decreasing the apparent specific intensity of the source and thereby safeguarding the eyes; pure decoration. The efficiency of an illumination installation often depends to a very great degree on the selection of proper auxiliaries.

The illumination on a surface is equal to the luminous flux in lumens per unit area of the surface, e.g. the foot-candles are equal to the lumens per square foot. The average illumination on a plane of reference is equal to the lumens through the plane divided by its area. Hence we have the following definitions: The *net efficiency* of an illumination installation is equal to the ratio of lumens through the horizontal plane of reference to the total lumens generated by the lamps. The *gross efficiency* of an installation is the ratio of the watts supplied to the lamps to the lumens on the plane of reference.

The net efficiency depends only on the method of installing the lamps, on the reflectors, etc., used, and on the coefficient of reflection of the walls, ceiling, floor and contents of the room. If we represent this average co-

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* The values of $\sin^3\theta$ and $\cos^3\theta$ are given in Table I.

efficient by k, multiple reflections theoretically increase the illumination in the ratio $\frac{1}{1-k}$.* In practice this is found to be modified by many conditions. A general knowledge of the value of the net efficiency to be expected in any case enables the illuminating engineer to form a very ready estimate of the number of lamps required.

Table I.

0° to 29°.			30° to 59°.			60° to 89°.		
θ.	Cos³ θ.	Sin³ θ.	θ.	Cos³ θ.	Sin³ θ.	θ.	Cos³ θ.	Sin³ θ.
0	1.0000	0000	30	0.6495	1250	60	0.1250	6495
1	0.9994	0000	31	.6299	1366	61	.1139	6690
2	.9982	0000	32	.6098	1488	62	.1035	6882
3	.9958	0001	33	.5900	1615	63	.0936	7073
4	.9928	0003	34	.5697	1749	64	.0843	7261
5	.9886	0007	35	.5498	1887	65	.0755	7444
6	.9836	0011	36	.5295	2031	66	.0673	7623
7	.9777	0018	37	.5093	2180	67	.0596	7800
8	.9712	0027	38	.4893	2334	68	.0526	7971
9	.9636	0038	39	.4693	2492	69	0460	8137
10	.9551	0052	40	.4495	2656	70	.0400	8298
11	.9458	0069	41	.4299	2824	71	.0345	8452
12	.9357	0090	42	.4103	2996	72	.0295	8604
13	.9251	0114	43	.3913	3172	73	.0250	8745
14	.9135	0142	44	.3722	3353	74	.0209	8883
15	.9011	0173	45	.3535	3535	75	.0173	9011
16	.8883	0209	46	.3353	3722	76	.0142	9135
17	.8745	0250	47	.3172	3913	77	.0114	9251
18	.8604	0295	48	.2996	4103	78	.0090	9357
19	.8452	0345	49	.2824	4299	79	.0069	9458
20	.8298	0400	50	.2656	4495	80	.0052	9551
21	.8137	0460	51	.2492	4693	81	.0038	9636
22	.7971	0526	52	.2334	4893	82	.0027	9712
23	.7800	0596	53	.2180	5093	83	.0018	9777
24	.7623	0673	54	.2031	5295	84	.0011	9836
25	.7444	0755	55	.1887	5498	85	.0007	9886
26	.7261	0843	56	.1749	5697	86	.0003	9928
27	.7073	0936	57	.1615	5900	87	.0001	9958
28	.6882	1035	58	.1488	6098	88	.0000	9982
29	.6690	1139	59	.1366	6299	89	.0000	9994

* Values of k are given in Table II.

Table II. Showing the Intensity of the Illumination in Foot Candles Produced at Various Points in Horizontal Planes by a Light Source of I. C. P.: the Angle Made by the Light Ray and a Line Perpendicular to the Horizontal Plane.

From a Pamphlet by the National Electric Lamp Association.

Horizontal Distance in feet from Point Directly under Lamp to Point where Intensity of Illumination is desired.

Height of Lamp in ft. above Plane illuminated	0		2		4		6		8		10	
	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles
			° ′		° ′		° ′		° ′		° ′	
2	0	.250	45	.0883	63 25	.02240	71 35	.00790	76 0	.00355	78 40	.001907
4	0	.0625	26 35	.0447	45 0	.02206	56 20	.01064	63 25	.00560	68 10	.003220
6	0	.02775	18 25	.02365	33 40	.01600	45 0	.00980	53 5	.00602	59 0	.003802
8	0	.01563	14 0	.01428	26 35	01119	36 50	.008015	45 0	.00552	51 20	.003815
10	0	.010	11 20	.009417	21 50	.007997	31 0	.00630	38 40	.004757	45 0	.003530
12	0	.006945	9 30	.00665	18 25	.00592	26 35	.00496	33 40	.00400	39 50	.003120
14	0	.005105	8 10	.004905	16 0	.00453	23 10	.00397	29 45	.003335	35 35	.002745
16	0	.00391	7 10	.003818	14 0	.003567	20 35	.003202	26 35	.002795	32 0	.002383
18	0	.00309	6 20	.003030	12 30	.002875	18 25	.002648	24 0	.002353	29 5	.002060
20	0	.00250	5 45	.002460	11 20	.002355	16 40	.002197	21 50	.002000	26 35	.001786
22	0	.002065	5 10	.002047	10 20	.001963	15 15	.001852	20 0	.001711	24 30	.001553
24	0	.001736	4 45	.001715	9 30	.001662	14 0	.001582	18 25	.001480	22 35	.001365
26	0	.00148	4 25	.001465	8 45	.001428	13 0	.001369	17 5	.001290	21 5	.001200
28	0	.001276	4 5	.001265	8 10	.001225	12 5	.001190	16 0	.001132	19 40	.001062
30	0	.001111	3 50	.001105	7 35	.001080	11 20	.001045	14 55	.001002	18 25	.000947

Height of Lamp in ft. above Plane illuminated	12		14		16		18		20	
	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles	Angle	Foot Candles
	° ′		° ′		° ′		° ′		° ′	
2	80 35	.001109	81 50	.000722	82 55	.000473	83 40	.000341	84 15	.000242
4	71 35	.001975	74 5	.001436	76 0	.0008875	77 30	000631	78 40	.000476
6	63 25	.002485	66 50	.001689	69 25	.001207	71 35	.000876	73 20	.000654
8	56 20	.002665	60 15	.001913	63 25	.001402	66 0	.001050	68 10	.000805
10	50 10	.002623	54 30	.001960	58 0	.001490	60 55	.001149	63 25	.000897
12	45 0	.002450	49 25	.001900	53 5	.001506	56 20	.001181	59 0	.000950
14	40 40	.002220	45 0	.001801	48 50	.001455	52 10	.001178	55 0	.000965
16	36 50	.002001	41 10	.001665	45 0	.001380	48 25	.001142	51 20	.000954
18	33 40	.001781	37 55	.001517	41 40	.001288	45 0	.001090	48 0	.000927
20	31 0	.001575	35 0	.001375	38 40	.001189	42 0	.001025	45 0	.000883
22	28 35	.001398	32 36	.001240	36 5	.001088	39 20	000955	42 20	.000835
24	26 35	.001240	30 15	.001118	33 40	.001000	35 50	.000890	39 50	.000785
26	24 45	.001108	28 20	.001008	31 35	.000915	34 45	.000821	37 35	.000736
28	23 10	.000991	26 35	.000911	29 45	.000834	32 45	.000758	35 35	.000686
30	21 50	.000889	25 0	.000826	28 5	.000765	31 0	.000700	33 40	.000640

Graphic Illuminating Chart.

A. E. PARKS, Trans. I. E. S., Oct., 1907.

The equation upon which the chart is based is the well-known one,

$$I = \frac{C}{H^2} \cos^3 a.$$

Where I = Illumination in foot-candles normal to the plane to be illuminated.
C = Candle-power reading from a photometric curve.
a = Angle made by reading C with normal to plane illuminated.
H = Minimum distance source of illumination to this plane.

Solving this equation by logarithms consists, as is well known, of finding log of C, log of $\cos^3 a$, adding same together and subtracting log of H^2, the remainder giving the logarithm of the result desired, this being exactly the graphic method followed in working the chart.

In Fig. 1, if the distance A–B be laid off representing log C, and A–C a distance representing log $\cos^3 a$, completing the rectangle will give point D. It is desired to add the length of A–C to the length A–B, however, and fortunately we may do this graphically if from D we draw a line D–E at an angle of 45 degrees till it cuts the line A–B produced. A–E now represents log C + log. $\cos^3 a$ We now wish to subtract from A–E a distance equal to log H^2.

Laying off vertically from E such a distance E–F, we may, by means of a 45-degree line through F, subtract from A–E this distance E–F, giving us the point G, A–G then representing the solution of the problem or A–G = log C + log $\cos^3 a$ − log H^2. If now the diagonal G–F be properly labeled, all values of E–F falling on this line will have the same foot-candle readings, and for every other foot-candle reading there will be a diagonal parallel to F–G.

While a chart constructed exactly as per the foregoing description may be conveniently used, the form here presented is somewhat different in arrangement, for by a proper manipulation of axes, one set of diagonals may be made to do duty for both D–E and F–G functions, and considerable saving in space and complexity results.

A few samples will elucidate the working of the chart.

Say that from a photometric curve we get 50 candle-power in a vertical direction, and 100 candle-power at an angle of 45 degrees. It is desired to find the illumination on a plane at six feet below the source of light.

Taking first the 50 candle-power reading. As a in this case is 0, we find 50 on the top candle-power scale, and follow the diagonal lines to the right hand margin, giving the point 5. We now follow horizontally toward the left to the vertical through the point 6 found on the lower inclined margin. Following a diagonal again to the right hand margin we find for the value required 1.40 foot-candles.

Again from 100 candle-power on the top scale we follow vertically to the horizontal line through 45 degrees found on left hand margin, from this intersection follow diagonal to right hand margin to 3.5.

Proceed toward the left horizontally to vertical through 6 as before, and again along a diagonal from this intersection to the right hand margin, giving 1 foot-candle as the desired result.

As an example of the reversibility of the chart, the following problem will be solved. Let it be required to construct a photometric curve that will produce a uniform illumination of 1.5 foot-candles upon a plane seven feet below the light source. Find the intersection of the diagonal from 1.5 on right hand margin with vertical through 7 on lower scale.

Follow horizontally to the right to right hand margin, continue from this point along a diagonal toward the top, and where this diagonal cuts the several degree lines, will be found the candle-power readings required at these angles. As 205 candle-power at 45 degrees, 165 candle-power at 40 degrees, 132 candle-power at 35 degrees, 110 candle-power at 30 degrees, 96 candle-power at 25 degrees, etc. etc., to 72 candle-power at zero degrees.

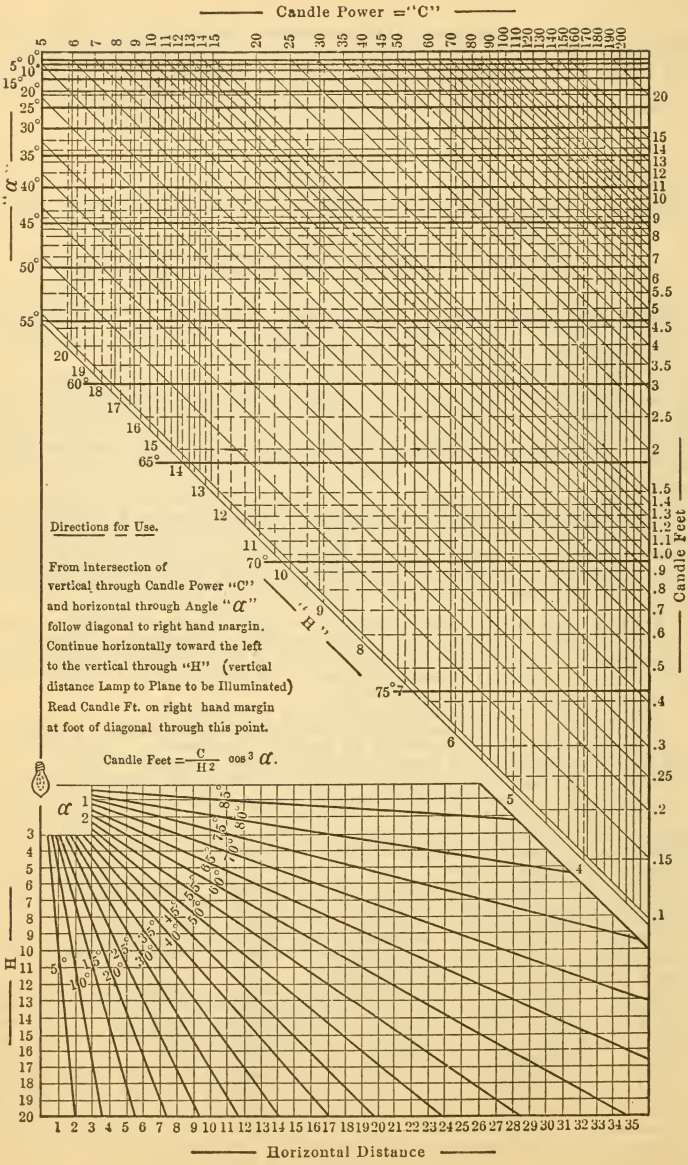

Candle Power = "C"
"α"
Candle Feet
"H"
H
Horizontal Distance
Directions for Use.
From intersection of vertical through Candle Power "C" and horizontal through Angle "α" follow diagonal to right hand margin. Continue horizontally toward the left to the vertical through "H" (vertical distance Lamp to Plane to be Illuminated) Read Candle Ft. on right hand margin at foot of diagonal through this point.
Candle Feet = $\frac{C}{H^2}$ cos^3 α.

FIG. 1.

Table III. Required Illumination for Various Classes of Service.

From a pamphlet by the National Electric Lamp Association.

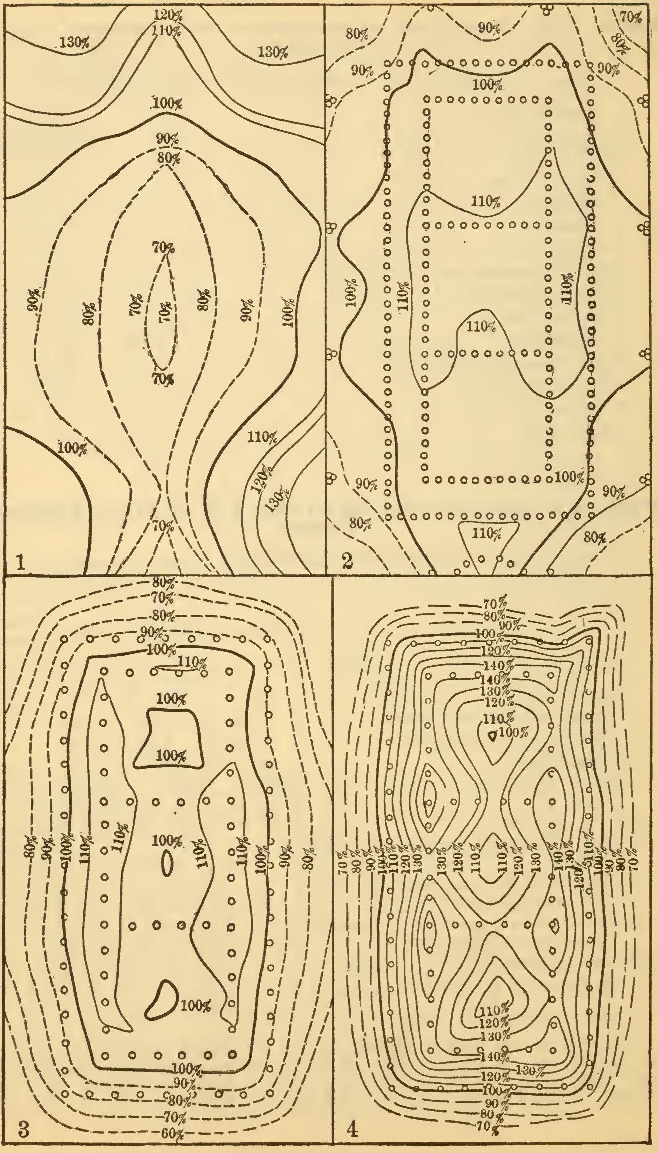
Class of Service.	Light Intensity in Foot-Candles.
General illumination of:	
Auditoriums	1 to 3
Theaters	1 to 3
Churches	3 to 4
Reading	1 to 3
General illumination of residences	1 to 2
Desk illumination	2 to 5
Postal service	2 to 5
Bookkeeping	3 to 5
Stores, general illumination	2 to 5
Stores, clothing	4 to 7
Drafting	5 to 10
Engraving	5 to 10

Table IV. Showing Saving by the Use of High Efficiency Lamps.

From a pamphlet by the National Electric Lamp Association.

		Carbon.	Carbon.	Gem.	Tantalum.
1	Candle-power	20.	20.	20.	20.
2	Watts per candle, nominal	3.5	3.0	2.5	2.1
3	Watts per candle, actual	3.48	3.04	2.5	2.1
4	Total watts	69.6	60.8	50.0	42.0
5	Hours total life	1040.	520.	560.0	600.
6	Cost of lamp	$0.16	$0.16	$0.20	$0.54
7	Cost of renewals per year of 1000 hours	0.154	0.308	0.36	0.90
8	Cost of power per year of 1000 hours at 10 c. per k.w. hour	6.96	6.08	5.00	4.20
9	Cost of power and lamp renewals per year of 1000 hours	7.11	6.39	5.36	5.10
10	Saving over 3.5 W. P. C. lamp	...	0.72	1.75	2.01
11	Saving over 3.0 W. P. C. lamp	...	...	1.03	1.29

Line 5 gives our best knowledge of the life of our lamps with good voltage regulation. A slight difference in standards, a variable regulation or a poor regulation will cause lamps to average better or poorer than these figures. Line 6 shows the cost of lamp in 10,000 quantity.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130%
120%
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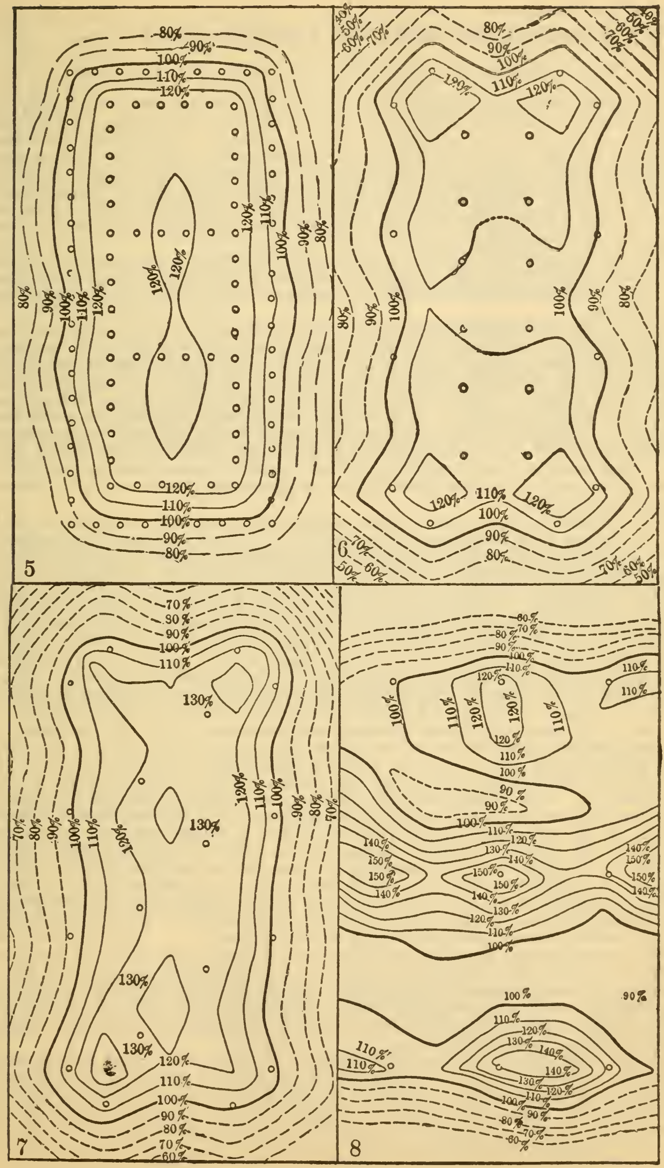
FIG. 2.


5
80%
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7
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80%
90%
100%
110%
120%
130%
8
60%
70%
80%
90%
100%
110%
120%
130%
140%
150%

Fig. 3.

Experimental Data on Illuminating Values.

From paper by Sharp & Millar before Edison Association.

This auditorium is equipped with a cove-lighting installation and with an arrangement of ceiling lamps and side brackets. The Edison Company undertook the work of arranging such temporary installations as were required for the purpose of the test. These installations were selected at the suggestion of the advisory committee in such a way as, first, to bring out the relative illumination efficiencies obtainable with similar illuminants, variously arranged and variously equipped with reflectors, etc.; second, to give a basis for reliable comparisons of the illuminating efficiencies of illuminants of different types.

The fact should be emphasized, however, that the results here given apply in all strictness only to the room in question, and that in using these data in connection with other installations, proper consideration should be given to this fact.

The sixteen candle-power carbon incandescent lamps which were used in the installations requiring such lamps, were new lamps taken from a package which had been purchased recently subject to the inspections of the Electrical Testing Laboratories, and which could therefore be considered as well-rated lamps. These lamps were burned about fifty hours before the first test was undertaken. The frosted lamps were selected in a similar manner. The actual candle-power and watts of these lamps were determined by selecting a considerable number of representative ones and photometering them in the laboratory, at the actual voltages used in the tests. The deterioration of these test lamps in successive tests was also determined in this way.

It is desirable, also, to know what ratio of the total light which is emitted by the lamps in a room may be expected to fall on a plane of reference, i.e., the horizontal plane on which measurements of the intensity of the illumination are commonly made. This ratio of the light generated to the light utilized on the plane of reference gives a value for the net efficiency of the installation. However, in order to arrive at an expression for this efficiency, it is necessary to employ some unit in which the total light from the lamps and the total light falling on the plane of reference can be expressed. For this purpose the notion of the flux of light is used, and the unit in which luminous flux is measured is introduced. This unit is the "lumen," which is defined as the flux of light emitted by a source of one candle-power in a unit solid angle. The total luminous flux from a source of light is equal to 4π, or 12.57 times its mean spherical candle-power. We can measure in lumens not only the output of the lamps, but also the flux of light through the plane of reference, and the ratio of the lumens through the plane of reference to the lumens yielded by the lamps gives the net efficiency of the installation. In a similar way the efficiency of the lamps may be measured by their lumens per watt; and the gross efficiency of the illumination installation can be measured by the lumens on the plane of reference per watt expended in the lamp. The lumens on the plane of reference are determined by multiplying the intensity of illumination on this plane, as expressed in candle-feet, by the area of the plane in square feet, i.e., the flux through a plane is equal to the intensity of the illumination on the plane multiplied by the area of the plane, or the illumination on the plane is equal to the density flux of the light falling on that plane.

In measuring the illumination, forty-five stations were selected, equally spaced over the floor of the auditorium. The values of illumination were then plotted on a map of the floor area, and then all points having the same illumination were connected by lines. This gives a set of lines which we have called *equilucial lines*, by analogy with equipotential lines of an electrostatic or a magnetic field.

If the lines are plotted representing in all cases the same percentage variation of illumination, the closeness of the lines to each other represents the illumination gradient, or the rate at which the illumination is changing from place to place on the plane of reference, and consequently the lack of uniformity in the illumination. Diagrams of this character have been prepared for the various tests.

A number of such diagrams are given on pages 590 and 591. These, in each case, show the arrangement of the lamps and a condensed description of the type of installation is given. These diagrams show lines of uniform illumination for various types of installation. The equilucial lines show differences in intensity of ten per cent. Diagram 1 shows the effect of the cove lighting alone; 2, ceiling lamps and brackets frosted; 3, concentrating prismatic reflections, high level; 4, mirror reflectors, high level; 5, distributing reflectors, low plane; 6, gem lamps; 7, tungsten lamps; 8, arc lamps, with diffuser shades.

In a general way the tests made were intended to show, first, the comparison between the various permanent installations in the auditorium; second, the increase in illumination efficiency resulting from equipping the ceiling lamps with various reflectors, and the effect of using frosted instead of clear bulb lamps; third, the effect of lowering the same equipment to a point nearer the floor. Furthermore, gem lamps, tungsten lamps, Nernst lamps and arc lamps were installed with the idea of obtaining comparative data on their illuminating values as used in a room of the dimensions and characteristics of this auditorium. These varying results are summarized in the accompanying table.

By a comparison of the lumens which become effective on the plane of reference with the lumens which are generated by the lamps, we get a value for the net efficiency of the installation. The value of this efficiency indicates the degree of skill with which the installation has been planned and carried out. It is totally unaffected by the efficiency of the lamps employed and refers only to the illumination installation as such, irrespective of the illuminants used. It is, however, largely affected by the character of the room which is illuminated, as is also the gross efficiency of the installation.

Coefficients of Reflections.

BELL.

Many experiments have been made to find the absolute loss of intensity due to reflection. This absolute value of what is called the coefficient of reflection, that is to say, the ratio of the intensity of the reflected to that of the incident light, varies very widely according to the condition of the reflecting surface. It also — in case the surfaces are not without selective reflection in respect to color — varies notably with the color of the incident light.

The following table gives a collection of approximate results derived from various sources. The figures show clearly enough the uncertain character of the data.

Material.	Coefficient of Reflection.
Highly polished silver	.92
Mirrors silvered on surface	.70 to .85
Highly polished brass	.70 " .75
Highly polished copper	.60 " .70
Highly polished steel	.60
Speculum metal	.60 " .80
Polished gold	.50 " .55
Burnished copper	.40 " .50

Smooth papers and paint give a very considerable amount of surface reflection of white light, in spite of the pigments with which they may be colored. The diffusion from them is very regular, except for this surface sheen, and may be exceedingly strong. When light from the radiant point falls on such a surface it produces a very wide scattering of the rays, and an object indirectly illuminated therefore receives in the aggregate a very large amount of light. A great many experiments have been tried to determine the amount of this diffuse reflection which becomes available for the illumination of a single object. The general method has been to compare the light received directly from the illuminant with that received from the same illuminant by a reflection from a diffusing surface.

Table V. Comparative Values of Illumination and

	Installation.				Test No.	Equipment.			
			No. of Lamps.	Height from Floor.		Border.	Center.	Cove and Brackets.	Reflector.
				′ ″					
A	Permanent Installation, 16 c.p. Lamps Oval Anchored	Cove	121	10-8	1			Clear	
		Brackets	42	8-0	2	Clear	Clear	Clear	
		Border	104	14-10	3	Clear	Clear	Clear Clear	
		Center	98	15-6	4	Frosted	Frosted	Frosted	
					5	Frosted	Frosted	Clear Frosted	
B	16 c.p. Lamps Suspended from Alternate Sockets	Center Border	52 48	14-9 14-1	6 7 8 9	All Lamps Clear	All Lamps Clear	No Side Lamps	Holophane Concentrating Holophane Diffusing Mirrored Concentrating
C	Same at Different Height	Center Border	52 48	12-6 11-10	10 11 12 13	All Lamps Clear	All Lamps Clear	No Side Lamps	Holophane Concentrating Holophane Diffusing Mirrored Concentrating
D	Same Lamps	Center Border Brackets	38 48 12	14-9 14-1 8-0	14	Clear	Clear	Clear	Mirrored Pendent Concentrating
					15	Clear	Clear	Clear	Mirrored Tilted Concentrating
E	No. 16, Gem				16	Gem Frosted Tip	Gem Frosted Tip	Border Center	Holophane Bowl Holophane Concentrating
	No. 17, Tungsten	Center Border	12 12	13-5 13-5	17	Tungsten Clear	Tungsten Clear		Holophane Bowl
	Nos. 18 & 19, Nernst	Center Border	12 12	13- 13-	18	Opal	Opal		
					19	Opal	Opal		Holophane Diffusing
F	5 Ampere Enclosed D.C. Arc		9	12-5	20	38″	Concentric	Diffuser	Outer Alabaster Bobesche Inner Clear
					21			Alabaster Globe Clear	Outer Inner

Efficiency of Various Methods of Lighting.

Photometric Data.						Illumination Values Foot Candles.					Lamp.	Efficiency Values Illumination.	
No. of Lamps.	Average M. H. c.p.	Average M. S. c.p.	Watts per M. H. c.p.	Watts per M. S. c.p.	Total Watts.	Maximum.	Minimum.	Mean.	Variation.	52°.	Lumens per Watt.	Gross Lumens Effective per Watt.	Net Lumens Effective per Lumen Generated.
									%				%
121	16.28	13.42	3.08	3.73	6210	2.27	1.11	1.72	29.7	1.48	3.38	0.8	23.7
244	14.8	12.2	3.26	3.95	11600	7.10	3.92	6.18	25.7	5.52	3.16	1.54	48.8
365	14.05	11.59	3.38	4.05	17300	8.41	5.60	7.58	21.0	6.72	3.06	1.265	41.3
244	13.86	11.41	3.48	4.36	11930	6.53	3.70	5.65	25.1	5.07	2.89	1.365	47.3
365	...	...	...	...	17760	8.00	5.57	7.23	16.85	6.42	3.03	1.18	39.0
100	15.5	12.78	3.12	3.84	4910	3.80	1.98	3.30	28.5	..	3.28	1.91	58.2
100	15.33	12.64	3.22	3.89	4930	5.47	2.08	4.07	36.8	...	3.23	2.35	72.7
100	15.17	12.5	3.26	3.95	4940	5.16	2.08	4.02	38.3	...	3.19	2.31	72.4
100	15.43	12.71	3.17	3.85	4900	7.69	1.50	4.92	62.9	...	3.26	2.86	87.7
100	16.11	13.28	3.06	3.72	4940	4.15	2.38	3.50	25.3	...	3.38	2.02	59.8
100	14.72	12.13	3.30	4.0	4865	5.83	1.85	3.94	50.9	...	3.13	2.30	73.5
100	15.4	12.69	3.22	3.9	4951	5.92	1.91	4.28	46.9	...	3.22	2.46	76.4
100	15.33	12.63	3.19	3.87	4892	8.20	1.12	4.45	72.4	...	3.25	2.59	79.6
98	14.9	12.28	3.29	3.99	4798	7.07	.83	...	66.4	4.70	3.76	2.79	88.3
98	15.25	12.58	3.19	3.87	4775	6.82	.64	...	76.9	3.92	3.26	2.33	71.5
24 {	39.1 105.8	32.9 87.8	2.67 2.43	3.14 2.93	4328	4.61	2.08	3.33	37.8	...	4.21	2.0	52.2
24	79.3	63.4	1.19	1.49	1694	4.75	1.88	3.29	30.2	...	8.46	5.52	65.2
24	...	37.0	...	3.15	2802	3.08	1.14	2.09	46.4	...	3.98	2.12	53.2
24	...	36.9	...	3.16	2798	3.55	.95	2.24	58.0	...	3.98	2.28	57.3
9	...	22.9	...	2.7	5530	7.88	2.07	4.31	67.5	...	4.54	2.22	48.9
9	...	22.9	...	2.7	5530	6.46	1.73	4.01	58.6	...	4.54	2.06	45.3

The following table gives an aggregation of the results obtained by several experimenters, mostly from colored papers:

Material.	Coefficient of Diffuse reflection.
White blotting paper	.82
White cartridge paper	.80
Ordinary foolscap	.70
Chrome yellow paper	.62
Orange paper	.50
Plane deal (clean)	.40 to .50
Yellow wall paper	.40
Yellow painted wall (clean)	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Brown cardboard	.20
Plane deal (dirty)	.20
Yellow painted wall (dirty)	.20
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue green paper	.12
Cobalt blue	.12
Black	.05
Deep chocolate paper	.04
French ultra-marine blue paper	.035
Black cloth	.012
Black velvet	.004

Interior Illumination.

BELL.

To illuminate a room 20 ft. square and 10 ft. high on the basis of a minimum of 1 candle-foot, will require from 80 to 144 effective candle-power, according to the arrangement of the lights, if the finish is light, and half as much again, at least, if the finish is dark. The floor space being 400 sq. ft. it appears that the illumination is on the basis of about 3 to 5 sq. ft. per effective candle-power. The former figure will give good illumination under all ordinary conditions; the latter demands a combination of light finish and very skillfully arranged lights.

For very brilliant effects, no more than 2 sq. ft. per candle should be allowed, while if economy is an object, 1 c.p. to 4 sq. ft. will furnish a very good groundwork of illumination, to be strengthened locally by a drop-light or reading lamp. The intensity thus deduced may be compared to advantage with the results obtained by various investigators, reducing them all to such terms as will apply to the assumed room which is under discussion.

Just deduced	1 c.p. per 3 sq. ft.
Uppenborn	1 c.p. per 3.6 sq. ft.
Piazzoli	1 c.p. per 3.5 sq. ft.
Fontaine	1 c.p. per 7.0 sq. ft. (approximation).

In very high rooms the illumination just indicated must be materially increased, owing to the usual necessity for placing the lamps rather higher than in the case just given, and on account of the lessened aid received from diffuse reflection. The amount of this increase is rather uncertain, but in very high rooms it would be wise to allow certainly 1 c.p. for every 2 sq. ft., and sometimes, as in ball-rooms and other special cases requiring the most brilliant lighting, as much as 1 c.p. per square foot.

Perhaps the most important rule for domestic lighting is never to use, indoors, an incandescent or other brilliant light, *unshaded*. Ground or frosted bulbs are particularly good when incandescents are used, and opal shades, or holophane globes, which also reduce the intrinsic brilliancy, are available with almost any kind of radiant. Ornamental shades of tinted glass or of fabrics are exceedingly useful now and then, when arranged to harmonize with their surroundings.

The table below is intended as a hint about the requirements for domestic lighting, and while it is laid out for a fairly large house, containing twenty rooms and three baths, its details will furnish suggestions applicable to many cases. An 8-c.p. lamp of the reflector variety should be placed in the ceiling of every large closet, and controlled by a switch from the room or by an automatic switch, turning it on when the door is fully opened.

Room.	8 c.p.	16 c.p.	32 c.p.	Sq. Ft. per c.p.	Remarks.
Hall	8	..	..	4.7	
Library	12	..	1	3.1	8-c.p. reflector lamps
Reception room	4	..	..	7.0	
Music room	12	..	2	3.0	
Dining room	14	..	..	2.7	Eight reflector lamps
Billiard room	..	..	4	2.3	32 c.p. with reflectors
Porch	..	..	1	..	
Bedrooms (6)	..	14	..	7.0	
Dressing rooms (2)	..	4	..	4.7	
Servants' rooms (3)	..	3	..	9.4	
Bathrooms (3)	..	3	..	5.0	
Kitchen	..	..	..	..	
Pantry	..	3	..	..	
Halls	..	..	..	..	
Cellar	10	3	..	..	
Closets (4)	4	..	..	..	Reflector lamps
Total	64	30	8	...	

Watts at Lamp Terminals Per Square Foot Floor Space for High Class Arc Lighting.

(By W. D'A. Ryan.)

Building.	Range.	Average Conditions.
Machine shops; high roofs, electrically driven machinery, no belts	.5 to 1	.75
Machine shops; low roofs, belts, other obstructions	.75 to 1.25	1
Hardware and shoe stores	.5 to 1	.75
Department stores; light material, bric-à-brac, etc.	.75 to 1.25	1
Department stores; colored material	1 to 1.5	1.25
Mill lighting; plain white goods	.9 to 1.3	1.1
Mill lighting; colored goods, high looms	1.1 to 1.5	1.3
General office; no incandescents	1.25 to 1.75	1.5
Drafting rooms	1.5 to 2	1.75

Note: Energy based on watts at lamp terminals.

Table VI. Data on Successful Arc Lighting Installations in Operation.

(Westinghouse Elec. & Mfg. Co.)

	Clothing Store.	Weaving Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Drafting Room.
No. of sq. ft. in place lighted	4000′	14,400	281,600′	42,250′	6275′	6275′	5690′
Number of lamps used	12	50	200	42	27	35	24
Sq. ft. lighted per lamp	333	288	1408	1006	232	179	237
Sq. ft. lighted per ampere of current	55.6	88.6	227	162.2	30.9	35.8	59.2
Terminal-watts used per sq. ft.	1.29	1.24	.53	.74	2.02	2.04	2.02
K.W. at terminals entire installation	5.16	17.85	148.80	31.25	12.69	12.78	11.52
K.W. at arc entire installation	4.62	13.	99.2	20.8	12.00	12.6	7.68
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D.C.Mult.	A. C. Ser.	D. C. Ser.	D. C. Mult.
Volts terminals	104	110	120	120	76	73	120
Volts arc	72	80	80	80	72	72	80
Amperes	6	3.25	6.2	6.2	7.5	5	4
Actual watts per lamp	430	357	744	744	470	365	480
Enc. globe used	Opal	Opal	Opal	Opal	Opal	Opal	Opal
Reflector used	Diff.	Diff.	....	....	Inv. Ceil.	Diff.	Diff.
Height of arc from floor	9′ 6″	12′–15′	46′	47′	9′	9′	15′
Distance between lamps	14′–18′	24′ Approx.	32′–38′	30′ 9″	15′	12′–25′	12′–25′
Power factor of lamp, at terminals	.69		....	....	.82	....	....
Height and style of ceiling	12′ Steel, white	Saw Tooth, roof	Trussed	Trussed	12′ Board, white	12′ Board, white	20′ Trussed white
Frequency	60 Cyc.	....	....	....	60 Cyc.	....	....

General Illumination.

The subject of illumination has been divided by Mr. E. L. Elliott, to whom we are indebted for many suggestions, into the following sub-divisions: Intensity or brilliancy, distribution, diffusion, and quality.

Intensity of Brilliancy. — The average brilliancy of illumination required will depend on the use to which the light is put. "A dim light that would be very satisfactory for a church would be wholly inadequate for a library, and equally unsuitable for a ballroom."

The illumination given by one candle at a distance of one foot is called the "candle-foot" or "foot-candle," and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16 candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming the 16 candle-power lamp as the standard, it is generally found that two 16 candle-power lamps per 100 square feet of floor space give good illumination, three very bright, and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination and producing a glaring intensity," which should be avoided as carefully as too little intensity of illumination.

Distribution of Light. — Distribution considers the arrangement of the various sources of light, and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points, in contrast with the general illumination."

The arrangement of the lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings, and large rooms, excellent effects are obtained by dividing the ceiling into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the wall near the ceiling.

For the illumination of show windows and display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in case of an equivalent number of 16 candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general, a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16 candle-power lamps. For instance, sixteen 64 candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16 candle-power lamps distributed over the same area. High candle-power lamps are chiefly useful when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

Diffusion of Light. — "Diffusion refers to the number of rays that cross each point. The amount of diffusion is shown by the character of the shadow. Daylight on a cloudy day may be considered perfectly diffused; it produces no shadows whatever. The light from the electric arc is least diffused, since it emanates from a very small surface; the shadows cast by it have almost perfectly sharp outlines. It is largely due to its high state of diffusion that daylight, though vastly more intense than any artificial illumination, is the easiest of all lights on the eyes. It is a common and serious mistake, in case of weak or overstrained eyes, to reduce the intensity of the light, instead of increasing the diffusion."

Quality of Light. — "Aside from difference in intensity, light produces many different effects upon the optic nerves and their centers in the brain. These different impressions we ascribe to difference in the quality of the light. Thus, 'hard light,' 'cold light,' 'mellow light,' 'ambient light,' etc., designate various qualities. Quality in light is exactly analogous to timbre or quality in sound, which is likewise independent of intensity. The most obvious differences in quality are plainly those called color. But color is by no means the element of quality. The proportion of invisible rays and the state of diffusion, are highly important factors, but on account of not being directly visible, they have been generally overlooked, and are but imperfectly understood."

The Correct Use of Light.

How to Avoid Harmful Effects on the Eyes. — An objection frequently urged against the incandescent lamp is that it is harmful to the eyes and ruins the sight. This is true only in so far as the lamp may be improperly used. Any form of light as frequently misused would produce the same harmful results. Few people think of attempting to read by an unshaded oil lamp, and yet many will sit in the glare of a clear glass incandescent lamp. Incandescent lamps are more generally complained of, because, unlike oil or gas, they can be used in any position. Bookkeepers and clerks are often seen with an incandescent lamp at the end of a drop hanging directly in front of their eyes — an impossible position of the light from gas or oil.

The first hygienic consideration in artificial lighting is to avoid the use of a single bright light in a poorly illuminated room. In working under such a light the eye is adapted to the surrounding darkness, and yet there is one spot in the middle of the eye that is kept constantly fixed on the very bright light. The brilliancy of the single light acting on the eye adjusted to darkness, works harm. There should be a general illumination of the room in addition to any necessary local light. If sufficient general illumination is provided, the eye is adjusted to the light, and the local light can be safely used. The ideal arrangement provides general illumination so strong that a pencil placed on the page of a book casts two shadows of nearly equal intensity — one coming from the general light and the other from the local light.

Care should also be taken to prevent direct rays from striking the eye. The light that reaches the eye by day is always reflected. In reading or writing, to avoid shadows, the light should come over the left shoulder. Only the reflected rays can then reach the eye.

Another point to be avoided is the careless, general use of clear glass, unshaded lamps. Frosted bulbs should be used in place of clear glass where soft light for reading is required. The intensity of light reflected from a small source is increased, and intense light injures the eye. With a clear glass globe the whole volume of light proceeds directly from the small surface of the lamp filament. With a frosted bulb the light is radiated from the whole surface of the bulb, and while the total illuminating effect is practically undiminished, the light is softened by diffusion, to the great comfort and relief of the eyes.

Finally, the use of old, dim, and blackened lamps, giving but a small fraction of their proper light, is very often a source of trouble in not supplying a sufficient quantity of light. Users of lamps are not otfen aware of the loss in candle-power a lamp undergoes, and so it happens that lamps are retained in use long after their efficient light-giving power has vanished. Proper attention to lamp renewals on the part of Central Stations is necessary to correct this evil.

The correct use of light requires:

That there should be general illumination in addition to the light near at hand.

That only reflected light should reach the eye. The light should be so placed as to throw the direct rays on the book or work, and not in the eye.

That the light should be placed so that shadows will not fall on the work in hand.

That shades and frosted bulbs should be used to soften the light.

That lamps be frequently renewed to keep the light up to full candle-power.

Distribution of Light by Incandescent Lamps.

The best form of lighting interiors is to have single lamps uniformly distributed over the ceiling; unless the room has been especially designed with this in view, it is sometimes difficult to accomplish.

Another method giving most excellent results, but requiring more candle-power, is the arrangement of lamps around the sides of the room close to the ceiling. If the walls and ceiling are of a light color, this method is quite satisfactory, and easier to wire.

If the chandeliers, or more correctly in this case, electroliers, are used, it is best to have but one main or large one in the room, balancing the light by side brackets.

All such suspended lights should be above the line of vision as far as convenient.

The most economical distribution, as far as candle-power necessary, is the first mentioned, where lights are evenly distributed over the ceiling. To obtain the same luminosity by using clusters of lamps more widely distributed instead of single ones, will require much more candle-power.

The 16 candle-power lamp is the universal standard in the United States when rating lamps or illumination, and following are given some ratings on which illumination of different classes of buildings is figured.

Ordinary illumination, 1 lamp, 8 feet from floor for 100 square feet, as in sheds, depots, walks, etc.

In waiting-rooms, ferry-houses, etc., 1 lamp for 75 square feet.

In stores, offices, etc., 1 lamp for 60 square feet.

Of course the above must be varied to suit the circumstances, such as dark walls or other surroundings requiring more light, as the walls reflect little of that furnished; and in rooms with dead white walls the reflection approaches 90 per cent, and less lamps would be required than in interiors having worse reflecting surfaces.

A very ingenious and satisfactory method of illuminating high arched and vaulted interiors, developed first by Mr. I. R. Prentiss of the Brush Company, is to place a number of lamps around the lower edge of the arch or dome, with reflectors under them, and so located behind the cornice as to be invisible to the eye from the floor.

The dome or arch will reflect a large part of the light so placed, giving a very fine, even illumination to the whole interior, without shadows, and very restful to the eye.

Of course the arch must be of good color for reflecting the light, or much of it will be wasted.

Concealed Lighting Systems.

The elements of inefficiency of systems in which the lighting is by concealed sources of light, or different lighting systems, have been classified by Millar* under four heads as follows:

1. Light absorbed by ceilings and walls.
2. Loss due to unnecessary intensity at unimportant points.
3. Ineffectiveness of sharply inclined rays.
4. Higher intensity necessary with diffused lighting.

Some of his experimental data illustrating these elements quantitatively are given in the following tables.

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* Millar, Trans. Illuminating Engineering Society, Oct., 1907.

Table VII.

MILLAR.

	Temporary Installation at Electrical Testing Laboratories.		Harlem Office of New York Edison Company.	
	System.		System.	
	Direct.	Diffused.	Direct.	Diffused.
Total flux of light, lumens	424	4824	13938	30532
Flux on working plane, lumens . .	180	579	6642	4689
Efficiency of light utilization . . .	42.3%	12.0%	47.7%	15.4%
Efficiency of illuminants (lumens per watt).	2.92	2.01	3.34	3.34
Relative eff. of systems; $\frac{\text{Diffused}}{\text{Direct}}$	28 per cent.		32 per cent.	
Sacrificed to secure diffusion . . .	72 per cent.		68 per cent.	

Table VIII. Illumination Intensity Required for Reading.

MILLAR.

Observer.	Angle of Paper with Horizontal.	Foot-Candles.		
		Direct.	Diffused.	Diff. in Per Cent of Direct.
H. E. Allen	46°	2.5	4.7	184
Night watchman . .	42°	3.7	4.8	130
Dynamo tender . . .	35°	1.85	2.7	144
H. E. Allen	47°	3.0	5.3	180
W. S. Howell	47°	2.95	6.3	217
C. H. Sharp	44°	3.6	5.0	140
Z. N. Corraz . . .	49°	2.3	3.1	135
P. S. Millar	46°	2.75	5.0	181
F. M. Farmer . . .	49°	2.1	5.0	237
E. Fitzgerald	49°	2.9	2.6	100
		2.7	4.45	165%

NOTE. — The last value obtained, in which the experimenter required the same intensity of illumination with the diffused lighting system that was desired for the direct lighting system, differs from all the other values. Subsequently it was learned that this observer was influenced by the brightness of the walls to select the stated intensity upon the paper, feeling that greater brightness upon the walls would be annoying and unpleasant.

Millar's conclusions are as follows:

"The conditions of the installations were such that the increase in intensity required for reading with diffused lighting was probably larger than may be considered a representative value. The factor is a function chiefly of the brightness of the walls and of the extent to which the walls and other brightly illuminated objects come within the angle of vision.

"It was found that if a placard was viewed at a distance of eight or ten feet, thirty times as much light was required to enable an observer to read it as well with the diffused lighting as with the direct lighting arrangement. In this test large portions of the walls were within the angle of vision, and exercised a powerful influence upon the eyes of the observer with both lighting systems. With the direct lighting system the walls were relatively dark, influencing the pupilary action of the eye so that a low intensity upon the placard appeared satisfactory. With the diffused lighting system they were brilliantly illuminated and so affected the eye that a very intense illumination was required upon the placard.

"From the foregoing, the writer has drawn the following conclusions: In diffused lighting systems of the class considered, where the illumination of a working plane is one of the prime objects, a large proportion of the light is lost; that which is not lost becomes less effective; brilliant illumination is produced where it is useless and even undesirable; and conditions are established which create a demand for an unduly high intensity of illumination on objects viewed.

"These effects are present in varying degree in all systems in which control of any large proportion of the light is lost. Among such are cove lighting, lighting with skylight effects, tube lighting, and all systems in which the brilliancy of the light source is reduced by diffusing surfaces used without any directing adjuncts. Lighting with large sources is more liable to these effects than lighting with small sources.

"The facts indicate the need for devoting as much care to securing suitable minimum intensities, as is generally expended in striving for maximum values. In certain classes of lighting where more light is asked for, the requirements may be served by reducing the intensity of illumination on unimportant objects which are unnecessarily well illuminated. By taking advantage of opportunities to minimize intensities at unimportant places efficiency is gained, and, in the opinion of many, good lighting as well."

LIGHTING SCHEDULES.

General Rule for Construction of Schedules.

Moonlight Schedules. — Start lamps one half hour after sunset until fourth night of new moon; start lamps one hour before moonset.

Extinguish lamps one hour before sunrise, or one hour after moon-rise.

No light the night before, the night of, and the night after full moon.

During summer months there will be found nights near that of full moon when, under the rule, the time of lighting would be very short. It may not be positively necessary to light up during such times.

If better service be desired, but not full every night and all-night service; lamps can be started at sunset and run to 12 or 1 o'clock on full-time schedule, and after 12 or 1 on the moonlight basis.

The above rules by Alex. C. Humphreys, M.E., have been modified by Frund as follows: Light every night from dusk to 12 o'clock; after 12 o'clock follow Humphrey's rule for moonlight schedule, excepting there will be no light after 12 o'clock during the three nights immediately preceding full moon.

All-Night, Every-Night Schedule. — Start lamps one half hour after sunset, and extinguish them one half hour before sunrise every day in the year. Full schedule commonly called 4000 hours for the year.

All the above rules serve to make schedules for any locality, and such schedules must be based on *sun time* for the locality, and not on *standard time.*

Permanent average schedules are used in New York City, but for other cities they are usually made up fresh every year.

Following will be found New York City time tables, also another set by Humphreys that is a good average for *sun time* in any locality.

Lighting Table for New York City.

Night of	January.			February.			March.			April.			May.			June.		
	Light.	Extin-guish.	Time Burn-ing.	Light.	Extin-guish.	Time Burn-ing.	Light.	Extin-guish.	Time Burn-ing.	Light.	Extin-guish.	Time Burn-ing.	Light.	Extin-guish.	Time Burn-ing.	Light.	Extin-guish.	Time Burn-ing.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
1	5.14	6.54	13.40	5.48	6.39	12.51	6.22	6.02	11.40	6.54	5.14	10.20	7.26	4.27	9.01	7.54	4.01	8.07
2	5.15	6.54	13.39	5.49	6.37	12.48	6.23	6.01	11.38	6.56	5.12	10.16	7.27	4.26	8.59	7.55	4.01	8.06
3	5.16	6.54	13.38	5.50	6.36	12.46	6.24	5.59	11.35	6.57	5.10	10.13	7.28	4.24	8.56	7.56	4.00	8.04
4	5.17	6.54	13.37	5.52	6.35	12.43	6.25	5.58	11.33	6.58	5.08	10.10	7.29	4.23	8.54	7.56	4.00	8.04
5	5.18	6.54	13.36	5.53	6.34	12.41	6.26	5.57	11.31	6.59	5.06	10.07	7.30	4.22	8.52	7.57	3.59	8.02
6	5.19	6.54	13.35	5.54	6.33	12.39	6.27	5.55	11.28	7.00	5.04	10.04	7.31	4.21	8.50	7.57	3.59	8.02
7	5.20	6.54	13.34	5.55	6.32	12.37	6.29	5.54	11.25	7.01	5.03	10.02	7.32	4.20	8.48	7.58	3.58	8.00
8	5.21	6.54	13.33	5.56	6.31	12.35	6.30	5.52	11.22	7.02	5.01	9.59	7.33	4.19	8.46	7.58	3.58	8.00
9	5.22	6.54	13.32	5.58	6.30	12.32	6.31	5.50	11.19	7.03	4.59	9.56	7.34	4.18	8.44	7.59	3.58	7.59
10	5.23	6.53	13.30	5.59	6.29	12.30	6.32	5.48	11.16	7.04	4.58	9.54	7.35	4.17	8.42	8.00	3.58	7.58
11	5.24	6.53	13.29	6.00	6.28	12.28	6.33	5.46	11.13	7.05	4.56	9.51	7.36	4.16	8.40	8.00	3.58	7.58
12	5.25	6.53	13.28	6.01	6.27	12.26	6.34	5.45	11.11	7.06	4.55	9.49	7.37	4.15	8.38	8.01	3.58	7.57
13	5.26	6.52	13.26	6.03	6.24	12.21	6.35	5.43	11.08	7.07	4.54	9.47	7.38	4.14	8.36	8.01	3.58	7.57
14	5.27	6.52	13.25	6.04	6.23	12.19	6.36	5.42	11.06	7.08	4.52	9.44	7.39	4.13	8.34	8.02	3.58	7.56
15	5.28	6.52	13.24	6.06	6.21	12.15	6.37	5.40	11.03	7.09	4.51	9.42	7.40	4.12	8.32	8.02	3.58	7.56
16	5.29	6.51	13.22	6.07	6.20	12.13	6.38	5.39	11.01	7.10	4.49	9.39	7.41	4.12	8.31	8.02	3.58	7.56
17	5.30	6.51	13.21	6.08	6.19	12.11	6.39	5.37	10.58	7.11	4.47	9.36	7.41	4.11	8.30	8.03	3.58	7.55
18	5.31	6.50	13.19	6.10	6.18	12.08	6.40	5.35	10.55	7.12	4.46	9.34	7.42	4.10	8.28	8.03	3.58	7.55
19	5.33	6.49	13.16	6.11	6.16	12.05	6.41	5.33	10.52	7.13	4.44	9.31	7.43	4.10	8.27	8.03	3.58	7.55
20	5.34	6.48	13.14	6.13	6.15	12.02	6.42	5.32	10.50	7.14	4.43	9.29	7.44	4.09	8.25	8.03	3.58	7.55
21	5.35	6.48	13.13	6.14	6.12	11.58	6.43	5.31	10.48	7.15	4.42	9.27	7.45	4.08	8.23	8.04	3 58	7.54
22	5.36	6.47	13.11	6.15	6.11	11.56	6.44	5.30	10.46	7.16	4.40	9.24	7.46	4.07	8.21	8.04	3.58	7.54
23	5.37	6.46	13.09	6.17	6.09	11.52	6.45	5.28	10.43	7.17	4.39	9.22	7.47	4.06	8.19	8.04	3.58	7.54
24	5.39	6.45	13.06	6.18	6.08	11.50	6.46	5.26	10.40	7.18	4.37	9.19	7.48	4.05	8.17	8.04	3.59	7.55
25	5.40	6.45	13.05	6.19	0.07	11.48	6.47	5.24	10.37	7.19	4.36	9.17	7.49	4.05	8.16	8.04	3.59	7.55
26	5.41	6.44	13.03	6.20	6.06	11.46	6.48	5.23	10.35	7.20	4.35	9.15	7.49	4.04	8.15	8.05	4.00	7.55
27	5.42	6.43	13.01	6.21	6.05	11.44	6.49	5.22	10.33	7.22	4.33	9.11	7.50	4.04	8.14	8.05	4.00	7.55
28	5.43	6.42	12.59	6.22	6.04	11.42	6.50	5.20	10.30	7.23	4.32	9.09	7.51	4.03	8.12	8.05	4.00	7.55
29	5.45	6.42	12.57	6.22	6.03	11.41	6.51	5.18	10.27	7.24	4.30	9.06	7.52	4.03	8.11	8.05	4.01	7.56
30	5.46	6.41	12.55	. . .	. . .	. . .	6.52	5.16	10.24	7.25	4.29	9.04	7.53	4.02	8.09	8.05	4.01	7.56
31	5.47	6.40	12.53	. . .	. . .	. . .	6.53	5.15	10.22	. . .	. . .	. . .	7.53	4.02	8.09	. . .	. . .	. . .
			413.10			355.27			341.29			290.17			264.39			238.51

Lighting Table for New York City — *Continued.*

Night of	July. Light.	July. Extin-guish.	July. Time Burn-ing.	August. Light.	August. Extin-guish.	August. Time Burn-ing.	September. Light.	September. Extin-guish.	September. Time Burn-ing.	October. Light	October. Extin-guish.	October. Time Burn-ing.	November. Light.	November. Extin-guish.	November. Time Burn-ing.	December. Light.	December. Extin-guish.	December. Time Burn-ing.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
1	8.04	4.02	7.58	7.46	4.26	8.40	7.03	4.58	9.55	6.13	5.27	11.14	5.27	6.01	12.34	5.04	6.36	13.32
2	8.04	4.03	7.59	7.45	4.27	8.42	7.01	4.59	9.58	6.11	5.28	11.17	5.26	6.02	12.36	5.04	6.37	13.33
3	8.04	4.03	7.59	7.44	4.28	8.44	7.00	5.00	10.00	6.10	5.30	11.20	5.25	6.03	12.38	5.04	6.38	13.34
4	8.03	4.04	8.01	7.43	4.29	8.46	6.58	5.01	10.03	6.08	5.31	11.23	5.24	6.05	12.41	5.03	6.39	13.36
5	8.03	4.05	8.02	7.41	4.30	8.49	6.56	5.02	10.06	6.07	5.32	11.25	5.23	6.06	12.43	5.03	6.40	13.37
6	8.03	4.05	8.02	7.40	4.31	8.51	6.54	5.03	10.09	6.05	5.33	11.28	5.21	6.08	12.47	5.03	6.41	13.38
7	8.03	4.06	8.03	7.39	4.32	8.53	6.53	5.04	10.11	6.03	5.34	11.31	5.20	6.09	12.49	5.03	6.42	13.39
8	8.02	4.07	8.05	7.37	4.33	8.56	6.51	5.05	10.14	6.02	5.35	11.33	5.19	6.10	12.51	5.03	6.43	13.40
9	8.02	4.07	8.05	7.36	4.34	8.58	6.49	5.06	10.17	6.00	5.36	11.36	5.18	6.12	12.54	5.03	6.44	13.41
10	8.02	4.08	8.06	7.35	4.35	9.00	6.47	5.07	10.20	5.58	5.37	11.39	5.17	6.13	12.56	5.03	6.45	13.42
11	8.01	4.09	8.08	7.34	4.36	9.02	6.46	5.08	10.22	5.57	5.38	11.41	5.16	6.14	12.58	5.03	6.46	13.43
12	8.01	4.10	8.09	7.33	4.37	9.04	6.44	5.09	10.25	5.55	5.39	11.44	5.15	6.16	13.01	5.03	6.47	13.44
13	8.00	4.10	8.10	7.31	4.38	9.07	6.43	5.10	10.27	5.54	5.40	11.46	5.14	6.17	13.03	5.03	6.48	13.45
14	8.00	4.11	8.11	7.30	4.39	9.09	6.41	5.11	10.30	5.52	5.41	11.49	5.13	6.18	13.05	5.03	6.48	13.45
15	7.59	4.12	8.13	7.28	4.40	9.12	6.39	5.12	10.33	5.51	5.42	11.51	5.12	6.19	13.07	5.04	6.49	13.45
16	7.59	4.13	8.14	7.27	4.41	9.14	6.37	5.13	10.36	5.49	5.43	11.54	5.11	6.20	13.09	5.04	6.49	13.45
17	7.58	4.14	8.16	7.26	4.42	9.16	6.35	5.14	10.39	5.47	5.45	11.58	5.10	6.21	13.11	5.04	6.50	13.46
18	7.58	4.15	8.17	7.25	4.43	9.18	6.34	5.14	10.40	5.46	5.46	12.00	5.10	6.22	13.12	5.04	6.50	13.46
19	7.57	4.15	8.18	7.24	4.44	9.20	6.32	5.15	10.43	5.44	5.47	12.03	5.09	6.23	13.14	5.05	6.51	13.46
20	7.56	4.16	8.20	7.23	4.45	9.22	6.31	5.16	10.45	5.43	5.48	12.05	5.08	6.24	13.16	5.05	6.51	13.46
21	7.56	4.17	8.21	7.21	4.46	9.25	6.30	5.17	10.47	5.42	5.49	12.07	5.08	6.25	13.17	5.06	6.52	13.46
22	7.55	4.18	8.23	7.20	4.47	9.27	6.28	5.18	10.50	5.41	5.50	12.09	5.07	6.28	13.21	5.06	6.52	13.46
23	7.54	4.19	8.25	7.18	4.48	9.30	6.26	5.19	10.53	5.39	5.51	12.12	5.06	6.29	13.23	5.07	6.52	13.45
24	7.53	4.20	8.27	7.16	4.49	9.33	6.24	5.20	10.56	5.38	5.52	12.14	5.06	6.30	13.24	5.07	6.52	13.45
25	7.52	4.21	8.29	7.13	4.50	9.37	6.23	5.21	10.58	5.36	5.53	12.17	5.05	6.31	13.26	5.08	6.53	13.45
26	7.51	4.22	8.31	7.12	4.51	9.39	6.21	5.22	11.01	5.35	5.54	12.19	5.05	6.32	13.27	5.08	6.53	13.45
27	7.50	4.23	8.33	7.11	4.52	9.41	6.19	5.23	11.04	5.33	5.55	12.22	5.05	6.32	13.27	5.09	6.53	13.44
28	7.49	4.24	8.35	7.09	4.53	9.44	6.18	5.24	11.06	5.32	5.56	12.24	5.05	6.33	13.28	5.09	6.53	13.44
29	7.48	4.24	8.36	7.08	4.54	9.46	6.16	5.25	11.09	5.30	5.57	12.27	5 04	6.34	13.30	5.10	6.54	13.44
30	7.48	4.25	8.37	7.06	4.55	9.49	6.15	5.26	11.11	5.29	5.59	12.30	5.04	6.35	13.31	5.11	6.54	13.43
31	7.47	4.26	8.39	7.05	4.57	9.52	...	...	...	5.28	6.00	12.32	...	...	...	5.12	6.54	13.42
			256.12			286.26			316.48			368.50			392.59			424.52

Summary of New York City Lighting Table.

	Hours for the Month.	Average.	Average Day.
	h.m.	h.m.	
January	413.10	13.19	18th
February	355.27	12.15	15th
March	341.29	11.01	16th
April	290.17	9.40	16th
May	264.39	8.32	15th
June	238.51	7.57	12th
July	256.12	8.16	17th
August	286.26	9.14	16th
September	316.48	10.33	15th
October	368.50	11.54	16th
November	392.59	13.05	14th
December	424.52	13.42	10th
Total hours	3950		
		h.m.	
Shortest	June 21	7.54	
Longest	Dec. 21	13.46	
Average	Mar. 21 & Sept. 21	10.47	

NOTE.—*Lights started 30 minutes after sunset. Lights stopped 30 minutes before sunrise.*

For commercial lighting: add 1 hour for part night lights, add 2 hours for all night lights to above schedule.

Table Showing Number of Hours Artificial Light is Needed in Each Month of the Year.

DR. LOUIS BELL.

Evening from	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Total.
Dusk to 6 o'clock	...	...	2	33	62	80	65	33	4	...	...	...	279
Dusk to 7 o'clock	...	14	22	62	92	111	96	61	31	4	...	...	493
Dusk to 8 o'clock	...	40	52	93	122	142	127	89	62	28	4	...	759
Dusk to 9 o'clock	13	71	82	124	152	173	158	117	93	58	29	8	1078
Dusk to 10 o'clock	44	102	112	155	182	204	189	145	124	88	60	38	1443
Dusk to 11 o'clock	75	133	142	186	212	235	220	173	155	118	91	68	1808
Dusk to 12 o'clock	116	164	172	217	242	266	251	201	186	148	122	98	2183
All night	217	307	345	421	473	527	512	411	382	295	242	195	4327
Morning from													
4 o'clock to dawn	...	16	48	80	110	137	137	93	71	28	2	...	722
5 o'clock to dawn	...	...	18	49	80	106	106	70	40	3	...	...	472
6 o'clock to dawn	...	...	...	18	50	75	75	42	9	...	...	...	269
7 o'clock to dawn	...	...	...	...	20	44	44	14	...	...	...	...	122

Humphreys' Lighting Tables.

(All Night, Every Night Schedule.)

JANUARY.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	4.40	6.30	13.50
2	4.40	6.30	13.50
3	4.40	6.30	13.50
4	4.50	6.30	13.40
5	4.50	6.30	13.40
6	4.50	6.20	13.30
7	4.50	6.20	13.30
8	4.50	6.20	13.30
9	4.50	6.20	13.30
10	4.50	6.20	13.30
11	4.50	6.20	13.30
12	4.50	6.20	13.30
13	4.50	6.20	13.30
14	5.00	6.20	13.20
15	5.00	6.20	13.20
16	5.00	6.20	13.20
17	5.00	6.20	13.20
18	5.00	6.20	13.20
19	5.00	6.20	13.20
20	5.00	6.20	13.20
21	5.00	6.20	13.20
22	5.10	6.20	13.10
23	5.10	6.20	13.10
24	5.10	6.20	13.10
25	5.10	6.20	13.10
26	5.10	6.20	13.10
27	5.10	6.10	13.00
28	5.10	6.10	13.00
29	5.10	6.10	13.00
30	5.10	6.10	13.00
31	5.20	6.10	12.50
Total number of hours .			414.10

FEBRUARY.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	5.20	6.10	12.50
2	5.20	6.10	12.50
3	5.20	6.10	12.50
4	5.20	6.10	12.50
5	5.20	6.10	12.50
6	5.20	6.00	12.40
7	5.20	6.00	12.40
8	5.30	6.00	12.30
9	5.30	6.00	12.30
10	5.30	6.00	12.30
11	5.30	6.00	12.30
12	5.30	6.00	12.30
13	5.30	6.00	12.30
14	5.30	5.50	12.20
15	5.30	5.50	12.20
16	5.40	5.50	12.10
17	5.40	5.50	12.10
18	5.40	5.50	12.10
19	5.40	5.50	12.10
20	5.40	5.50	12.10
21	5.40	5.40	12.00
22	5.40	5.40	12.00
23	5.40	5.40	12.00
24	5.40	5.40	12.00
25	5.50	5.40	11.50
26	5.50	5.40	11.50
27	5.50	5.40	11.50
28	5.50	5.30	11.40
Total number of hours . . .			345.10

MARCH.

Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.
1	5.50	5.30	11.40
2	5.50	5.30	11.40
3	5.50	5.30	11.40
4	5.50	5.30	11.40
5	6.00	5.30	11.30
6	6.00	5.20	11.20
7	6.00	5.20	11.20
8	6.00	5.20	11.20
9	6.00	5.20	11.20
10	6.00	5.20	11.20
11	6.00	5.20	11.20
12	6.00	5.20	11.20
13	6.00	5.10	11.10
14	6.10	5.10	11.00
15	6.10	5.10	11.00
16	6.10	5.10	11.00
17	6.10	5.10	11.00
18	6.10	5.10	11.00
19	6.10	5.00	10.50
20	6.10	5.00	10.50
21	6.10	5.00	10.50
22	6.10	5.00	10.50
23	6.10	5.00	10.50
24	6.20	5.00	10.40
25	6.20	4.50	10.30
26	6.20	4.50	10.30
27	6.20	4.50	10.30
28	6.20	4.50	10.30
29	6.20	4.50	10.30
30	6.20	4.50	10.30
31	6.20	4.40	10.20
Total number of hours . .			341.50

Humphreys' Lighting Tables — *Continued.*

(All Night, Every Night Schedule.)

April.				May.				June.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	6.20	4.40	10.20	1	7.00	4.00	9.00	1	7.20	3.30	8.10
2	6.30	4.40	10.10	2	7.00	4.00	9.00	2	7.20	3.30	8.10
3	6.30	4.40	10.10	3	7.00	3.50	8.50	3	7.30	3.30	8.00
4	6.30	4.40	10.10	4	7.00	3.50	8.50	4	7.30	3.30	8.00
5	6.30	4.40	10.10	5	7.00	3.50	8.50	5	7.30	3.30	8.00
6	6.30	4.30	10.00	6	7.00	3.50	8.50	6	7.30	3.30	8.00
7	6.30	4.30	10.00	7	7.00	3.50	8.50	7	7.30	3.30	8.00
8	6.30	4.30	10.00	8	7.00	3.50	8.50	8	7.30	3.30	8.00
9	6.30	4.30	10.00	9	7.00	3.50	8.50	9	7.30	3.30	8.00
10	6.30	4.30	10.00	10	7.00	3.50	8.50	10	7.30	3.30	8.00
11	6.30	4.30	10.00	11	7.10	3.50	8.40	11	7.30	3.30	8.00
12	6 40	4.20	9.40	12	7.10	3.50	8.40	12	7.30	3.30	8.00
13	6.40	4.20	9.40	13	7.10	3.40	8.30	13	7.30	3.30	8.00
14	6.40	4.20	9.40	14	7.10	3.40	8.30	14	7.30	3.30	8.00
15	6.40	4.20	9.40	15	7.10	3.40	8.30	15	7.30	3.30	8.00
16	6.40	4.20	9.40	16	7.10	3.40	8.30	16	7.30	3.30	8.00
17	6.40	4.20	9.40	17	7.10	3.40	8.30	17	7.30	3.30	8.00
18	6.40	4.20	9.40	18	7.10	3.40	8.30	18	7.30	3.30	8.00
19	6.40	4.10	9.30	19	7.10	3.40	8.30	19	7.30	3.30	8.00
20	6.40	4.10	9.30	20	7.10	3.40	8.30	20	7.30	3.30	8.00
21	6.40	4.10	9.30	21	7.20	3.40	8.20	21	7.30	3.30	8.00
22	6.50	4.10	9.20	22	7.20	3.40	8.20	22	7.30	3.30	8.00
23	6.50	4.10	9.20	23	7.20	3.40	8.20	23	7.30	3.30	8.00
24	6.50	4.10	9.20	24	7.20	3.40	8.20	24	7.30	3.30	8.00
25	6.50	4.10	9.20	25	7.20	3.30	8.10	25	7.30	3.30	8.00
26	6.50	4.00	9.10	26	7.20	3.30	8.10	26	7.30	3.30	8.00
27	6.50	4.00	9.10	27	7.20	3.30	8.10	27	7.30	3.30	8.00
28	6.50	4.00	9.10	28	7.20	3.30	8.10	28	7.30	3.30	8.00
29	6.50	4.00	9·10	29	7.20	3.30	8.10	29	7.30	3.30	8.00
30	6.50	4.00	9.10	30	7.20	3.30	8.10	30	7.30	3.30	8.00
				31	7.20	3.30	8.10				
Total number of hours .			290.20	Total number of hours . . .			264.30	Total number of hours . .			240.20

Humphreys' Lighting Tables — *Continued.*

(All Night, Every Night Schedule.)

July.				August.				September.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	7.30	3.30	8.00	1	7.10	4.00	8.50	1	6.30	4.30	10.00
2	7.30	3.30	8.00	2	7.10	4.00	8.50	2	6.30	4.30	10.00
3	7.30	3.30	8.00	3	7.10	4.00	8.50	3	6.30	4.30	10.00
4	7.30	3.40	8.10	4	7.10	4.00	8.50	4	6.30	4.30	10.00
5	7.30	3.40	8.10	5	7.10	4.00	8.50	5	6.30	4.30	10.00
6	7.30	3.40	8.10	6	7.10	4.00	8.50	6	6.20	4.30	10.10
7	7.30	3.40	8.10	7	7.10	4.00	8.50	7	6.20	4.30	10.10
8	7.30	3.40	8.10	8	7.10	4.00	8.50	8	6.20	4.40	10.20
9	7.30	3.40	8.10	9	7.10	4.10	9.00	9	6.20	4.40	10.20
10	7.30	3.40	8.10	10	7.00	4.10	9.10	10	6.20	4.40	10.20
11	7.30	3.40	8.10	11	7.00	4.10	9.10	11	6.20	4.40	10.20
12	7.30	3.40	8.10	12	7.00	4.10	9.10	12	6.10	4.40	10.30
13	7.30	3.40	8.10	13	7.00	4.10	9.10	13	6.10	4.40	10.30
14	7.30	3.40	8.10	14	7.00	4.10	9.10	14	6.10	4.40	10.30
15	7.30	3.40	8.10	15	7.00	4.10	9.10	15	6.10	4.40	10.30
16	7.30	3.40	8.10	16	7.00	4.10	9.10	16	6.10	4.40	10.30
17	7.30	3.40	8.10	17	6.50	4.10	9.20	17	6.10	4.40	10.30
18	7.30	3.50	8.20	18	6.50	4.10	9.20	18	6.00	4.50	10.50
19	7.30	3.50	8.20	19	6.50	4.20	9.30	19	6.00	4.50	10.50
20	7.30	3.50	8.20	20	6.50	4.20	9.30	20	6.00	4.50	10.50
21	7.30	3.50	8.20	21	6.50	4.20	9.30	21	6.00	4.50	10.50
22	7.20	3.50	8.30	22	6.50	4.20	9.30	22	6.00	4.50	10.50
23	7.20	3.50	8.30	23	6.50	4.20	9.30	23	6.00	4.50	10.50
24	7.20	3.50	8.30	24	6.40	4.20	9.40	24	5.50	4.50	11.00
25	7.20	3.50	8.30	25	6.40	4.20	9.40	25	5.50	4.50	11.00
26	7.20	3.50	8.30	26	6.40	4.20	9.40	26	5.50	4.50	11.00
27	7.20	3.50	8.30	27	6.40	4.20	9.40	27	5.50	4.50	11.00
28	7.20	3.50	8.30	28	6.40	4.20	9.40	28	5.50	5.00	11.10
29	7.20	3.50	8.30	29	6.40	4.30	9.50	29	5.50	5.00	11.10
30	7.20	4.00	8.40	30	6.40	4.30	9.50	30	5.40	5.00	11.20
31	7.20	4.00	8.40	31	6.30	4.30	10.00				
Total number of hours			257.00	Total number of hours . . .			288.00	Total number of hours .			317.20

Humphreys' Lighting Tables — *Continued.*

(All Night, Every Night Schedule.)

OCTOBER.				NOVEMBER.				DECEMBER.			
Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.	Day of Month.	Light.	Extinguish.	Number of Hours.
	h.m.	h.m.	h.m.		h.m.	h.m.	h.m.		h.m.	h.m.	h.m.
1	5.40	5.00	11.20	1	5.00	5.30	12.30	1	4.30	6.10	13.40
2	5.40	5.00	11.20	2	5.00	5.30	12.30	2	4.30	6.10	13.40
3	5.40	5.00	11.20	3	4.50	5.30	12.40	3	4.30	6.10	13.40
4	5.40	5.00	11.20	4	4.50	5.40	12.50	4	4.30	6.10	13.40
5	5.40	5.00	11.20	5	4.50	5.40	12.50	5	4.30	6.10	13.40
6	5.30	5.00	11.30	6	4.50	5.40	12.50	6	4.30	6.10	13.40
7	5.30	5.00	11.30	7	4.50	5.40	12.50	7	4.30	6.10	13.40
8	5.30	5.10	11.40	8	4.50	5.40	12.50	8	4.30	6.10	13.40
9	5.30	5.10	11.40	9	4.50	5.40	12.50	9	4.30	6.10	13.40
10	5.30	5.10	11.40	10	4.50	5.40	12.50	10	4.30	6.10	13.40
11	5.30	5.10	11.40	11	4.50	5.40	12.50	11	4.30	6.20	13.50
12	5.20	5.10	11.50	12	4.40	5.50	13.10	12	4.30	6.20	13.50
13	5.20	5.10	11.50	13	4.40	5.50	13.10	13	4.30	6.20	13.50
14	5.20	5.10	11.50	14	4.40	5.50	13.10	14	4.30	6.20	13.50
15	5.20	5.10	11.50	15	4.40	5.50	13.10	15	4.30	6.20	13.50
16	5.20	5.10	11.50	16	4.40	5.50	13.10	16	4.30	6.20	13.50
17	5.20	5.20	12.00	17	4.40	5.50	13.10	17	4.30	6.20	13.50
18	5.20	5.20	12.00	18	4.40	5.50	13.10	18	4.30	6.20	13.50
19	5.10	5.20	12.10	19	4.40	5.50	13.10	19	4.30	6.20	13.50
20	5.10	5.20	12.10	20	4.40	5.50	13.10	20	4.40	6.20	13.40
21	5.10	5.20	12.10	21	4.40	6.00	13.20	21	4.40	6.20	13.40
22	5.10	5.20	12.10	22	4.40	6.00	13.20	22	4.40	6.20	13.40
23	5.10	5.20	12.10	23	4.40	6.00	13.20	23	4.40	6.20	13.40
24	5.10	5.20	12.10	24	4.40	6.00	13.20	24	4.40	6.20	13.40
25	5.10	5.20	12.10	25	4.40	6.00	13.20	25	4.40	6.20	13.40
26	5.00	5.30	12.30	26	4.30	6.00	13.30	26	4.40	6.20	13.40
27	5.00	5.30	12.30	27	4.30	6.00	13.30	27	4.40	6.20	13.40
28	5.00	5.30	12.30	28	4.30	6.00	13.30	28	4.40	6.20	13.40
29	5.00	5.30	12.30	29	4.30	6.00	13.30	29	4.40	6.20	13.40
30	5.00	5.30	12.30	30	4.30	6.10	13.40	30	4.40	6.20	13.40
31	5.00	5.30	12.30					31	4.40	6.20	13.40
Total number of hours .			369.40	Total number of hours . . .			393.10	Total number of hours .			425.10
								Total for year			3946.40

Hours of Lighting per Annum by Different Schedules.

Regular all-night schedule	4000 hours
New York City schedule	3950 hours
Philadelphia schedule	4288 hours
Providence schedule	4012 hours
Philadelphia moonlight schedule	2190 hours
Frund schedule	3000 hours

Hours of Burning Commercial Lights.

Time of Sunrise and Sunsets.

	Sun Sets.	Lights Start.	Used to 8 p.m.	Used to 9 p.m.	Used to 9.30 p.m.	Used to 10.00p.m.	Used to 11.00p.m.	Used to 12.00 m.	Sun Rises.	All night lights. L'ts go out.	All night lights. Us'd all n'gt.
	h.m	h.m	h.m.	h.m.	h.m.	h.m.	h.m.	h.m	h.m.	h.m.	h.m.
Jan. 15	4.55	4.30	3.30	4.30	5.00	5.30	6.30	7.30	7.25	8.00	15.30
Feb. 15	5.31	5.00	3.00	4.00	4.30	5.00	6.00	7.00	6.56	7.30	14.30
Mar. 15	6.06	5.30	2.30	3.30	4.00	4.30	5.30	6 30	6.12	6.45	13.15
April 15	6.41	6.15	1.45	2.45	3.15	3.45	4.45	5.45	5.16	5.45	11.30
May 15	7.13	6.45	1.15	2.15	2.45	3.15	4.15	5.15	4.39	5.15	10.30
June 15	7.37	7.00	1.00	2.00	2.30	3.00	4.00	5.00	4.24	5.00	10.00
July 15	7.32	7.00	1.00	2.00	2.30	3.00	4.00	5.00	4.39	5.15	10.45
Aug. 15	7.00	6.30	1.30	2.30	3.00	3.30	4.30	5.30	5.08	5.45	11.45
Sept. 15	6.09	5.30	2.30	3.30	4.00	4.30	5.30	6.30	5.40	6.15	12.45
Oct. 15	5.19	4.45	3.15	4.15	4.45	5.15	6.15	7.15	6.13	6.45	14.00
Nov. 15	4.39	4.00	4.00	5.00	5.30	6.00	7.00	8.00	6.52	7.15	15.45
Dec. 15	4.31	4.00	4.00	5.00	5.30	6.00	7.00	8.00	7.20	7.45	15.45
Aver'ge for y'r	6.06	5.30	2.30	3.30	4.00	4.30	5.30	6.30	5.54	6.26	13.00

Graphic Lighting Schedule for London, England.

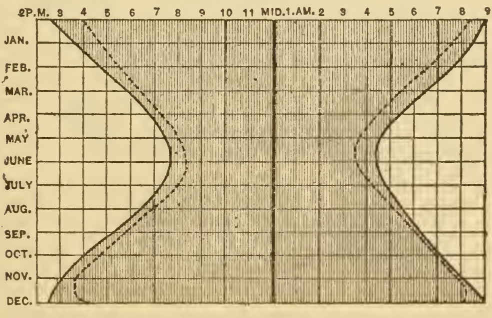


FIG. 4.—The shaded area represents the time during which light is required. The horizontal lines show the months of the year. The vertical lines show the hours of the day and night. The inner dotted lines show the time of sunset and sunrise. The outer lines show the time of lighting up and extinguishing. Each square is an hour month, *i.e.*, 30.4 hours.

ELECTRIC RAILWAYS.

Revised by A. H. Armstrong, C. Renshaw and N. W. Storer.

The electric railway motor has made such rapid strides in traction that it has pre-empted the entire urban field, taken most of the traffic from the suburban steam lines and is now appearing as a formidable competitor to the steam locomotive in heavy haulage. In considering, therefore, the application of the electric motor to traction work, it is necessary to determine its capacity and characteristics for city service and single car operation, and also for electric locomotives hauling heavy trains, either high speed passenger or slow speed freight. Small cars weighing 10 to 12 tons may be fitted with two 35 h.p. motors and be geared for a maximum speed of 25 to 30 m.p.h. Larger cars of the single truck variety weighing close to 15 tons may be equipped with motors of 40 h.p. capacity. Single truck cars are used (to a large extent) for city work, although in this class of work the use of double truck cars is rapidly increasing.

Suburban cars weighing 18 to 25 tons and measuring 45 ft. overall may be equipped with four 50 h.p. motors and be geared for a maximum speed of 40 m.p.h. Such cars usually make stops approximately every mile, and a schedule speed of about 20 m.p.h. outside of the city limits. Larger types of suburban cars 50 ft. overall, seating 52 passengers, weigh 28 to 30 tons and are equipped with four 75 h.p. motors geared for maximum speed of 45 m.p.h. These cars usually make a stop every mile and a half, and a schedule speed of 25 m.p.h. for the local and 35 m.p.h. for the express cars outside of the city limits. The largest type of suburban car, of which that of the Aurora, Elgin & Chicago is typical, is equipped with four 125 h.p. motors, is geared for maximum speed of 60 m.p.h. and stops but once in two or three miles, making a schedule speed of about 35 m.p.h. These cars represent the highest type of interurban electric railway and their use seems justified under certain conditions.

Grades. — Grades upon city lines may run as high as 13 per cent, and to surmount these it is necessary to have every axle on the cars equipped with motors; thus a single-truck car would require two motors and double-truck cars four motors; and even then the cars will be unable to surmount these grades with very bad conditions of track. Surface cars operating over city streets have no option but to use the prevailing grades, hence for city work where heavy grades are liable to be met, the motor capacity per car should be liberal, not so much on account of the danger of overheating the motors, as to prevent undue sparking when surmounting the heavy grades. The tendency of the suburban roads is to operate over private right of way, and grades on these roads do not generally exceed two or three per cent, except for very short runs where they may reach four or five per cent. Grades exceeding these are infrequent, and on the best high speed suburban roads two per cent grade is the maximum allowable. The effect of grades upon the heating of motors is largely compensating as the motors cool off nearly as much in coasting down grades as they overheat when doing extra work in surmounting the grades.

Curves. — In city work sharp curves are necessary in rounding street corners and curves of 50 ft. radius are sometimes met. These curves are oftentimes so sharp as to prevent the use of heavy, long double-truck suburban cars. Such curves cannot easily be avoided and city cars are designed with short wheel base of trucks, generally not over 6 ft. in order to be able to round these sharp curves. The maximum speed of city cars is limited to about 15 m.p.h., so that these sharp curves cannot interfere seriously with the schedule.

Suburban cars operate over much straighter track and have a maximum speed of 25 to 50 miles per hour. It is seldom that the curves are sharp enough to seriously inconvenience the purely suburban class of service. Roads operating over private right of way endeavor to limit the curves to five degrees, which can be rounded at a speed of 35 miles per hour, so that they do not seriously interfere with the schedule. Very high speed suburban roads will not permit curves of more than three degrees, as a sharper curvature interferes with free running speed of the cars, which sometimes approaches 60 miles per hour. Sharp curves are more detrimental to the maintenance of high speed than grades of four or five per cent unless the latter be of considerable length.

Systems of Operation. —There are four systems of operation now in use for electric railways, each of which has some distinctive advantages warranting its use under certain conditions.

1. *D. C. generation and D. C. distribution with the possible use of boosters or floating storage batteries.* — This system is pre-eminently adapted to the very congested travel of the more densely populated sections of our larger cities. It is not well adapted to the operation of roads covering large areas and is rapidly becoming obsolete, owing to the great amount of feeder copper required to transmit large amounts of energy at 600 volts, which is the standard potential used. The use of boosters is objectionable for continuous work as they add largely to the fuel expense, while a floating storage battery at the end of a long feeder is oftentimes more expensive to install and operate than some of the other systems described later. The direct-current generating system for larger supply is rapidly becoming obsolete, except in localities where the conditions are very favorable for its retention.

2. *Alternating current generation and transmission to rotary converter substations.* — This system is being used almost entirely for our suburban roads and larger city systems. Alternating current generation and transmission offers the advantage of the ability to transmit great power over long distances at very high potentials, in some cases reaching 60,000 volts, so that the copper expense is relatively small. New York City is fed entirely from rotary converters which receive their power from alternating current generators and alternating current transmission lines at 11,000 and 6,600 volts. The office of the rotary converter substation, which was first used in 1897, is to reduce the high potential alternating current to low potential alternating current, then convert it into 600 volts direct current which feeds into the trolley or third rail, as the case may be.

3. *Three-phase alternating current feeding direct into high potential trolley and thence into three-phase motors upon the cars* is used on some European roads.

4. *The single-phase alternating current commutating motor* has been developed in several forms since 1904, and there are now quite a large number of roads operating in this country and abroad, using this type of motor. This motor is said to be more flexible than the three-phase motor, as it has a variable speed characteristic very similar to that of the direct current series motor. Its application in the railway field is therefore much more general and it will undoubtedly find considerable use in suburban work and in the heavier class of electric railways.

Train Friction. — The resistance offered by air against the front and sides of a rapidly moving car forms a very important factor and has been the subject of a large number of experiments. The most complete are probably the Berlin-Zossen experiments where speeds of 125 miles per hour were reached and wind pressures noted. A large number of formulæ have been introduced by different authorities covering the resistance offered by the air, rails, journals, etc., when operating single cars and trains at different speeds. The formulæ developed by steam railroad experimenters using heavy trains of many cars may be discarded as worthless when applied to electric traction using single car units. In the same way the results obtained from the operation of single cars cannot be applied to trains, as the wind friction of the succeeding cars is not as great as that of the leading car. These train friction results will be treated and commented on later on in this chapter. Wind friction plays a very important part in determining the power consumption of electric cars operating at high speeds, and both the energy consumption and capacity of the motive power plant must be carefully determined with a full experimental knowledge of wind friction in view.

Car Equipments. — Car equipments have increased from motors of 25 h.p. for small single-truck cars on city streets to motors of 550 h.p. each, as in the "Mohawk" type of electric locomotive designed for the New York Central Railroad. Electric motors can be designed to meet practically any conditions of operation, but the standard lists of manufacturers run from

25 h.p. to 200 h.p. in about 25 h.p. steps, in the larger sizes, and less difference in capacities in the smaller sizes. It is better to refer to the manufacturers when a motor is to be selected for a given class of service which differs materially from a known service upon which full data is at hand. With such a wide range in capacity of motors it is necessary to study the conditions very carefully in order to properly determine the correct size of motor to use. Some general curves are given later from which reasonably correct approximations can be made, but these should be verified by consultation with experts in motor design.

Locomotives. — Electric locomotives have been built for a variety of purposes from yard shifting to the hauling of passenger trains weighing 900 tons at speeds approaching 60 miles per hour. Nearly all these electric locomotives so far have been equipped with direct current series wound motors operating at 600 volts. A number of locomotives in Europe, however, have been equipped with three-phase alternating current motors and a few with single-phase motors. In this country there are now in operation on the Spokane & Inland Railway, 1907, six 50-ton locomotives, each equipped with four 150 h.p. single-phase motors arranged to operate on either 600 volts direct current, or 6600 volts single-phase alternating current. The Westinghouse Electric & Manufacturing Company, who built these locomotives, have recently completed thirty-five 88-ton electric locomotives, each equipped with four 250 h.p. single-phase motors arranged to operate on either 600 volts direct current, or 11,000 volts single-phase, alternating current for the New York, New Haven & Hartford Railroad, and also six 60-ton locomotives, each equipped with three 240 h.p. motors for operation on 3300 volts alternating current for use by the Grand Trunk Railroad in the Sarnia Tunnel. The use of electric locomotives is rapidly increasing as the economic operation and other advantages of their operation are appreciated.

Desirable Points in Motors and Car Equipment.—It is desirable that motors should be electrically sound, i.e., that their insulation should be high, mechanically strong, and waterproof. It is of great advantage in this connection if the entire frame of the motor can be insulated from the car truck and consequently from the ground, thus relieving the insulation of the armature and fields of half the strain. The mechanical difficulties in the way of accomplishing this, however, go a great way towards counterbalancing the advantage gained.

A high average efficiency between three quarters and full load should be obtained if possible, but mechanical points should not be neglected to obtain this.

A motor should run practically sparkless up to $\frac{2}{3}$ of its rated capacity. A low starting current obviously is desirable, and for obtaining this nothing is better for continuous current operation than a multiple series controlling device, which cuts the starting current in half. This device also enables cars to be run at a slow speed with good efficiency.

Mechanically, the motor should be simple. The fewer the parts, and especially the wearing parts, the better. It should be well encased in a covering strong enough not only to keep out water, pebbles, bits of wire, etc., encountered on the track, but to shove aside or slide over an obstruction too high to be cleared. At the same time, the case should be hinged so that by the removal of a few bolts access can be had to the whole interior of the motor. The brush holders and commutator should be easily accessible through the traps in the car floor at all times. As much of the weight of the motor as possible should be carried by the truck on springs; if practicable all of it. This arrangement saves much of the wear and tear on the tracks.

A switch in addition to the controlling stand should always be provided, by which the motorman himself can cut off the trolley current, in case of accident to the controlling apparatus.

Roads having long, steep grades should have their cars provided with a device for using the motors as a brake in case the wheel brake gives out. There are several methods of accomplishing this, but limited space prohibits any description of them.

Last, but by no means least, all wearing parts should be capable of being *easily* and *cheaply* replaced.

WEIGHTS OF RAILS.

Pounds per Yard.	Weight per Mile. Long Tons.		Weight per 1000′. Long Tons.	
25	$39\frac{640}{2240}$	39.286	$7\frac{986.7}{2240}$	7.441
30	$47\frac{320}{2240}$	47.143	$8\frac{2080}{2240}$	8.929
35	55	55	$10\frac{933.3}{2240}$	10.417
40	$62\frac{1920}{2240}$	62.857	$11\frac{2026.6}{2240}$	11.905
45	$70\frac{1600}{2240}$	70.714	$13\frac{880}{2240}$	13.393
48	$74\frac{960}{2240}$	74.428	$14\frac{635.5}{2240}$	14.284
50	$78\frac{1280}{2240}$	78.571	$14\frac{1973.3}{2240}$	14.881
52	$81\frac{1600}{2240}$	81.714	$15\frac{1066.7}{2240}$	15.477
55	$86\frac{960}{2240}$	86.428	$16\frac{826.6}{2240}$	16.369
56	88	88	$16\frac{1604.4}{2240}$	16.667
58	$91\frac{320}{2240}$	91.143	$17\frac{586.7}{2240}$	17.262
58½	$91\frac{2080}{2240}$	91.928	$17\frac{1920}{2240}$	17.411
60	$94\frac{640}{2240}$	94.286	$17\frac{920}{2240}$	17.857
62	$97\frac{960}{2240}$	97.428	$18\frac{1013.3}{2240}$	18.452
63	99	99	$18\frac{1680}{2240}$	18.75
63½	$99\frac{1760}{2240}$	99.785	$18\frac{2013.3}{2240}$	18.899
65	$102\frac{320}{2240}$	102.143	$19\frac{773.3}{2240}$	19.345
66	$103\frac{1600}{2240}$	103.714	$19\frac{1440}{2240}$	19.643
66½	$104\frac{1120}{2240}$	104.5	$19\frac{1773.3}{2240}$	19.792
67	$105\frac{640}{2240}$	105.286	$19\frac{2106}{2240}$	19.940
68	$106\frac{1920}{2240}$	106.857	$20\frac{533.3}{2240}$	20.238
70	110	110	$20\frac{2000}{2240}$	20.833
71	$111\frac{280}{2240}$	111.125	$21\frac{293.3}{2240}$	21.131

WEIGHTS OF RAILS — *Continued.*

Pounds per Yard.	Weight per Mile. Long Tons.		Weight per 1000′. Long Tons.	
72	$113\frac{320}{2240}$	113.143	$21\frac{960}{2240}$	21.429
75	$117\frac{1920}{2240}$	117.857	$22\frac{720.2}{2240}$	22.322
77	121	121	$22\frac{2053.3}{2240}$	22.917
78	$122\frac{320}{2240}$	122.143	$23\frac{480}{2240}$	23.214
80	$125\frac{1600}{2240}$	125.714	$23\frac{1813.3}{2240}$	23.810
82	$129\frac{1920}{2240}$	129.857	$24\frac{906.6}{2240}$	24.405
85	$133\frac{1280}{2240}$	133.571	$25\frac{666.6}{2240}$	25.298
90	$141\frac{960}{2240}$	141.428	$26\frac{1760}{2240}$	26.786
91	143	143	$27\frac{186.6}{2240}$	27.083
98	154	154	$29\frac{373.3}{2240}$	29.167
100	$157\frac{320}{2240}$	157.143	$29\frac{1706.7}{2240}$	29.762

For iron or steel weighing 480 lbs. per cubic foot: Cross-section in square inches = weight in lbs. per yard ÷ 10.

$$\text{Gross tons of rails in 1 mile single track} = \frac{\text{weight per yard} \times 11}{7}.$$

RADII OF CURVES FOR DIFFERENT DEGREES OF CURVATURE.

Degree of Curve.	Radius in Feet.	Degree of Curve	Radius in Feet.	Degree of Curve.	Radius in Feet.	Degree of Curve.	Radius in Feet.	Degree of Curve.	Radius in Feet.
1	5730	11	522	21	274	31	187	41	143
2	2865	12	478	22	262	32	181	42	140
3	1910	13	442	23	251	33	176	43	136
4	1433	14	410	24	241	34	171	44	133
5	1146	15	383	25	231	35	166	45	131
6	955	16	359	26	222	36	162	46	128
7	819	17	338	27	214	37	158	47	125
8	717	18	320	28	207	38	154	48	123
9	637	19	303	29	200	39	150	49	121
10	574	20	288	30	193	40	146	50	118

GRADES IN PER CENT AND RISE IN FEET.

Per Cent Grade.	Rise in Feet at Given Distances. 500 Feet.	1000 Feet.	5,280 Feet (1 Mile).
½	2.5	5	26.4
1	5	10	52.8
1.5	7.5	15	79.2
2	10	20	105.6
2.5	12.5	25	132
3	15	30	158.4
3.5	17.5	35	184.8
4	20	40	211.2
4.5	22.5	45	237.6
5	25	50	264
5.5	27.5	55	290.4
6	30	60	316.8
6.5	32.5	65	343.2
7	35	70	369.6
7.5	37.5	75	396
8	40	80	422.4
8.5	42.5	85	448.8
9	45	90	475.2
9.5	47.5	95	501.6
10	50	100	528
11	55	110	580.8
12	60	120	633.6
13	65	130	686.4
14	70	140	739.2
15	75	150	792

NOTE NO. 1.—For other distances interpolate the table by direct multiplication or division.

ELEVATION OF OUTER RAIL ON CURVES.

Degree of Curve.	Radius of Curve.	Speed in Miles per Hour. 10	15	20	25	30	35	40	45	50	60
		Elevation of Outer Rail in Inches.									
1	5730	1/16	3/16	1/4	7/16	5/8	13/16	1 1/16	1 3/8	1 11/16	2 1/2
2	2865	1/8	5/16	9/16	7/8	1 1/4	1 11/16	2 3/16	2 3/4	2 7/16	4 15/16
3	1910	3/16	1/2	13/16	1 5/16	1 7/8	2 1/2	3 5/16	4 1/8	5 1/8	7 3/8
4	1432	1/4	5/8	1 1/16	1 11/16	2 1/2	3 3/8	4 3/8	4 9/16	6 13/16	9 3/4
5	1146	3/8	3/4	1 3/8	2 3/8	3 1/16	4 3/16	5 7/16	6 7/8	8 1/2	12 1/16
6	955	7/16	15/16	1 5/8	2 9/16	3 11/16	5	6 9/16	8 1/4	10 1/8	
7	818	1/2	1 1/16	1 15/16	3	4 5/16	5 7/8	7 5/8	9 9/16	11 3/4	
8	716	9/16	1 1/4	2 3/16	3 7/16	4 15/16	6 11/16	8 11/16	10 7/8		
9	636	5/8	1 3/8	2 1/2	3 13/16	5 1/2	7 1/2	9 3/4	12 13/16		
10	573	11/16	1 7/16	2 3/4	4 1/4	6 1/8	8 5/16	10 3/4			
11	521	3/4	1 11/16	3	4 11/16	6 3/4	9 1/8	11 13/16			
12	477	13/16	1 7/8	3 5/16	5 1/8	7 5/16	9 15/16	12 13/16			
14	409	15/16	2 3/16	3 13/16	5 15/16	8 9/16	11 1/2				
16	358	1 1/16	2 1/2	4 3/8	6 13/16	9 11/16					
18	318	1 1/4	2 3/4	4 15/16	7 5/8	10 7/8					
20	286	1 3/8	3 1/16	5 7/16	8 1/2	12					

NOTE NO. 1.—When E = elevation in inches of outer rail above the horizontal plane:

V = velocity of car in feet per second;
R = radius of curve in feet;

Therefore $E = 1.7879 \frac{V^2}{R}$ when gauge of track is 4′–8½″

SPIKES.

Size.	No. per Keg of 200 Lbs.	Lbs. per Spike.	Spikes per Lb.
$4\frac{1}{2} \times \frac{1}{2}$	533	.3752	2.66
$5 \times \frac{7}{16}$	650	.3077	3.25
$5 \times \frac{1}{2}$	520	.3846	2.6
$5 \times \frac{9}{16}$	393	.5089	1.96
$5\frac{1}{2} \times \frac{1}{2}$	466	.4292	2.33
$5\frac{1}{2} \times \frac{9}{16}$	384	.5208	1.92
$6 \times \frac{9}{16}$	350	.5714	1.75
$6 \times \frac{5}{8}$	260	.7692	1.3

SPIKES PER 1000′ AND PER MILE SINGLE TRACK, WITH FOUR SPIKES PER TIE.

Spacing of Ties.	Per 1000′.	Per Mile.
10 ties to 30′ rail	$1333\frac{1}{3}$	7040
11 " " " "	$1466\frac{2}{3}$	7744
12 " " " "	1600	8448
13 " " " "	$1733\frac{1}{3}$	9152
14 " " " "	$1866\frac{2}{3}$	9856
15 " " " "	2000	10560
16 " " " "	$2133\frac{1}{3}$	11264

JOINTS PER MILE OF SINGLE TRACK.

	Per 1000′.	Per Mile.
Joints — 30′ rails	$66\frac{2}{3}$	352
Angle bars	$133\frac{1}{3}$	704
Bolts — 4 hole bars	$266\frac{2}{3}$	1408
" 6 " "	400	2112
" 8 " "	$533\frac{1}{3}$	2816
" 12 " "	800	4224

TIES PER 1000′ AND PER MILE.

Spacing.	Per 1000′.	Per Mile.
10 ties to 30′ rail	$333\frac{1}{3}$	1760
11 " " " "	$366\frac{2}{3}$	1936
12 " " " "	400	2112
13 " " " "	$433\frac{1}{3}$	2288
14 " " " "	$466\frac{2}{3}$	2464
15 " " " "	500	2640
16 " " " "	$533\frac{1}{3}$	2816

BOARD FEET, CUBIC FEET, AND SQUARE FEET OF BEARING SURFACE PER TIE.

Size.	Board Feet.	Cubic Feet.	Bearing Surface
5″ × 5″ × 7′	14.56	1.213	2.91
5″ × 6″ × 7′	17.5	1.458	3.5
5″ × 7″ × 7′	20.41	1.7	4.08
5″ × 8″ × 7′	23.33	1.944	4.66
6″ × 6″ × 7′	21	1.75	3.5
6″ × 7″ × 7′	24.5	2.041	4.08
6″ × 8″ × 7′	28	2.333	4.66
6″ × 9″ × 7′	31.5	2.625	5.25
6″ × 10″ × 7′	35	2.916	5.83
6″ × 8″ × 8′	32	2.666	5.33
6″ × 9″ × 8′	36	3	6
6″ × 10″ × 8′	40	3.333	6.66

REPORT OF U. S. DEPARTMENT OF AGRICULTURE ON DURABILITY OF RAILROAD TIES.

White oak	8 years.
Chestnut	8 "
Black locust	10 "
Cherry, black walnut, locust	7 "
Elm	6 to 7 "
Red and black oaks	4 to 5 "
Ash, beech, and maple	4 "
Redwood	12 "
Cypress and red cedar	10 "
Tamarack	7 to 8 "
Longleaf pine	6 "
Hemlock	4 to 6 "
Spruce	5 "

PAVING.

Paving prices vary so that it is difficult to state even an approximate cost that will not be dangerous to use. Prices are not at all alike for asphalt, even in cities in the same localities; other styles vary according to proximity of material, cost of labor, and amount of competition.

Square yards of paving between rails, 4′ 8½″ gauge, less 4″ for width of carriage tread:

Per 1000′ run = 485.89 sq. yards.
Per mile run = 2565.5 "

Square yards paving for 18″ outside both rails:

Per 1000′ run = 333⅓ sq. yards.
Per mile run = 1760 "

Approximate Cost of Paving. (Davis.)

PAVEMENT.	Cost of all Material and Labor. Per Sq. Yd.	Cost of all Material and Labor. Per ft. of Single Track.	Cost of all Material and Labor. Per Mile of Single Track.	Cost of Tearing up Existing Pavement and Replacing as Found. Per ft. Single Track.	Cost of Tearing up Existing Pavement and Replacing as Found. Per Mile of Single Track.
	$	$	$	$	$
Granite blocks on gravel foundation	2.80	2.24	12000	.35	1900
Gravel blocks on concrete foundation	3.60	2.88	15500	.45	2400
Asphalt on concrete foundation	3.80	3.04	16000		
Vitrified brick on broken stone	2.15	1.72	9000	.45	2400
Wood without concrete	1.50	1.20	8000		
Cobble without concrete	2.00	1.60	8500	.30	1600
Macadam	1.00	.80	4500	.50	2700

ESTIMATE OF TRACK LAYING FORCE.

One engineer, 1 rodman, 1 foreman of diggers, 1 foreman of track-layers, 4 spikers, 20 laborers, 2 general helpers. Such a gang can lay from 400 to 900 feet of single track per day.

In case it is desired to proceed more rapidly, the above number of men should be increased proportionately, omitting the engineer and rodman, as these two will be able to handle any ordinary number of gangs, no matter how widely scattered, if a horse and buggy is placed at their disposal.

Tools for Track Gang as Above.—One portable tool-box padlocked, 1 small flat car, 1 portable forge, 4 cold chisels, 2 ball pein hammers, 6 lbs.; 1 sledge, 12 lbs.; 2 axes, 2 adzes, 1 cross-cut saw, 1 large double-handled saw, 6 track wrenches, 2 monkey wrenches, 1 complete ratchet track drill with bits, 1 track "Jimmy" for bending rails, 1 reel line cord, braided; 30 picks, 15 extra pick-handles, 25 long-handled, round-nose shovels, 6 short handled, square-nose shovels, 10 tampers, 5 wheelbarrows, 2 track gauges, 1 level, 1 straight-edge, 4 pair rail tongs, 6 spiking hammers, 3 crow-bars, one end sharp, the other end chisel-pointed, 2 spike claw-bars, 1 engineer's transit, 1 leveling-rod, 10 surveyor's marking-pins, 1 steel tape, 10 red lanterns, 1 box lump chalk, 1 squirt oil-can, 1 quart black oil, 5 gals. kerosene, 1 flag-rod, 1 paper of tacks, 1 broad-blade hatchet.

RAILWAY TURNOUTS.

By W. E. Harrington, B. S.

For example, assume a railway to operate 4 cars, the distance between terminals four miles, the time of round trips 60 minutes, and the headway 15 minutes, with a lay over at each end of five minutes. Take a piece of cross-section paper, and make the vertical lines represent distance, and the horizontal lines represent time.

The time necessary to run from terminus to terminus is half of 60 minutes, less ½ of ten minutes (the layover time), or 25 minutes. Let each division on the ordinate axis represent the distance traversed by a car in one minute, which in the above case is 844.8 feet per minute, assuming that the car is to run at the average speed of 9.6 miles per hour. Let each division on the axis of abscissas represent five minutes. The first car will travel from terminus to terminus as represented by the diagonal line OA. This line shows the car's position at any instant of time, assuming, of course, that the car is running at a uniform rate of speed. The car upon its arrival at the other terminus will have a layover of five minutes as represented by the horizontal space AB.

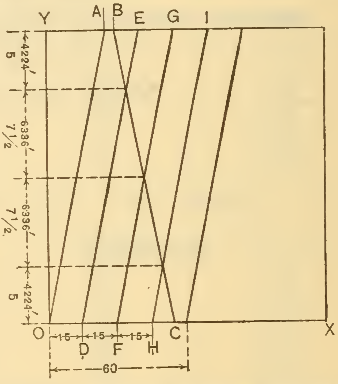


FIG. 1. Location of Street Railway Turnouts.

Upon the expiration of the time of lay-over the car starts upon its return run. This determines the locus of the several turnouts, as the car has to pass each of the remaining cars. The line of the return run is represented by the line BC. Upon the arrival of the car at the original terminus and a lay-over of five minutes, the cycle of trips will be repeated. During the time the first car is running its round trip the other cars are leaving at intervals of 15 minutes, as represented by the lines DE, FG, and HI. Where these three lines intersect the line BC turnouts must be located, as the cars meet and pass at these points. The distance apart of the turnouts, as well as their distance from the starting terminus O, may be readily determined by projecting the intersections on the axis of ordinates OY.

1. The number of turnouts for a given number of cars is one less than the number of cars running.

2. The time consumed running between turnouts must be the same between all the turnouts. For instance, if it is found necessary to irregularly locate turnouts for any reason, then the time consumed by a car running between these two turnouts farthest apart determines the time the cars must run between the remaining turnouts, even though two or more of the turnouts be only a slight fraction of the distance apart of the two greater ones.

3. The time consumed running between two consecutive turnouts is one-half the running time between cars.

For determining the distance apart of turnouts without the aid of graphical methods :

RULE.—To the length of the railway from terminus to terminus add the distance a car would travel running at the same rate of speed as running on the main line, for the time of lay-over at one terminus. Divide the above result by the number of cars desired to be run, the result is the distance between turnouts. Multiply this latter result by two less than the number of cars, and deduct the result obtained from the length of the line from terminus to terminus, and divide by two. The result is the distance from either terminus and the first adjacent turnout.

To operate more or less cars on a railway than it is designed for is a question most frequently met in railway practice.

Rule 1 tells us that we must have one turnout less than the number of cars running. In Fig. 1 we have four cars and three turnouts. If we propose running three cars we would use two turnouts, by omitting the middle turnout. The result is at once apparent ; for according to Rule 2, the time to run between turnouts is determined by the time consumed in running between those two turnouts farthest apart. Since the distance is doubled, the time consumed is doubled. Where with four cars, with fifteen minutes between cars, and sixty minutes for the round trip, with three cars the time between cars as by Rule 2 is thirty minutes, and the time of round trip is ninety minutes, making at once a very pronounced loss.

The better plan, and the one usually pursued by railway managers, is to run the lesser number of cars on the same trip time as the railway was designed for. In our example above, the three cars would be run as if the four cars were running, with the exception that the space which the car should be running in will be omitted, leaving an interval between two of the cars of thirty minutes, giving only the loss occasioned by the omission of one car.

Another method to pursue, especially so where additional cars will be run at times, such as holidays, excursions, and other times of travel requiring more than the regular number of cars to accommodate the travel, is to provide and locate more turnouts. The expense of doubling the number of turnouts, while they would be a great convenience, would not be warranted without the railway were doing a large and growing business, with a fluctuating number of cars in service. Two cases should be considered.

First—If a certain fixed number of cars are to be operated for the greater portion of time and the extra cars for odd and infrequent intervals, locate the turnouts to suit the regular business.

Second—In the case of a railway running an irregular number of cars—for instance, a railway running a heavy business at certain times of the day—as the lesser number of cars are subordinate to the greater number, locate the turuouts to run the greater number of cars the most efficiently.

In conclusion, we might state that the grades, the running through crowded business streets, stoppages occasioned by grade railroad crossings, and varying business, all enter in and must be considered while designing.

ELECTRIC RAILWAY AUTOMATIC BLOCK SIGNALLING.

By Charles F. Hopewell, S.B.

Block signalling on single-track railways accomplishes two purposes, namely, that of ensuring safety and of obviating delays in traffic necessitated by cars always meeting at predetermined turnouts.

Electric Railway Signal Systems have three positions of signal display, viz.: normal; safety, indicated by green; danger, indicated by red. The red signal is at the leaving end of a block and the green signal operating in unison with it is at the entering end of the block. Were it not so, a car entering a block could not determine if it set a danger signal or the same was set by another car entering from the other end. This requires the

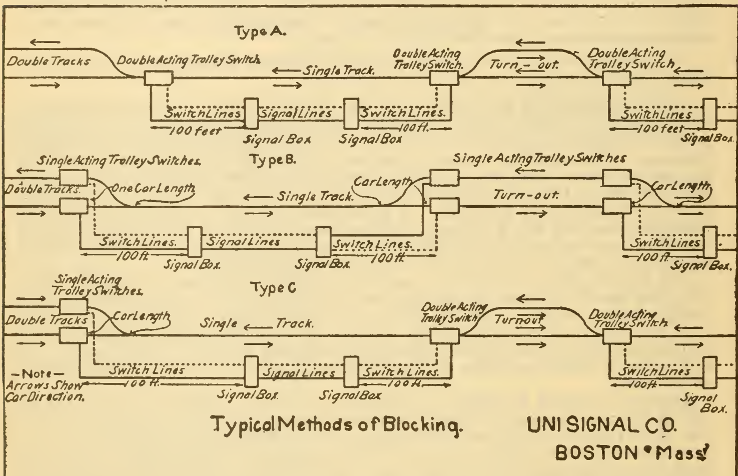


Fig. 2.

normal position of signalling to be when no car is in the block. A motorman of a car approaching a block may have one of three indications signalled to it: No distinctive signal or light, indicating that the block is clear; a green signal indicating that a car has entered the block proceeding in the same general direction as the observing car, and a red signal indicating that a car has entered the block from the distant end and is coming towards the observer.

There are three distinctive methods of blocking a single track for operating in both directions. These are represented in Fig. 2. *Type A* shows the trolley switches which operate the signalling mechanisms located at each end of the section between turnouts or double tracks. The signal boxes are set one pole stretch in advance of the trolley switches. This type requires two differentiating double-acting trolley switches per block. A condition sometimes happens that a car has a red or danger signal set against it just before it passes under a trolley switch, due to a car entering the block from the distant end. Under this condition the car could not be stopped before it had passed under the switch. It will, therefore, be necessary that when the car backs out it must have its trolley pulled down, and coasts under the switch, otherwise it would restore the signal set by the car already in the block.

Type B. — In this type the trolley switches are located on the double tracks or turnouts. These switches are single acting and will only set or restore the signal as arranged for. This type requires four switches per block, but has the advantage that a car can pass under the switch in the reverse direction without restoring the signal. It requires that the cars shall take the turnouts in one fixed direction.

Type C represents a combination of Type A and Type B, and can be used to meet special conditions of road and travel.

The Requirements of a Signal System are as follows:

Mechanical and electrical simplicity of all signal movements and appliances

Must be automatic, non-interfering and interlocking;

Must be incapable of wrong indications under any of the following mentioned conditions, and must not permit restoring to normal except under normal conditions of operation, otherwise it could be set or reversed by another car entering the block.

Loss of current on signal lines.

Cross of signal lines.

Ground on the setting signal lines or on the restoring signal lines.

Cross with the trolley wire between the setting or restoring signal lines.

If the signal is set in one direction and the line then opened, it must be incapable of being set from the other direction, i.e., the signal must be interlocking

If a car should run under a trolley switch when the signal is set against it, it must not restore the signal, i.e., it must be non-interfering.

It should employ as few wires as possible.

It must be impossible to get two safety signals should cars operate the switches at each end simultaneously. In this case both signal movements would set, and it is desirable that they may be automatically restored by the car leaving the block without being required to be manually reset.

The installation of an electric railroad signal requires at each end of a block which passes cars in both directions the following, with the necessary connections.

A signal movement and a lighting and extinguishing switch.

The wires required are these:

A lighting switch wire from same to signal box.

An extinguishing switch wire from same to signal box.

The signal line wires.

Generally a lighting and an extinguishing signal line wire running between the signal boxes at each end of the block.

A ground connection between signal movement and rail.

A permanent feed connection between signal movement and trolley.

A lightning arrester should be attached to the permanent feed wire and one each to the signal line wires.

It should be remembered that the trolley is connected to the ground whenever the signal is set and thus a path of low resistance and inductance is provided for any lightning discharge which may take place on the trolley lines.

The above is based upon the signal systems that are in practical operation to-day on trolley roads, and does not apply to systems as used upon elevated railroads. The latter are operated by track instruments and give only clear and danger indications.

The manual system consists simply of a group of lamps at each end of a block, and a switch to light and extinguish the same. This system operates in a manner similar to the automatic system referred to in the first part of this article but requires the stoppage of the car to set the same or to restore the signal, and in practice it has been found that the signal has at times been tampered with by people who are able to reach the switches which are located on poles alongside the track.

The trolley switches in use are of two types. One consists of a parallel way upon which the trolley runs and in so doing connects the two sides of the switch. One side is permanently connected to the trolley wire and the other to the signal movement. This switch will not differentiate in direction and must therefore be placed upon turnouts and not upon the main line.

The other type is a mechanically operated switch which has a pendant lever hanging down and straddling the trolley wire. The trolley wheel strikes this and moves it in the direction in which the car is going. As the pendant arm is about four inches long it remains in contact with the trolley wheel only about one-fifth of a second for a car speed of a mile per hour and proportionally less for higher speeds. This requires that all switches have a retarding device to keep the contacts closed longer than would the trolley wheel. The most common switches to-day use a pallet and wheel escapement as retarding devices.

Typical Automatic Two-Line Wire, Non-Interfering Block Signal.

The following description of the Block Signal System made by the Uni Signal Co. of Boston, Mass., is illustrative of what such a signal must accomplish. Fig. 3 shows the wiring for a complete block and Fig. 4 the detail wiring at each end of the block.

The signal movement consists of iron back plate upon which are mounted three magnets known respectively as the lighting magnet, extinguishing magnet, and locking magnet. The first two mentioned are of 70 ohms resistance while the third is of 10 ohms resistance. The magnets are of the well known semaphore type. The lighting and extinguishing magnets have notched iron cores in which loosely play one arm of a switching lever. In the extinguishing magnet there is also an additional magnet core which when down closes a pair of contacts. The other two contacts are shown in Fig. 4 directly above the large magnets and are circular contact discs loosely mounted upon a rod between stops. These rods rest directly upon the magnet cores and are moved to open or close the contacts as the movement operates. The armature of the locking magnet is attached directly to the rod over the extinguishing magnet and is so adjusted that it is against its seat when that contact is made and the rod in its lowest position. The lamps are of 110 volts and one-half ampere and the resistance plate of 600 ohms is clearly shown.

The operation of the signal is as follows, and can be seen by reference to Fig. 3.

When a car enters a block it causes current to pass from the trolley wire through the lighting magnet and resistance plate to ground at that end. This causes the switch lever to be thrown over to the left hand contact, thus causing current to be taken from the leaving end of the block, passing through the red lamp, locking magnet at that end, and then through the lighting signal line to the entering end, where it traverses the green lamp and resistance plate to ground.

To extinguish the signal, current is taken from the trolley at the leaving end of the block through the extinguishing magnet at that end, thence through extinguishing line to the entering end and through the extinguishing magnet at that end to ground through the resistance plate. It might appear at first sight that there would be current through both magnets at the entering end, and under such condition impossible for the switch lever to be restored to its normal position. Examination, however, will show that as soon as current is established in the extinguishing circuit the gravity armatures, so called, at their lower end, are raised, and the one in the leaving end of the block cuts off the current of the lighting magnet in the entering box, thereby allowing the extinguishing magnet in that box to operate. By taking the permanent feed from the leaving end and also opening that circuit at that end, it will be apparent that grounds on the lighting line will not prevent the restoration of the signal. A cross between the signal lines will not restore the signal, but will extinguish the green signal, which will, however, relight as soon as the cross is removed. Grounds on either lines will not restore the signal when set. Ground over 1500 ohms resistance will not affect the operation of the signal even if on both signal lines at the same time. This is equivalent to $\frac{1}{4}$ ampere leak while the normal current in the signal circuit is only $\frac{1}{2}$ ampere. Loss of current will not restore the signal when set and when the current is returned the signal will indicate the same as before.

Should the lighting circuit be open after the signal is set, for instance by a lamp being burned out, and another car at distant end should enter the block, it will be seen by Fig. 3 that the switch lever in that signal movement at that end would be thrown over to the left-hand contact as in the box shown at the left hand, the result being that the permanent feed is cut off at both ends and no signal is obtained. Lack of green signal on entering is construed as a danger or cautionary signal.

Suppose that a car should pass under the lighting switch at the red lamp end of a block, as represented by the movement at the right hand side of Fig. 3, it will be seen that current will be taken through the lighting magnet at that end and thence through the resistance plate to ground. This

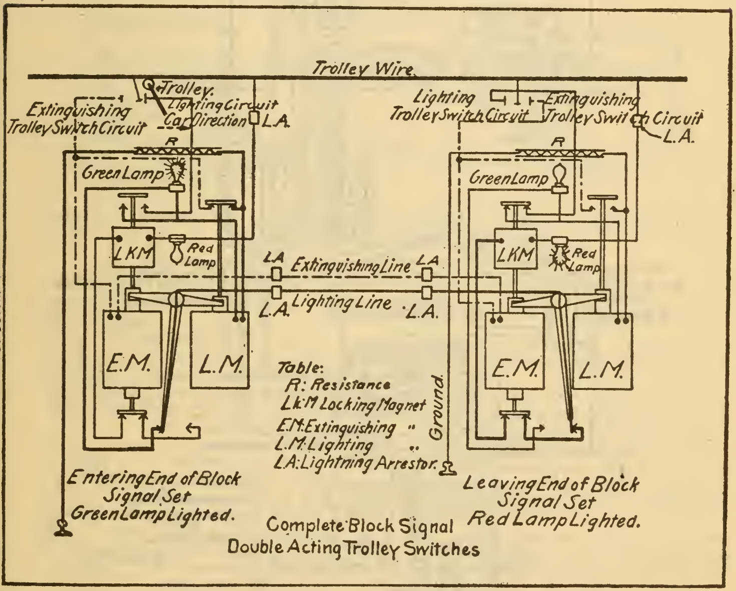


FIG. 3.

would tend to move the lever or switch arm over to the left hand contact, and thus put out the signal were it not for the locking magnet whose sole function is to prevent this movement. As soon as the lighting circuit has been established the locking magnet at the red end is energized and its core being against its seat at that time it is held there. To the core is attached a tail rod at the other end of which is one of the contact discs mentioned before. This tail rod pressing against the lever arm prevents the lighting magnet from operating it. It will be noted that the locking magnet is instantaneous as it has no moving part to operate before locking, and on account of its closed magnetic circuit is more powerful than the lighting magnet, whose armature is retracted at that time, and has a large air gap in circuit. The signal thus is made non-interfering.

In Type B signal made by the same company, the wiring is the same except that the resistance plate is placed in the permanent feed, and two additional graphite resistance rods of 600 ohms are placed in each trolley switch leg. Each lamp is further protected by a paper shunt which closes the circuit when the lamp burns out. Furthermore there is a magnet operating a red, and one operating a green semaphore disc signal, which are cut into the circuit adjacent to the red and green lamps.

The trolley switches are double acting and differentiating, operating as

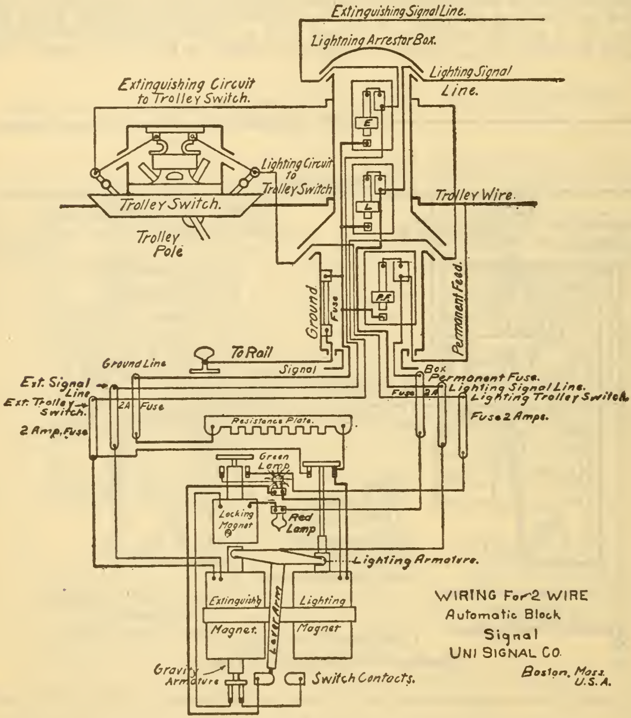


FIG. 4. Signal Set at Entering End of Block, Green Lamp Lighter.

follows: The first blow of the trolley wheel hits a pendant hanging over the wire and brings the switch contacts into mechanical lock. At the same time it winds up a pallet escapement, which, when it runs down, kicks the lock off and allows the contact to open after a predetermined time. The working parts are in balance and made as light as consistent with strength. There are two contacts, but only one common escapement. The switch lights when passed under in one direction, and restores the signal when operated in the other direction. A time element is necessary, as it requires about ¼ second for the signal mechanism to operate. The power required to operate the signal switch is 2½ pounds pull, while the tension on a trolley wheel to hold it against the trolley wire is over twenty pounds.

Distributed Signal Block System.

(Developed by R. D. SLAWSON, Electrical Engineer of Easton Transit Co.)

This is a manual system, and is used by the Easton Transit Company on the Easton, Palmer and Bethlehem division, and differs from others in having the signals distributed along the line between turnouts. There are two sets of signals, one being used for out-bound and one for return cars. The signal lamps are enclosed in galvanized iron boxes, attached to poles along the line. Signal poles are also painted with two 12 inch bands of white, and a band of either red or green, as the case may be. Switches are located at each end of the turnouts on poles and the covers are marked "Throw on"

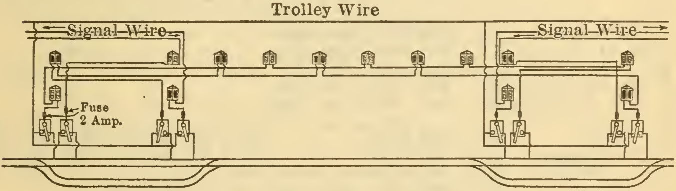


FIG. 5. Diagram of Connections of Slawson's Distributed Signal Block System for Single-Track Railways.

and "Throw off," and each conductor is responsible for maintaining his own right of way.

No. 14 insulated iron wire is used for the signal circuits. 16 c.p. 110 volt lamps are used for signals, and as the signal boxes are triangular, the lamp can be seen from almost any position.

The red lamps are used for out-bound, and the green for return cars.

The operation of the system is as follows: The conductor of a car leaving a terminal out-bound, first throws the switch marked "Throw on." This lights the five lamps in the red boxes in the section ahead of him, and he proceeds to the first turnout, and, if there is no green lamp burning at that place, he throws off the red signals behind and sets the red lights in the section ahead.

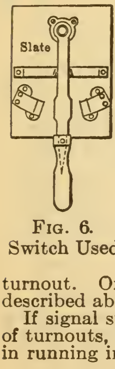


FIG. 6.
Switch Used.

If a lamp should burn out while the car is running between turnouts, warning of the fact is given by the absence of the red light, and by watching the green signals the motorman can tell when a car is coming in the opposite direction.

If the out-bound car, coming to a turnout, finds the red signal burning for the section ahead, showing that the section is occupied by a car going in the same direction, it must wait until the section is cleared by the car ahead.

The signals may then be reset, and the car can proceed. Should a crew find that they are unable to light the red signals, they may use the reverse, or green signal, to the next turnout. On the return the green signals are used in the same manner as described above for the red signals and an out-bound car.

If signal switch boxes are placed about a car's length outside of the ends of turnouts, cars will always approach at slow speed, which is quite desirable in running into a turnout.

LIST OF MATERIAL REQUIRED FOR ONE MILE OF OVERHEAD LINE FOR ELECTRIC STREET RAILWAY.

Material for Railway Construction.			1 Mile Overhead.				Curve Overhead Material.					Anchorage.	
			Cross Suspension.		Bracket Suspension.		Main Line.		Branch Line.		Turnout, 200 ft.		
			Single Tr.	Double Tr.	Single Tr.	Double Tr.	Single Tr.	Double Tr.	Single Tr.	Double Tr.		Single Tr.	Double Tr.
Copper.	No. 0 B. & S. H. D. Trolley	Ft.	5280	10560	5280	10560					250		
		Lb.	1685	3369	1685	3369					80		
	No. 0 B. & S. S.D. F'd'r T'ps	Ft.	400	500	90	180							
		Lb.	154	192	35	69							
Galv. Iron	7 strand No. 12 span	Ft.	3600	3600			800	800	800	800	200	400	600
		Lb.	756	756			168	168	168	168	42	84	122
	7 strand No. 15 guy	Ft.	3000	4500	1500	2000	100	100	100	100			
		Lb.	300	450	150	200	10	10	10	10			
Plain ears			45	90	45	90	5	10	5	15	4		
Strain ears							2	4	1	2			
Splicing ears . . .			1	2	1	2							
Feeder ears			10	20	10	20							
Insulating caps . .			45	90	45	90	7	4	6	17	4		
Insulating cones . .			45	90	45	90	7	4	6	17	4		
Ins. Holders	Straight line . .		45	90									
	Single curve . .						3	3	3	5			
	Double curve .						4	11	3	12	4		
	Bracket . . .				45	90							
Strain insulators . .			90	90			4	4	2	2		1	2
Turnbuckles . . .			90	90			4	4	2	2		2	2
Section insulators .			2	4	2	4							
Frogs									1	2	2		
Frog crossings . . .										1			
Hardwood pins . .			45	45									
Eye bolts			90	90			2	2	2	2	2	2	2
Cast-iron brackets .					45	90							
Gas-pipe arms . . .					45	90					2		
Cross arms (1¼″–18) .			45	45	48	48							
Cross-arm braces (½″×8″)			90	90									
Bolts for brackets (½″×4″)					45	90							
Lag screws for brackets (½″×7″) . . .					45	90							
Lag screws for cross arms (⅜″×3″) . .			45	45									
Lag screws for braces			144	144									
Poles, 125 ft. apart .			90	90	45	45	2	2	2	2		2	2
Bonds			400	800	400	800							
Lightning arresters .			3	3	3	3							
Section switch boxes			2	2	2	2							

ESTIMATE OF COST TO PRODUCE ONE MILE OF DOUBLE TRACK OVERHEAD TROLLEY CONSTRUCTION FOR CITY STREETS.

(Report of Bion J. Arnold, November, 1902.)

100	Iron poles, set in concrete, at $28	$2,800.00
50	4-pin iron cross arms, with pins and ins., at $3.95	197.50
100	Small Brooklyn insulators for spans, at 50c.	50.00
100	Globe strain insulators for spans, at 22c.	22.00
90	Straight line hangers, at 32½c.	29.25
10	Feed-in hangers, at 50c.	5.00
140	Soldered 9-inch ears, at 16c.	22.40
12	Live cross-overs (estimated), at $3	36.00
8	Insulated cross-overs (estimated), at $6	48.00
8	2-way frogs (estimated), at $3.	24.00
3000	Feet 5-16 inch galv. strand wire for spans, at $10 per M.	30.00
6	Strain plates (strain layout), at 32c.	1.92
12	Small Brooklyn (strain layout) at 50c.	6.00
12	Globe insulators (strain layout) at 22c.	2.64
1500	Feet ¼-inch galv. strand wire (strain layout), at $7.25 per M.	10.88
20	Double hangers (2 double curve layouts), at 44c.	8.80
20	Single hangers (2 double curve layouts), at 35c.	7.00
1000	Feet ¼-inch strand wire (2 double curve layouts), at $.725 per M.	7.25
4	Heavy Brooklyn (2 double curve layouts), at 70c.	2.80
10560	Feet 2-0 trolley wire, 4246 pounds, at 13¼c.	562.59
2	00 splicing ears, at 50c.	1.00
Labor, placing spans, trolleys, etc.		225.00
Total cost exclusive of feeder wire		$4,100.03
Cost of feeder wire estimated average per mile		4,000.00
		$8,100.03

STANDARD IRON OR STEEL TUBULAR POLES.

Tubular poles for electric railway lines are made up of the regular pipe sections, both standard and extra heavy.

The combinations in common use are :

Pole made of standard tubing.
Pole made of extra heavy tubing.
Pole made with bottom section of extra heavy tubing, and other sections of standard weight.
Pole made with bottom and middle sections of extra heavy tubing, other sections of standard weight.

Standard lengths are 28 feet end to end for side or line poles, and 30 feet for corner or strain poles. The standard joint insertion is 18 inches, and total weights can be calculated from regular standard pipe list (see pages 1426–1427). Two section poles are most commonly made up of 6 and 5 and 7 and 6 inch-pipe, for side or line poles; and 8 and 7 inch pipe for corner or strain poles.

Three section poles are 6 and 5 and 4 or 7 and 6 and 5-inch pipe for side or line and 8 and 7 and 6-inch for corner and strain poles.

Standard Pole Line Construction.

For most urban and all interurban or suburban lines, wooden poles are used, and are either octagon or shaved. The following cuts show common standards of dimensions and arrangments of cross arms, brackets, etc.

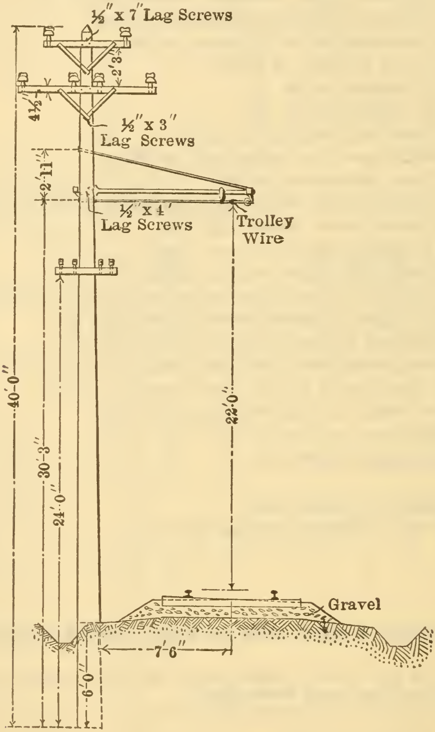


FIG. 7. Standard Pole Line Construction of the Union Traction Company of Indiana.

Double Track Center Pole Construction.

Electric roads use a greater distance between track centers than do steam roads, hence permitting center pole construction, with less cost per mile than would be the case if double pole bracket or cross suspension construction were used, although the latter is often preferred.

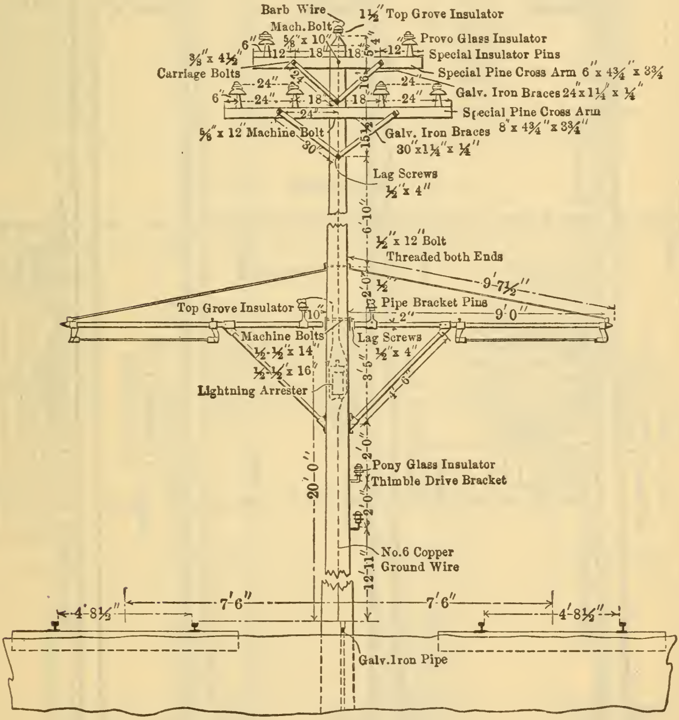
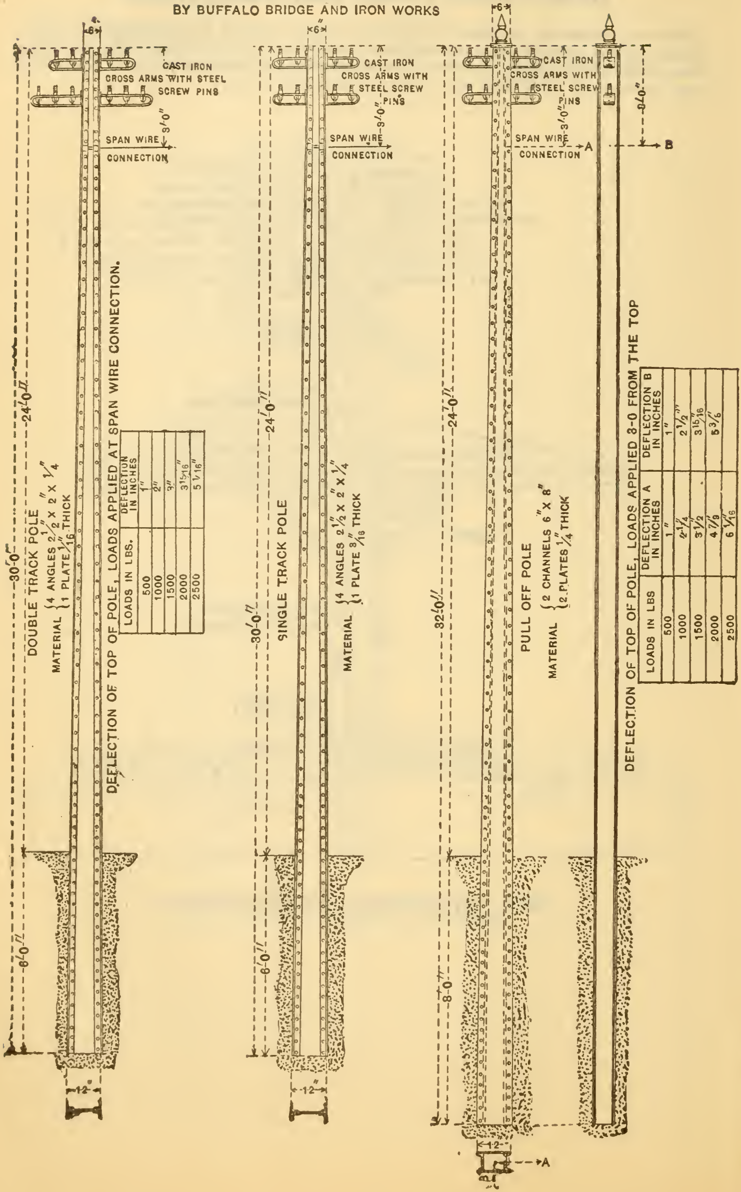


FIG. 8. Typical Center Pole Construction.

Plate Box Poles.

BY BUFFALO BRIDGE AND IRON WORKS



Deflection of top of pole, loads applied at span wire connection (Double Track Pole):

LOADS IN LBS.	DEFLECTION IN INCHES
500	1"
1000	2"
1500	3"
2000	3 15/16"
2500	5 1/16"

Deflection of top of pole, loads applied 3-0 from the top (Pull Off Pole):

LOADS IN LBS	DEFLECTION A IN INCHES	DEFLECTION B IN INCHES
500	1"	1"
1000	2 1/4"	2 1/2"
1500	3 1/2"	3 15/16
2000	4 7/8	5 3/8"
2500	6 1/16"	

TUBULAR IRON OR STEEL POLES.

By Morris, Tasker, & Co. (Inc.).

Size.	Wrought Iron or Steel.	Length.	Weight.
No. 1, light	5 in., 4 in., 3 in.	27 ft.	350 lbs.
No. 1, heavy . . .	5 in., 4 in., 3 in.	27 ft	500 lbs.
No. 2, light	6 in., 5 in., 4 in.	28 ft.	475 lbs.
No. 2, heavy . . .	6 in., 5 in., 4 in.	28 ft.	700 lbs.
No. 3, light	7 in., 6 in., 5 in.	30 ft.	600 lbs.
No. 3, heavy . . .	7 in., 6 in., 5 in.	30 ft.	1000 lbs.
No. 4, light	8 in., 7 in., 6 in.	30 ft.	825 lbs.
No. 4, heavy	8 in., 7 in., 6 in.	30 ft.	1300 lbs.

POLES.

Dimensions and Weights Wrought-Iron and Steel Poles.

Length.	Diameter.	Weights.
27 ft.	5 in., 4 in., 3 in.	350 lbs. to 515 lbs.
28 ft.	6 in., 5 in., 4 in.	475 lbs. to 725 lbs.
30 ft.	6 in., 5 in., 4 in.	510 lbs. to 775 lbs.
30 ft.	7 in., 6 in., 5 in.	600 lbs. to 1000 lbs.
28 ft.	8 in., 7 in., 6 in.	775 lbs. to 1260 lbs.
30 ft.	8 in., 7 in., 6 in.	825 lbs. to 1350 lbs.

Cubic Contents of Wooden Poles, in Feet.

Length.	Diameter.	Section.	Cubic Feet.
27 ft.	6 in. × 8 in.	Circular	7.36
27 ft.	7 in. × 9 in.	Circular	9.56
27 ft.	7 in. × 9 in.	Octagonal	10.1
28 ft.	7 in. × 9 in.	Circular	9.92
28 ft.	7 in. × 9 in.	Octagonal	10.46
28 ft.	8 in. × 10 in.	Circular	12.52
28 ft.	8 in. × 10 in.	Octagonal	13.2
30 ft.	7 in. × 9 in.	Circular	10.63
30 ft.	7 in. × 9 in.	Octagonal	11.21
30 ft.	8 in. × 10 in.	Circular	13.41
30 ft.	8 in. × 10 in.	Octagonal	14.15
30 ft.	9 in. × 12 in.	Octagonal	19.06

Rake of Poles.

Wooden poles should be given a rake of 9 to 18 inches away from the street. Iron or steel poles set in concrete need be given but 6 to 9 inches rake. Corner poles, and those supporting curves, should be given additional rake or be securely guyed.

AVERAGE WEIGHTS OF VARIOUS WOODS, IN POUNDS.

Kind.	Condition.	Weight per Cubic Foot.
Live oak	Perfectly dry	59
White oak	Perfectly dry	48
Red oak	Perfectly dry	35
Chestnut	Perfectly dry	41
Southern yellow pine	Perfectly dry	45
Northern yellow pine	Perfectly dry	34
Long-leaf yellow pine	Unseasoned	65
Norway pine	Perfectly dry	46
Spruce	Perfectly dry	25
Hemlock	Perfectly dry	25

The weight of green woods may be from one-fifth to one-half greater than the weight when perfectly dry.

DIP IN SPAN WIRE.

(Merrill.)

The following tables give the dip of the span wire in inches under the combined weight of span wire and trolley wire, for various spans and strains. Length of trolley wire between supports, 125 feet. Weight of trolley wire, 319 lbs. per 1000 feet. Weight of span wire, 210 lbs. per 1000 feet.

Single Trolley Wire.

Spans in Feet.	Strain on Poles, in Pounds.						
	500	800	1000	1500	2000	2500	3000
30	7.8	4.9	3.9	2.6	1.9		
40	10.6	6.5	5.3	3.5	2.7		
50	13.6	8.5	6.8	4.5	3.4	2.7	
60	16.7	10.4	8.3	5.6	4.2	3.3	2.8
70	19.9	12.4	9.9	6.6	4.9	4	3.3
80	23.2	14.5	11.6	7.7	5.6	4.6	3.9
90	26.7	16.7	13.4	8.9	6.6	5.3	4.5
100	30.3	18.9	15.2	10.1	7.6	6.1	5.1
110	34	21.3	17	11.3	8.5	6.8	5.7
120	37.9	23.7	18.9	12.6	9.5	7.6	6.3

Two Trolley Wires, 10 Feet Apart.

Span in Feet.	Strain on Poles, in Pounds.							
	500	800	1000	1500	2000	2500	3000	3500
40	15.4	9.6	7.7	5.1	3.9	3.1		
50	20.8	13.	10.4	6.9	5.2	4.2		
60	26.3	16.4	13.1	8.8	6.6	5.3	4.4	
70	31.9	19.9	15.9	10.6	8.	6.4	5.3	
80	37.6	23.5	18.8	12.5	9.4	7.5	6.3	5.4
90	43.5	27.2	21.8	14.5	10.9	8.7	7.3	6.2
100	49.5	30.9	24.8	16.5	12.4	9.9	8.3	7.1
110	55.6	34.7	27.8	18.5	13.9	11.1	9.3	7.9
120	61.9	38.7	30.9	20.6	15.5	12.4	10.3	8.7

NOTE. — See also chapter on *Conductors.*

For table of stranded wire for spans and guys see page 200, Properties of Conductors.

Span Wires should be stranded galvanized iron or steel, sizes $\frac{1}{4}$ inch diameter $\frac{5}{16}$, $\frac{1}{2}$, or $\frac{3}{8}$ inch according to the weight of trolley wire, etc., to be supported. Where wooden poles are used it is not necessary to provide other insulation for the span wire, and the wire can be secured to the loop of an eye-bolt that is long enough to pass through the pole at a point from twelve to eighteen inches below the top, and that has a long thread to allow taking up slack. Where metal poles are used it is necessary to insulate the span wire from the pole. This has been done in some cases by inserting a long wooden plug in the top of tubular poles, capping it with iron, the wooden plug then being provided with the regular eye-bolt. The most modern way is to provide a good anchor bolt or clasp on the pole, then insert between the span wire and this bolt one of the numerous forms of line or circuit-breaking insulators devised for the purpose. If the anchor bolt is not made for taking up slack, the insulating device can be so designed as to be used as a turnbuckle. Of course insulation must be provided for both ends of the span wire.

Span wire must be pulled taut when erected so that the sag under load will be a minimum. Height above rail surface should be at least 18 feet after the trolley wires are in place. This height is regulated by statute in some states, and runs all the way from 18 to 21 feet.

Side Brackets. — Along country roads and in such places as the track is along the side of the roadway or street, it is customary to use single poles with side brackets to support the trolley wire.

Where side brackets are used it is not safe to place the pole less than four feet away from the nearest rail, and to give flexibility to the stranded sup-

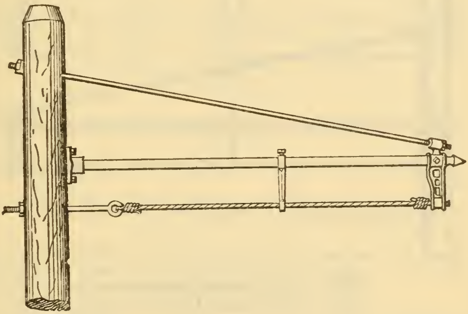


FIG. 10. Single Suspension.
For Wood Poles.

porting wire, now always provided for the trolley wire, the bracket should be long enough to reach the distant rail, thus giving a little more than two feet of cable for flexibility. A common length of bracket is 9 feet.

Figures 10 and 12 show the simple form of side bracket in most general use, and Figs. 11 and 13 show variations of the same. It is obvious that this method of support may be made as elaborate and ornamental as may be desired.

On double-track roads *center-pole* construction is sometimes used, in which poles are placed along the center line between the two tracks, and brackets are erected on each side of the poles overhanging the tracks. Where wooden poles are used a good form of construction is to bore the pole at the proper height and run through it the tube for the arms, this long tube being properly stayed on both sides of the pole by irons from the pole-top to the bracket ends, or by braces against the pole. The trolley supporting wire can extend from end to end of the brackets *through* the pole, or can be cut at the pole, and eye-bolts be used, as in the side-bracket construction shown by Fig

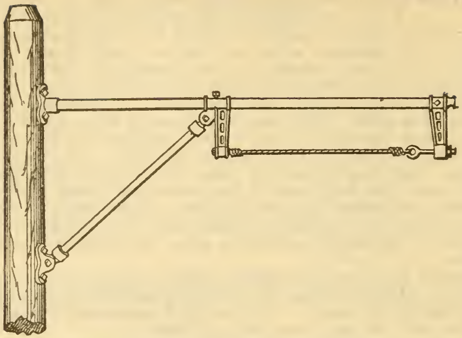


Fig. 11. Single Suspension.
For Wood Poles.

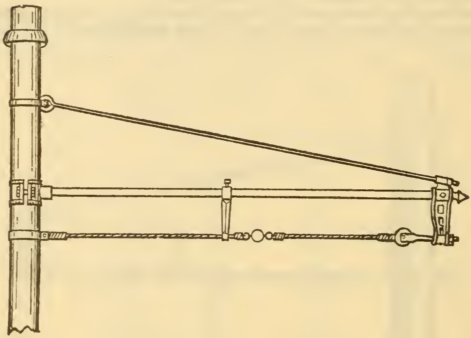


Fig. 12. Single Suspension.
For Iron Poles.

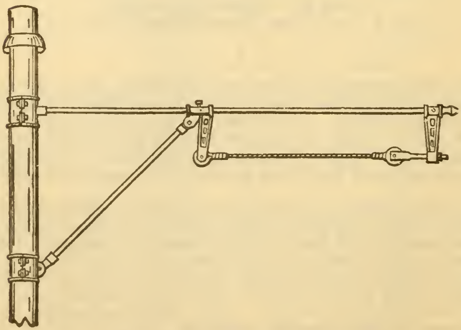


Fig. 13. Single Suspension.
For Iron Poles.

Figures 14 and 15 illustrate simple forms of center-pole brackets.

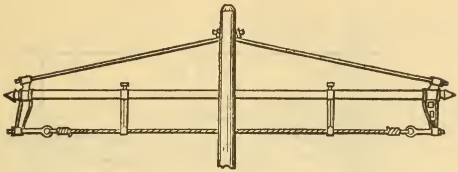


FIG. 14. Double Suspension. For Wood Poles.

Center-pole construction is quite often used on boulevards in cities, where the brackets and poles can be made quite ornamental.

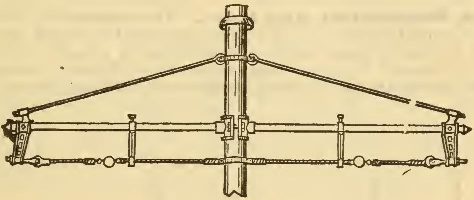


FIG. 15. Double Suspension. For Iron Poles.

TROLLEY WIRE SUSPENSION.

The support of the trolley wire along straight lines is a simple matter and needs no explanation; at curves and ends there have been some simple forms developed in practice that are handy to have at hand. Following are some of the points:

Terminal anchorage. — Single track. See Fig. 16.

Line anchorage. — See Figs. 17 and 18. To be placed at the foot of all grades, at the top of hills, and at tangents, three (3) per mile is good practice; where curves are frequent they will afford all the anchorage necessary.

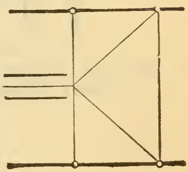


FIG. 16.

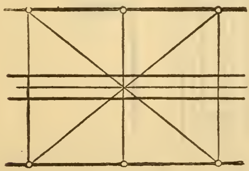


FIG. 17. Single Track.

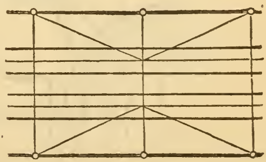


FIG. 18. Double Track.

Turnout and Siding Suspension. — Following is a sketch of a very simple arrangement of suspension and guys for a single-track turnout.

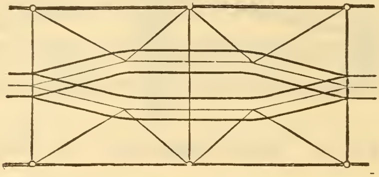


FIG. 19.

Curves, Suspension, and Guys.—The suspension of the trolley wire at curves is complicated or simple, according as the track may be single or double, or the curve may be at a crossing or a simple curve. Below are sketches of several types of suspension for different forms of curves, for single and double track, for cross suspension, and for center-pole construction.

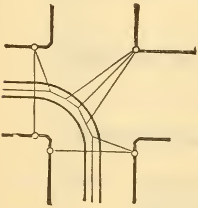


FIG. 20. Simple Right-angle Curve, Single Track.

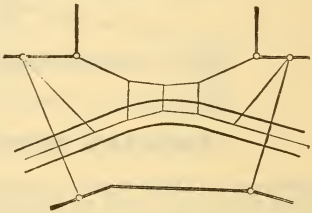


FIG. 21. Single Track, Obtuse Angle.

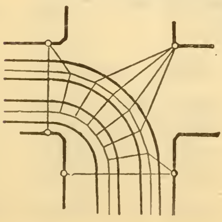


FIG. 22. Double Track, Right-angle Turn, Cross Suspension.

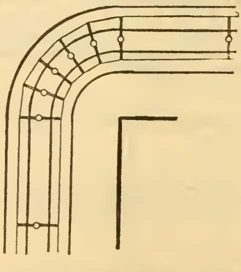


FIG. 23. Double Track, Right-angle Turn, Center Pole.

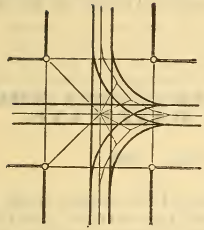


FIG. 24. Single Track Crossing, Cross Suspension.

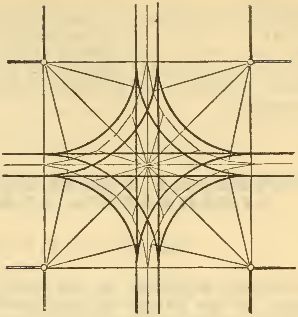


FIG. 25. Single Track Crossing, Cross Suspension.

Crossings, Suspension, and Guys. — Simple crossings of tracks make no complication in the suspension of the trolley wires. When curves are added to connect one track with the other, complications begin, and where double tracks cross double tracks, and each is connected to the other by curves each way, the network of trolley wires becomes very complicated. Above are sketches of a couple of simple crossings which will clearly enough illustrate the methods of suspension commonly used.

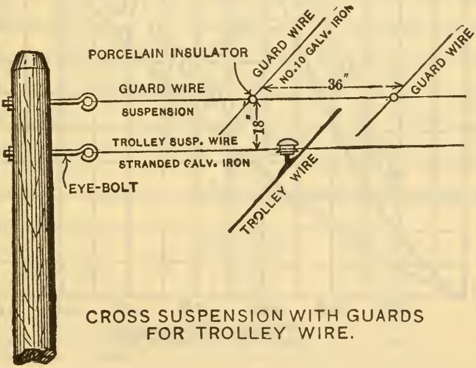


FIG. 26.

Guard Wires.

Where trolley wires are used in cities or in any location where there are other overhead conductors liable to fall across the trolley wire, it is customary to place guard wires parallel with but above the trolley wire, as shown in the above sketch. A piece of No. 6 B. & S. galvanized iron or steel wire is drawn taut above the regular suspension wire ; porcelain insulators are secured to the same at a point about a foot or 18 inches either side of the trolley wire, and through these insulators is threaded and tied a No. 10 galvanized iron wire. This guard should be broken at least every half-mile where it is in any great length, as it is not advisable to have it a continuous conductor for any great distance, and it is advisable to avoid its use wherever possible.

CATENARY TROLLEY CONSTRUCTION FOR ALTERNATING CURRENT RAILWAYS.

Abstract of G. E. Co. Bulletin, Nov., 1907.

The radical departure in the design of trolley line construction made necessary by the advent of high tension alternating current distribution for electric railway operation has resulted in the catenary system of line construction, which while providing ample insulation surface for the high-

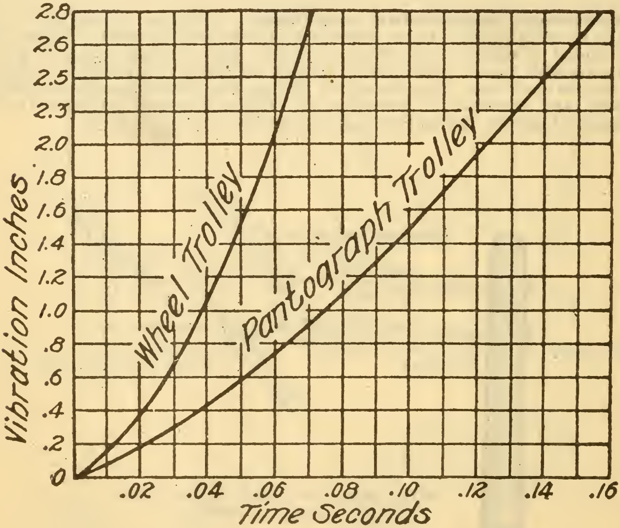


FIG. 27.

est potentials used or contemplated, also incidentally affords marked mechanical improvement which is important with the high speeds of modern suburban and interurban operation, and steam railroad electrification.

The catenary system which is equally applicable to bracket or cross span construction, consists essentially of an arrangement of a slack messenger cable and suitable hangers so distributed as to maintain the trolley wire practically without sag between suspension points, or to limit the sag as may be necessary for various conditions of operation.

The blow of a collector passing suspension points at high speed is thus greatly reduced. The shorter distance between hangers necessitates less stress in the trolley wire and reduces danger of break in the line.

The catenary system, therefore, offers the mechanical advantages of a longer pole spacing and a flatter trolley wire, and a flexibility in the line which obviates the hammer blow of the collector at suspension points, and reduces danger of mechanical breakage.

The three-point suspension in which, with 150 ft. pole spacing, the

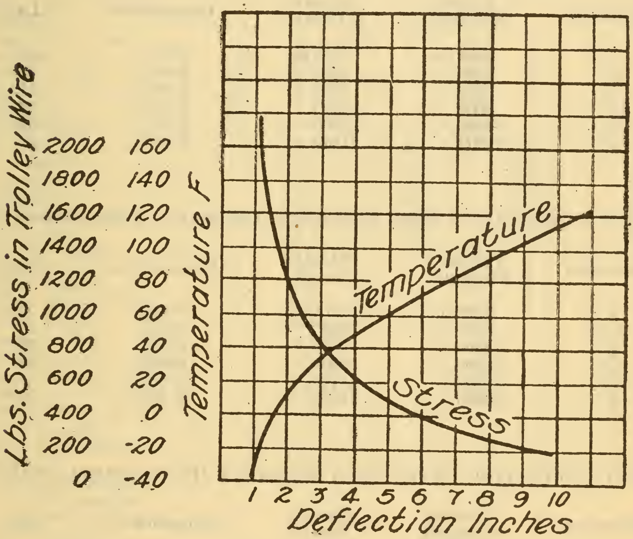


Fig. 28.

hangers are 50 ft. apart, has been found ample to maintain a sufficiently level trolley wire for operation with wheel collector at speeds up to sixty-five miles per hour. A new element is, however, introduced by the sliding pantograph or bow trolley which, on account of its great inertia, requires a closer spacing of the trolley support.

Fig. 27 shows comparative curves of time required for vertical vibration of wheel and pantograph trolley respectively. It has been found that an eleven-point suspension renders the trolley wire sufficiently level for the relatively sluggish action of the pantograph collector. This brings the hangers 13.6 feet apart, and for all operative conditions with sliding collectors the eleven-point suspension is recommended.

Fig. 28 shows the effect of temperature variation on sag and stress in trolley wire with the three-point construction.

Steel Strand.

Common galvanized strand is not recommended for any purpose in catenary construction, and wherever steel strand is used it should be one of the three special grades, properties of which are given in the following table.

Physical Properties of Seven Wire Extra Galvanized Steel Strand.

EXTRA GALVANIZED SIEMENS-MARTIN STRAND 90,000 PER SQ. IN.

Diameter.	Tensile Strength.	Elastic Limit.	Elongation.	Lay.
1/4″	3060 lb.	1830 lb.	6–9%	3″
5/16″	4860 "	2910 "	6–9%	3½″
3/8″	6800 "	4080 "	5–8%	4″
7/16″	9000 "	5300 "	5–8%	4½″
1/2″	11000 "	6600 "	5–8%	4½″
5/8″	19000 "	11400 "	4–6%	5″

EXTRA GALVANIZED HIGH STRENGTH (CRUCIBLE) STEEL STRAND.

Diameter.	Tensile Strength.	Elastic Limit.	Elongation.	Lay.
1/4″	5100 lb.	3315 lb.	3–5%	3½″
5/16″	8100 "	5265 "	3–5%	4″
3/8″	11500 "	7475 "	3–5%	4½″
7/16″	15000 "	9500 "	3–5%	5″
1/2″	18000 "	11700 "	3–5%	5″
5/8″	25000 "	16250 "	2–4%	5½″

EXTRA GALVANIZED EXTRA HIGH STRENGTH (PLOW) STEEL STRAND.

Diameter.	Tensile Strength.	Elastic Limit.	Elongation.	Lay.
1/4″	7600 lb.	5700 lb.	2½–4%	4″
5/16″	12100 "	9075 "	2½–4%	4½″
3/8″	17250 "	12930 "	2½–4%	5″
7/16″	22500 "	16800 "	2½–4%	5½″
1/2″	27000 "	20250 "	2½–4%	5½″
5/8″	42000 "	31500 "	1½–3%	6″

For ordinary conditions, the messenger cable should be of 7/16″ extra galvanized Siemens-Martin steel. For pull-offs ¼″ cable is satisfactory, and for general guying purposes ⅜″ extra galvanized Siemens-Martin strand is generally recommended. Special conditions may call for "high strength" cable, but as this cable requires mechanical fastenings on account of its stiffness, it should be used only where absolutely necessary.

Line Material per Mile of Tangent Track for Catenary Construction.

	Single Track.				Double Track.			
	Bracket Construction.		Cross Span Construction.		Center Pole Construction.		Cross Span Construction.	
	3 Point	11 Point	3 Point	11 Point	3 Point	11 Point	3 Point	11 Point
Span wire messenger hangers	......	......	36	36	......	......	72	72
Strain insulators	4	4	80	80	8	8	88	88
Brackets	36	36	......	......	72	72	......	......
Insulator pins	36	36	......	......	72	72	......	......
Messenger insulators	36	36	......	......	72	72	......	......
4″ hangers	36	......	36	......	72	......	72	......
$12\frac{3}{4}$″ hangers	68	......	68	......	136	......	136	......
4″ hangers	......	36	......	36	......	72	......	72
$4\frac{3}{4}$″ hangers	......	72	......	72	......	144	......	144
$6\frac{1}{2}$″ hangers	......	72	......	72	......	144	......	144
9″ hangers	......	72	......	72	......	144	......	144
$12\frac{3}{4}$″ hangers	......	72	......	72	......	144	......	144
$17\frac{1}{4}$″ hangers	......	72	......	72	......	144	......	144
Splicing sleeves	3	3	3	3	6	6	6	6
Anchor hangers	4	4	4	4	8	8	8	8
Anchor eyes	2	2	......	......	4	4	......	......
Anchor turnbuckles	4	4	4	4	4	4	8	8
Anchor clamps	......	......	2	2	......	......	4	4
Material for curves, crossings, etc., dependent upon local conditions:								
Strain insulators								
Steady braces								
Steady brace ears								
Spreaders								
12″ pull-off hangers								
15″ pull-off hangers								
18″ pull-off hangers								
Anchor hangers								
Feeder ears								
Anchor eyes								
Anchor clamps								
Anchor turnbuckles								
Section insulators								
Strain insulators								
Frogs								
Crossings								
Line Material:								
3-bolt cable clamp	8	8	88	88	......	......	88	88
Eye-bolts	8	8	88	88	......	......	88	88
Anchor rods	......	......	72	72	72	72	72	72
Feet of grooved trolley wire	5300	5300	5300	5300	10600	10600	10600	10600
Feet of messenger strand	5400	5400	5400	5400	10800	10800	10800	10800
Feet of anchor strand	1400	1400	2600	2600	2600	2600	2600	2600
Feet of cross span and pole guy strand	......	......	3200	3200	3200	3200	3200	3200
Feet of pull strand	......	......	......	......	......	......	......	......

Staggering Trolley for Sliding Contact.

Where a sliding collector is to be used, it is recommended that the tangent line be staggered by means of steady braces in bracket construction, or pull-off, in span construction, to avoid wearing grooves in the collector contact surface.

For this purpose the trolley wire should be displaced approximately eight inches on each side of the center line of the track every 1000 ft., i.e., there should be one complete wave from the extreme position on one side across the track and back to the extreme position on the same side in each 2000 ft. of line.

When the road bed is new, it is well to simply make provisions for staggering the trolley wire, but to defer actual staggering until the road bed is settled and put in final shape, as the sway of the car due to irregularities in the track may be great enough to throw the sliding contact entirely off the wire.

Bracket Construction.

After the poles are installed the brackets should be located at a height of sixteen inches more than the required distance between the top of the rail and the trolley wire. This allows for two inch sag of the bracket due to the yielding of the pole when loaded, in single track construction. For double construction this distance should be fourteen inches greater than the desired height of trolley above top of rail. The messenger wire should next be adjusted for tension to give a sag at the center of span of about 9 inches at 30° F., 10 inches at 60° F., and 11 inches at 85° F.

Span Construction.

In span construction the span wire should be installed so that when the weight of the messenger and trolley is put on it, there will be a sag of at least three or four feet between a straight line drawn through the points of support of the span wire and the point on the span wire where the messenger hanger is attached. When unusually long distances are necessary between the poles the sag should be greater. The back guys should be insulated for full line potential.

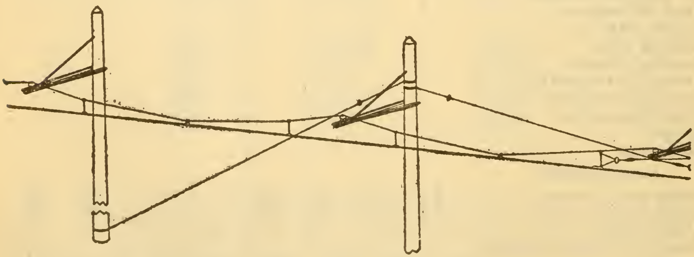


FIG. 29. Catenary Construction. Single Track Bracket.

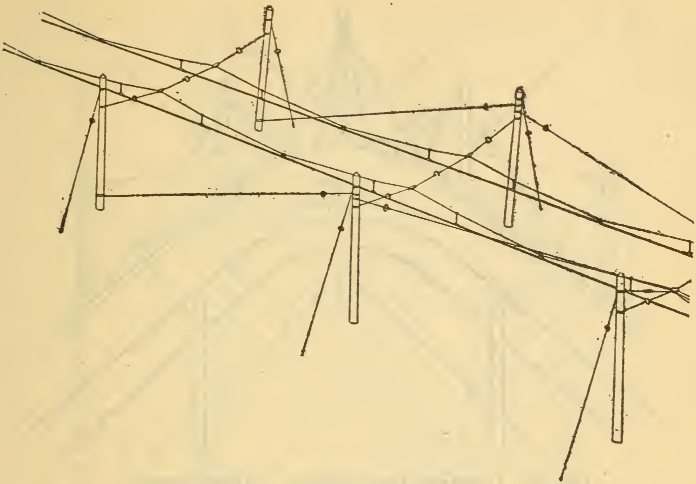


FIG. 30. Catenary Construction. Double Track Span.

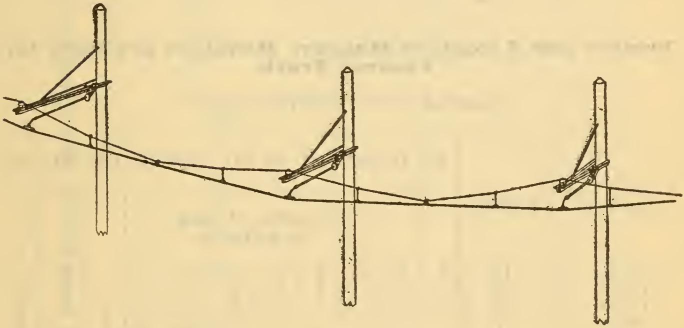


FIG. 31. Catenary Curve Construction Using Steady Brace.

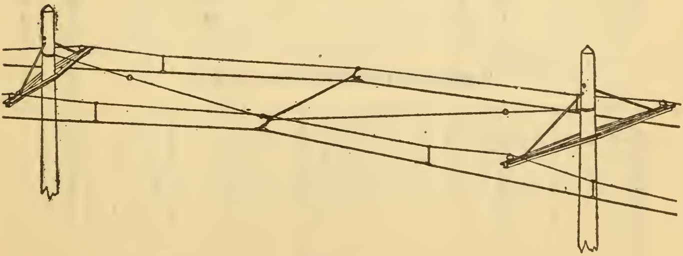


FIG. 32. Spreader Curve Construction.

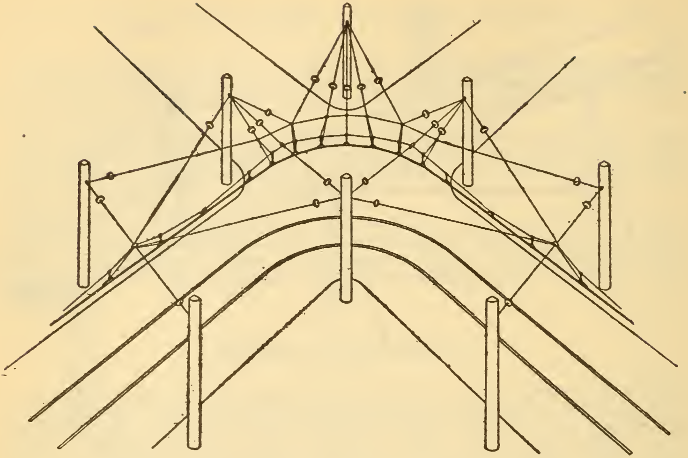


FIG. 33. Catenary Construction. Street Corner.

Number and Length of Hangers Required per Span for Tangent Track.

ELEVEN-POINT CONSTRUCTION.

Length Pole Spacing.	Points.	4″	4¾″	6½″	9″	10′	11½″	12¾″	14″	15½″	17¼″	18½″
					Number of hangers required.							
150 ft.	11	1	2	2	2	....	....	2	....	....	2	....
125 "	9	....	....	....	1	2	2	....	2	....	2	....
110 "	8	....	....	....	....	....	2	2	....	2	....	2
95 "	7	....	....	....	....	....	....	....	3	2	....	2
80 "	6	....	....	....	....	....	....	....	....	2	2	2
70 "	5	....	....	....	....	....	....	....	....	....	3	2
55 "	4	....	....	....	....	....	....	....	....	....	....	4

THREE-POINT CONSTRUCTION.

Length Pole Spacing.	Points.	4″	4¾″	6½″	9″	10′	11½″	12¾″	14″	15½″	17¼″	18½″
150 ft.	3	1	....	....	....	....	....	2	....	....	....	...
125 "	3	....	....	....	1	....	....	....	....	2	....	....
110 "	3	....	....	....	....	....	1	....	....	2	....	....
95 "	3	....	....	....	....	....	....	....	1	....	2	....
80 "	3	....	....	....	....	....	....	...	....	1	2	....
70 "	2	....	...	....	....	....	....	....	....	....	....	2
55 "	2	....	....	....	....	....	....	....	....	....	....	2

Number and Length of Hangers Required per Span for Pull-off Curve Construction.

ELEVEN-POINT CONSTRUCTION.

Length of Hangers. Angle of Curves.	Radius.	Pole Spacing.	No. of Pull-off Points.	Straight Line Hangers. 9″	10″	11½″	12¾″	14″	15½″	17¼″	18½″	Pull-off Hangers. 12″	15″	18″
4°–6°	1433′–955′	125′	2	1	2	....	....	2	....	2	....	2	....	....
6°–14°	955′–410′	95′	2	....	....	....	....	3	....	....	2	....	2	....
14°–20°	410′–288′	70′	2	....	....	....	....	....	....	3	2	....	....	2
	288′–150′	70′	3	....	....	....	....	....	....	2	2	....	....	3
	150′– 50′	55′	4	....	....	....	....	....	....	....	....	....	....	4

THREE-POINT CONSTRUCTION.

Angle of Curves.	Radius.	Pole Spacing.	No. of Pull-off Points.	9″	10″	11½″	12¾″	14″	15½″	17¼″	18½″	12″	15″	18″
4°–6°	1433′–955′	125′	2	1	....	....	....	....	....	....	....	....	2	....
6°–14°	955′–410′	95′	2	....	....	....	....	1	....	....	....	....	2	....
14°–20°	410′–288′	70′	2	....	....	....	....	....	....	....	....	....	....	2
	288′–150′	70′	3	....	....	....	....	....	....	....	....	....	1	2
	150′– 50′	55′	4	....	....	....	....	....	....	....	....	....	....	4

NOTE.—Brackets and insulators have not been included in the table. A strain insulator sufficient for the line voltage should be used for each pull-off.

"Where three or more tracks are equipped as on the New York, New Haven & Hartford Railroad, the trolley wire is generally supported from two catenary cables, which are carried on steel bridges, placed 300 feet apart. Heavier bridges are used at intervals to anchor the system, and views of one of these anchor bridges are shown in Figs. 34, 35, and 36."

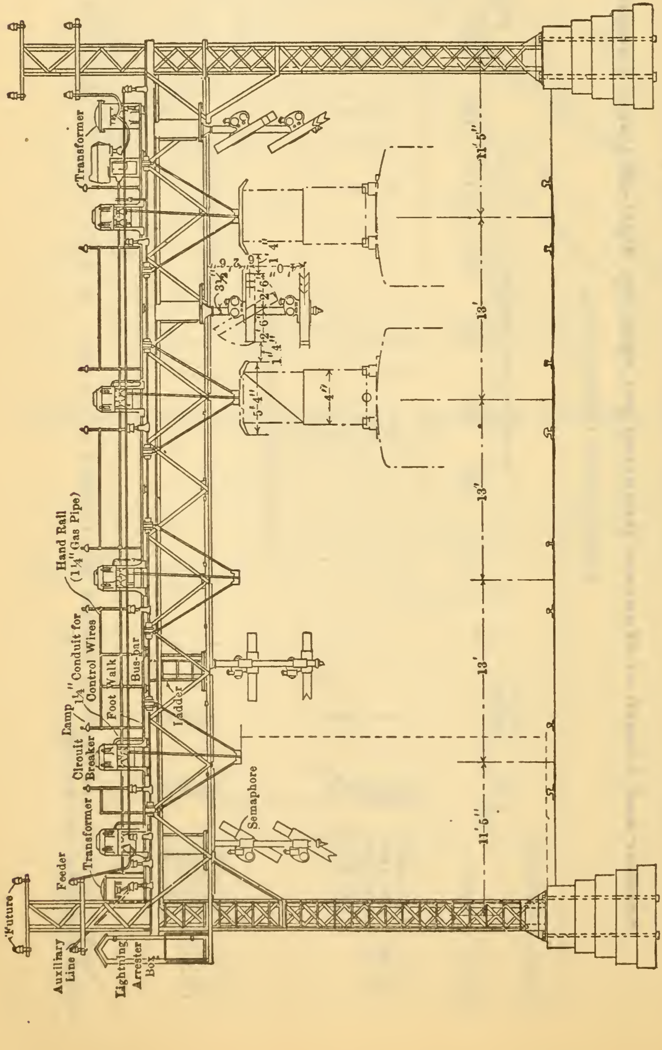


FIG. 34. Bridge Across Tracks for Supporting Catenary Hung Trolley, N.Y., N.H. & H. R.R.

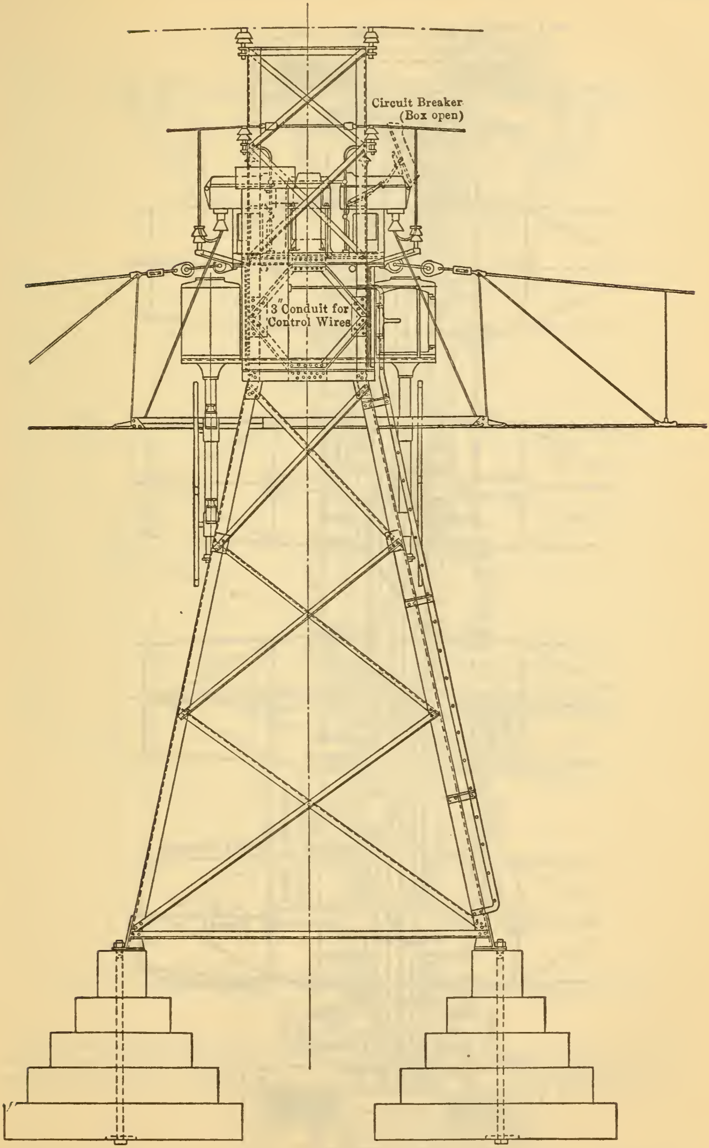


FIG. 35. End View of Bridge for Supporting Catenary Hung Trolley, N.Y., N.H. & H. R.R.

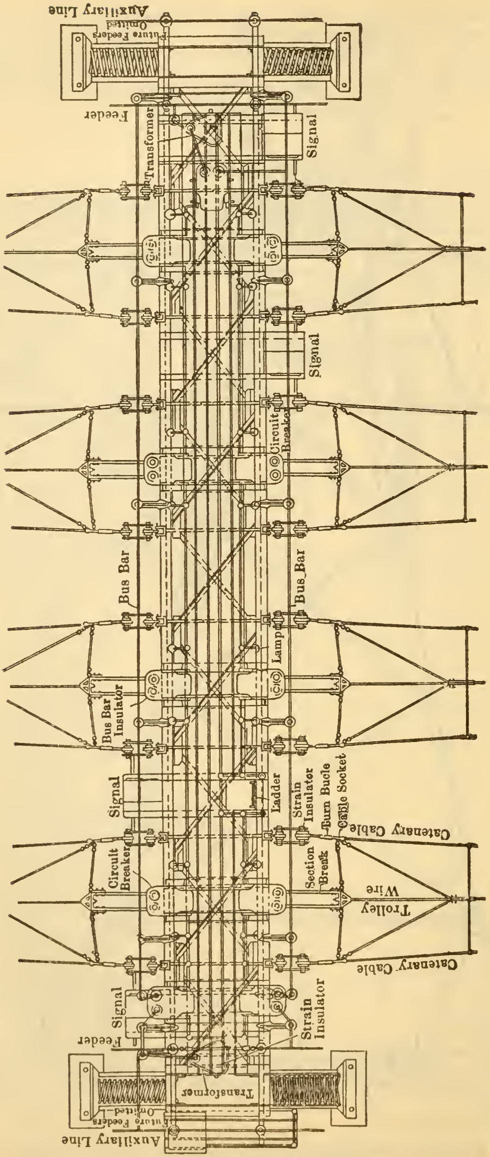


FIG. 36. Plan View of Bridge for Supporting Catenary Hung Trolley. N.Y., N.H. & H. R.R.

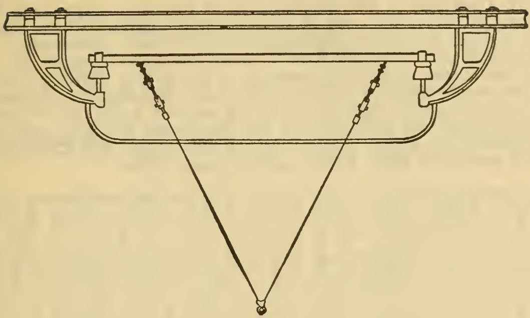


FIG. 37. Detail of Catenary Construction, Spendersfelds Line

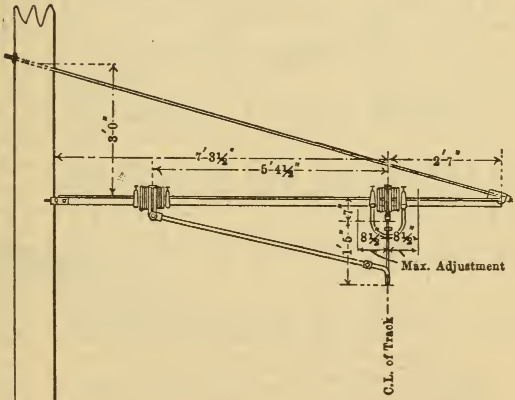


FIG. 38. T-Iron Bracket with Main Insulator and Steady Strain.

The future development of the A. C. motor is in no way handicapped by the ability of the trolley construction to withstand high potential, as A. C. trolleys have been worked successfully at 10,000 volts and 15,000 volts.

ENERGY CONSUMPTION.

Power Curves. — For convenience in quickly ascertaining the horsepower required to propel a car of known weight under known conditions of speed and grade, the curves shown below have been calculated.

The left-hand portion of the lower horizontal line represents the speed in miles per hour; the right-hand portion of same line, the h.p. per car; the oblique lines in left-hand side of cut, the per cent grade as marked on each line; the oblique lines on right-hand side of cut, the weight of car as marked; while the vertical line in center of cut represents the h.p. per ton. This curve is based upon a flat friction rate of 20 lbs. per ton (2000 lbs.) for all speeds and weight of cars, and is approximate only.

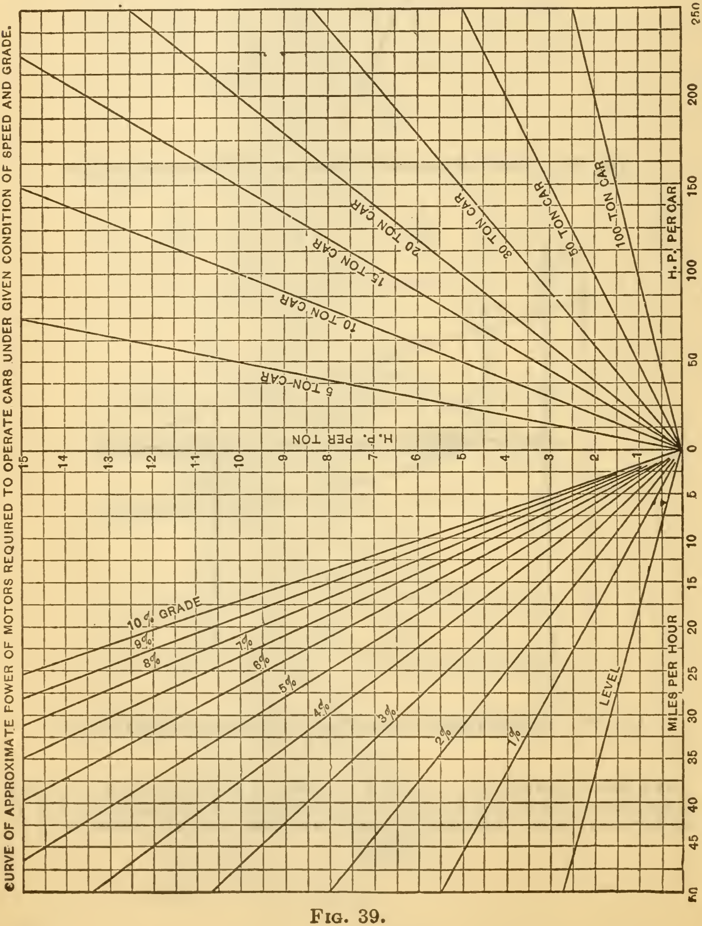


FIG. 39.

TABULATED CONSTANTS FOR DETERMINING THE HORSE-POWER OF TRACTION.

(Computed by W. F. D. Crane, M.E.)

Miles per Hour.	H on Levels. $K=10$	H′ on Grades — To be Added to Horse-Power on Levels.												
		1%	1½%	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%
¼	.00666	.01333	.0200	.0266	.0333	.0400	.0466	.0533	.0600	.0666	.0800	.0933	.1166	.1200
½	.01333	.0266	.0400	.0533	.0666	.0800	.0933	.1066	.1200	.1333	.1600	.1866	.2133	.2400
¾	.0200	.0400	.0600	.0800	.1000	.1200	.1400	.1600	.1800	.2000	.2400	.2800	.3200	.3600
1	.0266	.0533	.0800	.1066	.1333	.1600	.1866	.2133	.2400	.2666	.3200	.3733	.4266	.4800
1½	.0400	.0800	.1200	.1600	.2000	.2400	.2800	.3200	.3600	.4000	.4800	.5600	.6400	.7200
2	.0533	.1066	.1600	.2133	.2666	.3200	.3733	.4266	.4800	.5333	.6400	.7466	.8533	.9600
2½	.0666	.1333	.2000	.2666	.3333	.4000	.4866	.5333	.6000	.6666	.8000	9.333	1.066	1.200
3	.0800	.1600	.2400	.3200	.4000	.4800	.5600	.6400	.7200	.8000	.9600	1.120	1.280	1.440
3½	.0933	.1866	.2800	.3733	.4666	.5600	.6533	.7466	.8400	.9333	1.120	1.306	1.493	1.680
4	.1066	.2133	.3200	.4266	.5333	.6400	.7466	.8533	.9600	1.066	1.280	1.493	1.706	1.920
4½	.1200	.2400	.3600	.4800	.6000	.7200	.8400	.9600	1.080	1.200	1.440	1.680	1.920	2.160
5	.1333	.2666	.4000	.5333	.6666	.8000	.9333	1.066	1.200	1.333	1.600	1.866	2.133	2.400
5½	.1466	.2933	.4400	.5866	.7333	.8800	1.026	1.173	1.320	1.466	1.760	2.053	2.346	2.640
6	.1600	.3200	.4800	.6400	.8000	.9600	1.120	1.280	1.440	1.600	1.920	2.240	2.560	2.88
6½	.1733	.3466	.5200	.6933	.8666	1.040	1.213	1.386	1.560	1.733	2.080	2.426	2.773	3.120
7	.1866	.3733	.5600	.7466	.9333	1.120	1.3066	1.413	1.680	1.866	2.240	2.613	2.986	3.360
7½	.2000	.4000	.6000	.8000	1.000	1.200	1.400	1.600	1.800	2.000	2.400	2.800	3.200	3.600
8	.2133	.4266	.6400	.8533	1.066	1.280	1.493	1.706	1.920	2.133	2.560	2.986	3.413	3.840
8½	.2266	.4533	.6800	.9066	1.133	1.360	1.586	1.813	2.040	2.266	2.720	3.173	3.626	4.080
9	.2400	.4800	.7200	.9600	1.200	1.440	1.680	1.920	2.160	2.400	2.880	3.360	3.840	4.320
10	.2666	.5333	.8000	1.066	1.333	1.600	1.866	2.133	2.400	2.666	3.200	3.733	4.266	4.800
11	.2933	.5866	.8800	1.173	1.466	1.760	2.053	2.346	2.640	2.933	3.520	4.106	4.693	5.280
12	.3200	.6400	.9600	1.280	1.600	1.920	2.240	2.560	2.880	3.200	3.840	4.480	5.120	5.700
13	.3466	.6933	1.040	1.3866	1.733	2.080	2.426	2.773	3.120	3.466	4.160	4.853	6.346	6.240
14	.3733	.7466	1.120	1.493	1.866	2.240	2.663	2.986	3.360	3.733	4.480	5.226	5.973	6.72
15	.4000	.8000	1.200	1.600	2.000	2.400	2.800	3.200	3.600	4.000	4.800	5.600	6.400	7.200

H. P. $= \frac{Wn}{375}(K \pm 2000 \sin\theta)$. W = Load in tons. n = Speed in miles per hour,

$\doteq Wn \times .0026\frac{2}{3}(K \pm 2000 \sin\theta)$. K = Resistance in lbs. per ton. $K' = \frac{K}{10}$

H = Constants of power required to move ONE TON ON LEVEL at speeds in table with $K = 10$.

H' = Constants of ADDITIONAL POWER required to raise ONE TON ON GRADES and at speeds given.

$H \times WK'$ = H. P. required on LEVELS alone for speeds given.

$H' \times W$ = H. P. additional on GRADES alone for speeds and % given.

$W(K'H \pm H')$ = total H. P. required.

Example: Given a motor car, total weight 9 tons, to ascend a 7 per cent grade at a speed of six miles per hour. What is the estimated horse-power required, with $K = 30$ lbs.?

H for 6 miles per hour is .16, which, multiplied by $9 \times \frac{30}{10}$, = 4.32 h.p., in overcoming the track resistances alone.

$H' = 2.240$, which, multiplied by 9, = 20.16. The sum of the two will give the total theoretical, i.e., 24.48 h.p. required. Allowing 50 per cent as the combined efficiency of motors and gearing, to operate this car would require a draft of 48.96 h. p. upon the line.

HORSE-POWER OF TRACTION. (Davis.)

Per Cent Grade.	Speed in Miles per Hour.												
	4	6	8	10	12	15	20	25	30	35	40	50	60
	Horse-Power Required to Propel One Ton at Various Speeds up Various Grades.												
0	.32	.48	.64	.80	.96	1.20	1.60	2.00	2.40	2.80	3.20	4.00	4.80
1	.53	.80	1.07	1.33	1.60	2.00	2.66	3.33	4.00	4.66			
2	.74	1.12	1.49	1.87	2.24	2.80	3.63	4.66	5.60				
3	.93	1.44	1.92	2.40	2.88	3.60	4.80	6.00					
4	1.17	1.76	2.34	2.93	3.52	4.40	5.47						
5	1.39	2.08	2.77	3.46	4.16	5.20							
6	1.60	2.40	3.20	4.00	4.80								
7	1.86	2.72	3.62	4.53									
8	2.02	3.04	4.05										
9	2.24	3.36	4.48										
10	2.47	3.68	4.90										
11	2.67	4.00											
12	2.88	4.32											
13	3.09												
14	3.29												
15	3.52												

NOTE No. 1. — The h.p. required to propel a car equals the total weight of car plus its load (in tons) multiplied by the h.p. in table corresponding to assumed grade and speed.

STREET RAILWAY.

Tractive Force.

F. E. Idell, M. E.

On Good Track. — To start car . . . . 116 lbs. per ton.
To keep in motion at 6 miles per hr. 15.6 lbs. per ton.

On Bad Track. — To start car . . . . 135 lbs. per ton.
To keep in motion . . . . 32 lbs. per ton.

On Curves. — To start car from 0 to 6 miles per hour . 284 lbs. per ton.
average, 264 feet per minute.

TRACTION.

(Davis.)

Per cent Grade.	Tractive Force in Pounds per Ton.	Load of Trailer Cars in Tons which a Motor Car of one Ton will Haul.		
		Snowy Rail.	Wet Rail.	Dry Rail.
0	30	8.50	12.33	16.00
1	50	4.70	7.00	9.00
2	70	3.07	4.21	6.14
3	90	2.17	3.44	4.55
4	110	1.60	2.63	3.54
5	130	1.19	2.07	2.84
6	150	0.90	1.66	2.33
7	170	0.70	1.35	2.00
8	190	0.50	1.10	1.63
9	210	0.35	0.90	1.38
10	230	0.24	0.74	1.17
11	250	0.14	0.60	1.00
12	270	0.05	0.48	0.85
13	290	Wheels slip.	0.38	0.77
14	310	...	0.30	0.61
15	330	...	0.21	0.51
16	350	...	0.14	0.43
17	370	...	0.08	0.35
18	390	...	0.02	0.28
19	410	...	Wheels slip.	0.22
20	430	...	...	0.16
21	450	...	...	0.11
22	470	...	...	0.06
23	490	...	...	Wheels slip.

NOTE No. 1.—Multiply figures in table by weight of motor car (in tons) to get weight of trailer (in tons) that said motor car will haul up corresponding grades.

REVOLUTIONS PER MINUTE OF VARIOUS SIZED WHEELS TO MAKE VARIOUS SPEEDS.

Diameter of Wheel.	Miles per Hour.									
	2	4	6	8	10	15	20	25	30	40
	Feet per Minute.									
	176	352	528	704	880	1320	1760	2200	2640	3520
24 in.	28	56	84	112	140	210	280	350	420	560
26 in.	26	52	78	103	129	194	258	323	388	517
28 in.	24	48	72	96	120	180	240	300	360	480
30 in.	22	45	67	90	112	168	224	280	336	448
33 in.	20	41	61	82	102	153	204	255	306	408
36 in.	19	37	56	75	93	140	187	234	280	374
42 in.	16	32	48	64	80	120	160	200	240	320

POWER REQUIRED FOR DOUBLE AND SINGLE TRUCK CARS.

Wattmeter placed on car. (McCulloch.)

	Average Watts.	Average Watt-hours per Car-mile.	Average Speed. Miles per Hour.	Average Watts, per Seat Capacity.	Average Watts per Ton (car empty).	Average Watt-hours per Car Mile per 1000 Passengers.
Double-truck car. Seats 36; weight, 11.75, tons; average for entire day	12040	1334	9.03	335	1025	5.9
Same as above. Average for heaviest trip . . .	13080	1412	9.25	335	1025	—
Single-truck car, no trailer. Seats 28; weight, 8 tons	8471	921	9.20	303	1060	—
Single-truck car. Trailers operated 26% of the time. Average for the entire day	9400	1110	8.42	254	1088	7.9
Single-truck motor and open trailer. Seats, 63; weight, 10.5 tons. Average for heaviest trip	12680	1440	8.84	201	1208	—

Memo for Determination of Power Required for Operation of Street Railways.

$$\text{H.P.} = \frac{\text{Pounds torque} \times \text{R.P.M.}}{5252}.$$

$$\text{H.P.} = \frac{\text{Pounds tractive effort} \times \text{M.P.H.}}{375}.$$

$$\left.\begin{array}{l}\text{Pounds}\\ \text{tractive}\\ \text{effort}\end{array}\right\} = \frac{\text{Number gear teeth} \times 24 \times \text{gear efficiency} \times \text{pounds torque}}{\text{Number pinion teeth} \times \text{inches diameter of wheels.}}.$$

$$\left.\begin{array}{c}\text{Miles}\\ \text{Per Hour.}\end{array}\right\} = \frac{\text{Inch diameter of wheels} \times \text{number pinion teeth} \times \text{R.P.M.}}{336 \times \text{number gear teeth}}.$$

Assumed—3 miles per hour speed on curve, 4 ft. 8½ in. gauge.

TRACTIVE EFFORT ON GRADES.

Pounds per Ton for 15 Ton Car.

Grade. Per Ct.	Speed — Miles per Hour.									
	2	4	6	8	10	12	14	16	18	20
0	15.03	15.11	15.24	15.42	15.66	15.95	16.29	16.69	17.14	17.64
1	35.03	35.11	35.24	35.42	35.66	35.95	36.29	36.69	37.14	37.64
1½	45.03	45.11	45.24	45.42	45.66	45.95	46.29	46.69	47.14	47.64
2	55 03	55.11	55.24	55.42	55.66	55.95	56.29	56.69	57.14	57.64
2½	65.03	65.11	65.24	65.42	65.66	65.95	66.26	66.69	67.14	67.64
3	75.03	75.11	75.24	75.42	75.66	75.95	76.29	76.69	77.14	77.64
3½	85.03	85.11	85.24	85.42	85.66	85.95	86.29	86.69	87.14	87.64
4	95.03	95.11	95.24	95.42	95.66	95.95	96.29	96.69	97.14	97.64
5	115.03	115.11	115.24	115.42	115.66	115.95	116.29	116.69	117.14	117.64
6	135.03	135.11	135.24	135.42	135.66	135.95	136.29	136.69	137.14	137.64
7	155.03	155.11	155.24	155.42	155.66	155.95	156.29	156.69	157.14	157.64
8	175.02	175.11	175.24	175.42	175.66	175.95	176.29	176.69	177.14	177.64
9	195.03	195.11	195.24	195.42	195.66	195.95	196.29	196.69	197.14	197.64
10	215.03	215.11	215.24	215.42	215.66	215.95	216.29	216.69	217.14	217.64

KILOWATTS ON GRADES.

15 Ton Car. Energy Measured Input to Car.

Grade Per Cent.	Speed — Miles per Hour.									
	2	4	6	8	10	12	14	16	18	20
0	1.09	2.19	3.31	4.45	5.67	6.92	8.25	9.65	11.15	12.75
1	2.54	5.07	7.65	10.25	12.90	15.60	18.35	21.20	24.10	27.20
1½	3.26	6.52	9.80	13.15	16.50	19.90	23.42	27.00	30.62	34.40
2	3.98	7.96	12.00	16.09	20.10	24.22	28.50	32.80	37.20	41.70
2½	4.71	9.41	14.15	18.90	23.70	28.60	33.60	38.50	43.70	48.90
3	5.43	10.85	16.30	21.80	27.30	32.90	38.60	44.30	50.20	56.20
3½	6.15	12.30	18.50	24.70	30.90	37.22	43.70	50.10	56.70	63.30
4	6.87	13.75	20.70	27.60	34.60	41.60	48.70	55.80	63.20	70.60
5	8.32	16.65	25.00	33.40	41.80	50.30	58.90	67.40	76.20	85.00
6	9.77	19.60	29.40	39.20	49.10	58.90	69.10	78.00	89.30	99.40
7	11.20	21.48	33.80	45.00	56.30	67.60	79.20	90.50	102.50	114.00
8	12.65	25.30	38.10	50.80	63.50	76.30	89.30	102.20	115.30	128.50
9	14.10	28.30	42.50	56.50	70.70	85.00	99.40	113.80	128.50	143.00
10	15.56	31.10	46.70	62.10	78.30	95.10	109.80	125.8	141.50	157.20

The above table is based upon an average efficiency of 83 per cent for the motor equipment. This efficiency is assumed flat for all loads, hence giving values slightly high for the low kilowatt car inputs and slightly low for the heavier inputs.

Power Consumption. Schedule Speed 25 M.P.H. 35 Ton Car.

Stops per Mile.	Kilowatts.	Maximum Speed.	Total Motor Capacity.
0	29	25 m.p.h.	143
.2	35	29	175
.4	44	31	186
.6	51	33	207
.8	63	37	245
1.0	79	43	301
1.2	100	51	395

The energy values given in above table represent input to the car not including any line losses. The maximum speed values represent maximum speed reached during the run. Motor capacity is based upon a temperature rise of 60° C., above surrounding air, taken at 25° C., after a full days' run at the schedule of 25 miles per hour noted.

Possible Schedule with 45 M.P.H. Maximum Speed with Varying Frequency of Stops. 35 Ton Car.

Schedule Speed.	Kw. Input.	Number Stops per Mile.
45	106	0
40	101	.18
35	97	.40
30	93	.70
25	87.5	1.08
20	84.	1.80

NO. OF CARS ON TEN MILES OF TRACK, VARIOUS SPEEDS AND HEADWAYS.

Minutes Apart or H'dway.	Average Speed in Miles per Hour.									
	6	7	8	9	10	12	15	20	25	30
1	100	86	75	67	60	50	40	30	24	20
2	50	44	38	33	30	25	20	15	12	10
3	33	29	25	22	20	17	13	10	8	7
4	25	22	19	14	15	13	10	8	6	5
5	20	17	15	13	12	10	8	6	5	4
6	17	14	13	11	10	8	7	5	4	3
7	14	12	11	10	9	7	6	4	3	3
8	13	11	9	8	8	6	5	4	3	3
10	10	9	8	7	6	5	4	3	2	2
15	7	6	5	4	4	3	3	2	2	1
20	5	4	4	3	3	3	2	2	1	1
30	3	3	3	2	2	2	1	1	1	1

NOTE.—Fractions above one-half are considered whole numbers, and fractions below one-half are neglected.

To obtain the number of cars required to operate any length road, divide the number found in the table under the desired average speed and headway by ten, and multiply by the length of the road in question. Should it

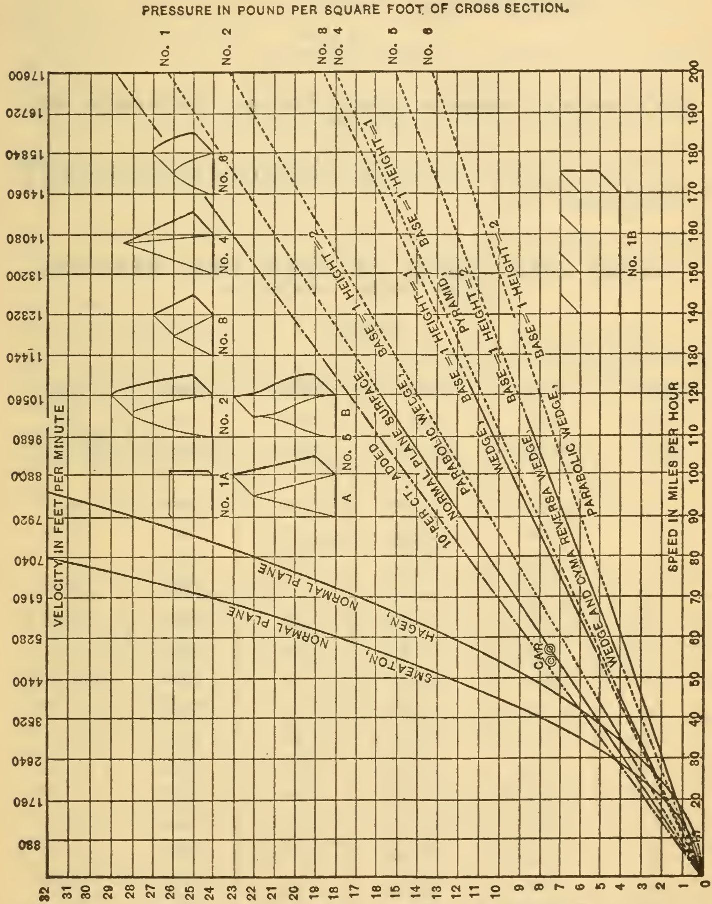


FIG. 40. "Effect of Shape of Moving Body on Air Resistance," Crosby's Experiments.

be desired to run at different average speeds on various portions of the road, treat each portion as a separate road, and add the results together. To the number of cars thus obtained should be added 20 per cent for reserve for roads under 20 cars. For roads over 20 cars, 10 per cent reserve will be enough.

Formula: —

Let n = number of cars required.
m = miles of track.
S = average speeds in miles per hour.
I = interval or headway in minutes.

Then, $$n = \frac{m \times 60}{S \times I}.$$

HEADWAY, SPEED, AND TOTAL NUMBER OF CARS.

Total number of cars on a given length of street on which cars are running both ways = (length of street × 120) ÷ (headway in minutes × speed in miles per hour).

MILES PER HOUR IN FEET PER MINUTE AND PER SECOND.

(Merrill.)

Miles per Hour.	Feet per Minute.	Feet per Second.	Miles per Hour.	Feet per Minute.	Feet per Second.
1	88	1.46	16	1408	23.47
2	176	2.94	17	1496	24.93
3	264	4.4	18	1584	26.4
4	352	5.87	19	1672	27.86
5	440	7.33	20	1760	29.33
6	548	8.8	21	1848	30.8
7	616	10.26	22	1936	32.26
8	704	11.73	23	2024	33.72
9	792	13.2	24	2112	35.2
10	880	14.67	25	2200	36.67
11	968	16.13	26	2288	38.14
12	1056	17.6	27	2376	39.6
13	1144	19.07	28	2464	41.04
14	1232	20.52	29	2552	42.50
15	1320	22	30	2640	44

RATING STREET-RAILWAY MOTORS.

(Condensed from W. B. Potter in Street Railway Journal.)

Rise of temperature after one hour's run under rated full load not to exceed 75° C.; room being assumed at 25° C. Average load for a day's run should not exceed 30 per cent of its rated full load, which will give a rise of temperature of about 60° C.

The above ratings are based on a line potential of 500 volts, but the average performance can generally be increased in proportion to the increase in line voltage; that is, a motor will do approximately 10 per cent heavier service for the same temperature rise when operated at 550 volts.

With electric brakes, motors must have increased capacity, as heating increases 20 to 25 per cent. The 20 per cent increase is on roads having few grades and stops, while the 25 per cent is on hilly roads with frequent stops.

Approximate rated horse-power of motors =

$$\frac{(\text{total weight of car in tons}) \times (\text{max. speed in miles per hour on level})}{5}.$$

For equipments with electric brakes, divide by 4 instead of 5. When maximum speed is not known, it may be assumed as twice the schedule speed.

Example 1:

$$\frac{20 \text{ ton car (loaded)} \times 50 \text{ m. p. h.}}{5} = 200 \text{ h. p., or four } 50 \text{ h. p. motors.}$$

In this case, if the line pressure were raised to 600 volts, electric brakes could be used on the equipment by changing the gear ratio so as to have the same maximum speed.

Example 2:

$$\frac{11 \text{ ton car (loaded)} \times 25 \text{ m. p. h.}}{5} = 55 \text{ h. p., or two } 30 \text{ h. p. motors,}$$

These rules indicate minimum capacity under ordinary conditions.

Tractive Effort.

Tractive effort is dependent on the rate of acceleration, grade, car friction, and air resistance, which latter is ordinarily included in friction. Acceleration is expressed in miles an hour per sec. 1 mile per hour per sec. = 1.466 feet per sec. Excluding car friction, a tractive effort of 92⅓ lbs. per ton (2000) will produce an acceleration of 1 mile per hour per sec. on a level track, and the rate of acceleration will vary in direct proportion to the amount of tractive effort. On ordinary street cars, tractive effort during acceleration often rises to 200 or 300 lbs. per ton.

On elevated or suburban roads the maximum tractive effort is generally 100 to 150 lbs. per ton. For heavy freight work with slow speeds, the tractive effort seldom exceeds 30 to 40 lbs. per ton.

Grades are commonly expressed in percentage of feet rise in 100 feet of distance, and tractive effort for a grade is the same percentage of the weight to be drawn as the rise is of the length of 100 feet. For instance, the tractive effort for a weight of one ton (2000 lbs.) up a grade of 3 per cent would be 3 per cent of 2000 lbs., or 60 lbs. For the total tractive effort there must be added to this, the effort for overcoming the car, wind, and rolling friction on a level.

Average tractive efforts from numerous tests are shown in the following table:

	Tractive effort in lbs. per ton.
15 ton car, up to 25 m. p. h.	25
" " " " " 50 " " "	50
25 " " " " 25 " " "	20
" " " " " 50 " " "	25
100 " train " " 25 " " "	15
Heavy freight train up to 25 m. p. h.	6 to 10.

The above rates have to be increased for snow and ice on the track.

Tractive Coefficient.

This coefficient is usually expressed as the ratio between the weight on the driving-wheels and the tractive effort, and varies largely with the condition of the rails.

In train work, the weight on drivers should be six times the tractive effort.

Example: — Required the weight of a locomotive to draw a 100-ton train up a 2 per cent grade.

For train.

100 tons × 15 lbs. for friction =	1500 lbs.
" " × 40 " " grade =	4000 "
	5500 lbs.

Assume a 20-ton locomotive.

20 tons × 15 lbs. for friction =	300 lbs.
20 " × 40 " " grade =	800 "
Total tractive effort,	6600 lbs.

6600 lbs. equals 16.5 per cent of 20 tons, or a tractive coefficient of 16.5 per cent. Starting the train on a 2 per cent grade with acceleration of $\frac{1}{3}$ m. p. h. per sec. would mean additional tractive effort equivalent to $\frac{91.1}{3} = 30.4$ lbs. per ton.

This would add to the requirements as follows:

Train 100 tons, for friction and grade as above . . .	5500 lbs.
" " " at 30.4 lbs. for acceleration	3040 "
Total for train	8540 lbs.

Assume 35-ton locomotive with motors on all axles.

35 tons at 15 lbs. for friction	525 lbs.
" " " 40 " " grade	1400 "
" " " 30.4 for acceleration	1064 "
Total tractive effort . . .	11529 lbs.

or a tractive coefficient of 16.5 per cent for the 35-ton locomotive.

Tests show the following tractive coefficients:

	per cent.	Sanded per cent.
Dry rail	28	30
Thoroughly wet rail	20	25
Greasy moist rail .	15	25

With ice and snow on the track, the coefficient is lower, and the rolling-friction higher.

Average energy. — Approximate capacity of a power station may be assumed as about 100 watt-hours per ton mile of schedule speed for ordinary conditions of city and suburban service.

Example: — 15-ton car, 12 miles per hour schedule,

k.w. at station = 100 × 15 × 12 = 18 k.w.

If stops are a mile or more apart, only 60 to 70 watt-hours may be necessary.

Frequent stops and high schedule speeds take 120 or more watt-hours.

The following table of efficiencies will be found convenient in estimating the power required for operation of motor cars, using three-phase transmission and direct current motors. The efficiencies would vary somewhat with the load factor, but can be taken as generally applicable.

Considering the I.H.P. of the engine as a basis, for the

Average efficiency of engine	90 per cent.
" " " generator	94 " "
" " " high potential lines	95 " "
" " " substations	90 " "
" " " direct current lines	92 " "
" " " motors, including losses of control	72 " "
Combined efficiency of the motors and series parallel control during period of cutting out the controller may be taken as	63 " "
Efficiency of motors after cutting out the controller, depending on size of motors	80 to 85 per cent.

TRAIN PERFORMANCE DIAGRAMS.

In order to accurately ascertain the power required to operate a given railway system it is necessary to analyze the performance of its trains or other units of transportation. This is best done by constructing train performance diagrams. Such diagrams may be constructed for a desired schedule and other data, in order to determine the size and type of motor best adapted to the purpose; or they may be made up from the characteristic curves of a given motor, to determine if that particular motor will fit the case in point, or just what will be the result from its use. Such diagrams are also useful in predetermining the heating effect upon the motors.

The diagram ordinarily includes:

Speed-time curve.
Distance-time curve.
Current curve.
Voltage curve and
Power or kilowatt curve.

While it is possible to construct a performance diagram for a given line of road, this diagram must be based upon the characteristics of some known motor, and it is necessary therefore that the schedule be stated, and requirements as to heating and economy be given and that motors to produce these results be designed by makers of such apparatus — or that motors from their standard designs be selected, which come nearest to fitting the requirements of the case; and in determining this fitness, performance diagrams can be constructed from the known characteristics of the motor selected.

In stating the conditions it is obvious that profile and contour maps of the road must be had in order to determine the effect of grades and curves.

In describing the method of laying out these curves, the first case given will be based upon a straight and level track and the simplest possible conditions, and a second example will be shown which includes grades and curves.

Figure 42 is a diagram of train performance, which shows the speed-time curve, distance-time curve, and the current curve, as well as the schedule required, and the distance between stops. This diagram is simply typical, to indicate methods.

Figure 41 is a typical Railway Motor characteristic, and for simplicity shows but two curves, that of tractive-effort and of speed, the speed being given in miles per hour and the tractive-effort in pounds draw-bar pull for 33-inch wheels and gear ratio 3.09. The ampere consumption at the different rates of speed is also given. Unless armature revolutions instead of speed in miles per hour be used, it always will be necessary to state the diameter of wheel and the gear ratio.

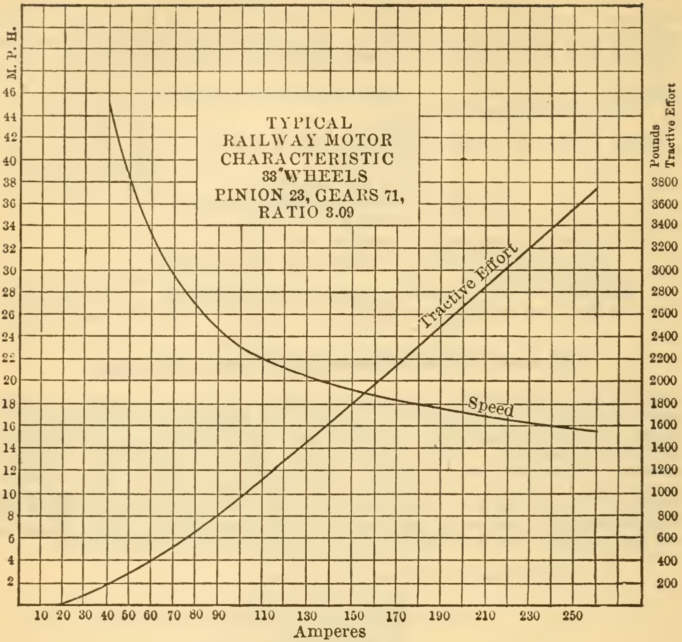


FIG. 41.

Acceleration. — Acceleration is the time rate of velocity and is produced by the application of force. The application of a constant force will tend to result in constant acceleration. The force of gravity will accelerate a falling body 32.2 feet per second. The relation of acceleration to train performance will be shown by the following formula: Let

T = the total tractive-effort or force applied in pounds.
t = tractive effort in pounds per ton due to train resistance.
a = acceleration in miles per hour per second, covering all train and motor friction.
W = weight in tons being accelerated.
w = weight in tons being accelerated plus 10 per cent for fly-wheel effect.

$$1.467 = \frac{5280 \text{ feet per mile}}{3600 \text{ seconds in an hour}}.$$

$$91.1 = \frac{1.467 \times 2000}{32.2}.$$

Then,

$$T = (91.1\,aW) + tW$$

$$a = \frac{T - tW}{91.1\,W}.$$

If the fly-wheel effect be considered, then

$$T = (91.1\,aw) + tW;$$

$$a = \frac{T - tW}{91.1\,w}.$$

Grades. — A grade of one per cent means a change in altitude of one foot for each 100 feet of track on the grade, and this is equivalent to a tractive force of 20 pounds per ton, which will be positive, or to be added to the tractive effort per ton, if the train is going up grade; or to be deducted from the same if the train is on down grade. Then if g = grade per cent $\times$ 20 the formula becomes

$$T = (91.1\ aw) + (t \pm g)\ W \quad \text{and}$$

$$a = \frac{T - (t \pm g)\ W}{91.1\ w.}.$$

Curves. — Values of railway curves are expressed in terms of the central angle subtended by a chord 100 feet long; thus a one degree curve means one such that the angle at the center end of the radius will be one degree, or a radius of 5730 feet, thus

$$\text{degre} = \frac{5730}{\text{radius in feet}}.$$

Experiment shows that the effect of curves is to introduce a resistance of about .6 pound per ton per degree of curve; thus a two degree curve will require a tractive effort of 1.2 pounds per ton of train to overcome the resistance.

If c = tractive effort of a curve at d, degrees, the formula will become

$$T = (91.1\ aW) + (t + c)\ W;$$

$$a = \frac{T - (t + c)\ W}{91.1\ w.}.$$

A combination of a grade and a curve will make the formula:

$$T = (91.1\ aW) + (t + c \pm g)\ W;$$

$$a = \frac{T - (t + c \pm g)\ W}{91.1\ w}.$$

The use of the polar planimeter will very much facilitate the construction of these diagrams.

The method of constructing the speed-time curve as described below is about as simple as can be made and was used by Mr. H. N. Latey in laying out the work of the Interborough Company in New York.

For purpose of explanation the following example of train performance is given:

Example 1. For Train Performance Diagram.

Train	3 motor cars, 2 trail cars.
Schedule	20 miles per hour.
Stops	2 per mile.
Acceleration	a = 1.25 m.p.h. per second.
Braking	b = 1.5 m.p.h. per second.
Tractive effort	t = 13 pounds per ton of train.
Fly-wheel effect	10 per cent of train weight.
Motors	4 for each motor car.
Motor cars	weigh 60,000 pounds each.
Trail cars	weigh 40,000 pounds each.
Weight of train	W = 130 tons.
Fly-wheel effect	= 13 tons
Total	= 143 tons.
Weight on drivers	all motor cars = 180,000 pounds.
Tractive effort	due to weight on drivers 18 % = 32,400 lbs.

Tractive effort, $T = (a \times w \times 91.1) + tW$,
or, $T = (1.25 \times 143 \times 91.1) + 13 \times 130 = 17{,}974$ lbs.
and T per motor = 17974 ÷ 12 = 1498 lbs.

From motor curve, Fig. 41, 1498 lbs. = 20 miles per hour at a = 1.25. 20 miles per hour at 1.25 miles per hour per second is the first point p on curve

Other points, p_1, p_2, p_3, etc., are determined by the formula,
$a = \frac{T - tW}{91.1\,w}$, where T is taken from the motor curve at the miles per hour the train is moving.

Then, let $T - tW = B$, and $a = \frac{B}{13027}$, from which the following table may be constructed for the diagrams:

Table I.

M.P.H.	T.	Motors	T.	tW	B	a
T at 20 =	1498 lbs.	× 12 =	17974	− 1690 =	16284 =	1.250
" 22 =	1100 "	× 12 =	13200	− 1690 =	11510 =	.840
" 24 =	840 "	× 12 =	10080	− 1690 =	8390 =	.644
" 26 =	700 "	× 12 =	8400	− 1690 =	6710 =	.515
" 28 =	590 "	× 12 =	7080	− 1690 =	5390 =	.414
" 30 =	500 "	× 12 =	6000	− 1690 =	4310 =	.331
" 32 =	420 "	× 12 =	5040	− 1690 =	3053 =	.257

$$\text{Coasting after shutting off current} = -\frac{tW}{91.1\,w}$$

or

$$\frac{13 \times 130}{91.1 \times 143} = \frac{1690}{13027} = -.129 \text{ m.p.h. per second.}$$

Table II.

Amperes per motor.		Amperes per train.
at 20 m.p.h.	= 134 × 12 =	1608
22 "	= 108 × 12 =	1296
24 "	= 93 × 12 =	1116
26 "	= 83 × 12 =	996
28 "	= 75 × 12 =	900
30 "	= 68 × 12 =	816
32 "	= 62 × 12 =	744

Construction of Speed-Time Curve. — An inspection of Fig. 42 will show that the speed-time curve is divided into four parts: (a) the acceleration due to starting the motors and bringing the train up to the speed that will be given by cutting out all resistance, and leaving them in multiple connection. This is shown on the diagram by *o.P.* (b) the acceleration in multiple, running from *P* to *s;* (c) at which point the current is cut off and the train allowed to coast for the distance indicated between *s* and *n*; and (*d*), where brakes are applied, and from *n* to *g* the curve is diagonally downward, assuming that the train retards at a regular rate, which obviously is never the case, but is near enough so to be indicated by the straight line as shown.

Referring to Fig. 42: The straight part of the curve, from *o* to *p*, is laid on the drawing at an angle determined by the rate of acceleration, which in this case is 1.25 miles per hour per second. The example shows that at this rate of acceleration and for the weight of train given, and at a tractive effort of thirteen pounds per ton, a total tractive effort per motor of 1498 pounds will be necessary, and by reference to the curve of tractive effort in Fig. 41, it is found that 1498 pounds correspond to a speed of twenty miles per hour, which becomes the first point *P* on the acceleration curve. At this point the resistance of the controlling devices is all cut out and the motors are in multiple from this point on, to the point *s*. When the current is cut off for coasting, the speed will be accelerated at a gradually decreasing rate as shown. The lines between the points p, p_1, p_2 p_3 and p_4 represent the *average rate of acceleration* for speeds of 22–24–26–28 and 30 miles per hour, and in each case start from a point half way between the lines which

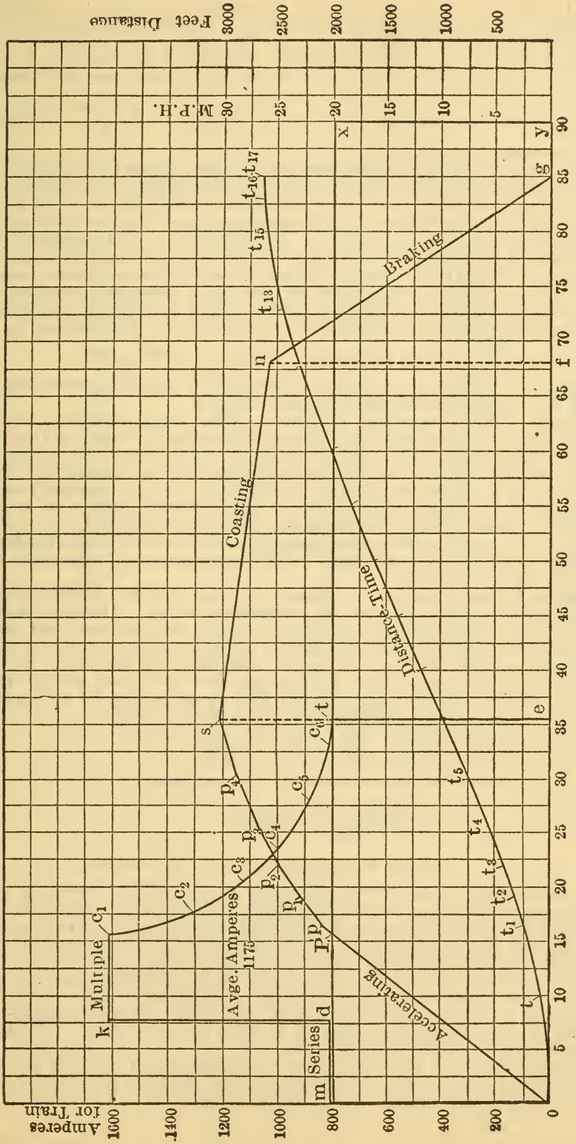


FIG. 42. DIAGRAM OF TRAIN PERFORMANCE STRAIGHT AND LEVEL TRACK

represent the rates of speed named, the acceleration curve o, p, being extended one-half of the speed interval selected, or to point p_1, the other sections being attached to the ends.

The angle of these lines is determined by the rate of acceleration for the intervals shown, and in this example is based upon rates of speed varying by intervals of two miles.

Table I has been calculated from the formula $a = \frac{T - tW}{91.1\,w}$, T being taken from curve sheet, Fig. 41.

An examination of Table I shows that at the rate of speed of 20 m.p.h., the rate of acceleration is 1.25 m.p.h. per second; at the average rate of 22 m.p.h., or from 21 miles to 23 miles, per hour, the rate of acceleration is .84 m.p.h. per second; at 24 m.p.h., or from 23 to 25 miles per hour, the rate of acceleration is .644 m.p.h. per second, etc., etc. In practical work intervals of one mile each should be taken, as the curve will then be more nearly correct.

Coasting.—At the point s current is cut off and the train allowed to coast to the point where brakes are applied and the train brought to rest at the point g, 85 seconds from the starting point o. The rate of retardation, or as it is sometimes called, deceleration a, of coasting is determined by the formula, $a = -\frac{tW}{91.1\,w}$, or in this case, — .129 m.p.h. per second.

Braking.—This line is laid on the sheet at an angle representing the rate of 1.5 m.p.h. per second stated in the example.

Locating the Coasting Line.—The area inclosed by the rectangle o, m, x, y, represents the distance traveled by train in the time shown, or a speed of twenty miles per hour, for a half mile, with a stop of 5 seconds duration. Therefore, the area inclosed by the speed-time curve o, p, s, n, g, must be equal to that of the rectangle o, m, x, y, which can be best determined by a polar-planimeter. The coasting line s, n is then adjusted up or down, always retaining the angle due to the rate of acceleration, until the area inclosed by the speed-time curve is the same as that of the rectangle. The maximum speed will then be shown by the point s, in this case 30.5 miles per hour.

Distance-Time Curve.—This curve should be plotted at the same time and in connection with the speed-time curve. Its value may be determined for as many points as desired, but it will be sufficient for all practical purposes if plotted for two second intervals at the start and at the end, as shown on Fig. 42, and at longer intervals, say 5 seconds for the straight part of the curve. The values may be calculated at any point along the speed-time curve and this has been done on Fig. 42, at the same points as were assumed for calculating the speed-time curve.

If D = distance from starting point in feet,

and d = distance in feet traversed in time t, then

$$d = \frac{5280\,vt}{3600} = 1.466\,vt,$$

and

$$D = d + d_1 + d_2 + d_3 + d_4, \text{ etc., etc.}$$

If the speed-time curve is very irregular it is more convenient to use a polar-planimeter in getting the average rate of speed, but in cases like that shown in Fig. 42, where the sections of the curve are drawn in straight lines, the average rate of speed will be at the center point of each section, and the time interval t is the time space covered between the ends of the section. For instance, to locate the first point on the distance-time curve at t, the average speed for the time interval of 10 seconds is $12.5 \div 2 = 6.25$, then $6.25 \times 10 \times 1.467 = 91$ feet and this value laid off on the sheet over the time 10 seconds, and at a value of 91 feet on the scale of "distance feet" shown at the right, gives the point t.

The average speed on the speed-time curve between 12.5 miles per hour and 21 miles per hour, is 16.75 miles per hour for the time interval t, between the two points shown, of 6.5 seconds; then $16.75 \times 6.5 \times 1.467 = 159$, and

$D = 91, + 159 = 250$, or the point t, on the distance-time curve. Again the average speed between the next two points p and p_1 is 22 miles per hour, and the time interval is 2.5 seconds, thus,

$$22 \times 2.5 \times 1.467 = 80 \text{ and } D = 250 + 80 = 330,$$

which is the location of point t_2.

The above described process is repeated to obtain each point on the curve. Table III has been constructed in this way in order to show the progressive value of D.

Great care should be exercised in plotting both speed-time and distance-time curves as errors of location are cumulative, and when many points are used the error at the end may throw the result quite out of line.

Table III. — Data For Distance-Time Curve.

Point Numbers.	v = Average Speed in M.P.H.	t = Time Interval.	Total Time from Start.	1.467 vt = Distance Intervals.	Total Distance in feet from Starting Point.
1	6.25	10	10	91	91.0
2	16.75	6.5	16.5	159	250
3	22	2.5	19	80	330
4	24	3.0	22	105	435
5	26	3.50	25.5	133	568
6	28	4.75	30.25	195	763
7	29.7	5.25	35.5	228	991
8	30	4.5	40	197	1188
9	29.5	5	45	215	1403
10	28.7	5	50	210	1613
11	28	5	55	204	1817
12	27.5	5	60	200	2017
13	26.7	5	65	195	2212
14	26.2	3	68	113	2325
15	22	5	73	158	2483
16	14.2	5	78	103	2586
17	6.7	5	83	48	2634
18	1.5	2	85	4	2638

Current Curve.— From the speed curve on Fig. 41, the current, taken at a speed of 20 miles per hour, is found to be 134 amperes, which for 12 motors will be 1608 amperes for the train. Point c is thus located, and the current taken with motors in multiple is twice that required for series running, which locates point d.

At 22 miles per hour the curve shows that the motor will require 108 amperes, or 1296 for the 12 motors, which locates point c. Table II gives the location of all the points on the current curve, having been made up from the curves on Fig. 41.

Voltage Curve. — It is only possible to plot this curve from actual test, though in estimating, it is common practice to assume an average voltage in order to work out the power curve.

Power or Kilowatt Curve. — This curve is plotted from a combination of the current curve and the voltage curve, the instantaneous values of each being multiplied to obtain the value of the power at the point taken. For simplicity neither of the last two curves are plotted here. In practice the kilowatt curve is ordinarily plotted by using the average line potential together with the current curve.

Example No. II. — This run is of the same length as that in Example No. I, i.e. one half mile, but instead of being all straight and level track, includes several grades and curves with a portion of track which is straight and level. At the right of Fig. 43 is shown the profile and contour of the line giving the length of each change, and opposite each section will be found the tractive effort per ton necessary to overcome the various conditions. thus: it requires 13 pounds per ton to overcome the train resistance on straight and level track; grades require an additional 20 pounds per ton for each per cent of change, and the values are shown in column g. In the

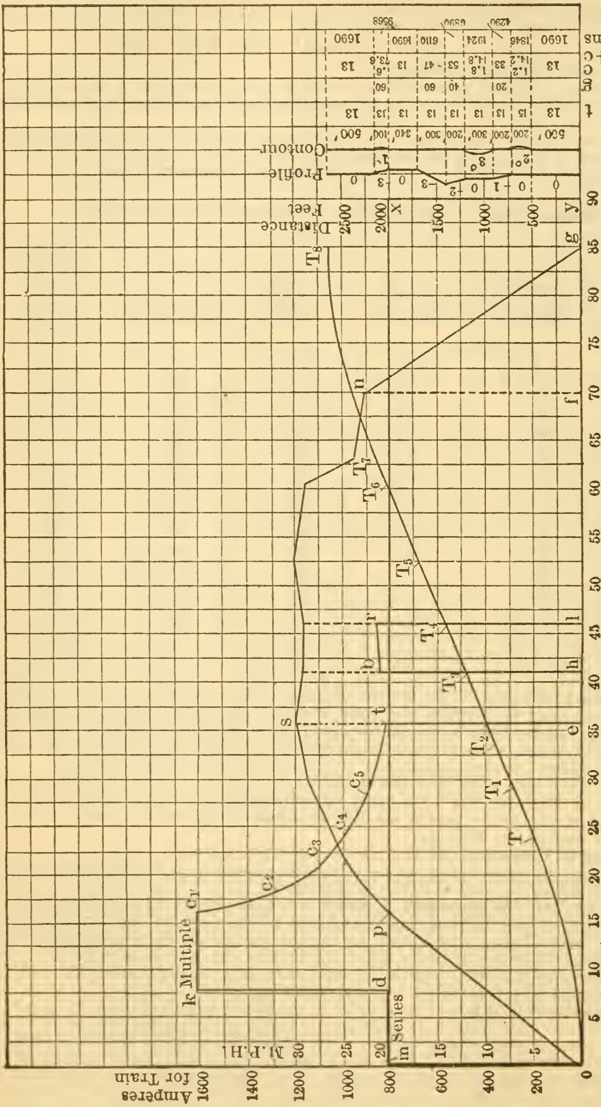


FIG. 43. DIAGRAM OF TRAIN PERFORMANCE.
RUN INCLUDES STRAIGHT AND LEVEL TRACK, GRADES AND CURVES.
ALL DATA SAME AS FOR FIG. 42.

third column are shown the various efforts per ton necessary to overcome the resistance of the curves, at the rate of .6 pounds per ton per degree. The fourth column shows the combined values of all the tractive efforts for each division of the run, and in the last column are given the total tractive effort for the train of 130 tons weight.

Table IV. — Data for Speed-Time Curve, Fig. 43.

M.P.H.	*T.* Per Motor.	No. Motors.	*T.* for Train.	*tW.*	*B.*	$a = \frac{B}{13027}$.
20	1498	12	17974	− 1690	16284	1.250
21	1300	"	15600	− 1690	13910	1.068
22	1100	"	13200	− 1690	11510	.883
23	960	"	11520	− 1690	9830	.754
24	870	"	10440	− 1690	8750	.672
25	760	"	9120	− 1690	7430	.570
26	700	"	8400	− 1690	6710	.515
27	640	"	7680	− 1846	5834	.448
28	580	"	6960	− 1846	5114	.393
28.5	560	"	6720	− 1846	4874	.375
28.7	550	"	6600	− 4290	2310	.177
29.7	500	"	6000	− 1924	4076	.313
...	...	...	Coast	− 1924	1924	− .148
29	540	"	6480	− 6890	− 410	− .032
	...	...	6110	− 1690	+ 4420	+ .340
	...	...	....	− 1690	− 1690	− .130
			Braking			− 2.05
			Coast	− 1690	− 1690	− .130
			Braking			− 1.5

Table V. — Data for Distance-Time Curve, Fig. 43.

Point Numbers.	*v.*	*t.*	Total Time from Start.	1.467 *vt* Distance Intervals.	Total Distance from Starting Point.
1	6.25	10.0	10.0	91	91
2	16.50	6.5	16.5	157	248
3	21.00	1.5	18.0	46	294
4	23.00	2.5	20.5	84	378
5	25.00	3.5	24.0	128	506
6	26.50	2.25	26.25	87	593
7	27.50	2.25	28.50	91	684
8	28.13	0.75	29.25	21	705
9	28.60	4.65	33.90	195	900
10	29.70	1.60	35.50	69	1969
11	28.70	5.50	41.00	238	1207
12	29.00	4.75	45.75	200	1407
13	28.70	7.15	52.90	300	1707
14	29.50	7.85	60.75	340	2047
15	27.50	2.5	63.25	100	2147
16	23.70	7.0	70.25	240	2387
17	18.75	5.0	75.25	148	2527
18	11.25	5.0	80.25	83.5	2610
19	3.75	5.0	85.25	28.5	2638

The speed-time curve on Fig. 43 is worked out in the same manner as that on Fig. 42, except that while the speed-time curve in Fig. 42 may be plotted without reference to the distance-time curve, in the case of Fig. 43, they both must be plotted together, as care must be taken that the speed-time curve is not carried beyond the point where the tractive effort, and, therefore, the acceleration changes, as at T, T_1, T_2, etc.

Table VI. — Current Data for Fig. 43.

M.P.H.	Amps. per Motor.	Amps. for Train. 12 Motors.
20	134	1608
22	108	1296
24	93	1116
26	83	996
28	75	900
30	68	816
29	71	852

Tables IV and V are made up as the plotting progresses, and in the former give the values of a at which to lay the speed-time curve, and in the latter show the distance D and the time t_1, being respectively the distance and time from the starting point o.

It requires considerably more care to work out one of these irregular curves for, while the method here explained is probably as short and as simple as any, yet it requires much cut-and-try to make the sections of the two curves fit for time and distance, and the location of the point s, at which current is cut off and coasting begins, requires experience and judgment, in order that the total area of the speed-time curve o, p, s, n, g, may equal that of the schedule o, m, x, y.

Both the previous examples have dealt with short runs where the motors are never left in circuit long enough to reach their speed and current limit. In case of long runs as on suburban lines, current is left on in full, and the train is accelerated until the values of $T = tW$, and B is therefore zero and there is neither acceleration or deceleration, the train moving forward at a level rate of speed, as the tractive effort is just enough to overcome the whole train resistance.

The values of T and tW will then only be varied by grades and curves, and the prolongation of the acceleration curve will have to be plotted to the point when coasting can begin in order to complete the time schedule. Of course if the track is straight and level, after $T = tW$, the speed-time curve will be straight and level to the coasting point s, and the current curve also will have reached a constant value and its curve will be a straight line until cut off for coasting.

Curves must be plotted for each run, then motors best adapted for all purposes can be selected and the amount of power needed and the best equipment for producing the same can be determined. After all points have been carefully considered, due attention must be given to future needs. and great care be taken that the equipment has not been worked up to so fine a point that no allowances have been made for the idiosyncrasies of the motorman who, in many cases, will entirely undo all the results of fine calculation.

Curves like that in Example II are seldom calculated as rolling-stock; being operated in both directions, grades practically neutralize each other, so that a curve like that in Example I for straight and level track is quite accurate enough for all practical purposes.

RATING THE CAPACITY OF RAILWAY MOTORS FROM PERFORMANCE CURVES.

The limiting condition in rating the capacity of a railway motor is the heat developed in its use.

When a motor is carrying any load, certain copper and iron losses take place in it, which depend upon the load. It is these losses, which appear as heat, that tend to raise the temperature of the windings. Thus a loss of three watts (neglecting radiation) will raise the temperature of one pound

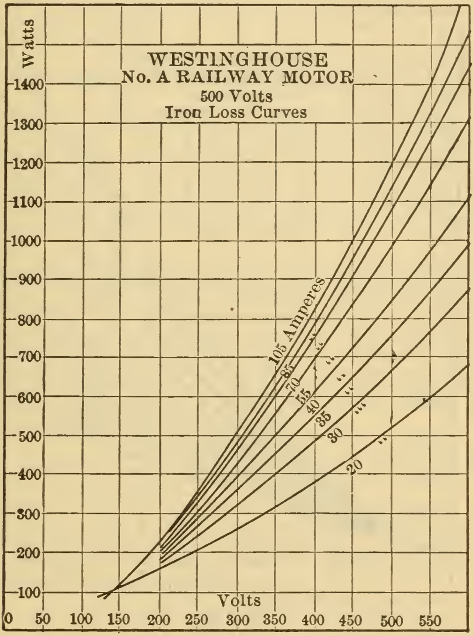


FIG. 44.

of copper approximately 1° C. per minute, or of one pound of iron approximately .8° C. per minute. The copper loss depends upon the current only, and is proportional to its square, but the iron, or core loss, depends upon both the current and the voltage and does not follow any simple law. The iron loss in the motors in question, when carrying any given current at any given voltage, is shown in Figs. 44 and 45. Its dependence on both current and voltage may be seen in Fig. 44, from the fact that 20 amperes at 500 volts produces the same loss as 105 amperes at 305 volts.

Owing to the great mass of metal in its frame, a motor has a considerable amount of heat-storage capacity. Instead of only a few hundred pounds of copper in the windings to be acted on, the temperature of the frame must also be raised; when cooling, the entire mass must cool off simultaneously.

That is, when the temperature of the windings is rising, that of the frame must also rise, and similarly when falling. The actual temperatures of the different parts may, of course, be widely different. Owing to this action, the temperature of the windings of the motor does not fluctuate in accordance with the instantaneous losses but rises at a fairly uniform rate depending on their average value.

The important factor as regards the effect of the service loads on the motors, provided that the maximum loads are within the proper limits, is thus the average value of the losses, averaged, of course, over the entire time of the cycle. It is evident that the average copper loss in any case is

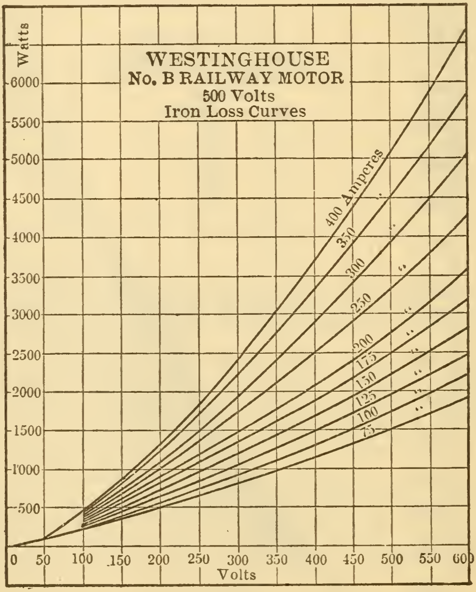


Fig. 45.

equal to that which would be produced by the continuous application of a current equal in value to the root mean square of the service currents. Thus, if this current and voltage is applied to the motor for the entire cycle, the average losses in the motors — both copper loss and iron loss — will have the same value and the same distribution as the losses due to the service loads. This voltage may be called the "equivalent" voltage of the service.

This method of equating the service loads on a railway motor to simple and intelligible terms was devised by Mr. N. W. Storer, of Pittsburg, and gives a convenient way of expressing the service capacity of railway motors in a usable manner.

The limiting capacity of any type of motor may be readily expressed by the manufacturer in terms of the current (root mean square) which it will carry continuously at various voltages (equivalent voltage) with a safe rise in temperature. In choosing a motor for a given service, the root mean square current and equivalent voltage can be calculated from the speed-time curves and a comparison of these results with the values allowable for the motor in question will determine its fitness. Where motors are already installed, the continuous equivalent of the service can be found by means of comparatively simple tests and the relation of the actual loads carried by the motors, to their safe capacity, thus determined.

It has been found that where the equivalent voltage is less than 300, a reduction of voltage, with the same current, makes but little difference in the temperature attained. Even when the equivalent voltage is changed from 300 to 400 volts only a comparatively slight reduction in current is necessary in order to maintain the same temperature rise. Thus the capacity need be stated at only one or two different voltages.

In many cases where tests or calculations are made to determine the approximate service loads on a motor, the average voltage at the motor terminals is a sufficient indication of the iron losses, and the equivalent voltage need not be determined.

An ammeter in the circuit of one motor and a voltmeter at the terminals of the same motor, read at suitable intervals during a typical round trip over a given route, will thus give sufficient data for determining the loads which a motor is carrying in service. From the current readings, the root mean square current can be found, and from the voltage readings, the average, or the equivalent voltage. The starting current is a most important factor in determining the copper loss, hence it is essential to get an accurate idea of this. On account of the rapid variations of the current while the car is starting and the short duration of the starting currents, readings should be taken at very close intervals, preferably at intervals of five seconds, or less, in order that the large currents used in starting may be duly represented in the results.

The capacity of a railway motor is expressed in two different ways:

1st Commercial Rating. — This is the horse-power output of the motor that will give a temperature rise of 75° C. above the surrounding air after a run of one hour. It also is about the maximum momentary output which the motor is called upon to deliver in service. The commercial or horse-power rating of a motor does not indicate its capacity to do work in regular operation where the demands upon the motive power are very irregular; hence there has arisen the need of a service rating by means of which the proper motor can be selected for a given service without the necessity of going through a mass of tedious calculations.

2nd Service Capacity.— The temperature of a railway motor in service should not rise more than 65° C. above that of the air, as a higher temperature is liable to cause deterioration of the insulation and thus increase the cost of maintenance.

The most convenient service rating of a railway motor shows the relation between the rate horse-power (commercial) and the weight of car in tons it can propel at any speed. This should be given also for both single car and train operation in order to comply with the different train friction rates with different composition of trains.

Example. — Given a 48-ton car running singly at 45 miles per hour, what capacity motor is required with a four-motor equipment? See curve sheet, Fig. 48, made from "C" friction curve for single car operation. Four-motor equipment and 48 tons gives 12 tons per motor. Follow 12-ton line horizontally until it cuts curve labeled 45 miles per hour, drop to scale at bottom and find 115 horse-power motor required. Select next larger size from standard lists of manufacturers.

Curve sheets 46, 47, 48 are made for

"A" Trains of 10 cars or more.
"B" Trains of two cars.
"C" Single cars.

The four curves on each plate are made for 30, 45, 60 and 75 miles per hour, and these values represent the *maximum* speed the car will reach with 550 volts on the motors and on a level tangent track.

Do not make the mistake of choosing a motor too small for the work to be done, as it will cost more in the end, due to increased cost of maintenance.

Lay-overs. — Should there be considerable lay-over at the ends of the run, it may be possible to select the next size smaller standard motor to the one indicated by the curves. By a considerable lay-over is meant 15 per cent of the running time. Thus a run of 20 miles, requiring 60 minutes for a suburban run, should have a lee-way or lay-over at each end of the run of 10 minutes, in which case it would be feasible to select the next smaller standard size motor than the one indicated by curves.

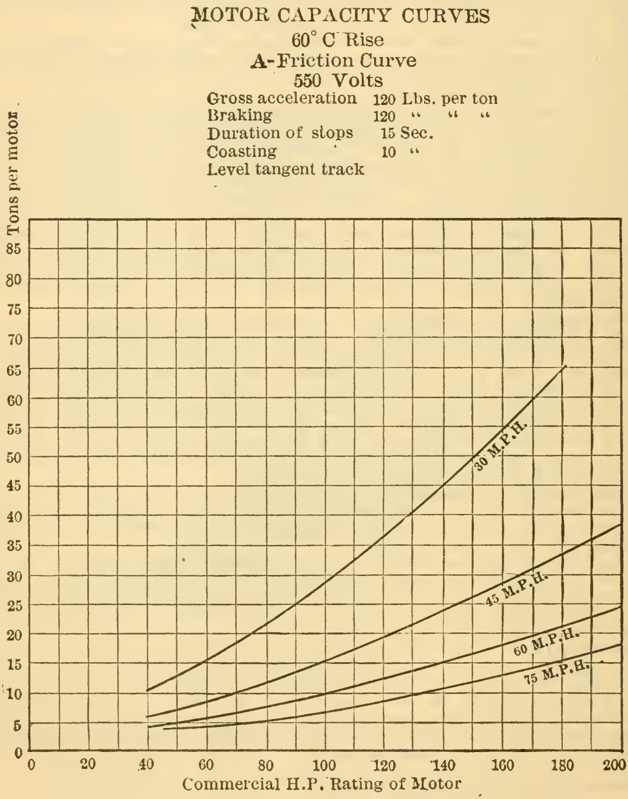


FIG. 46. Motor Capacity Curves, 60° C. Rise. A-Friction Curve.

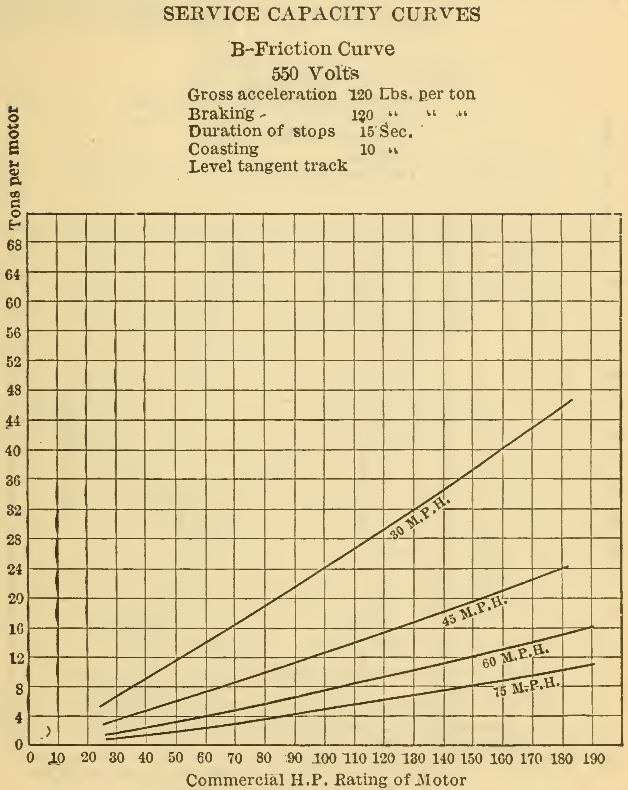


FIG. 47. Motor Capacity Curves, 60° C. Rise. B-Friction Curve.

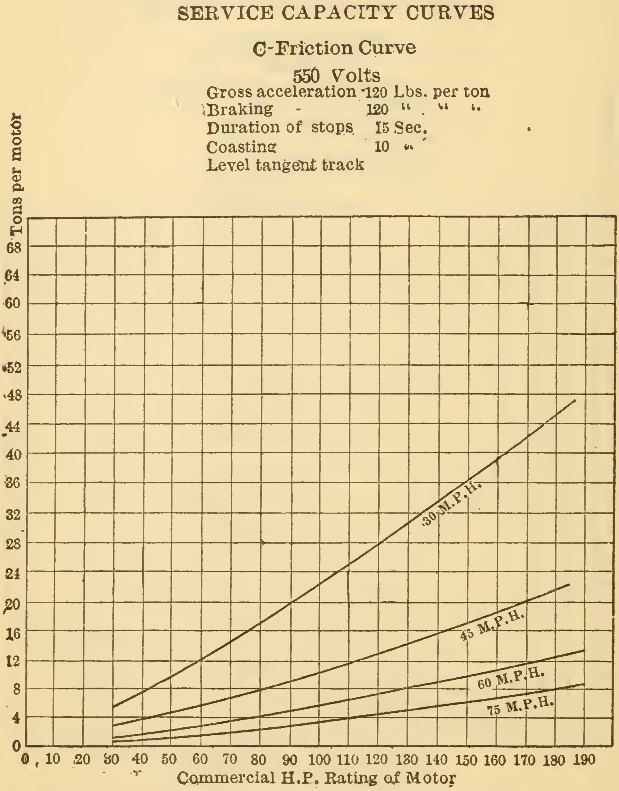


FIG. 48. Motor Capacity Curves, 60° C. Rise. C-Friction Curve.

GRAPHICAL APPROXIMATION OF ENERGY REQUIRED FOR ELECTRIC CARS.

Mr. A. H. Armstrong has developed a series of curves, based upon the friction diagram, Fig. 49, from experiments by W. J. Davis, Jr. By the use of these curves a quick approximate determination of power required may be made. The curves shown in Figs. 50, 51, and 52, are referred to curves *A*, *B*, *C*, respectively on diagram, Fig. 49.

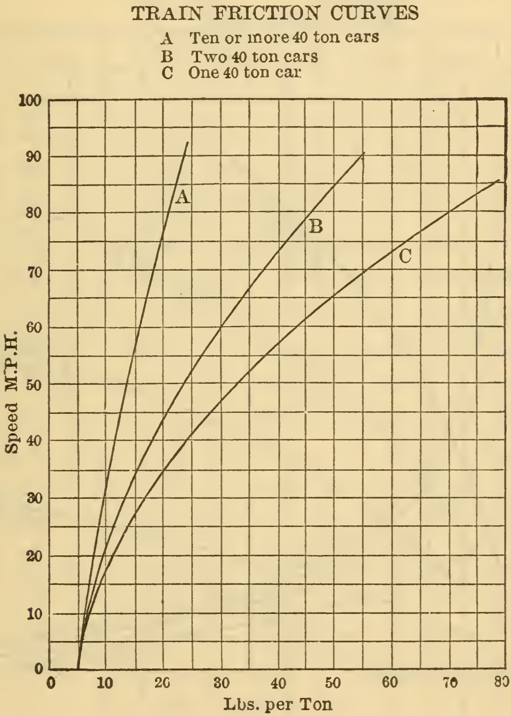


FIG. 49. Friction Curves.

Example:—Given an eight-car train for a schedule speed of 25 miles per hour; to find the maximum speed and watt-hours per ton-mile, at one stop per mile.

Look along the bottom of the diagram, Fig. 50, for one stop per mile; vertically above this, opposite 25 miles per hour will be found a curve; follow this curve upward to the left to the zero stops per mile where will be found the maximum speed 45 miles per hour. Again, above the one stop per mile the maximum speed curve of 45 miles per hour crosses, opposite 68 watt-hours per ton-mile in the first column.

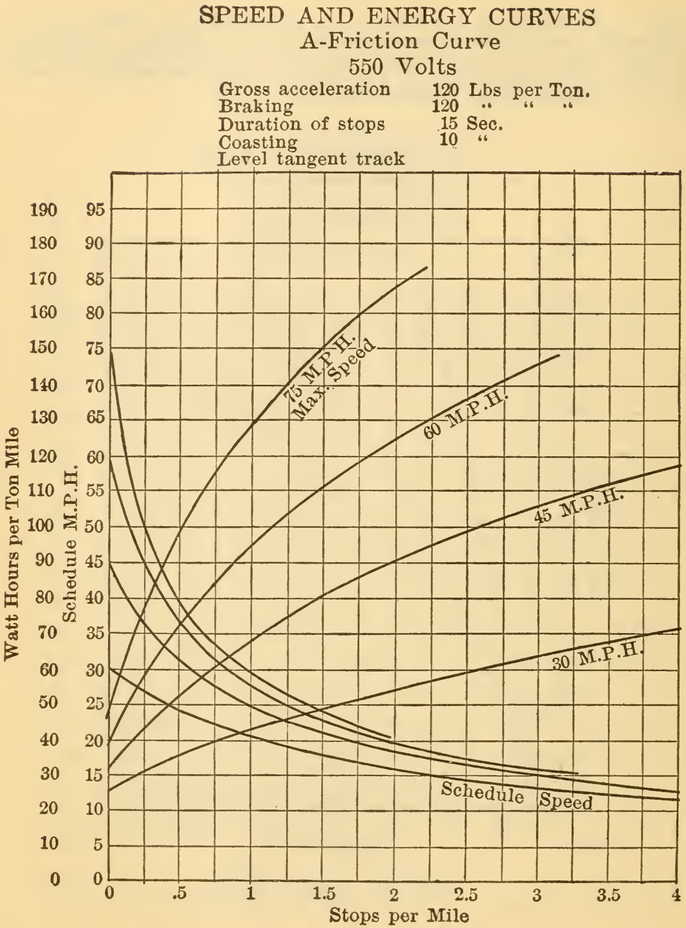


FIG. 50. Speed and Energy Curves. Referred to A-Friction Curve of Fig. 49.

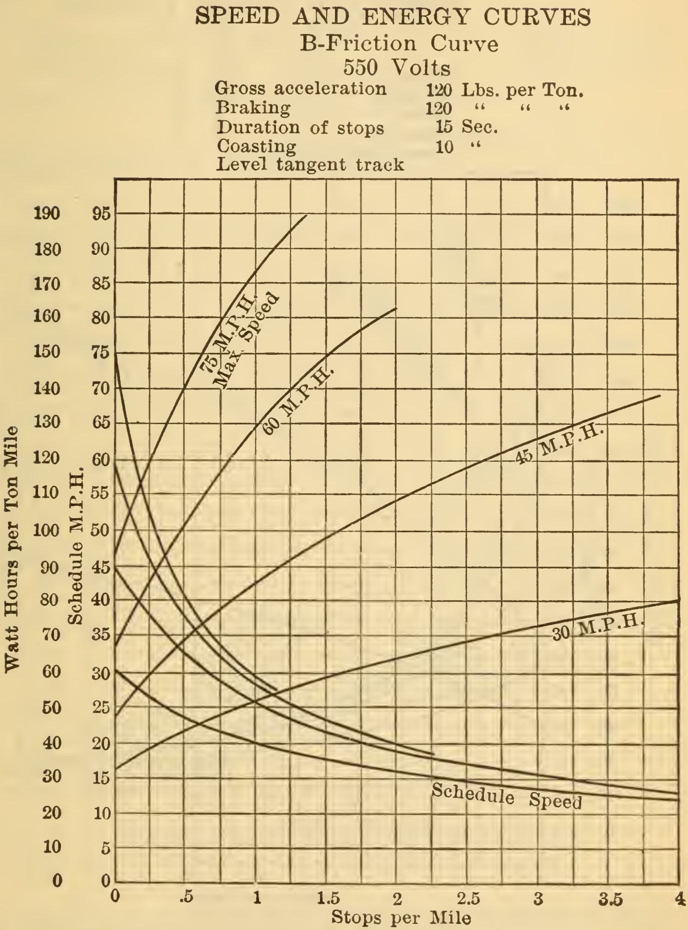


FIG. 51. Speed and Energy Curves. Referred to B-Friction Curve of Fig. 49.

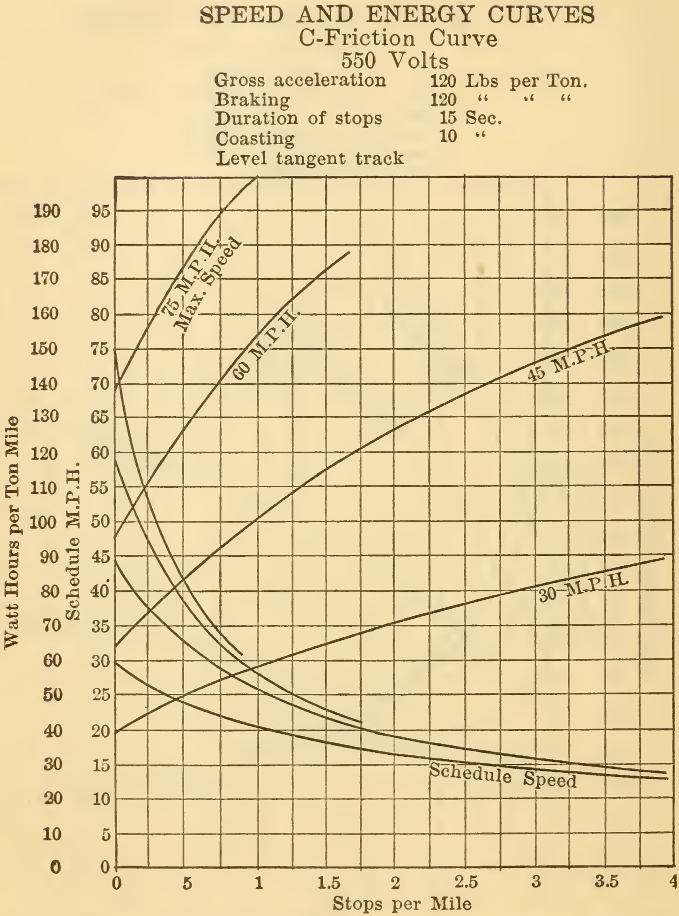


FIG. 52. Speed and Energy Curves. Referred to C-Friction Curve of Fig. 49.

The controlling factor in all of these curves is the friction curve, which includes track, rolling, journal and wind-friction.

The constants assumed in calculating the above curves are those pertaining to average high-speed suburban work as follows:

Gross accelerating rate	120 lbs. per ton
Braking effort (average)	120 lbs. per ton
Duration of stop	15 seconds each.

Track assumed to be perfectly straight and level.

In the above curves, due consideration is given to all the losses occurring during acceleration with the standard series-parallel controller and direct-current motors.

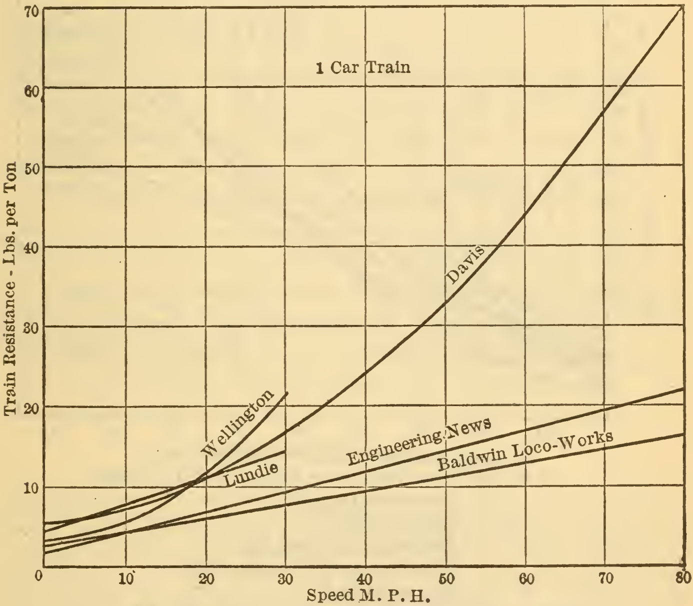


Fig. 53. - Train Resistance Curves for 1 Car Train

The inertia of the rotating parts of the equipment generally amounts to 5 per cent and this value is taken throughout, being perhaps a little high for the higher speeds and low for the lower speeds. The speed curve of a standard 125 horse-power motor is used throughout. The energy curves given are somewhat affected by the amount of coasting done, although this is not so determining a factor in high-speed work as it is in slow-speed accelerating problems. In order that the energy curves should be conservative, they are plotted with only 10 seconds of coasting permitted and therefore the schedule speeds given are nearly the maximum possible, and the energy curves given are also practically the maximum possible with the maximum speeds assumed. Should power be shut off earlier and more coasting be permitted, the energy consumption would have been decreased and the schedule speeds decreased somewhat also, especially with the more frequent stops per mile.

An inspection of these three sets of curves will bring out the very great effect of the wind-friction when using trains of one or two cars at very high speeds; in fact at 75 miles per hour maximum speed the operation of single car trains becomes impracticable with light 40-ton cars of standard construction, and even at 60 miles per hour is questionable. To quote from the curves, it requires an energy consumption of 47 watt-hours per ton-mile for a train of several cars, as against 137 watt-hours per ton-mile for a single

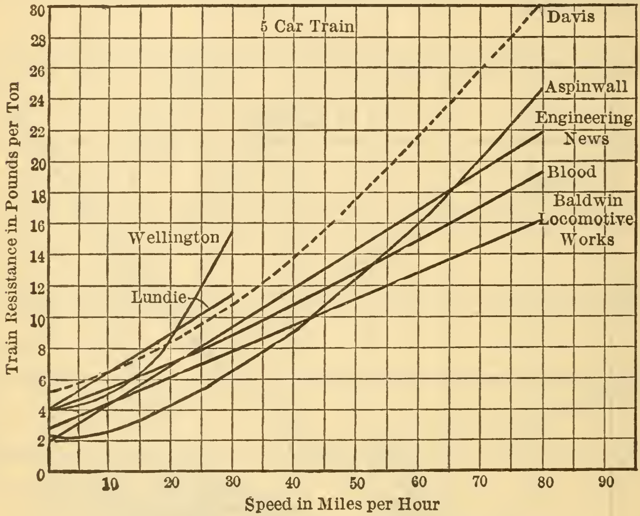


FIG. 54.-Train Resistance Curves for 5 Car Train
Length of Car, 51′ 5″
Height, 8′ 9⅞″
Diameter of wheel, 33″
Effective area, 96 square feet.
No. of units, 5.

car operating at 75 miles per hour without stops; that is, a single car operation would demand 3.7 times the energy per ton that would be required for the operation of a train of many similar cars. Even a two-car train will require but 92 watt-hours per ton-mile, or only 67 per cent of the energy required per ton for single car operation. As these values are for constant-speed running, while more or less frequent stops would obtain, a comparison at say one stop in 4 miles would be nearer the actual results in practice. Here a single car requires 157 watt-hours per ton-mile, a two-car train requires 120 and a train of several cars 79 watt-hours per ton-mile.

With one stop in 8 miles it is possible to make a schedule of 61 miles per hour with maximum speed of 75 miles per hour, and a schedule of 28 miles per hour with maximum speed of 30 miles per hour. If stops be increased so that they average one per mile, however, the schedule speed possible with a maximum speed of 75 miles per hour is dropped to 29 miles per hour, while the 30 miles per hour maximum speed permits of a schedule speed of 22 miles per hour. Thus while 30 miles is but 40 per cent of the higher maximum speed it permits a schedule at one stop per mile of 76 per cent of that possible with 75 miles per hour maximum speed. The fallacy of using high-speed equipments for frequent stops is forcibly brought out by referring to the energy curves in Figs. 50, 51, and 52. With one stop per mile it requires 200 watt-hours per ton-mile with 75 mile maximum speed equipment, and the 30 miles maximum speed equipment can obtain 76 per cent of the same schedule with an expenditure of only 28.5 per cent of the energy.

Figs. 53 and 54 show the comparative values of train resistance as determined by various authorities. Following are several train resistance formulæ.

Baldwin, $R = 3 + \frac{V}{6}$

Engineering News, $R = 2 + \frac{V}{4}$

Davis (45-ton car), $R = 4 + .13\,V + \frac{.003\,AV^2}{T}\,[1 + .1\,(N - 1)]$

Smith, $R = 3 + .167\,V + .0025\,\frac{A}{T}\,V^2$

Mailloux, $R = \left(\frac{b}{\sqrt{T}} + g\right) + .15\,V + \frac{.02\,N + .25}{NT}\,V^2.$

Where

R = resistance in pounds per ton.
V = velocity in miles per hour.
A = cross section of car in square feet.
T = weight of train in tons.
N = number of cars per ton.
b = constant depending on diameter of wheels and journals (6 to 9).
g = constant depending on condition of track (2 to 5).
n = total number of cars in train.

MOTOR CHARACTERISTICS.

Railway motor characteristics are generally expressed in curve form as speed in miles per hour for 33 inch wheel, tractive effort at the rim of a 33-inch wheel and efficiency. The efficiency is ordinarily expressed as the relation between the electrical input to the motor and the mechanical output from its armature shaft. When the losses in the gears connecting the armature shaft with the car axle are also deducted, the efficiency thus obtained gives the relation between the electrical input to the motor and the output at the rim of the car wheel. This relation is ordinarily referred to as "efficiency with gears." The efficiency with gears is the one most generally used, although it is best to have both given in order to eliminate errors made by determining gear and friction losses by different methods of unequal degree of accuracy.

Motor characteristics form the basis of all calculations involving maximum and schedule speeds and are generally determined for 500 volts, although nearly all railway motor are now designed to operate at 600 volts. Several typical motor characteristics follow. It is not practicable to include more, as styles of motors change so rapidly.

NOTE.—In changing gear ratio on the same class of motor the sum of the number of teeth in gear and pinion must always be the same. For example, for GE–58–A–3; GE–58–A–4; the sum of the number of teeth in gear and pinion is always 84.

40 H.P. output at 71 Amp. input
Volts at Motor Terminals 500
Diameter of car wheel 33″

Armature 3 turns, Field Spools 110.5 turns
Pinion 19, Gear 59, Ratio 3.42.

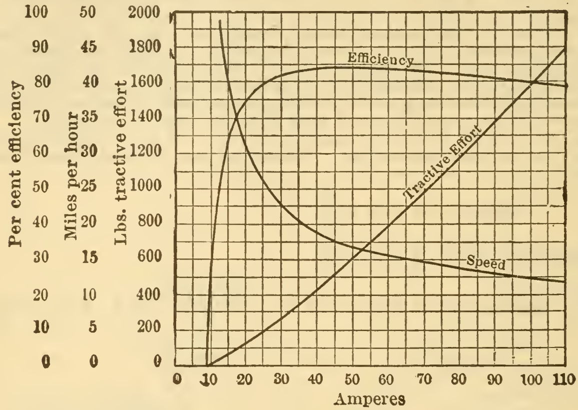


FIG. 55. G. E.-67-A-4.

65 H.P. output at 113 Amp. input
Volts at Motor Terminals 500
Diameter of car wheel 33″

Armature 2 turns, Field Spools 70.5 turns
Pinion 25, Gear 64, Ratio 2.56.

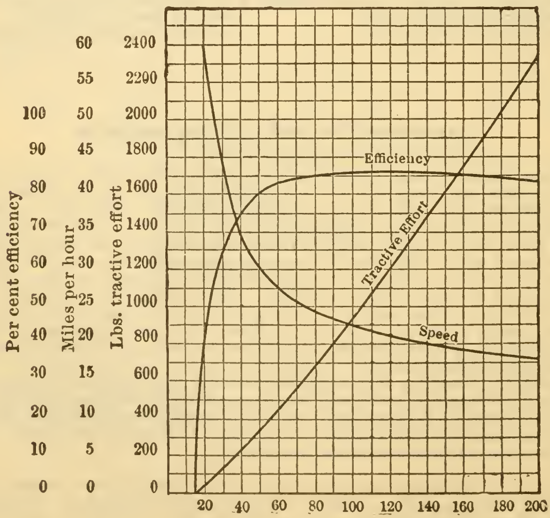


FIG. 56. G. E.-74-A-9.

75 H.P. output at 130 Amp. input
Volts at Motor Terminals 500
Diameter of car wheel 33″

Armature 2 turns, Field Spools { Large 80 turns / Small 40 turns }
Pinion 24, Gear 51, Ratio 2.12.

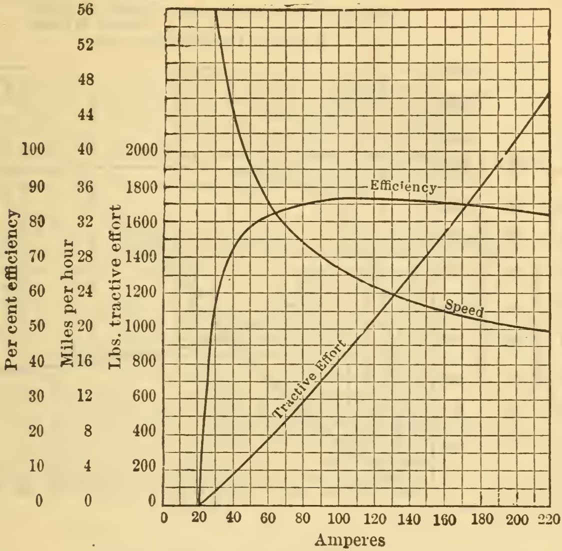


FIG. 57. G. E.-73-A-12.

35 H. P. output at 65 Amp. input
Volts at motor terminals 500
Diameter of Wheels 33″

Armature 3 turns, Field spools 143 turns
Pinion 15, Gear 69, Ratio 4.6

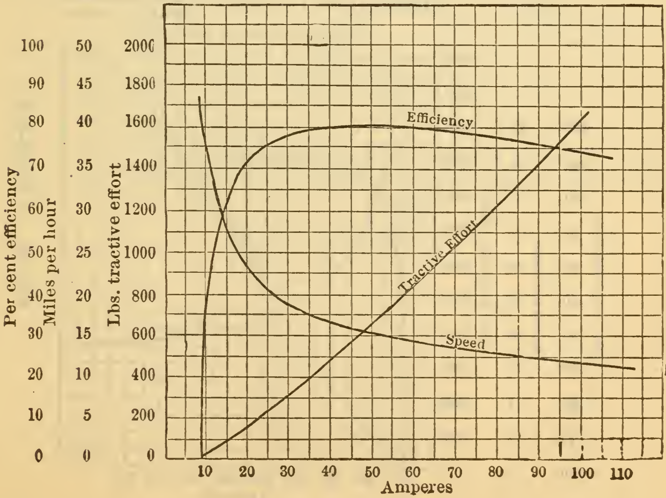


FIG. 58. G. E.-1000-A-4.

125 H.P. output at 208 Amp. input
Volts at motor terminals 500
Diameter of Wheels 33″
Armature 1 turn, Field spools { Large 56 turns / Small 29 turns }
Pinion 29, Gear 60, Ratio 2.07

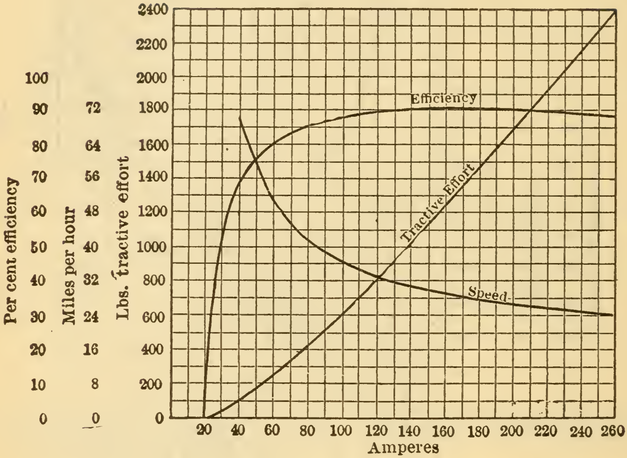


FIG. 59. G. E.-66-A-9.

200 H.P. output at 340 Amp. input
Volts at motor terminals 500
Diameter of Wheels 33″
Armature 1 turn, Field spools { Large 35 turns / Small 35 turns }
Pinion 20, Gear 63, Ratio 3.15

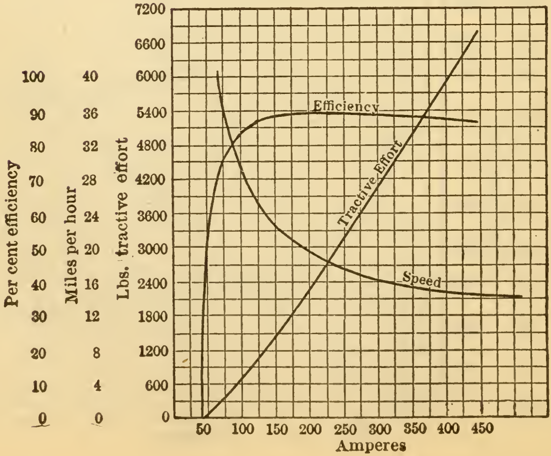


FIG. 60. G. E.-69-B-3

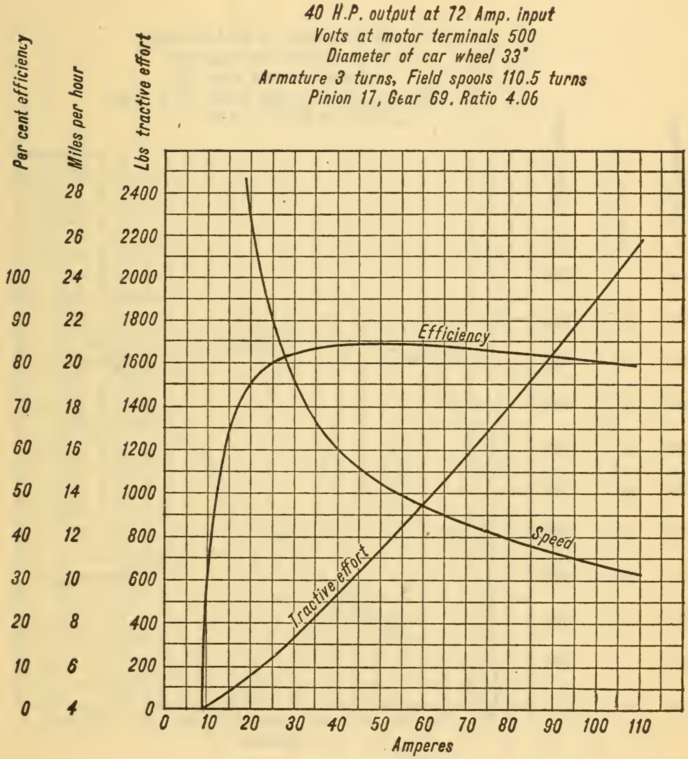


FIG. 61. G. E.-80-A-1.

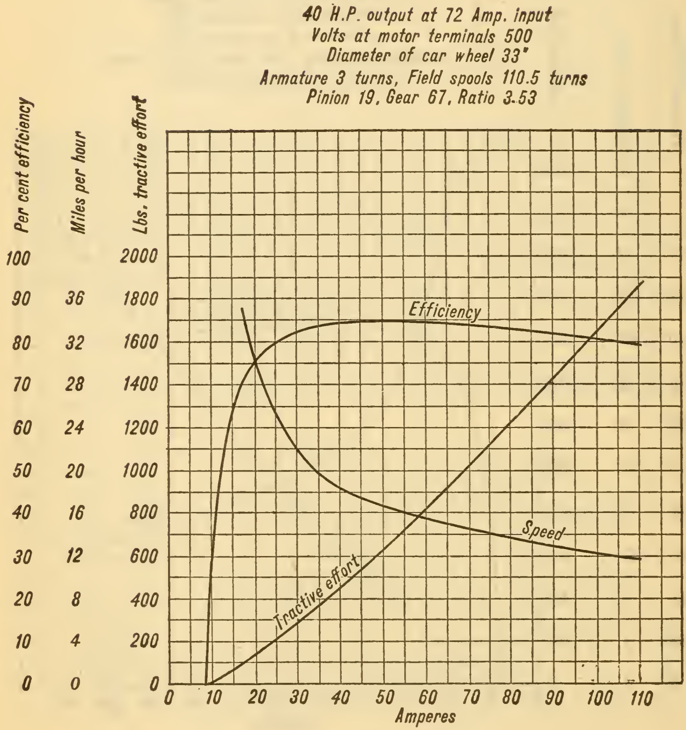


FIG. 62. G. E.-80-A-3.

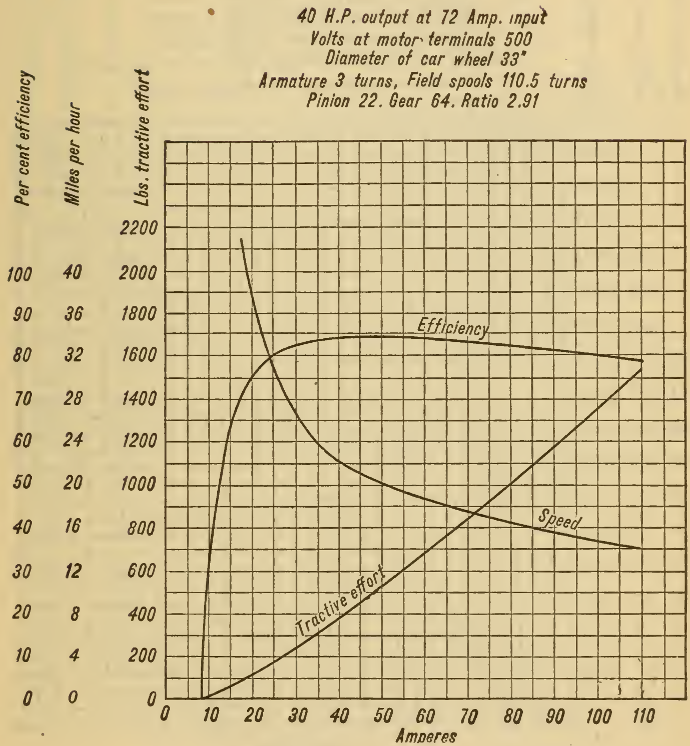


FIG. 63. G. E.-80-A-4.

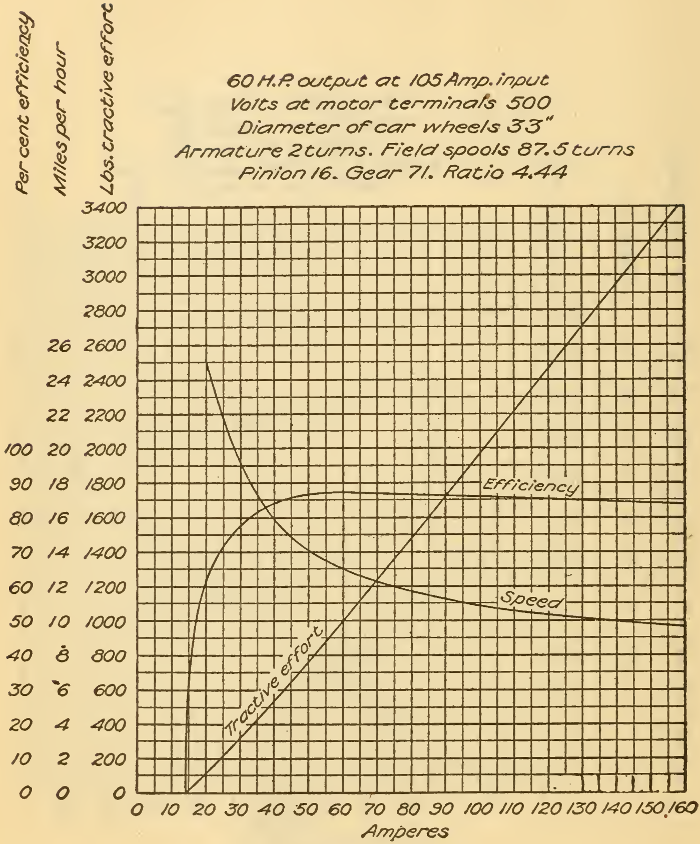


FIG. 64. G. E.-87-A or B-1.

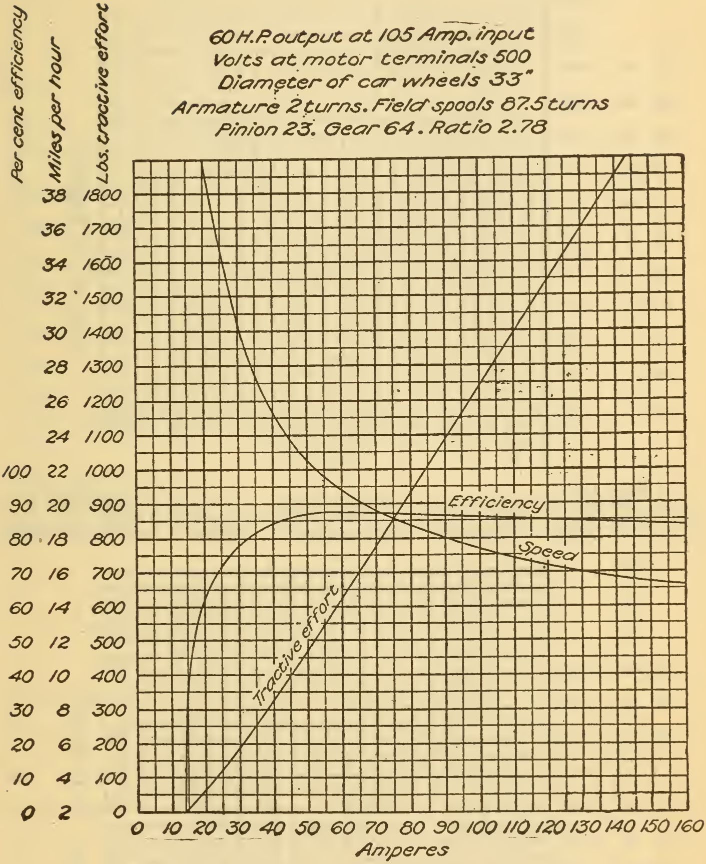


FIG. 65. G. E. -87-A or B-4

50 H.P. output at 88 Amp. input
Volts at motor terminals 500
Diameter of car wheels 33″

Armature 2 turns, Field spools 90.5 turns
Pinion 17, Gear 69, Ratio 4.06.

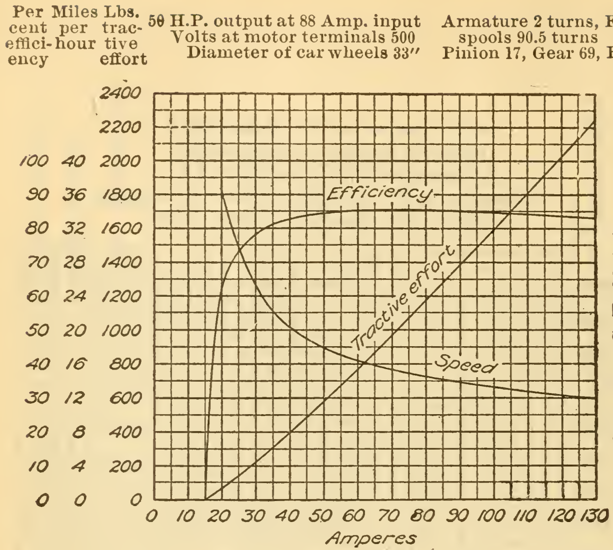


FIG. 66. G. E.-90-A-1.

50 H.P. output at 88 Amp. input
Volts at motor terminals 500
Diameter of car wheels 33″

Armature 2 turns, Field spools 90.5 turns
Pinion 22, Gear 64, Ratio 2.91.

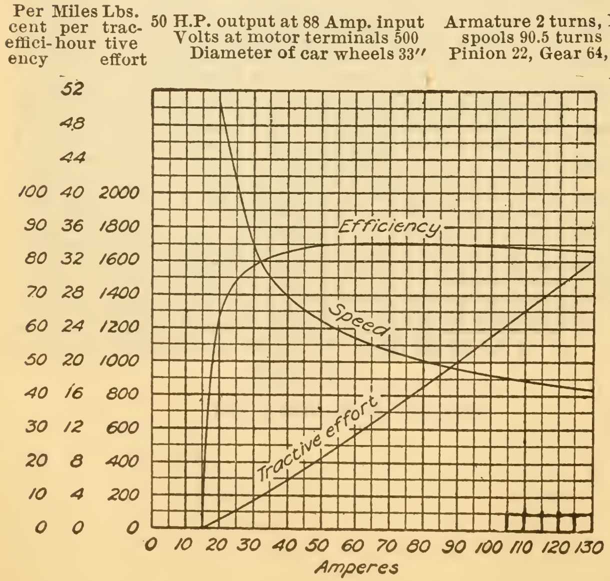


FIG. 67. G. E.-90-A-3.

35 H.P. output at 62 Amp. input
Volts at motor terminals 500
Diameter of car wheels 33″

Armature 3 turns, Field spools 110.5 turns
Pinion 14, Gear 69, Ratio 4.93.

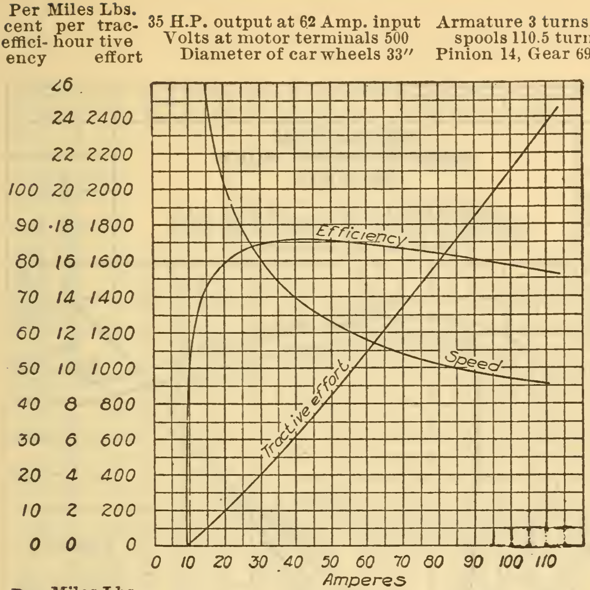


FIG. 68. G. E.-78-A-1.

35 H.P. output at 62 Amp. input
Volts at motor terminals 500
Diameter of car wheels 33″

Armature 3 turns, Field spools 110.5 turns
Pinion 21, Gear 62, Ratio 2.95.

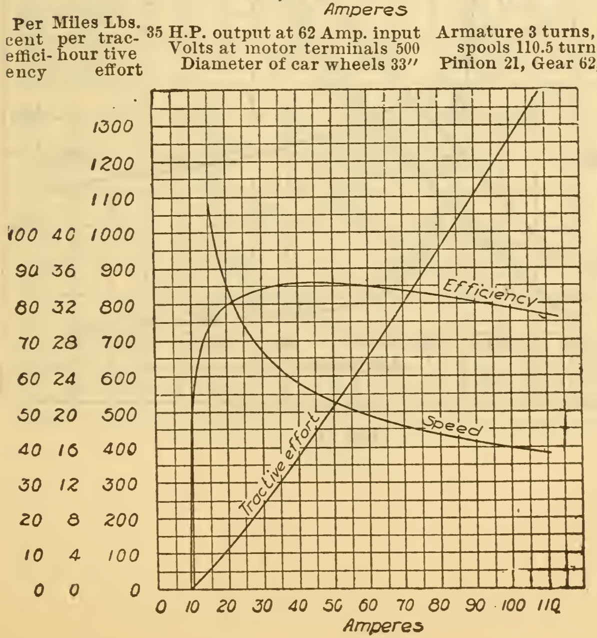


FIG. 69. G. E.-78-A-4.

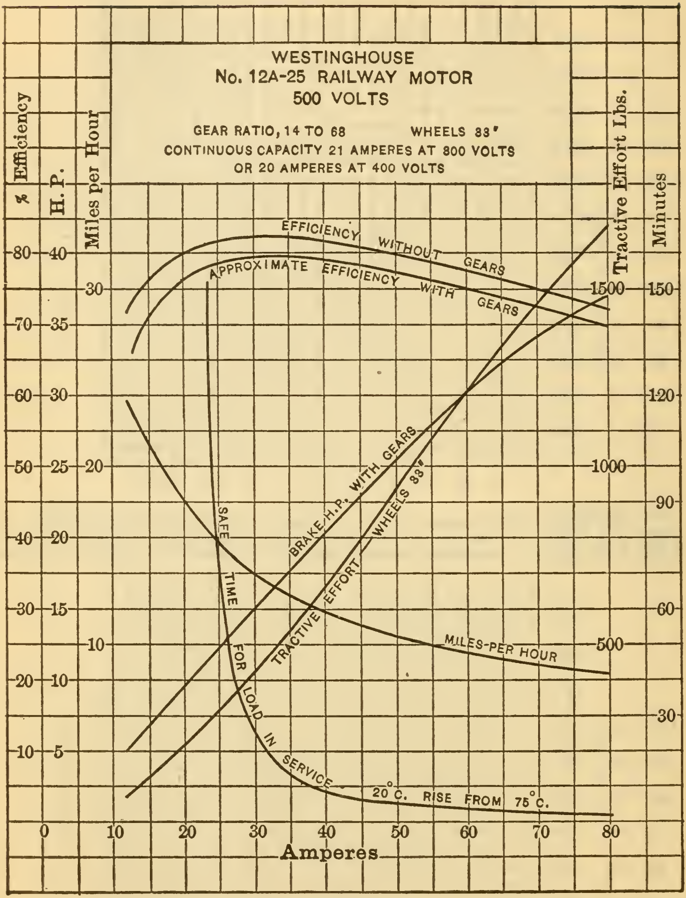

WESTINGHOUSE
No. 12A-25 RAILWAY MOTOR
500 VOLTS
GEAR RATIO, 14 TO 68 WHEELS 33"
CONTINUOUS CAPACITY 21 AMPERES AT 300 VOLTS
OR 20 AMPERES AT 400 VOLTS
% Efficiency
H. P.
Miles per Hour
Tractive Effort Lbs.
Minutes
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
BRAKE H.P. WITH GEARS
TRACTIVE EFFORT—WHEELS 33"
MILES-PER HOUR
SAFE TIME FOR LOAD IN SERVICE
20°C. RISE FROM 75°C.
Amperes
0
10
20
30
40
50
60
70
80
1500
1000
500
150
120
90
60
30

FIG. 70.

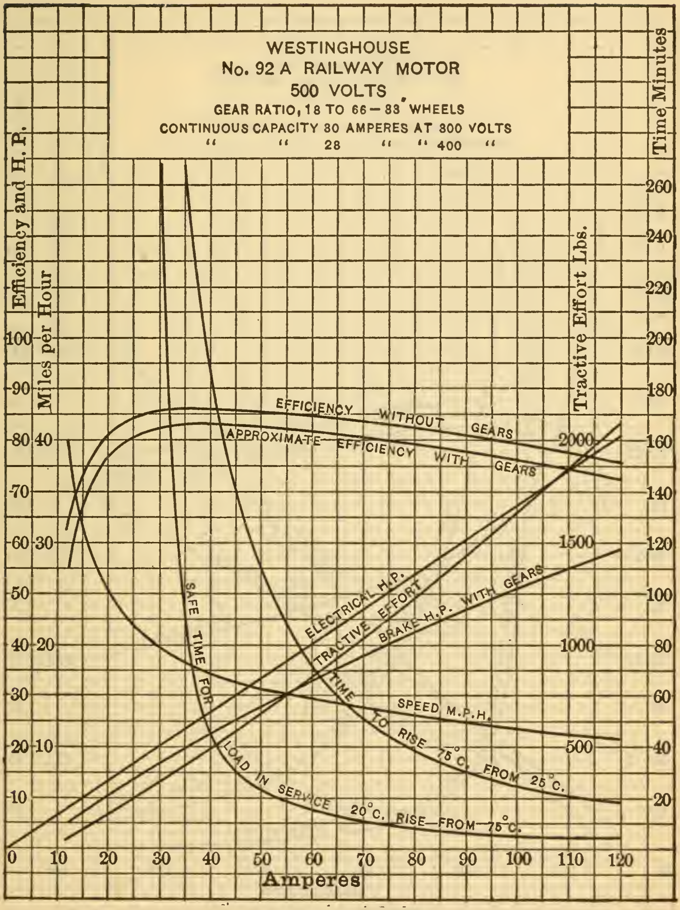
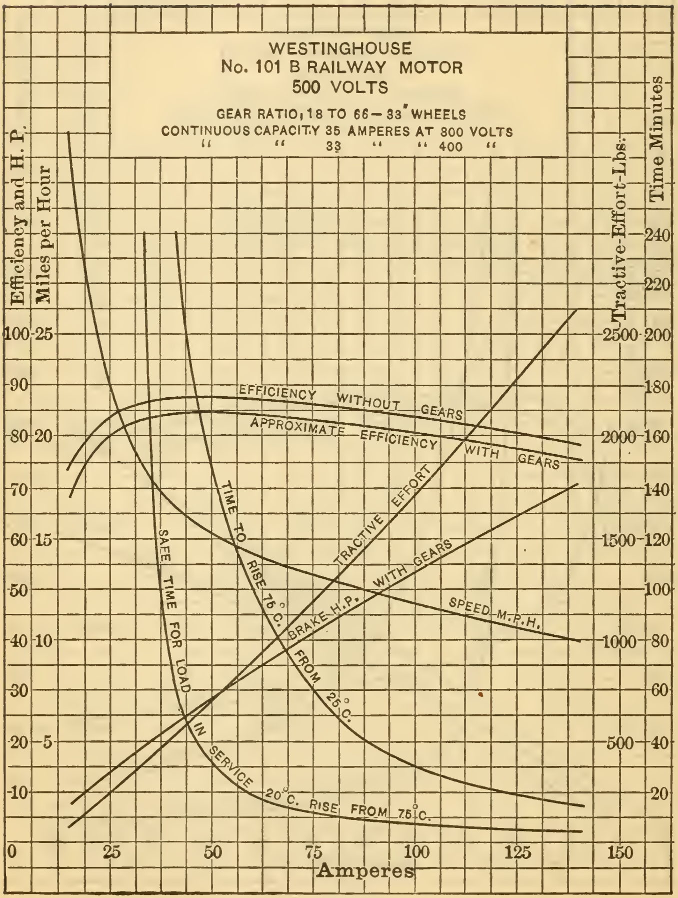
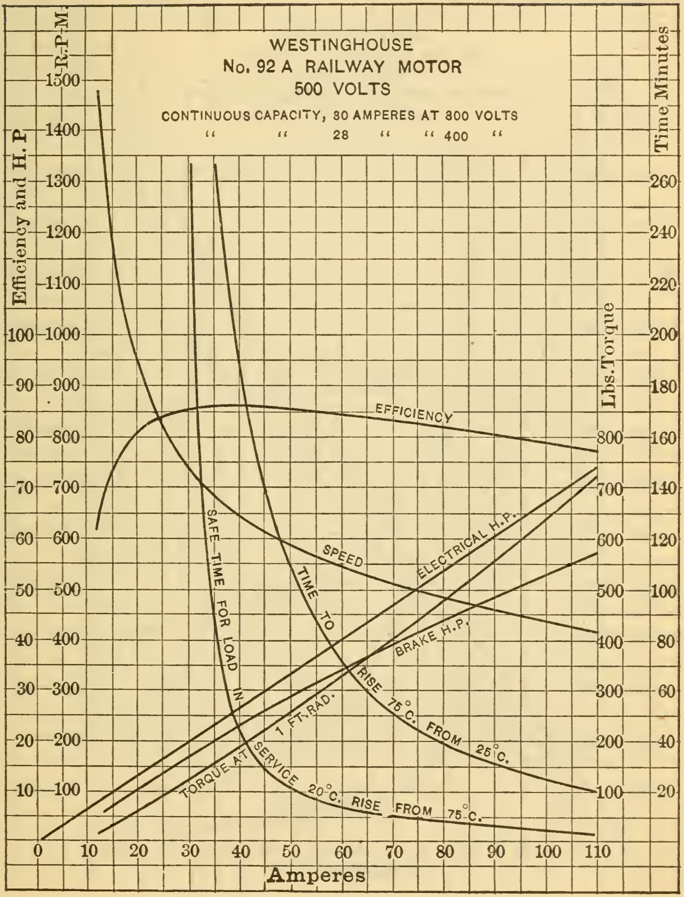

WESTINGHOUSE
No. 92 A RAILWAY MOTOR
500 VOLTS
GEAR RATIO, 18 TO 66 — 33" WHEELS
CONTINUOUS CAPACITY 80 AMPERES AT 300 VOLTS
" " 28 " " 400 "
Efficiency and H. P.
Miles per Hour
Tractive Effort Lbs.
Time Minutes
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
ELECTRICAL H.P.
TRACTIVE EFFORT
BRAKE H.P. WITH GEARS
SAFE TIME FOR LOAD IN SERVICE 20°C. RISE FROM 75°C.
TIME TO RISE 75°C. FROM 25°C.
SPEED M.P.H.
Amperes
0 10 20 30 40 50 60 70 80 90 100 110 120
10 20 30 40 50 60 70 80 90 100
10 20 30 40
500 1000 1500 2000
20 40 60 80 100 120 140 160 180 200 220 240 260

FIG. 71.



WESTINGHOUSE
No. 101 B RAILWAY MOTOR
500 VOLTS
GEAR RATIO; 18 TO 66 — 33" WHEELS
CONTINUOUS CAPACITY 35 AMPERES AT 300 VOLTS
" " 33 " " 400 "
Efficiency and H. P.
Miles per Hour
Tractive-Effort-Lbs.
Time Minutes
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
TIME TO RISE 75° C. FROM 25° C.
SAFE TIME FOR LOAD IN SERVICE 20° C. RISE FROM 75° C.
TRACTIVE EFFORT
BRAKE H.P. WITH GEARS
SPEED M.P.H.
100 25
90
80 20
70
60 15
50
40 10
30
20 5
10
0
25
50
75
100
125
150
Amperes
2500 200
2000 160
1500 120
1000 80
500 40
240
220
180
140
100
60
20

FIG. 72.



Without Gears

FIG. 73.

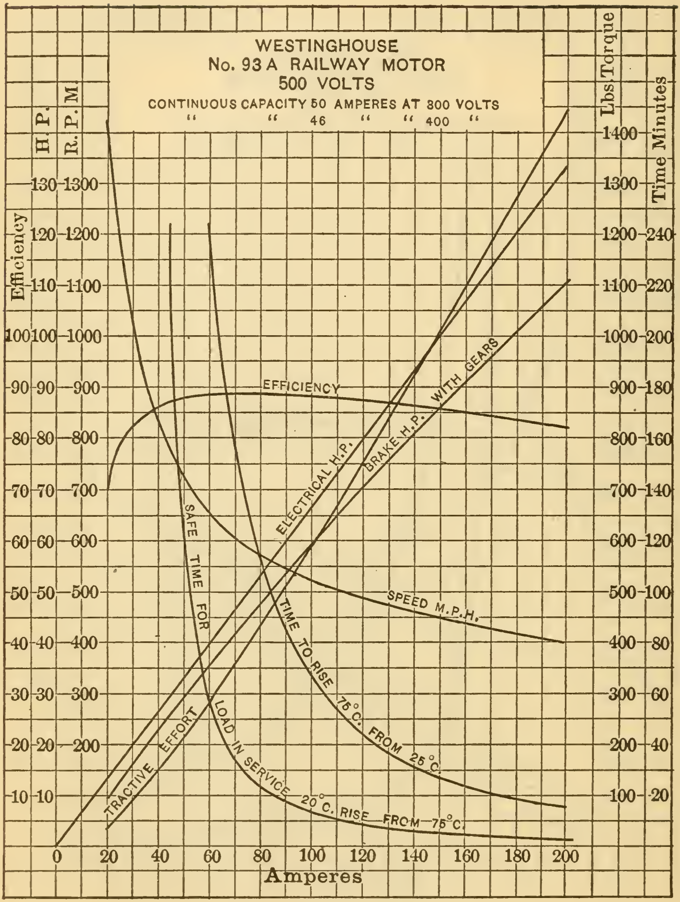

WESTINGHOUSE
No. 93 A RAILWAY MOTOR
500 VOLTS
CONTINUOUS CAPACITY 50 AMPERES AT 300 VOLTS
" " 46 " " 400 "
Efficiency
H. P.
R. P. M.
Lbs. Torque
Time Minutes
EFFICIENCY
ELECTRICAL H.P.
BRAKE H.P. WITH GEARS
SPEED M.P.H.
SAFE TIME FOR LOAD IN SERVICE 20°C. RISE FROM 75°C.
TIME TO RISE 75°C. FROM 25°C.
TRACTIVE EFFORT
Amperes

FIG. 74.

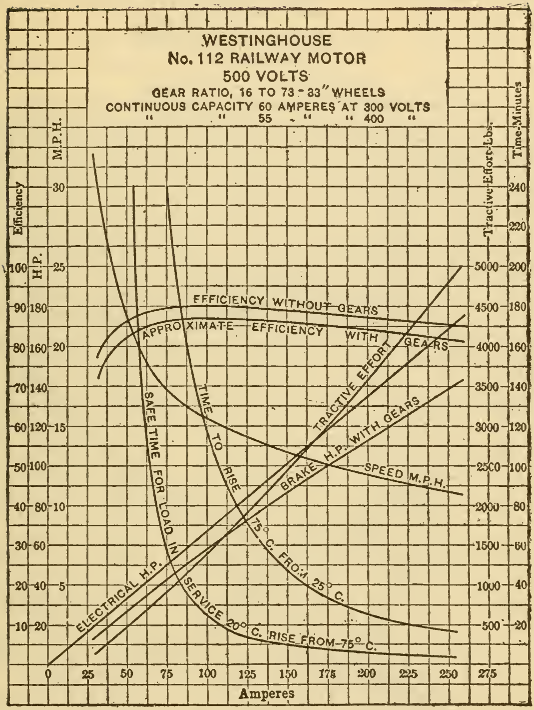

WESTINGHOUSE
No. 112 RAILWAY MOTOR
500 VOLTS
GEAR RATIO, 16 TO 73 - 33" WHEELS
CONTINUOUS CAPACITY 60 AMPERES AT 300 VOLTS
" " 55 " " 400 "
Efficiency
H.P.
M.P.H.
Tractive Effort Lbs.
Time-Minutes
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
TRACTIVE EFFORT
BRAKE H.P. WITH GEARS
SPEED M.P.H.
SAFE TIME FOR LOAD IN SERVICE 20° C. RISE FROM 75° C.
TIME TO RISE 75° C. FROM 25° C.
ELECTRICAL H.P.
Amperes

FIG. 75.

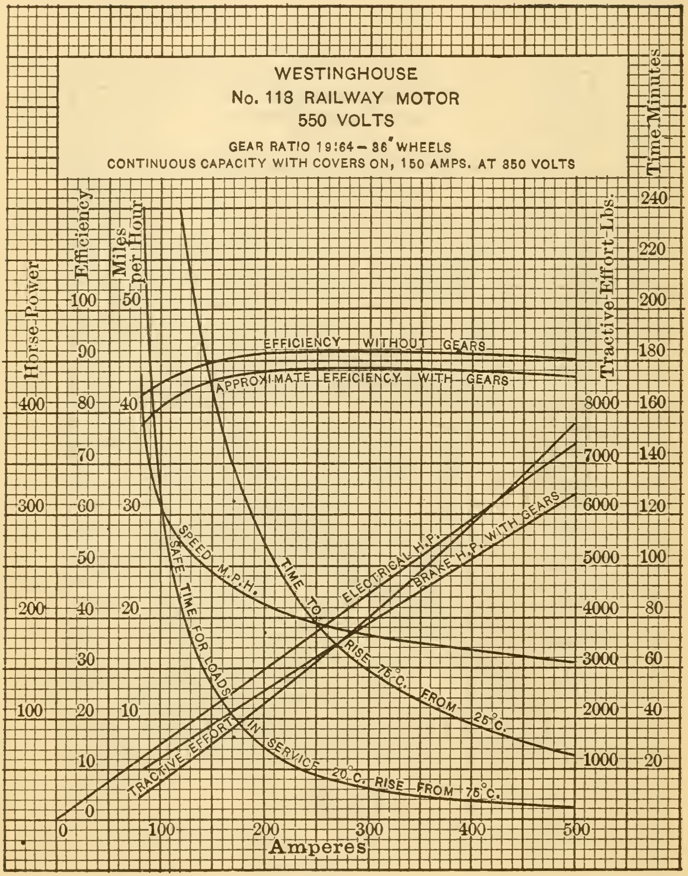

WESTINGHOUSE
No. 118 RAILWAY MOTOR
550 VOLTS
GEAR RATIO 19:64 – 36" WHEELS
CONTINUOUS CAPACITY WITH COVERS ON, 150 AMPS. AT 350 VOLTS
Horse-Power
Efficiency
Miles per Hour
Tractive-Effort-Lbs.
Time-Minutes
Amperes
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
SPEED M.P.H.
SAFE TIME FOR LOADS IN SERVICE 20°C. RISE FROM 75°C.
TIME TO RISE 75°C. FROM 25°C.
ELECTRICAL H.P.
BRAKE H.P. WITH GEARS
TRACTIVE EFFORT
0
100
200
300
400
500

FIG. 76.

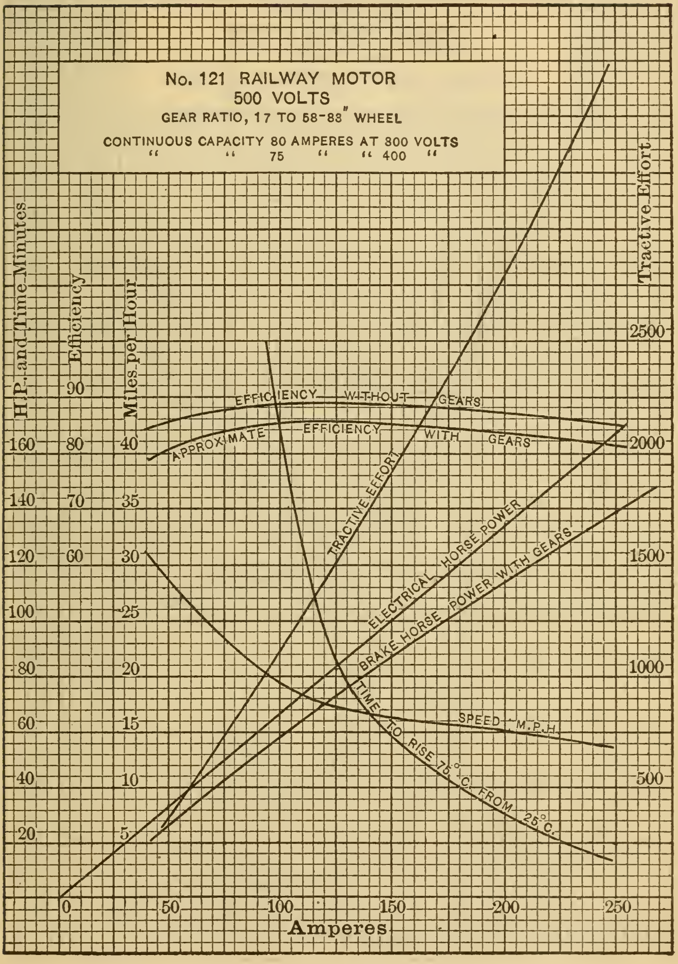

No. 121 RAILWAY MOTOR
500 VOLTS
GEAR RATIO, 17 TO 58-33" WHEEL
CONTINUOUS CAPACITY 80 AMPERES AT 300 VOLTS
" " 75 " " 400 "
H.P. and Time Minutes
Efficiency
Miles per Hour
Tractive Effort
EFFICIENCY WITHOUT GEARS
APPROXIMATE EFFICIENCY WITH GEARS
TRACTIVE EFFORT
ELECTRICAL HORSE POWER
BRAKE HORSE POWER WITH GEARS
TIME TO RISE 75° C. FROM 25° C.
SPEED M.P.H.
Amperes
0
50
100
150
200
250
2500
2000
1500
1000
500

FIG. 77.

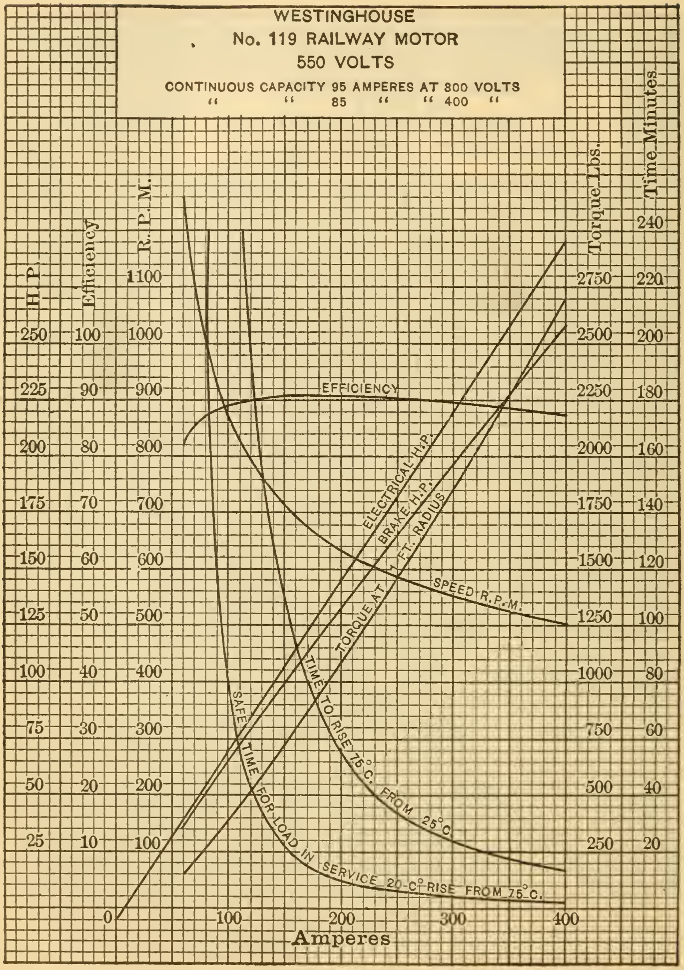

WESTINGHOUSE
No. 119 RAILWAY MOTOR
550 VOLTS
CONTINUOUS CAPACITY 95 AMPERES AT 300 VOLTS
" " 85 " " 400 "
H. P.
Efficiency
R. P. M.
Torque Lbs.
Time Minutes
EFFICIENCY
ELECTRICAL H.P.
BRAKE H.P.
TORQUE AT 1 FT. RADIUS
SPEED R.P.M.
TIME TO RISE 75°C. FROM 25°C.
SAFE TIME FOR LOAD IN SERVICE 20°C. RISE FROM 75°C.
Amperes

Fig. 78.

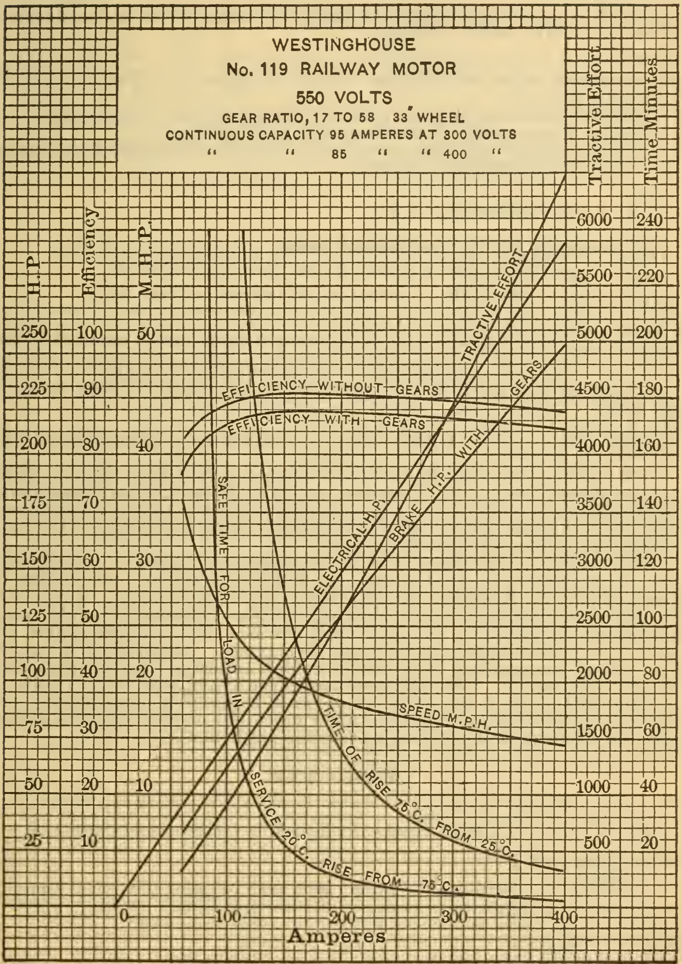

WESTINGHOUSE
No. 119 RAILWAY MOTOR
550 VOLTS
GEAR RATIO, 17 TO 58 33" WHEEL
CONTINUOUS CAPACITY 95 AMPERES AT 300 VOLTS
" " 85 " " 400 "
H.P.
Efficiency
M.H.P.
Tractive Effort
Time Minutes
EFFICIENCY WITHOUT GEARS
EFFICIENCY WITH GEARS
TRACTIVE EFFORT
ELECTRICAL H.P.
BRAKE H.P. WITH GEARS
SAFE TIME FOR LOAD IN SERVICE 20°C. RISE FROM 75°C.
TIME OF RISE 75°C. FROM 25°C.
SPEED M.P.H.
Amperes
0
100
200
300
400
250
225
200
175
150
125
100
75
50
25
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
240
220
180
160
140
120
80
60
40
20
90
70
30
10
20
40
60

FIG. 79.

DETERMINATION OF ENERGY.

Gotshall gives the following as a method of approximating the demand for energy of an electric railway.

Let

W = maximum weight of loaded car, or train unit, in tons of 2,000 pounds each.
D = length of road.
T = time in minutes occupied in running between termini = single trip.
K = energy consumption in watt hours per ton mile.
N = number of cars or train units on the road during time of maximum service of minimum headway.

Then,

$W \times D$ = ton mile per trip = P.

$$\frac{P \times K}{1000} = \text{energy per trip in kilowatt hours.}$$

$$\frac{P \times K}{1000} \times \frac{60}{T} = \text{mean rate of energy input per car or train unit.}$$

$$\frac{P \times K}{1000} \times \frac{60}{T} \times N = A = \text{total maximum average energy required at the car motors for maximum service condition.}$$

If to the foregoing, 25 per cent be added for transmission losses and heat and light,

$$\frac{60 \times P \times K \times N \times 100}{1000 \times T \times .75} = 0.08 \frac{P \times K \times N}{T} = \text{maximum average demand} = R.$$

To R must be added the fluctuations, which will vary from $.2\,R$ to $.33\,R$, as the number of train units in regular service are great and the average load consequently relatively high, or as the number of train units in regular service are few and far apart, and the consequent relative increase of the load during certain hours relatively great.

In the foregoing, the quantity K is the important quantity. K will vary with the schedule and the location, the distance between, and number of stops and stations, as well as with the alignment and gradients. Table VII, has been compiled from data showing relations between schedule speed and energy consumption in watt hours per ton mile. These figures are based upon approximately straight and level roads. As the effect of grades upon energy consumption is, to a large extent, compensating, the data may be used with safety. The compensating effect above referred to is due to the fact that while a car going up-grade is consuming more energy, per contra a car going down-grade consumes much less or none, thereby equalizing the effect of, or compensating for, the gradients.

Table VII.

Distance between Stops.		Watt Hours per Ton Mile for Schedule Speeds of					
		40 miles per hr.	35 miles per hr.	30 miles per hr.	25 miles per hr.	20 miles per hr.	15 miles per hr.
Miles.	Feet.						
3	15,840	110	80	78	65	53	40
2½	13,200	121	90	83	74	54	40
2	10,560	142	99	86	80	60	41
1½	7,920		123	95	85	68	43
1	5,280			128	90	74	50
½	2,640				145	119	56
¼	1,320						120
Train friction in pounds per ton		35	30	27.5	25	20	15

The breaking effort or retardation is taken at 150 pounds per ton. The stops are taken at 15 seconds each, except in the case of the 15 miles per hour schedule, where the stop is taken as 10 seconds.

The foregoing figures are for cases of approximately level and approximately straight roads.

For a schedule of 40 miles per hour the speed attained will be between 60 and 65 miles per hour. A schedule of 25 miles will require speeds of from 40 to 50 miles per hour, etc.

The rate of acceleration for the long runs varies from 75 to 110 pounds per ton, going as high as 210 pounds per ton for short runs.

The foregoing applies to single car units. If units of more than one car be used, the friction in pounds per ton will decrease and with it will also decrease the energy consumption in watt hours per ton mile.

SINGLE-PHASE ALTERNATING CURRENT SYSTEMS OF RAILWAY MOTORS.

The use of the single-phase commutator type motor for electric traction was first seriously advocated by the Westinghouse Electric & Manufacturing Company, and a description of a single-phase system, proposed by that company for the Washington, Baltimore & Annapolis Railway was read by Mr. B. G. Lamme before the American Institute of Electrical Engineers in October, 1902. The development of this type of motor was at once taken up by other manufacturers including the General Electric Company in this country and a number of prominent companies in Europe. The first railway to employ the system on a large commercial scale was the Indianapolis & Cincinnati Traction Company, which began operation over a short portion of its track on December 30, 1904.

Practically all manufacturers employ a laminated field, an armature winding similar in general to that used in direct-current machines, and an auxiliary or compensating winding on the field, to neutralize the armature reaction. In general, also, the single-phase motors of all manufacturers are designed for operation on 250 volts or less.

A frequency of twenty-five cycles has been used exclusively in this country. In Europe, however, some roads employ this frequency, some lower and some higher frequencies. Lower frequencies are now being advocated in the United States.

Sizes of motors up to 250 horse-power have been built. Those in service at the present time range from 40 to 150 horse-power and are used in both two and four-motor equipments.

One of the essential advantages of the single-phase system is the economy of feeder copper which is secured, due to the use of a high trolley voltage. The higher the voltage the greater the saving thus effected. On the other hand, the greater the trolley voltage the greater the difficulty of insulating the line.

Trolley voltages of 3300, 6600, 11,000 and as high as 13,000 are in use. No attempts have been made to standardize trolley voltages at present, but the general tendency seems to be toward the use of 6600 volts for ordinary trolley roads and of 11,000 volts for the electrification of existing steam railways.

Single-phase equipments in general include, in addition to the motors, a specially designed trolley to collect the high-voltage current, a transformer to reduce the voltage for use at the motors, and the necessary controlling devices to regulate the supply of the current and control the speed of the car. These latter devices consist of drum-type controllers for small equipments and single car operation and unit switches operated by independent power for large equipments, or where multiple unit service is desired.

The single-phase alternating current motor will operate equally well on direct current of the proper voltage and by connecting two or more motors in series a single-phase car equipment can be arranged to run from an ordinary direct-current trolley as well as from a high voltage single-phase trolley. With such an arrangement, cars can be run over the same tracks as ordinary city cars when entering a town.

Figure 80 shows a diagram of connections for a double equipment of 50 horse-power single-phase motors with hand control as supplied by the Westinghouse Electric & Manufacturing Company. It will be seen from

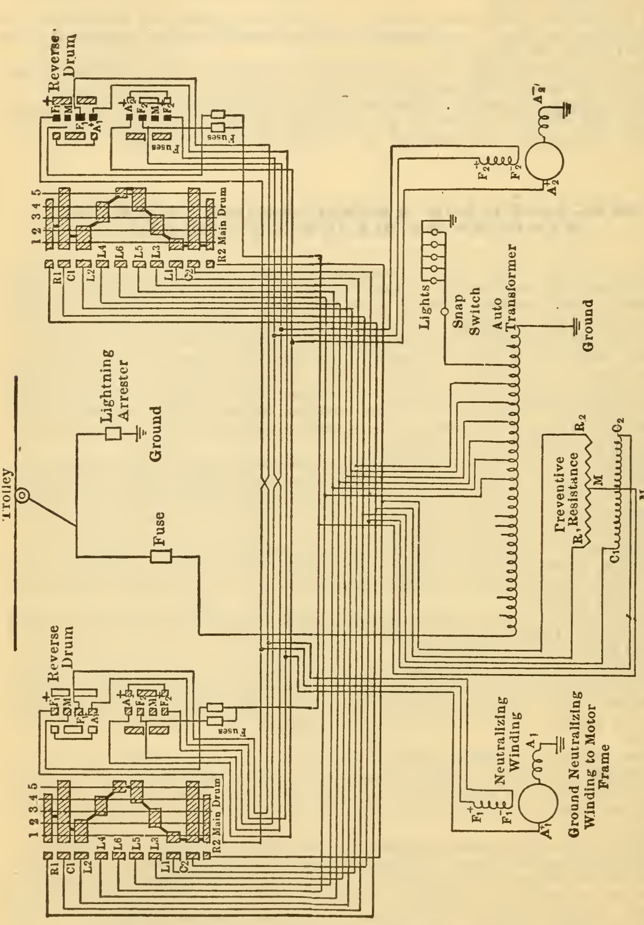


FIG. 80. Diagrams of Connections for Two 50 Horse-Power Single-Phase Motors with Hand Control. Westinghouse Electric Manufacturing Company.

the diagram that there are five different notches on the controller, by means of which the motors may be connected to five different points on the transformer and that the motors may be run continuously on any notch, thus giving five different car speeds. When running at less than the maximum speed, the power required is reduced in approximate proportion to the speed.

Figure 81 shows a schematic diagram of a car equipment for multiple unit operation on either direct or alternating current. In this equipment the main circuits are opened or closed by unit switches operated by compressed air from the brake system in the same way as those employed in the Westinghouse unit switch system of control for direct-current motors. The main switches are controlled by means of magnet valves operated through auxiliary circuits from a master switch. The auxiliary circuits are carried from car to car by flexible connections in the usual way so that the operation of the master switch on any car operates the main switches on all motor cars simultaneously. See Figs. 81 and 82.

The auxiliary circuits between the master switch and the main switches

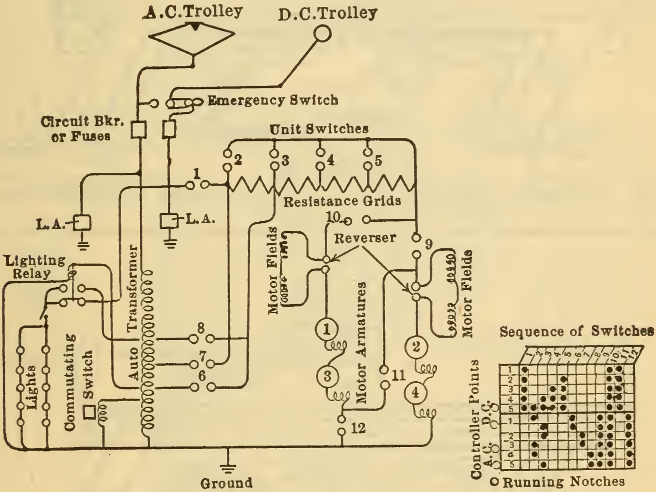


Fig. 81. Schematic Diagram of Westinghouse A.C.—D.C. Car Equipment.

are led through an automatic change-over switch, which normally remains in the position for direct-current operation but which changes to the position for alternating-current operation whenever alternating current is supplied to the car transformer. By this arrangement operating the same master controller closes different main switches, according to whether direct current or alternating current is being used by the car.

For the sake of clearness the auxiliary circuits are not shown on this diagram.

Figure 83 shows a schematic diagram of a car equipped with four 50 horse-power single-phase motors for operation on 3300 volts.

Figure 84 shows diagram of connections for a quadruple equipment of 75 horse-power motors with hand control, as supplied by the General Electric Company for operation on alternating current only, and figure 85 shows diagram of connections for the same equipment with multiple unit control for operation on both alternating current and direct current.

Figure 85 shows performance curves of typical single-phase motors manufactured by the Westinghouse and General Electric Companies.

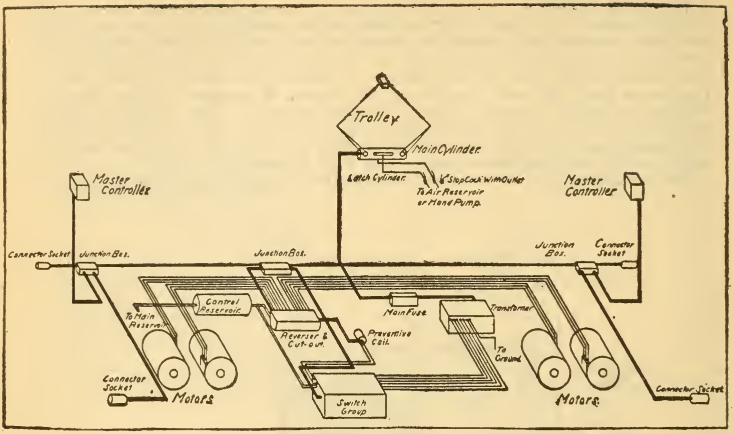


FIG. 82. Diagram of Apparatus for Unit Switch System of Multiple Control, A. C. Equipment.

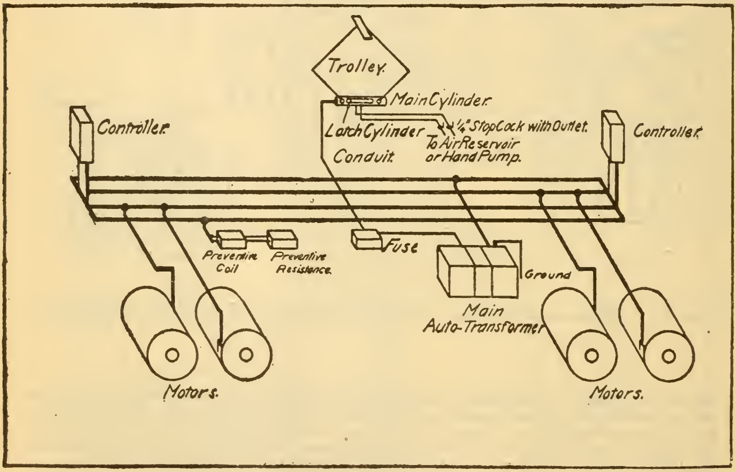


FIG. 83. Diagram of Apparatus for Hand Control, A. C. Equipment

General Electric Company's Hand Potential Control System.

This being a system of hand control for alternating current running only, it is less complicated and somewhat lighter than a train system. The General Electric potential control is also used for combined alternating current and direct current running by the addition of starting resistances and a commutating switch, whose office is to make the necessary change in connection. This potential control gives a higher efficiency equipment than is provided by any form of resistance control.

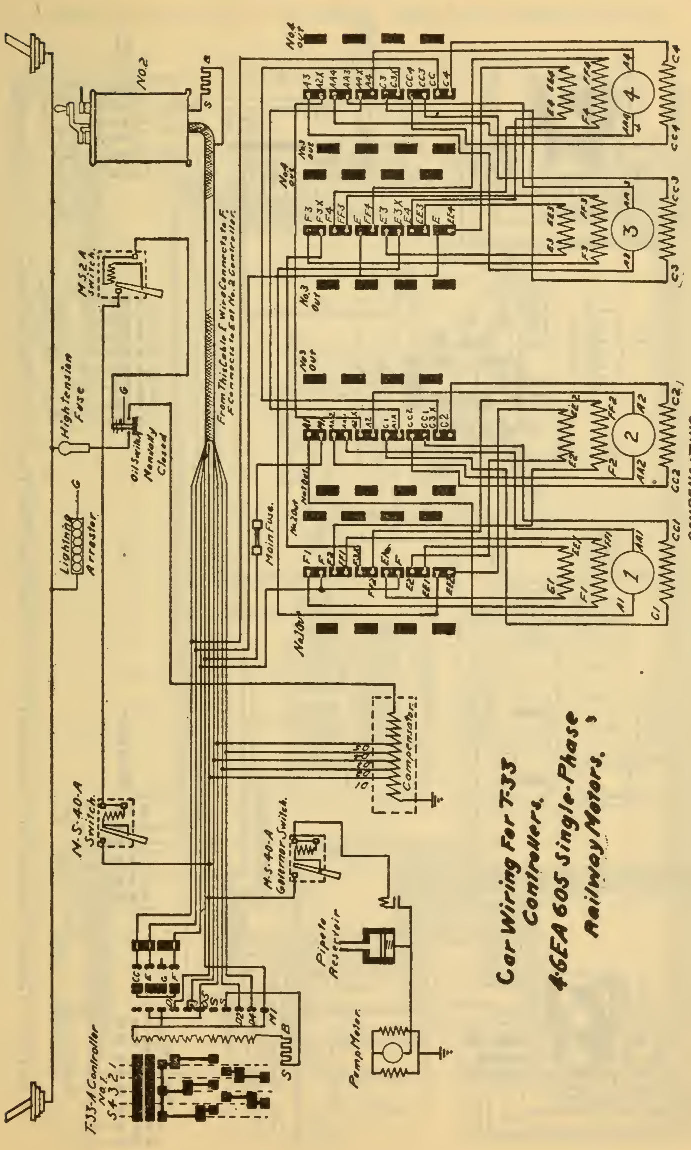


FIG. 84. Diagram of wiring for 4 A. ꓛ Single-Phase G. E. Motors, Hand Control.

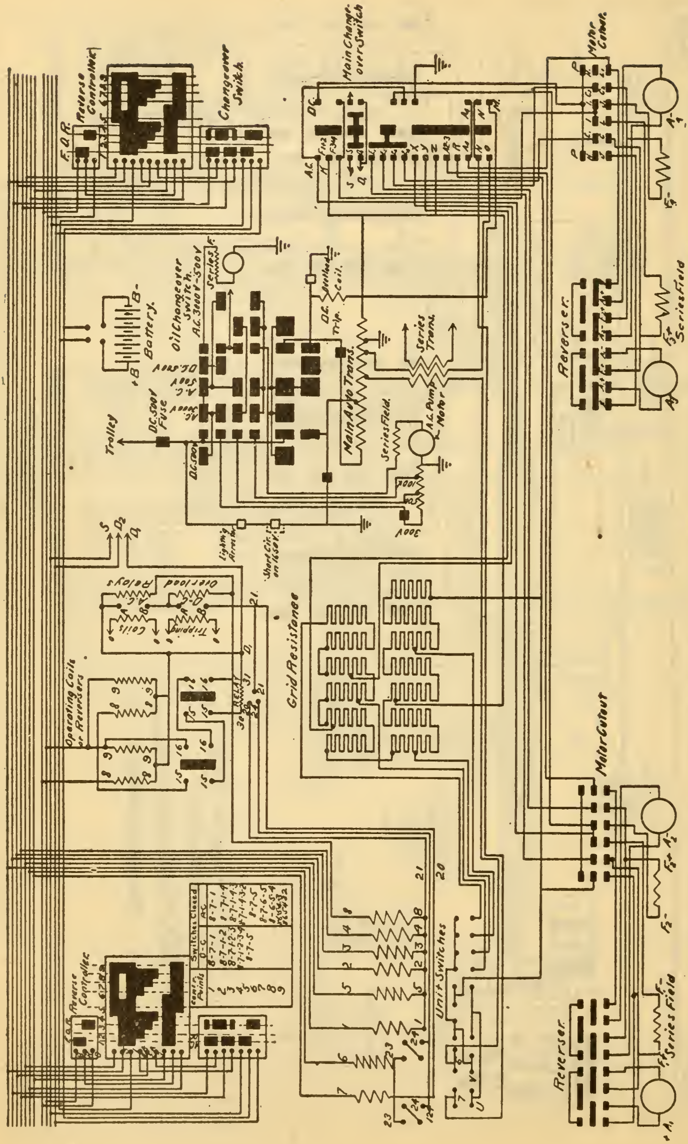


FIG. 85. General Diagram of Connections for G. E. Multiple Unit Control for Single-Phase A. C. Equipments.

SINGLE-PHASE MOTOR CHARACTERISTICS.

Following are a number of curves showing the characteristics of the General Electric and Westinghouse single-phase railway motors of this date, November, 1906.

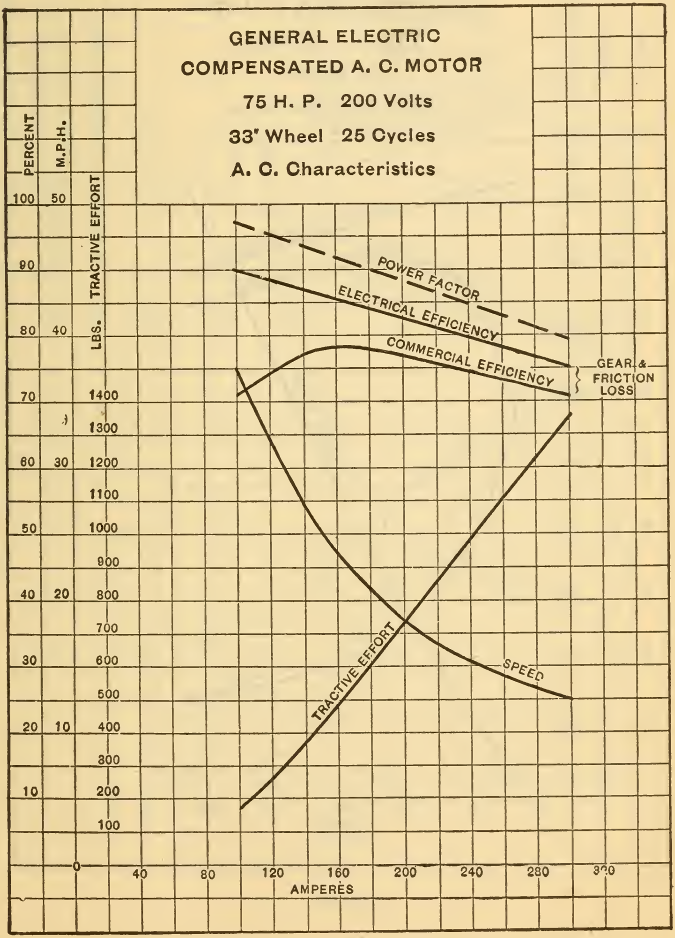


Fig. 86.

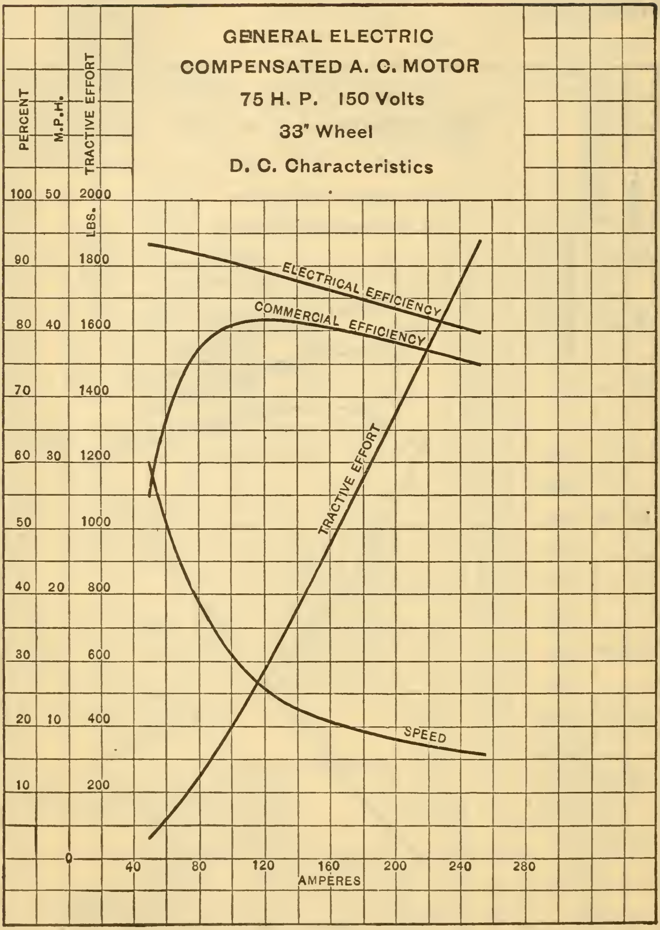

GENERAL ELECTRIC
COMPENSATED A. C. MOTOR
75 H. P. 150 Volts
33" Wheel
D. C. Characteristics
PERCENT
M.P.H.
TRACTIVE EFFORT
LBS.
100 50 2000
90 1800
80 40 1600
70 1400
60 30 1200
50 1000
40 20 800
30 600
20 10 400
10 200
0
40 80 120 160 200 240 280
AMPERES
ELECTRICAL EFFICIENCY
COMMERCIAL EFFICIENCY
TRACTIVE EFFORT
SPEED

FIG. 87.

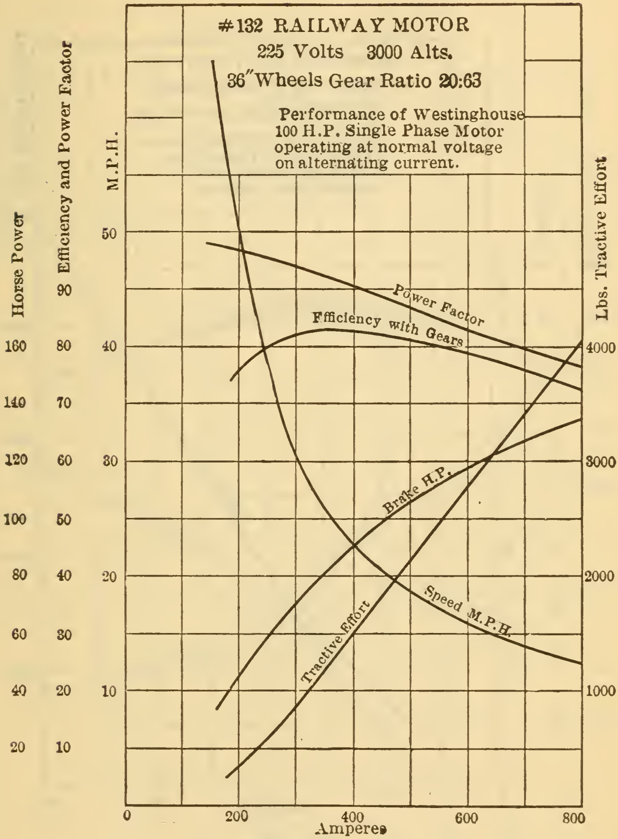

#132 RAILWAY MOTOR
225 Volts 3000 Alts.
36″ Wheels Gear Ratio 20:63
Performance of Westinghouse 100 H.P. Single Phase Motor operating at normal voltage on alternating current.
Horse Power
Efficiency and Power Factor
M.P.H.
Lbs. Tractive Effort
Power Factor
Efficiency with Gears
Brake H.P.
Speed M.P.H.
Tractive Effort
Amperes
0
200
400
600
800
160
140
120
100
80
60
40
20
90
80
70
60
50
40
30
20
10
50
40
30
20
10
4000
3000
2000
1000

FIG. 88.

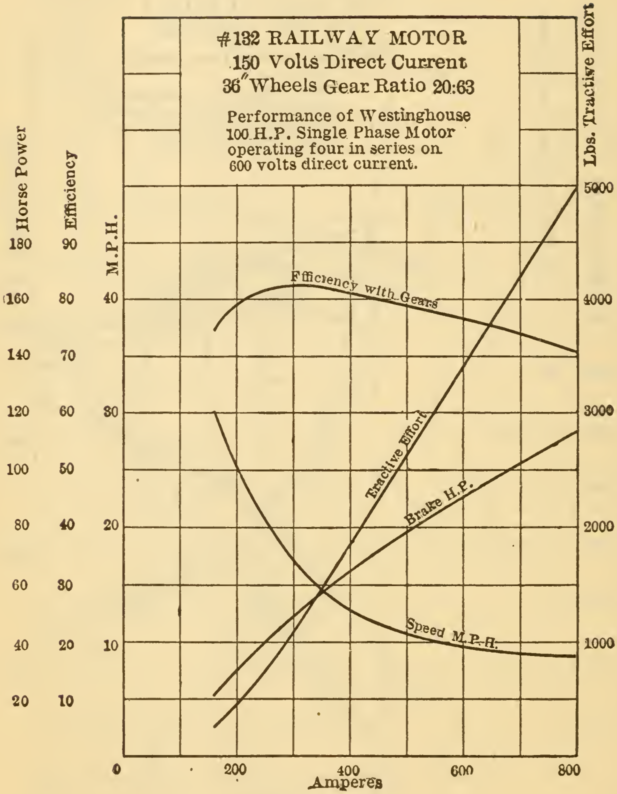
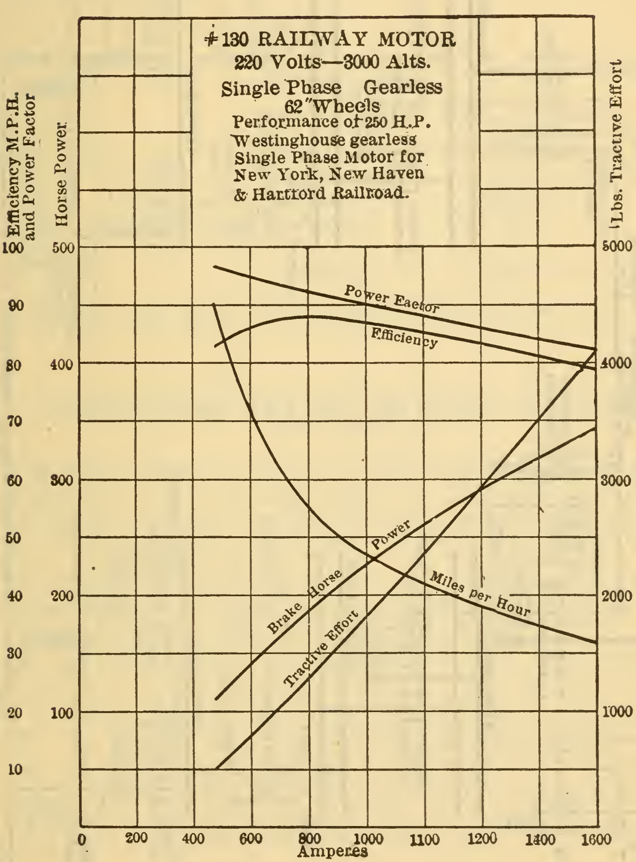

#132 RAILWAY MOTOR
150 Volts Direct Current
36" Wheels Gear Ratio 20:63
Performance of Westinghouse
100 H.P. Single Phase Motor
operating four in series on
600 volts direct current.
Horse Power
Efficiency
M.P.H.
Lbs. Tractive Effort
Efficiency with Gears
Tractive Effort
Brake H.P.
Speed M.P.H.
Amperes
180
160
140
120
100
80
60
40
20
90
80
70
60
50
40
30
20
10
40
30
20
10
5000
4000
3000
2000
1000
0
200
400
600
800

Fig. 89.



130 RAILWAY MOTOR
220 Volts—3000 Alts.
Single Phase Gearless
62" Wheels
Performance of 250 H.P.
Westinghouse gearless
Single Phase Motor for
New York, New Haven
& Hartford Railroad.
Efficiency M.P.H. and Power Factor
Horse Power
Lbs. Tractive Effort
100
90
80
70
60
50
40
30
20
10
500
400
300
200
100
5000
4000
3000
2000
1000
Power Factor
Efficiency
Brake Horse Power
Tractive Effort
Miles per Hour
0
200
400
600
800
1000
1100
1200
1400
1600
Amperes

FIG. 90.

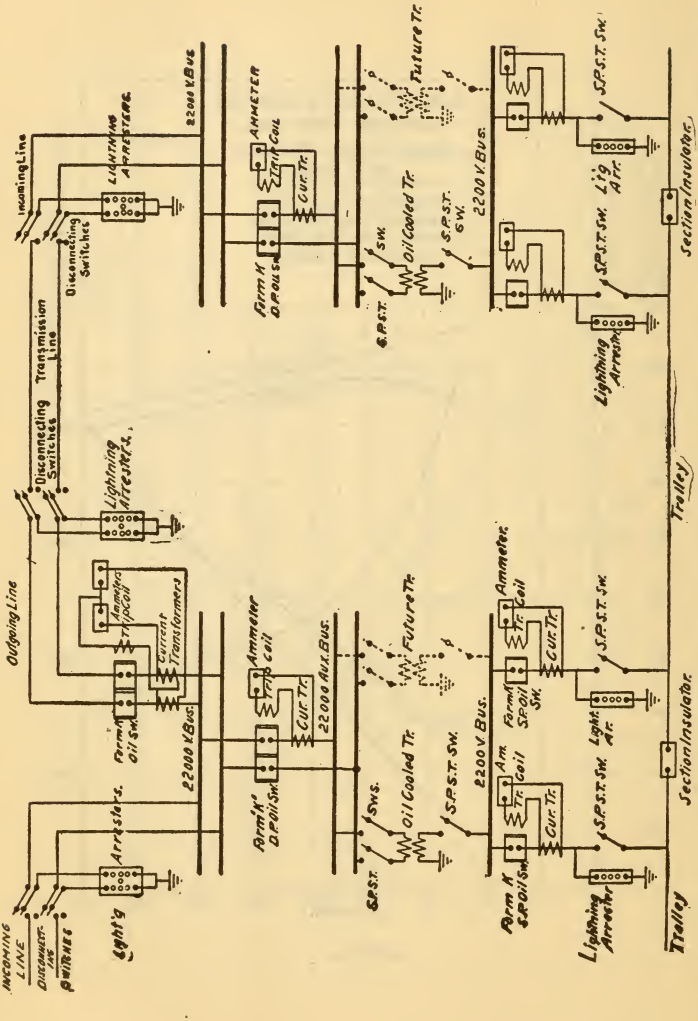


FIG. 91. Power Distribution System for Single-Phase Railway, Single-Phase Transmission, Single Track.

Weights of Alternating-Current Motor Equipments.

The alternating-current motors are somewhat heavier than direct-current motors of equal capacity.

Comparative Weights 75 Horse-Power, Four Motor Equipment.

	Direct Current.	Alternating Current.
Car body	22,000 lbs.	22,000 lbs.
Trucks	14,000 lbs.	14,000 lbs.
Motors	15,000 lbs.	20,000 lbs.
Transformers and control	6,000 lbs.	8,000 lbs.
Total	57,000 lbs.	64,000 lbs.

Increased weight $\frac{\text{A. C.}}{\text{D. C.}}$ = 12.3 per cent for total equipped car.

HIGH SPEED TRIALS ON LAKE ELECTRIC RAILWAY.

The motor equipment of car No. 18 with which the records were made comprises four G. E. No. 66 125 horse-power motors, and G. E. type C controller, connected up for train control. A speed of 65 miles per hour was attained at a pressure of 575 volts. The car requires between 400 and 600 amperes during acceleration, and 260 amperes at full running speed. It is vestibuled at both ends, seats 56, and is 49′ 6″ long by 8′ 6″ wide, weighing, loaded, 36 tons.

On a night run from Fremont to Toledo and return, with a loaded car weighing 36 tons and with a clear track, the distance of 33.16 miles was covered in 1 hour, 11 minutes and 10 seconds on the down trip and 1 hour and 10 seconds on the back trip, an average of 34.3 miles per hour on the down trip and 35.3 miles per hour on return trip. From Fremont to the Toledo city limits, 30.42 miles, the time was 52 minutes and 10 seconds, and on the return trip 44 minutes and 30 seconds, the former an average of 41.2 miles, and the latter an average of 41.85 miles per hour. It will be noticed from the accompanying table marked "theater run," that when the car was making its highest speed the watts per ton mile were practically equal to the speed in miles per hour. The current consumption within the city limits of Toledo where city cars were in operation, and where there were many bad curves, was about three times as great as on a straight level track and with less than one-fifth the speed. The increase of current consumption caused by grades and curves is also marked.

Table VIII. Car No. 18.—On Regular Passenger Service.

Distance	Schedule Time.	Date.	Watt-Hours.	Watt-Hours per Ton Mile.	Motorman.	Remarks.
27.54	1 hour 30 min.	Feb. 26, 1902	71,600	74.0	Rudes	Twenty-five stops.
27.54	1 " 30 "	Feb. 27, 1902	66,400	69.3	Jones	
27.54	1 " 30 "	April 7, 1902	68,400	71.0	Holmes	
27.54	1 " 30 "	Feb. 26, 1902	58,000	60.4	Rudes	Thirty stops.
27.54	1 " 30 "	Feb. 27, 1902	55,200	57.9	Jones	
27.54	1 " 30 "	April 7, 1902	69,200	71.9	Holmes	
30.72	1 " 37 "	Feb. 26, 1902	66,800	61.9	Sandwich	Left Fifth Street 15 minutes late.
30.72	1 " 37 "	Feb. 28, 1902	75,600	70.6	"	" " " 10 " "
30.72	1 " 37 "	Feb. 27, 1902	56,000	52.1	Jones	
30.72	1 " 37 "	Mar. 28, 1902	63,200	59.0	Holmes	
30.72	1 " 37 "	April 7, 1902	85,600	79.2	"	
5.48	0 " 46 "	Feb. 26, 1902	24,600	128.2	Sandwich	Time slow; many stops on account city cars.
5.48	0 " 46 "	Feb. 27, 1902	24,400	127.5	Jones	" " " "
5.48	0 " 46 "	Feb. 28, 1902	21,200	111.0	Sandwich	" " " "
5.48	0 " 46 "	Mar. 28, 1902	26,800	140.0	Holmes	" " " "
5.48	0 " 46 "	April 7, 1902	34,000	178.0	"	" " " "
30.72	1 " 37 "	Feb. 26, 1902	40,000	37.2	Sandwich	
30.72	1 " 37 "	Feb. 27, 1902	70,000	65.1	Jones	
30.72	1 " 37 "	Feb. 28, 1902	49,600	45.2	Sandwich	
30.72	1 " 37 "	April 7, 1902	68,400	71.0	Holmes	
27.54	1 " 30 "	Mar. 28, 1902	68,800	71.6	"	

Table IX. Car No. 18.—Theater Run; Loaded Weight 36 Tons.

Actual Running Time.	Distance.	Number of Stops.	Watt-Hours.	Watt-H'rs per Ton Mile.	Watt-H'rs per Car Mile.	Speed in M.P.H.	Remarks.
m. s.							
14 10	8.51	4	27,200	88.7	3195	36.0	One 7% grade 600 ft. long; 3 railroad crossings.
4 15	4.84	....	11,600	66.6	2397	67.0	Straight, level track.
8 35	5.62	....	16,000	79.4	2854	39.4	One 3% grade 1,500 ft. long; 4 curves.
17 20	11.45	1	27,000	65.5	2354	39.6	Block set against at L. S. & M. S. R.R.
14 0	2.74	7	17,800	180.0	6480	11.8	Interference with city cars.
13 0	2.74	7	19,200	195.0	7010	12.7	Many bad curves.
17 50	11.45	....	28,200	68.5	2465	38.5	Eight miles, 350,000 cm. feed.
8 30	5.62	....	19,200	95.1	3420	39.8	Four curves.
4 10	4.84	....	12,000	69.0	2480	69.0	Straight, level track.
13 15	8.57	2	24,200	79.2	2848	38.6	Three railroad crossings.
58 20	33.16	11	99,600	83.6	3010	34.3	
56 35	33.16	9	102,800	86.2	3105	35.3	
44 20	30.42	4	81,800	75.1	2700	41.2	
43 35	30.42	2	83,600	76.7	2725	41.85	

INTERURBAN CAR TESTS.

By W. E. Goldsborough and P. E. Fansler. Trans. A. I. E. E.

TESTS MADE UPON CARS OF THE UNION TRACTION COMPANY OF INDIANA.

The cars used measure 52 feet 6 inches over all and weigh 63,100 pounds. The motive power equipment consists of two number 50 C Westinghouse motors, which are mounted on the forward truck and are nominally rated at 150 horse-power each. The motors are geared with the ratio of 20 to 51 and are geared to 36-inch wheels. Records were obtained from 10 cars of this type.

The following tables give the results for several different cars used on various routes, a special test of three cars, and a table showing the personal factor of different motormen:

Table X. Train Log.

Train No.	Car No.	Direction.	K.W.H.	K.W.H. Per Car Mile.
1	246	East	131.2	2.32
12	246	West	128.5	2.28
19	246	East	125.6	2.21
28	246	West	134.8	2.38
35	246	East	119	2.11
Average, East				2.21
Average, West				2.33
9L	250	East	107.4	1.9
18L	250	West	123.8	2.19
25L	250	East	108.5	1.92
34L	250	West	119.6	2.11
Average, East				1.91
Average, West				2.15
39	252	East	128.7	2.27
32	252	West	139.5	2.46
44	252	West	113.1	2.00
Average, East				2.27
Average, West				2.23
6	254	West	142.5	2.52
13	254	East	137.6	2.43
22	254	West	139.2	2.46
29	254	East	162	2.86
41	254	East	119.0	2.10
42	254	West	126	2.23
Average, East				2.46
Average, West				2.40

Table X. Train Log. — *Continued.*

Train No.	Car No.	Direction.	K.W.H.	K.W.H. Per Car Mile.
10L	255	West	101.0	1.77
17L	255	East	96.0	1.70
26L	255	West	106.0	1.87
33L	255	East	101.0	1.78
Average, East				1.74
Average, West				1.83
2	260	West	122.4	2.16
7	260	East	130.6	2.30
15	260	East	127.5	2.25
16	260	West	114.2	1.85
23	260	East	133.5	2.35
38	260	West	128.5	2.27
Average, East				2.30
Average, West				2.09
31	261	East	156.5	2.59
8	261	West	142.0	2.51
24	261	West	132.8	2.34
Average, East				2.59
Average, West				2.42
30	262	West	127.0	2.24
3	262	East	111.0	1.96
14	262	West	122.0	2.15
21	262	East	123.0	2.17
37	262	East	112.5	1.98
Average, East				2.03
Average, West				2.19
11	263	East	124.5	2.20
20	263	West	135.5	2.39
27	263	East	94.5	2.48
40	263	West	134.0	2.37
43	263	East	118.5	2.09
4	263	West	140.0	2.48
Average, East				2.26
Average, West				2.41

Table XI. Comparison of Car Tests.

Number of car	255	252	252
Service, west bound	semi-limited	local	limited
Weight	63,100	63,100	63,100
Gear ratios	23:48	20:51	20:51
Total time trip, min.	122	156	126
Time urban work, min.	44	40	34
Time interurban work, min.	78	116	92
Average speed for trip, m.p.h.	28	22	27
Average urban speed, m.p.h.	8	9	10
Average interurban speed, m.p.h.	39	26	33
Total starts	18	44	12
Urban starts	5	15	7
Interurban starts	13	29	5
Maximum speed, m.p.h.	64	52	. . . . .
Running speeds	50–55	40–45	40–45
Running currents	173	145	145
Train resistance corresponding lbs. per ton	27.7	19.9	19.9
Time to reach 25 m.p.h.	30	30	30
Acceleration current, max. series	280–340	200–300	200–300
Acceleration current, max. par	320–540	250–300	250–300
Consumption, k.w.h., p.c.m., west	2.20	2.44	2.10
Consumption, k.w.h., p.c.m., east	2.38	2.80	2.32
Consumption, watt-hour per ton mile, west	69.7	77.5	66.7
Consumption, watt-hour per ton mile, east	75.5	89.0	73.5
Sq. root mean sq. current, west	95.6	92.1	78.0
Sq. root mean sq. current, east	105.5	98.4	87.2
Running factors, west	43.5	37.8	36.2
Running factors, east	43.3	31.5	37.6
Average voltage, west	485	429	. . . . .
Total consumption k.w.h., west	124.9	138.0	118.8
Total consumption k.w.h., east	134.3	176.2	131.2

Table XII. Personal Factor of Motormen. Local Runs.

Name.	East. Total K.W.H.			West. Total K.W.H.			Trips.	
	Min.	Average	Max.	Min.	Average	Max.	East	West
Eller	122	135	148	114	125	136	6	6
Lee	116	121	126	124	129	130	4	4
Robbins	122	131	138	119	124	128	4	4
Green	113	123	131	126	134	141	3	3
Young	118	122	128	112	128	145	3	6
Griffin	124	130	140	127	131	134	3	4
Embry	108	126	154	134	135	135	3	2
		127			130		26	29

Table XIII. Tests of Interurban Cars on the Lines of Northern Texas Traction Co.

By Mr. Bret Harter.

Car.	No. 1 and No. 7.	Sagamore.	No. 12.	No. 9.
Type	Standard Closed Interurban Passenger.	Interurban Parlor Car.	Standard Interurban Express.	15-Bench Open Interurban Trailer.
Make	Kuhlman.	Kuhlman.	Kuhlman.	Kuhlman.
Length over all	44′ 5″	59′ 6″	40′ 0″	45′ 8″
Width	8′ 4″	8′ 5″	8′ 4″	8′ 0″
Total Weight in Tons, Car and Equipment	25.4	31.0	20	17.4
Number Motors	4	4	. . . . . .	. . . . . .
Make	Westinghouse.	Westinghouse.	Westinghouse.	. . . . . .
Manufacturing No.	56	76	56	. . . . . .
Gear Ratio	32–50	24–58	24–58	. . . . . .
Controllers	K 14	L 4	K 14	. . . . . .
Number of Trucks	2	2	2	2
Make	McGuire.	Brill.	McGuire.	McGuire.
Manufacturing No.	35	27	35	40
Diameter of Wheels	33″	33″	33″	30″
Wheel Base	6′	6′	6′	4′ 3″
Make Brake	Christensen.	Christensen.	Christensen.	Christensen.
Type Brake	Direct Acting Storage Air.	Independent Direct Acting Air.	Independent Quick Acting Automatic Air.	Quick Acting Automatic Air.

Table XIV.

This gives the data obtained from the entire run of interurban cars, including runs in Ft. Worth and Dallas.

Place	Ft. Worth to Dallas.													to Siding.			No. 29 to Dallas.			
Date, 1902	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30												
Weight of Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Wt. of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt.	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.5	35.1	34.4	34.6	30.5	30.4	30.4	30.3	34.5	34.35	34.35	34.35
Time Mins.	82.0	95.5	89.0	96.0	90.0	96.0	88.5	97.5	99.5	109.5	102.5	121.0	74.7	82.0	88.5	93.0	113.5	113.5	91.85	108.5
Miles per Hour	25.1	21.6	23.1	21.4	22.8	21.4	23.2	21.2	20.8	19.2	20.1	17.1	24.4	22.2	20.6	19.6	18.2	18.1	22.4	19.0
Kw.-Hrs.	84.6	86.4	70.2	73.2	75.6	77.4	72.0	75.6	58.2	72.6	88.8	98.4	52.4	57.6	82.2	88.8	64.2	69.6	59.1	62.1
Kw.-Hrs. per Mile	2.46	2.52	2.04	2.13	2.2	2.26	2.1	2.2	1.69	2.07	2.58	2.84	1.72	1.9	2.7	2.93	1.86	2.03	1.72	1.81
Watt-Hrs. per Ton Mile	91.0	92.5	76.0	81.5	80.5	80.6	64.0	66.5	82.5	92.0	61.0	66.5	80.0	84.5	63.5	69.0	72.5	78.9	67.0	70.4
Avg. Kw.	61.8	54.3	47.3	45.8	50.4	48.4	58.8	46.6	35.5	39.9	52.0	48.8	42.0	42.2	55.6	57.3	33.9	36.7	38.6	34.4
Stops			25	27			24	24	19	14	15*	13*	13	9	8	8	29	30	15	11

*No. 9. Trailer dropped and picked up at Siding 29, Oak Cliff, City Limits.

Table XV.

This gives the results obtained on the high speed portion of the road, being strictly the interurban section.

Place	T. & P. Crossing to Oak Cliff City Limits.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Weight of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Weight in Tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.6	28.5	28.6	28.5	28.6	28.45	28.45	28.45
Time, Minutes	53.2	58.5	59.5	57.5	58.5	57.25	56.5	60.0	62.25	63.5	72.75	81.0	72.75	73.0	59.5	65.0
Miles per Hour	32.0	29.1	28.6	29.6	29.1	29.8	30.2	28.4	27.6	26.9	23.6	21.1	23.6	23.4	28.7	26.3
Kw.-Hours	72.0		57.6	54.0	61.8	57.0	61.2	57.0	49.2	51.0	76.2	79.8	55.8	53.4	48.3	46.5
Kw.-Hours per Mile	2.54		2.03	1.9	2.18	2.01	2.15	2.0	1.74	1.79	2.66	2.80	1.95	1.87	1.70	1.63
Watt-Hrs. per Ton Mile	94.0		75.5	72.5	80.0	72.0	65.5	60.0	84.0	79.5	63.0	66.0	78.9	78.0	66.1	63.6
Avg. Kw.	81.3		58.1	56.4	63.4	59.7	65.0	57.0	47.4	48.2	63.0	59.1	46.1	43.8	48.7	42.9
Stops			9	8			9	9	7	5	5	5	21	21	4	6

Table XVI.

This gives the results obtained in Ft. Worth.

Place	Ft. Worth Terminal to T. & P. Crossing.															
Date	9/16	9/16	9/17	9/17	9/17	9/17	9/19	9/19	9/22	9/22	9/24	9/24	11/14	11/14	11/14	11/14
Car	1	1	1	1	1	1	Sagamore		12	12	12 and 9		7	7	7	7
Direction	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Passengers	22	25	20	11	25	35	25	30								
Wt. Pass. or Freight	1.6	1.9	1.5	0.8	1.9	2.6	1.9	2.2	0.5	2.5	5.0	5.2	0.3	0.3	0.3	0.3
Weight of Car	25.4	25.4	25.4	25.4	25.4	25.4	31.0	31.0	20.0	20.0	37.4	37.4	25.4	25.4	25.4	25.4
Total Wt. in Tons	27.0	27.3	26.9	26.2	27.3	28.0	32.9	33.2	20.5	22.5	42.4	42.6	25.7	25.7	25.7	25.7
Miles	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Time, Minutes	13.3	11.5	13.0	14.5	15.0	14.25	16.5	13.5	12.5	18.5	15.75	12.0	12.75	17.0	14.25	12.5
Miles per Hour	8.1	9.4	8.3	7.45	7.2	7.6	6.55	8.0	8.64	5.8	6.9	9.0	8.47	6.35	7.58	8.66
Kw.-Hours	7.2		6.6	9.0	7.2	9.6	6.8	9.0	3.6	6.6	6.0	9.0	3.9	6.3	4.8	6.3
Kw.-Hrs. per Mile	4.0		3.66	5.0	4.0	5.34	3.78	5.0	2.0	3.66	3.33	5.0	2.16	3.5	2.66	3.5
Watt-Hrs. per Ton Mile	148.0		136.0	191.0	146.0	190.0	115.0	150.0	97.5	162.0	78.5	117.0	84.3	136.0	104.0	136.0
Average Kw.	32.4		30.4	37.2	28.8	40.4	24.7	40.0	17.3	21.4	22.8	45.0	18.3	22.2	20.2	30.3
Stops			10	14			10	10	6	4	3	3	4	3	5	1

Two Motor vs. Four Motors per Car.

TEST BY UNITED RAILWAYS AND ELECTRIC COMPANY OF BALTIMORE. REPORTED BY H. H. ADAMS.

CAR No. 710. — 31-foot body; double trucks; 33-inch wheels; weight, 45,000 pounds empty; seats 44 passengers; 4 Westinghouse 101 B motors; gear ratio 1:3.66.

CAR No. 730. — 31 foot body; maximum traction truck; 33-inch driving wheels; weight, 31,700 pounds empty; seats 46 passengers; 2 Westinghouse 56 motors; gear ratio, 1:3.56.

TEST.	Car No. 710.	Relative per cent.	Car No. 730.	Relative per cent.
Horse-power . . .	160	100	110	68.7
Gear ratio	18:66	100	18:64	97
Average kw. . . .	28.47	100	25.65	90
Average amperes (assuming 500 v.)	56.95	100	50.6	90
K.W.H. per car mile	3.525	100	3.17	90
Watt-hours per ton mile	155.5	100	200	128
Average number passengers carried per round trip .	145	100	148	102

Railway Motors, Standard Sizes and Ratings, Nov. 1906.

Type.	Make.	Rating.	Weight.
12A	Westinghouse	30 H.P.	2200 lbs.
49	"	35 "	1920 "
92	"	35 "	2265 "
68	"	40 "	2280 "
101	"	40 "	2730 "
38B	"	45 "	2390 "
56	"	50 "	3000 "
93	"	50 "	3350 "
112	"	65 "	3490 "
76	"	75 "	3840 "
121	"	90 "	4300 "
119	"	125 "	4600 "
50F	"	150 "	5550 "
114	"	160 "	5300 "
86	"	200 "	6600 "
113	"	200 "	6550 "
			Weight including Gear and Gear Case.
G.E. 800	Gen. Elec.	25 H.P.	1800 lbs.
" 52	" "	25 "	1725 "
" 1000	" "	35 "	2180 "
" 67	" "	40 "	2385 "
" 70	" "	40 "	2530 "
" 80	" "	40 "	2530 "
" 57	" "	50 "	2972 "
" 74	" "	65 "	3534 "
" 73	" "	75 "	4022 "
" 66	" "	125 "	4378 "
" 55	" "	160 "	5415 "
" 69	" "	200 "	6100 "

Weights of Railway Equipments, including Control Apparatus, Car Wiring and Motors.

Type of Motor.	Number of Motors.	Type of Control.	Weight.
G.E. 800	2	K 10	4,750 lbs.
" 800	4	K 6	8,740 "
" 52	2	K 10	4,390 "
" 52	4	K 12	8,100 "
" 1000	2	K 10	5,310 "
" 1000	4	K 6	10,290 "
" 67	2	K 10	5,710 "
" 67	4	K 6	11,090 "
" 57	2	K 11	6,994 "
" 57	4	K 14	14,108 "
" 74	2	Train Type M	9,000 "
" 74	4	"	16,586 "
" 73	2	"	11,044 "
" 73	4	"	20,768 "
" 66	2	"	13,230 "
" 66	4	"	23,760 "
" 55	2	"	13,680 "
" 55	4	"	26,640 "
" 69	2	"	13,600 "
" 69	4	"	26,600 "
Westinghouse 12A	2	K 10	5,400 "
" 12A	4	K 12	10,100 "
" 49	2	K 10	4,900 "
" 49	4	K 12	9,300 "
" 92A	2	K 10	5,570 "
" 92A	4	K 28	10,500 "
" 68	2	K 10	5,700 "
" 68	4	K 6	10,700 "
" 101B	2	K 10	6,600 "
" 101B	4	K 28	12,500 "
" 38B	2	K 11	5,950 "
" 38B	4	K 14	12,150 "
" 101D	2	K 11	6,600 "
" 101D	4	K 28	12,500 "
" 56	2	K 11	7,200 "
" 56	4	K 14	14,600 "
" 93A	2	K 11	7,310 "
" 93A	4	K 14	14,700 "
" 76	2	K 6	9,450 "
" 76	4	L 4	19,000 "
" 112	2	K 28	8,000 "
" 112	4	L 4	15,750 "
" 93A	4	Unit Switch	15,145 "
" 112	4	"	16,205 "
" 121	2	"	10,370 "
" 121	4	"	19,485 "
" 119	2	"	11,495 "
" 119	4	"	21,100 "
" 114	2	"	12,915 "
" 114	4	"	24,455 "
" 113	2	"	15,785 "
" 113	4	"	29,535 "

TORQUE AND HORSE-POWER.

H.P. per Lb. Applied at Periphery at 100 Rev. per Min.

Diameter Wheel.	26″	28″	30″	33″	36″
H.P.	.02062	.02221	.0238	.02618	.02856

Pounds at Periphery per H.P. at 100 Rev. per Min.

Diameter Wheel.	26″	28″	30″	33″	36″
Lbs.	48.481	45.018	42.017	38.197	35.014

$$\text{Lbs.} = \frac{126050.9 \times \text{H.P.}}{\text{Diam.} \times \text{Rev.}}$$

H.P. = .00000793 × diam. wheel × rev. × lbs. at periphery.
H.P. per lb. at periphery at one mile per hour = .002667.
Lbs. at periphery per H.P. at one mile per hour = 374.9.

Note on Emergency Braking of Cars.

In case of emergency, motormen often reverse the motors, which brings the car up with a severe jerk, and is quite apt to strip gears. This is not necessary, and should never be done unless the canopy switch is first thrown off, then when the motors are reversed and the controller handle thrown around to *parallel*, the motors will act as generators and will bring the car to an easy stop with no harm to the apparatus. In case circuit breakers are used in place of the plain canopy switches, the reversal of the motors will draw so much current from the line that the circuit breakers, if properly adjusted, will open the circuit and the controller can then be used as suggested above.

COPPER WIRE FUSES FOR RAILWAY CIRCUITS.

B. & S. Gauges.	17	16	15	14	13	12	11	10	9	8	7
Fuse Point in Amperes.	100	120	140	166	200	235	280	335	390	450	520

APPROXIMATE DIMENSIONS VARIOUS STYLES OF ELECTRIC CARS.

Motor Cars.

(Merrill.)

Kind.	Length over Platforms.	Length over Posts.	Length of Platforms.	Height over All.	Size of Wheels.	Height Inside.	Width.	Number of Seats.	Kind of Seats.	Seating Capacity.	Weight of Body, Lbs.
Closed	24′	16′	4′	10′ 6″ to 11″	33″ to 36″	7′ 8″ to 8′	7′ 6″	2	Length of car	22	4500 to 5000
Closed	26′	18	4′	"	"	"	"	2	" "	26	4800 to 5100
Closed	32′	24′	4′	"	"	"	"	2	" "	34	6000
Convertible Summer and winter . .	33′ 3″	25′ 6″	4′	"	"	"	7′ 10″	2	" "	40	6200
Combination open and closed . . .	29′	11′ 8″	. . .	"	"	"	7′ 6″	. . .	. . . . . .	open part 24 closed part 16	5500
Open, but closed ends .	26′	20′ 8″	2′ 8″	"	"	"	6′ 10″	8	Reversible	40	4400
Open, and open ends .	22′ 6″	. . .	. . .	"	"	"	"	7	"	35	3500
Open, and open ends .	30′ 9″	. . .	. . .	"	"	"	7′ 2″	10	"	50	5000
Double decked, open body	24′ 9″	. . .	. . .	15′ 3″	. . .	. . .	6′ 10″	7	"	below 35 top 24	4400
Double decked, closed body . . .	35′	25′ 6″	4′ 9″	15′	. . .	. . .	7′ 6″	. . .	"	below 36 top 36	7500

Funeral car, motor or trail	20′	13′ 10″	3′ 1″	. . .	. . .	8′ 2″	7′	. . .	. . . . . .	. . .	3900
Open	24′	19′	2′ 6″	10′ 6″ to 11′ 6″	33″	7′ 8″ to 8′ 6″	7′	18	10 reversible ½ seats, 8 stationary ½ seats, center aisle.	36	3800
Open	25′	. . .	. . .	"	"	"	7′ 6″	10	vis-à-vis stationary back	50	4000
Open	29′ 6″	25′	2′ 3″	"	"	"	. . .	10	8 reversible 2 stationary	50	4400
Open	44′	37′ 6″	3′ 3″	"	"	"	8′	15	13 reversible 2 stationary	90	9000
Convertible summer and winter	23′	16′ 7″	3′ 3½″	"	"	"	7′ 8″	12	6½ seats each side of aisle	24	4600
Double decked, open body	24′ 9″	. . .	. . .	15′ 3″	"	. . .	6′ 10″	7	reversible	below 35 top 24	4400
Double decked, closed body	26′	15′ 10″	5′ 5″	. . .	. . .	. . .	7′ 6″	. . .	. . . . . .	below 22 top 22	4000
Double decked, closed body	34′	28′	3′	16′	33″	8′ 6″	8′	. . .	. . . . . .	below 48 top 40	12000
4-wheel gondola	13′ 10″	. . .	. . .	. . .	. . .	. . .	7′ 10″	. . .	. . . . . .	10000 lbs.	3250
4-wheel box-car	15′ 3″	12′ 3″	1′ 6″	. . .	. . .	6′ 3″	6′ 6″	. . .	. . . . . .	11000 lbs.	3800
Express and baggage	21′	. . .	. . .	. . .	. . .	. . .	7′ 3″	. . .	. . . . . .	. . .	5000

WEIGHT OF CAR BODIES AND TRUCKS.

Closed Cars.

Maker.	Overall Length.	Length Body.	Weight, Body, Lbs.	Type of Trucks.	Weight, Trucks, Lbs.	Remarks.
* Stephenson	. . . . . .	16′ 0″	5,000	Single		
Brill Co.	22′ 0″	16′ 0″	6,000	Single Truck	4600	Closed Car.
"	26′ 0″	18′ 0″	6,940	" "	4400	" "
American Car Co.	26′ 6″	18′ 2″	7,000	" "	4500	" "
Brill Co.	26′ 0″	20′ 0″	7,100	" "	4400	Mail Car, no passengers.
"	28′ 0″	16′ 0″	8,350	" "	4600	Double Decked.
"	28′ 0″	20′ 0″	7,600	" "	4600	Closed Car.
"	28′ 0″	20′ 0″	8,950	" "	4600	Comb. Baggage and Passenger.
* Stephenson	. . . . . .	20′ 0″	7,500	" "		
* St. Louis	. . . . . .	20′ 0″	11,800	" "	5200	
Brill Co.	28′ 4″	21′ 3″	7,800	" "	4500	Closed Car.
"	29′ 7″	20′ 3″	8,000	" "	4500	" "
Pullman	29′ 10″	20′ 0″	9,530	" "	. . . . . .	" "
Brill Co.	30′ 0″	22′ 0″	8,400	Maximum Traction	3350	" "
Stephenson	32′ 2″	22′ 1″	7,500	Single Truck	4500	" "
* "	. . . . . .	25′ 0″	13,000	Double Truck		
Brill Co.	36′ 0″	25′ 0″	8,400	Maximum Traction	3350	" "
* "	35′ 2″	25′ 0″	9,600	Double, No. 27G	4200	
"	36′ 0″	25′ 0″	12,400	Maximum Traction	3350	Palace or Private Car.
* Laconia	35′ 4″	25′ 0″	10,700	Double, No. 8B	4500	Vestibule Type.
* Brill Co.	35′ 4″	25′ 9″	11,900	Max. Traction, No. 22	3200	Convertible Car, Brooklyn City Type.

* Data obtained in 1902.

WEIGHT OF CAR BODIES AND TRUCKS.—*Continued.*

Closed Cars.

Maker.	Overall Length.	Length, Body.	Weight, Body, Lbs.	Type of Trucks.	Weight, Trucks, Lbs.	Remarks.
* Brill Co.	37′ 0″	28′ 0″	10,350	Max. Traction, No. 22	3200	Metropolitan Street Ry. Type.
* "	. . . . . .	28′ 0″	13,730	Double, No. 27G	4200	Semi-convertible Car.
Pullman	39′ 0″	26′ 6″	16,800	Maximum Traction	3900	Closed Car.
"	37′ 11″	28′ 5″	15,670	Double Truck	5300	Interurban Car.
* Brill Co.	. . . . . .	29′ 0″	11,330	Double, No. 27	6200	Buffalo and Niagara Falls Type, seating capacity, 44.
* "	36′ 0″	29′ 0″	11,700	Max. Traction, No. 22	3200	Metropolitan St. Ry., N.Y., Type (combination open and closed).
* Laconia	39′ 8″	29′ 4″	12,600	Double, No. 8B	4500	Vestibule Type.
Brill Co.	40′ 0″	29′ 0″	13,460	Double Truck	5150	Interurban Car.
* "	. . . . . .	30′ 8″	18,600	Max. Traction, No. 22	3200	Convertible Type, Newcastle Rd.
* "	40′ 8″	31′ 8″	13,400	Double, No. 27	6300	Buffalo & Lockport Ry., seating capacity, 44.
* "	40′ 6″	32′ 0″	15,260	Double, No. 27	6300	Akron, Bedford & Cleveland Ry., seating capacity, 44.
"	42′ 0″	31′ 10″	16,740	Double Truck	5540	Interurban Service, high speed.
Pullman	37′ 1″	32′ 5″	15,800	" "	5050	Comb. Passenger and Baggage.
"	43′ 0″	32′ 6″	17,130	" "	5200	Closed Car, Interurban.
* St. Louis	. . . . . .	34′ 0″	23,100	Double, No. 23A	5900	Chicago Type.
* Laconia	45′ 0″	34′ 9″	15,850	Double Truck, No. 9B	5000	Seating Capacity, 48.
* St. Louis	47′ 2″	39′ 11″	19,800	Double Hedley Trailer	7100	Northwestern El. R.R. Trailer, seating capacity, 60.

* Data obtained in 1902.

WEIGHT OF CAR BODIES AND TRUCKS.—*Continued.*

Closed Cars.

Maker.	Overall Length.	Length, Body,	Weight, Body, Lbs.	Type of Trucks.	Weight, Trucks, Lbs.	Remarks.
Manhattan . . .	45′ 11″	39′ 4.5″	20,000	Double Truck	5000	Number of Motors used.
Wason Mfg. Co. .	46′ 11″	39′ 5.75″	22,350	. . . .	. . . . .	Brooklyn El. R.R. Trailer.
G. C. Kuhlman .	50′ 10″	. . . . . .	22,000	. . . .	7500	Rapid Railway.
St. Louis	55′ 0″	44′ 0″	32,000	Double Truck	. . . . .	Interurban Service, high speed.
* "	55′ 1″	48′ 0″	30,700	Brill, No. 27	6500	G. E. Motor Car No. 4, seating capacity, 64.
* "	56′ 6″	50′ 0″	. . . . .	. . . .	. . . . .	For Canton & Akron Ry. Co., seating capacity, 72.
* "	56′ 0″	51′ 0″	33,400	. . . .	. . . . .	For Michigan Con. Co., seating capacity, 63.
* Pa. R.R. Co. . .	58′ 5.5″	52′ 11″	50,000	Double Truck	8000	Std. P. R.R. Passenger Coach.

Open Cars.

Maker.	Overall Length.	Length, Body,	Weight, Body, Lbs.	Type of Trucks.	Weight, Trucks, Lbs.	Remarks.
Brill Co.	28′ 8″	10 bench	7,200	Single, No. 21E	4800	
St. Louis	. . . . . .	10 "	7,800	Single Truck	5200	
Brill Co.	34′ 0″	12 "	9,400	Max. Traction, No. 22	3200	Seating Capacity, 60.
St. Louis	. . . . . .	12 "	9,900	Single Truck	5200	
"	. . . . . .	14 "	11,125	Double Truck	5100	
Brill Co.	40′ 4″	15 "	15,050	Double, No. 27G	4200	Narragansett Type.

* Data obtained in 1902.

DIMENSIONS OF BRILL CARS.

(*Corrected to May 1, 1904.*)

Size of Car.	Lengths.			Widths.		Seating Capacity, @ 17 in. per Person.	Approximate Weight.			Remarks.
	Body.	Over All. (Bumpers.)	Platforms.	Over Sills.	At Belt Rails.		Body, Lbs.	Trucks, Lbs.	Running Gear, Lbs.	
16 foot closed . . .	15 ft. 10 in.	25 ft. 6 in.	4′	6 ft. 2 in.	7 ft. 6 in.	22	4500	4800	—	
16 " trailer . . .	15 " 10 "	25 " 6 "	4′	—	7 " 6 "	22	4000	—	1400	
16 " storage battery	15 " 10 "	25 " 6 "	4′	6 " 6 "	7 " 6 "	22	5000	4800	—	
Convertible summer and winter trailer .	16 " 7 "	26 " 3 "	4′	—	7 " 6 "	24	4600	—	1400	
do. do.	17 " 6 "	27 " 2 "	4′	—	7 " 7 "	28	4300	—	1400	
17 foot closed . . .	17 " 0 "	26 " 8 "	4′	—	8 " 0 "	24	4800	4800	—	8 feet high in Center
18 " " . . .	18 " 0 "	27 " 8 "	4′	6 " 2 "	7 " 6 "	24	4800	4800	—	Vestibules.
18 " " . . .	18 " 0 "	27 " 8 "	4′	6 " 2 "	7 " 6 "	24	5100	4800	—	Vestibules.
21 " " . . .	21 " 0 "	29 " 8 "	3′6″	6 " 2 "	7 " 6 "	28	5250	4800	—	
Convertible winter and summer trailer . .	22 " 0 "	30 " 8 "	3′6″	—	8 "	36	7400	—		
22 foot closed trailer .	22 " 0 "	30 " 8 "	3′6″		7 " 6 "	30	6000	3000	—	
24 " closed . . .	24 " 0 "	33 " 8 "	4′	6 " 6 "	7 " 6 "	32	6000	3200	—	
25 " " . . .	25 " 0 "	34 " 8 "	4′	6 " 6 "	7 " 6 "	34	5850	3200	—	
25 " " . . .	25 " 0 "	34 " 8 "	4′	6 " 6 "	7 " 6 "	34	6050	3200	—	Vestibules.
Convertible summer and winter	25 " 6 "	35 " 2 "	4′	7 " 0 "	7 " 10 "	40	6200	5200	—	Vestibules.
do. do.	27 " 6 "	37 " 2 "	4′	—	8 " 0 "	44	6200	5200	—	
Akron, Bedford & Cl.	31 " 10 "	42 " 0 "	—	—	—	44	—	—	—	Total Weight, 27860
Buffalo & Niagara Falls	29 " 0 "	38 " 8 "	—	7 " 5¼"	8 " 0 "	40	—	—	—	" " 23750
Semi-convertible . .	28 " 0 "	39 " 1 "	4′8½	7 " 11½"	8 " 2 "	40	14000	9000	—	Double Truck.
" " . .	30 " 8 "	41 " 9 "	4′8½	7 " 11½"	8 " 2 "	44	16000	9000	—	" "

DIMENSIONS OF BRILL CARS—(*Continued*).

Size of Car.	Lengths.			Widths.		Seating Capacity, Persons.	Approximate Weights.			Remarks.
	Body.	Over All. (Bumpers)	Platforms.	Over Sills.	At Belt Rails.		Body, Lbs.	Truck, Lbs.	Running Gear, Lbs.	
7 seat open	—	22 ft. 4 in.	4 ft.	6 ft. 2 in.	6 ft. 10 in.	35	3500	4800		
7 " " trailer . .	—	22 " 3 "	4 "	—	6 " 10 "	35	3400	1400		
8 " open	—	25 " 0 "	4 "	6 " 2 "	6 " 10 "	40	4000	4800		
8 " "	—	25 " 0 "	4 "	6 " 0 "	6 " 10 "	40	4400	4800		Closed ends.
9 " "	—	27 " 8 "	4 "	6 " 2 "	7 " 0½ "	45	6200	4800		
8 " "	—	25 " 0 "	4 "	—	6 " 10 "	40	4250	4800		Vestibules.
8 " "	—	25 " 0 "	4 "	6 " 2 "	7 " 0½ "	40	7200	4800		Vestibules.
10 " "	—	30 " 4 "	4 "	—	7 " 6 "	50	4000		1400	
18 foot trailer . . .	18 ft. 0 in.	25 " 0 "	3′6″	—	7 " 6 "	24	4000	—	1400	
10 seat open	—	30 " 4 "	—	6 " 2 "	7 " 2 "	50	5000	5800		
12 " "	—	35 " 8 "	—	6 " 2 "	7 " 2 "	60	6000	5800		
Open trailer	23 ft. 6 in.	27 " 6 "	4 ft.	—	7 " 6 "	32	5100	3000		Width at steps 8 ft. 4 in.
14 seat open trailer .		41 " 0 "	—	—	7 " 6 "	70	6500	3200		
15 " " " . .	37 " 4 "	42 " 8 "	—	—	8 " 0 "	75	9000	6000		
Combined baggage and passenger car . .	26 " 0 "	32 " 0 "	3 ft.	6 " 10 "	7 " 6 "	24	5850	5200		Pass. compt. 17 ft. 4 in. Bag. compt. 8 " 8 "
Heavy 12 bench . .	—	34 " 0 "	4 ft.	6 " 9 "	7 " 7½ "	60				Total weight, 16000 lbs.

ELECTRIC LOCOMOTIVES.

The number of electric locomotives in commercial operation is rapidly increasing. The service ranges from yard shifting, for which they are particularly well adapted, up to the hauling of passenger trains of 900 tons at 60 miles per hour. The motor capacity varies from two 50 horse-power motors of the geared type up to the four 550 horse-power gearless motors on the "Mohawk" type of the New York Central locomotive.

The following list is of interest: 1907.

Locomotives.	Year Completed.	Number Supplied.	Weight (Tons).	Operating Voltage.	Aggregate Nominal H.P. at Operating Voltage.	Gear Ratio.	Diameter of Wheels.	Service.
Cayadutta	1894	1	35	500	500	58/17	40″	Freight
96-Ton Baltimore & Ohio	1895	3	96	625	720	Gearless	62″	Passenger
Hoboken R.R. . . .	1897	1	28	500	560	54/17	40″	Freight
Buffalo & Lockport .	1898	2	36	500	*300 †600	52/21	36″	Freight
Paris & Orleans . .	1898	8	55	575	900	78/19	49″	Passenger
Compagnie Francais Thomson-Houston	1899	1	38	500	600	56/17	42″	Freight
St. Louis & Belleville	1901	2	50	500	360	56/17	33″	Freight
G. E. Co. 30-Ton Yard Locomotive.	1902	1	30	250	‡150 §300	72/17	36″	Switching
160-Ton Baltimore & Ohio	1903	2	160	625	1600	81/19	42″	Passenger
Bush Terminal Co. .	1904	1	50	500	360	52/21	33″	Freight
G. E. Co. 40-Ton Yard Locomotive.	1904	1	40	250	‡340 §680	59/18	33″	Switching
N.Y. C. & H. R. R.R. G. E. Co.	1904		95	625	2200	Gearless	44″	Passenger
N.Y., N.H., & H. R.R., W. E. & M. Co.	1906	‖	88	600	1000	Gearless	62″	Passenger

* Motors in series. † Motors in multiple. ‡ 250 Volts. § 500 Volts. ‖ Operates also on 11,000 volts, A. C.

No standard electric locomotive design has been reached, although many locomotives equipped with geared motors have the general shape shown in Fig. 92 (G. E. Co.). The motors, four in number, are geared to the axle by single reduction gears and are mounted on two bogie trucks, having about six-foot wheel base. The main cab contains the controller, and the sloping ends contain the necessary starting resistances. While this design using bogie trucks is suitable for locomotives of small capacity, it is not adapted to withstand the strains to which the larger locomotives are subjected, hence there has been developed a type having a solid cast-steel frame containing the motors of which the later B. & O. locomotives are

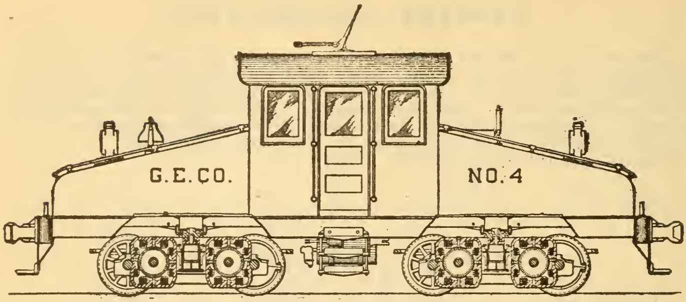


Fig. 92. Typical Electric Locomotive of G. E. Co.

typical. A cross section is shown in Fig. 93 of a half unit of the B. & O. locomotive. This locomotive has a rigid wheel base and contains four geared motors of a total capacity of 1600 horse-power. It is well adapted to stand the shocks of the most severe service and handles all passenger trains in the tunnel at Baltimore.

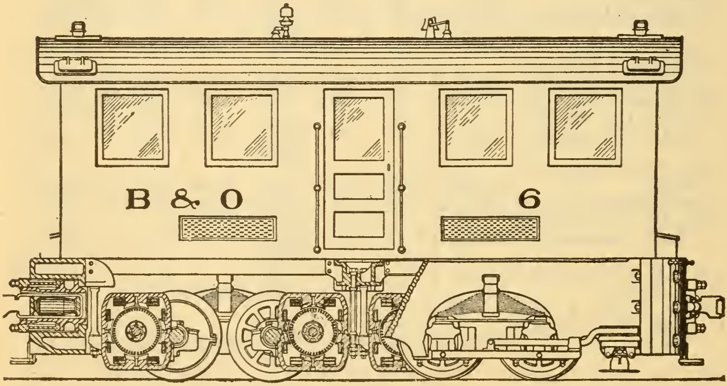


Fig. 93. Electric Locomotive used in Baltimore tunnel by B. & O. R.R.

The 6000 or "Mohawk" type of locomotive adopted by the New York Central R.R., shown in Fig. 94, differs from others in having four gearless motors mounted directly upon the axles. The armatures are not even spring suspended, but are keyed solidly to the axles. The dead weight per axle is said to be less than in the case of the larger types of steam locomotives. The fields are bipolar and are so arranged that the same flux passes through the four sets of fields in series, returning partly through the side frames and partly through an overhead longitudinal frame. The departure from the previous methods of construction, using geared motors, is pronounced, and exhaustive tests seem to prove its wisdom for the proposed service. In Fig. 95 are given the motor characteristics of the 550

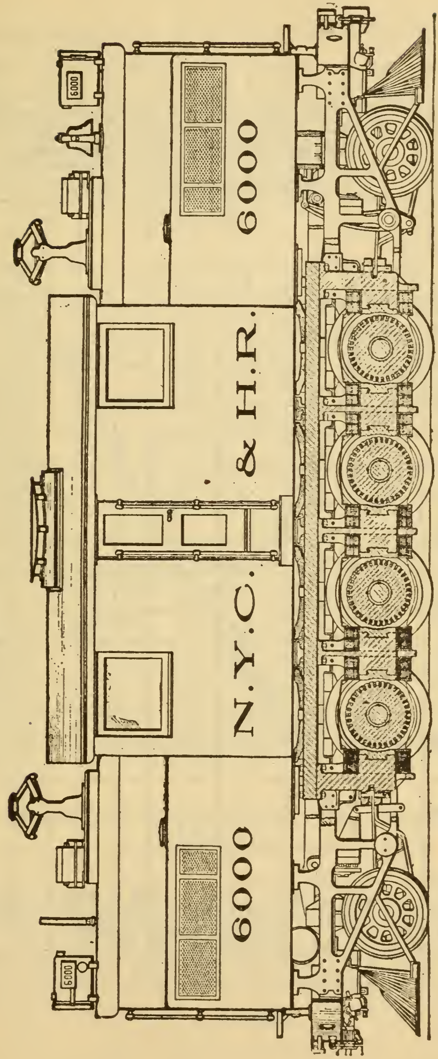


Fig. 94. D. C. Electric Locomotive used by the N. Y. C. & H. R. R.R.

New York Central & Hudson River R.R. Locomotive. Type of 1904. Weight, 95 tons. 2200 Horse-power Nominal Rating. 44″ Wheels Gearless. To Operate on 625 Volts.

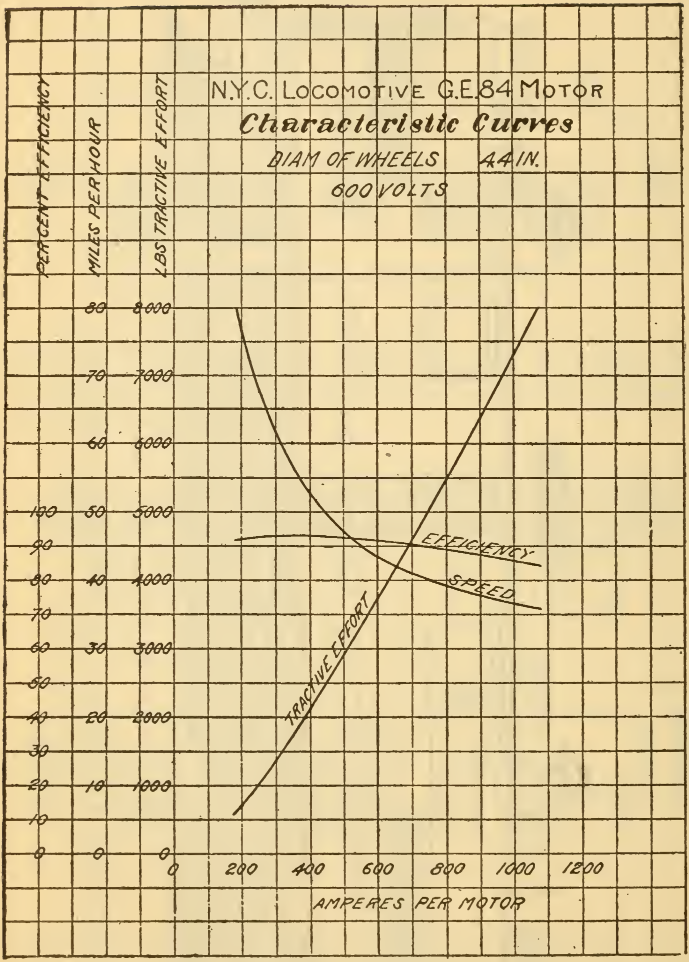

N.Y.C. LOCOMOTIVE G.E.84 MOTOR
Characteristic Curves
DIAM OF WHEELS 44 IN.
600 VOLTS
PERCENT EFFICIENCY
MILES PER HOUR
LBS TRACTIVE EFFORT
EFFICIENCY
SPEED
TRACTIVE EFFORT
AMPERES PER MOTOR
0
200
400
600
800
1000
1200

FIG. 95.

horse-power motor. Fig. 96 gives a specimen speed run of the 6000 locomotive hauling a train of 336 tons or a total train weight of 431 tons, including the locomotive itself. The speed reached, 63 miles per hour, has since been greatly exceeded, one run being made during which a speed of 84 miles per hour was recorded.

A locomotive which is of particular interest is that shown in Fig. 97. This is equipped with four 250 horse-power single-phase gearless motors, which are arranged for operation on either 600 volts direct current or 11,000 volts single-phase alternating current. This locomotive is the first of thirty-five (1907), which the Westinghouse Electric and Manufacturing Co. has supplied to the N.Y., N.H. & H. R.R.

It is of the double-truck type and has two swiveling trucks with a wheel base of 8 feet each and a distance between truck centers of 14 feet 6 inches.

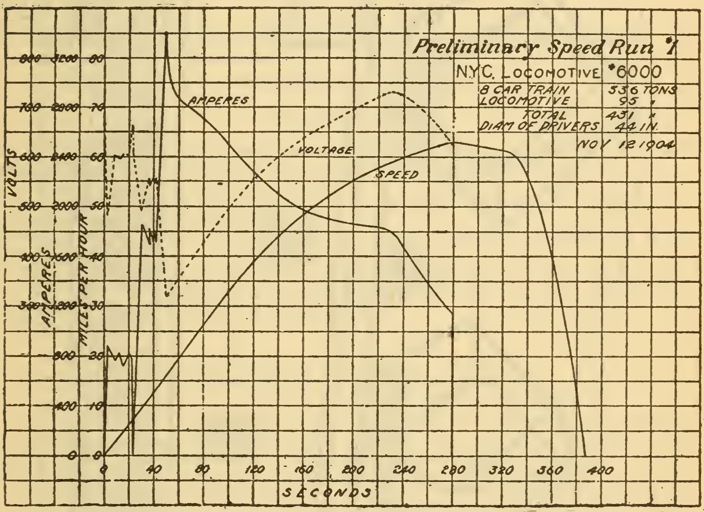


Fig. 96. Preliminary Speed Run of N. Y. C. Locomotive 6000. November, 1907.

This arrangement eliminates any danger of nosing and insures easy riding. The armatures of the motors are built on hollow shafts or quills which surround the axles and are connected to the driving wheels on each side by seven driving horns. These driving horns are surrounded by springs and fitted into pockets in the wheel hubs. The frames of the motors are spring supported from the journal boxes. The wheels are 62 inches in diameter and thus raise the center of gravity of the locomotive high above the track, similar to that of a steam locomotive. This arrangement, together with the spring supports of the motors, makes the locomotive particularly easy on the track. The general shape is such that ample room is obtained in the cab for mounting all apparatus so that it is readily accessible.

The tracks of the N.Y., N.H. & H. R.R. are equipped with an 11,000 volt overhead trolley wire, but those of the New York Central Railroad,

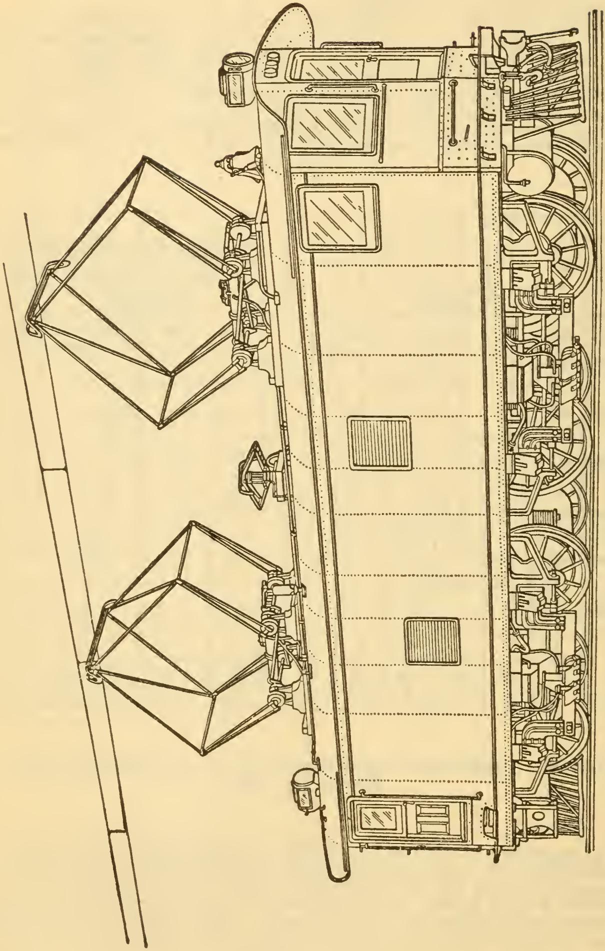


Fig. 97. Westinghouse A. C.-D. C. Electric Locomotive used by N.Y., N.H. & H. R.R.

over which the trains must run from Woodlawn Junction to Grand Central Station, are equipped with a direct current third rail. For this reason these locomotives are arranged to operate from either of these conductors and to change from one to the other without slackening speed.

The motors are cooled by means of an air blast forced through them by motor-driven blowers in the cab and on this account they are capable of developing 200 horse-power each continuously, although an ordinary railway motor of the same nominal rating could operate continuously at only about 110 horse-power. The performance of the motor is shown by the curves in Fig. 90, p. 717.

The weight of the locomotive complete is approximately 88 tons. A single unit is capable of handling a train of 200 tons in local service or a train of 250 tons in through service, and two or more units may be readily coupled together and operated as one for handling heavier trains.

INSTALLATION OF ELECTRIC CAR MOTORS.

(General Electric Company.)

In General.

In locating the various parts of the equipment and in wiring the car, particular attention should be taken to secure the following results:

1. Maintenance of high insulation.
2. Exclusion of all foreign material, particularly grease, dirt, and water, from the electrical equipment.
3. The avoiding of fire from arcs, naturally occurring at fuse-box, lightning arrester, etc.
4. The prevention of mechanical injury to the parts.
5. The placing of the parts so as to be accessible for operation and inspection, and yet out of the way of passengers.

Preparation of the Car Body.

The floor should be provided with a trap-door of such size as to allow as free access as possible to the motors. Particular attention is called to the advisability of having the bar across the car between the trap-doors removable, in order that the top of either motor can be thrown back.

The roof should be provided with a trolley board which strengthens it, and protects in case the trolley is thrown off; it also deadens the noise. A firm support should be provided for the light clusters. Grooves should be cut for the leading wires in the roof molding, and also in two of the corner posts, one for the trolley wire, the other for the ground wire of the lighting circuit.

On a closed car four 2-inch holes should be bored through the car floor under the seats, one as near each corner of the car as possible.

On one side of the car, four ⅝-inch holes should be bored in a line, and 4 inches apart, to receive the taps from the cable to the leads of motor No. 1. The exact location of these holes depends on the type of motor used. The distance from the center of the axle to the center of this group of holes should be about two and one-half feet for G. E. motors. On the same side of the car, and in the same line, four other ⅝-inch holes should be bored 4 inches apart, to receive the taps from the cable to the resistance boxes. On the other side of the car three ⅝-inch holes in a line and 4 inches apart should be bored to receive the taps from the cable to the leads of motor No. 2, and on same side of car and in the same line five other ⅝-inch holes 4 inches apart should be bored to receive the taps for the trolley, resistance, and shunt for Motor No. 2.

Reference should be made to diagram in order that each set of holes shall be on the proper side of the car, and at such a distance from side-sills as to be out of the way of wheel throw.

Measuring about 38 inches from the brake-staff and a suitable distance inside of the dash rail, an oval hole 5 in. x 2¾ in. should be cut in each platform to receive the cables.

On an open car no holes need be bored for the floor wiring except those through the platform.

Installing Controllers.

In the standard car equipment one controller is placed on each platform on the side opposite the brake handle, in such a position that the controller spindle and the brake-staff shall not be less than 36 inches, nor more than 40 inches apart. The exact position depends somewhat on the location of the sills sustaining the platform. The feet of the controller are designed to allow a slight rocking with the spring of the dasher. Two one-half inch bolts secure the feet to the platform. An adjustable angle iron is furnished to be used in securing the controller to the dash-rail. A wire guard is also furnished, to be secured to the platform in such a position that the cables pass through it into the controller. A rubber gasket is furnished with each controller, to be placed between the wire guard and the platform,to exclude water. For dimensions of controller, see Figs. 104 and 105.

Wiring.

This work can be conveniently divided into two parts; namely, **roof wiring** and **floor wiring**.

Roof wiring includes the running of the main circuit wire from the trolley through both main motor switches down the corner posts of the car to a suitable location for connecting to the lightning arrester and fuse box; also wiring the lamp circuit complete, leaving an end to be attached to the ground. Whenever wires lie on the top of the roof, they need not be covered with canvas or moulding, except to exclude water where they pass through the roof. In such cases a strip of canvas the width of the moulding, painted with white lead, should be laid under the wire, and over this and the wire should be placed a piece of moulding extending far enough in either direction to exclude water. The moulding should be firmly screwed down and well painted.

The above wiring should be done if possible while the cars are being built.

Floor wiring may be done after the car is completed without injuring the finish.

Made up cables give far better protection to the wiring, and are easier to install than separate wires, and should be used in the floor wiring if possible. The simplest way of installing them on box cars seems to be as follows:

After the car bodies are prepared according to the above instructions, the cables (one on each side of the car) should be run through holes in the platform, and the connections made to the motors and controllers.

After making connection to the controllers, all slack should be pulled up inside of the car under the seats, and held in place, preferably against the side of the car, by canvas or leather straps. Motor taps should project through the sills for attachment to the flexible motor leads just far enough to permit easy connection, leaving as little chance as possible for vibration. No rubber tubing will be required on taps, as they all have a weather-proof, triple-braided cotton covering outside of the rubber insulation to prevent abrasion. All joints should be thoroughly soldered and well taped. The portions of the cables passing under the platforms should be supported by leather straps screwed to the floors or sills. Cables should never be bent at a sharp angle. The ground wire should run under the car floor rather than under the seats.

On open cars all wires and cables must be run under the car, and should be well secured to the floor with cleats or straps.

A good joint can be made by separating the strands of the tap-wire, and wrapping the two parts in opposite directions around the main wire. Both Okonite and rubber tape are furnished. It is desirable that Okonite should be used first and rubber tape put over it, as the latter will not loosen and unwrap as Okonite will. All openings in the hose should be sewed up as tightly as possible around the wires.

Separate wires can be installed if necessary, observing the following directions :

The floor wires on box cars should be placed under the seats as much as possible. In the few places where it is necessary for wires to cross, wood should intervene in preference to a piece of rubber tubing or loop in the air. This rubber tubing is not necessary where wire is cleated under the floor (as on open cars), if it does not pass over iron work, or is not exposed to mud and water. Where so exposed, it should be covered with moulding, but where moulding is used it should be carefully painted inside and out with good insulating compound to exclude water. The wire passing to the fuse box should be looped downward to prevent water running along the wire and into the box. Care should be taken to avoid metal work about the car in running the wires, and that nails or screws are not driven into the insulation.

In general it is not desirable to use metallic staples and cleats for car-wiring, except about the roof, or inside the car. Where wires are subject to vibration, as between the car bodies and motors, flexible cable must always be used. A certain amount of slack should be left in the leads from the motor to the car body, depending on their length. On cars with swiveling trucks a greater amount of slack is necessary. As slack gives greater opportunity for abrasion, care should be taken to leave only what is absolutely necessary.

Operation and Care of Controller.

When starting, regulate the movement of the handle from point to point so as to secure a smooth acceleration of the car.

Do not run between points.

The resistance points 1st, 2d, 3d, 6th, and 7th, are intended only for the purpose of giving a smooth acceleration, and should not be used continuously.

For continuous running, use the 4th, 5th, 8th, and 9th points, which are shown by the longest bars on the dial.

When using the motor cut-out switches be sure that they are thrown up as far up as they will go.

In case the trolley is off and the hand-brakes do not hold the car, an emergency stop may be accomplished by reversing the motors, and turning the power-handle to the full speed, or next to full speed point.

To examine the controller, which should be done regularly, open the cover, remove the bolt with wrench attached, and swing back the pole-piece of the magnet.

The contact surfaces and fingers should be kept smooth, and occasionally treated with a small amount of vaseline to prevent cutting.

All bearings should be regularly oiled.

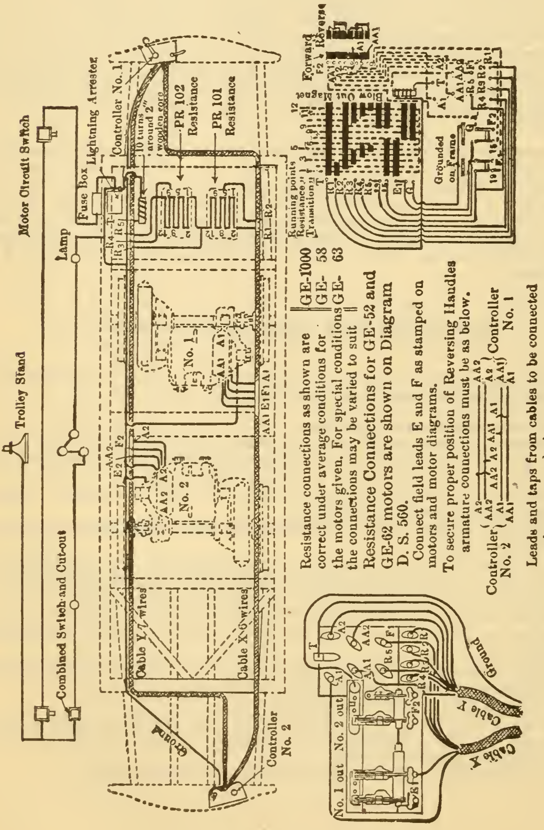
A repellent compound, paraffine, rosin, and vaseline, equal parts by weight, placed in the water-caps of the power and reversing shaft, is an efficient protection against water.

Dirt must not be allowed to collect inside of the controller.

Diagrams of Car Wiring.

In general car wiring is carried out in about the same manner for all styles and sizes of car, more particular description being given above. Wiring differs mainly in details, governed by the number, style and horsepower of motors used.

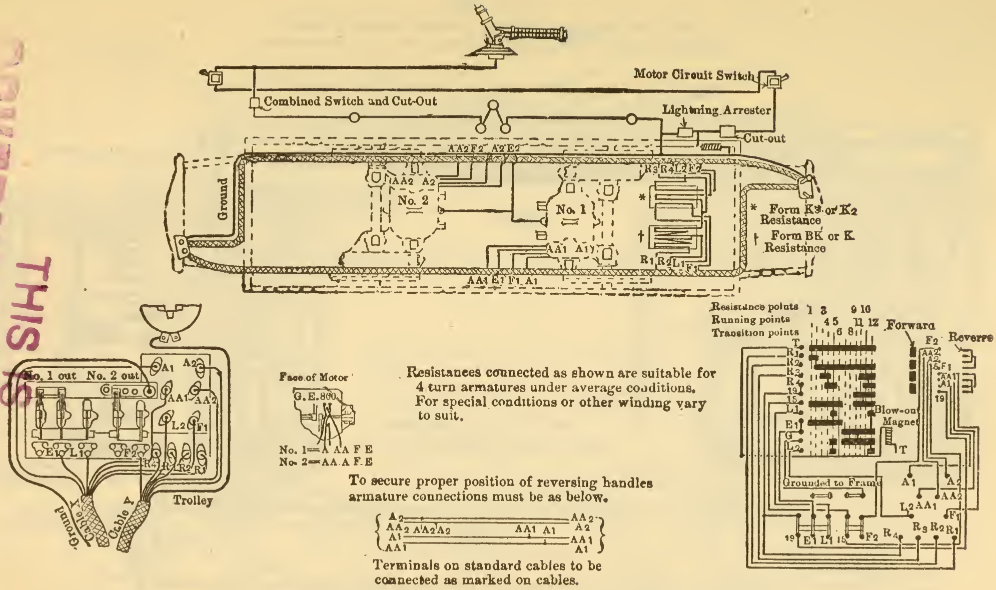
Diagrams of standard wiring for two motors per car and for four motors per car follow in Figs. 98, 99, 100, 101. They are all from the G. E. Co. lists, as controllers made by that Company are almost universally used, although many of older design by other companies are still in the field.



CAR WIRING FOR K 10 CONTROLLERS WITH TWO MOTORS

GENERAL ELECTRIC CO. 1898

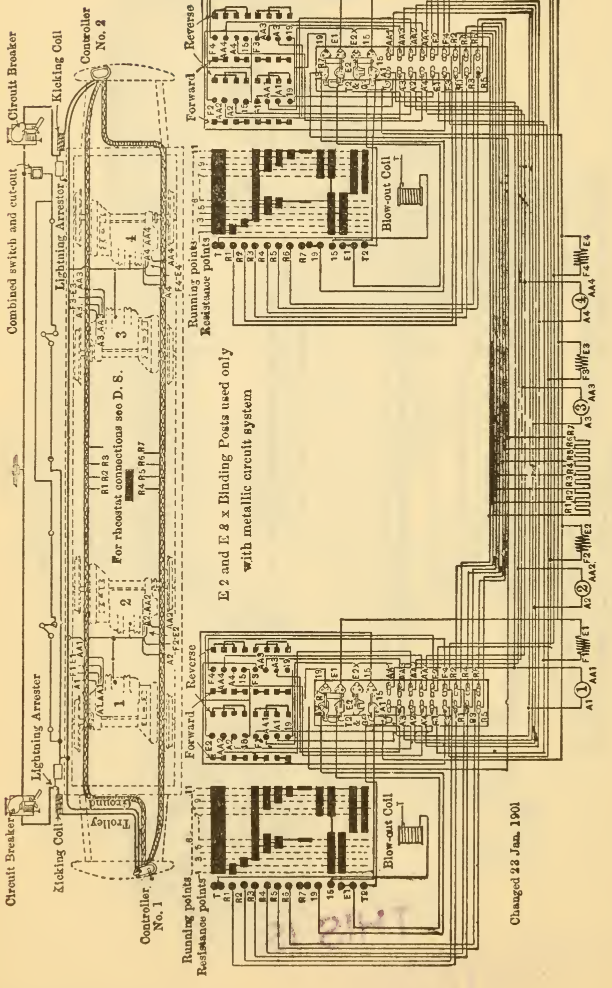
FIG. 98.



CAR WIRING FOR K 2 CONTROLLER WITH TWO GE-800 MOTORS

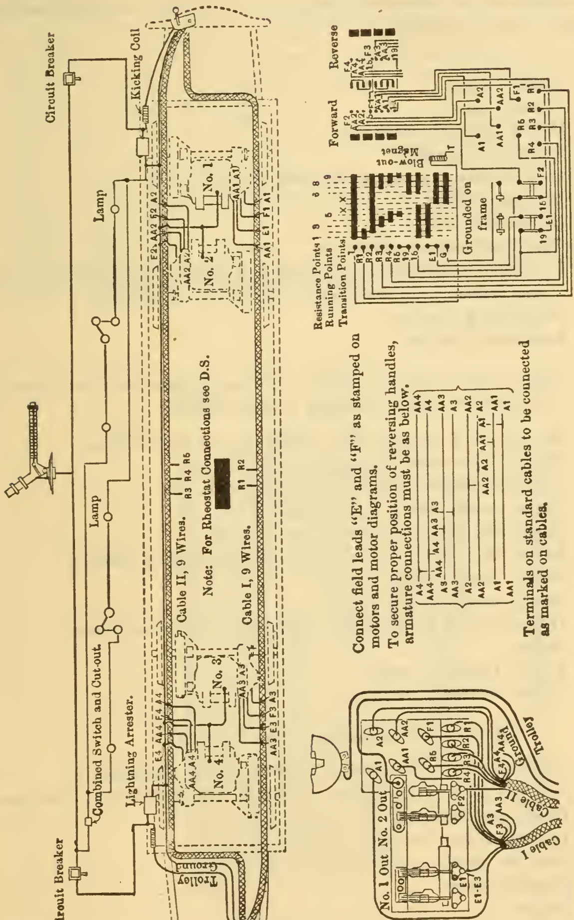
GENERAL ELECTRIC CO., 1898.

FIG. 99.



CAR WIRING FOR K-6 CONTROLLERS WITH FOUR MOTORS
GROUND RETURN SYSTEM, GENERAL ELECTRIC CO., 1899

FIG. 100.



CAR WIRING FOR K 12 CONTROLLERS WITH FOUR MOTORS

GENERAL ELECTRIC CO., 1899

FIG. 101.

EQUIPMENT LISTS.

The following is a list of material required for the electrical equipment of one car fitted with two motors:

QUANTITY.	
1	Trolley pole.
1	Trolley base.
2	Motor circuit switches.
1	Lightning arrester.
1	150 ampere magnetic cut-out (fuse-box).
1	Resistance box.
1	Resistance box.
1	Core for kicking coil.
2	Controllers (includes wire guard and gasket, supporting bracket, cap screws, and washers for fastening to dasher).
1	Controlling handle.
1	Reversing handle.
	One of each of these handles is always shipped with each pair of controllers unless specified to the contrary.
75 ft.	No. 6 B. & S. strand wire (7-.061 in.) for roof-wiring.
20	100 or 150 ampere fuses.
10	Two-way connectors, ¼-inch hole, No. 6.
30	Brass corner cleats, $\frac{7}{16}$-inch slot.
25	Brass flat cleats, $\frac{7}{16}$-inch slot.
110	½-inch No. 4 R. H. brass wood screws for brass cleats.
25	Wood cleats, ½-inch slot.
25	Wood cleats, ⅜-inch slot.
100	1¼-inch No. 8 R. H. blued wood screws for wood cleats.
1 lb.	Solder.
1 lb.	¾-inch Okonite tape.
1 lb.	1-inch adhesive tape.
	Material for set of cables as follows:
480 ft.	No. 6 B. & S. strand wire (7-.064 inches), single braid.
100 ft.	No. 6 B. & S. strand wire (7-.064 inches), triple braid for taps.
41	Brass marking-tags.
64 ft.	1½-inch cotton hose.
1½ lbs.	Rubber tape.
4 lbs.	Paragon tape.
1½ lbs.	Solder.
	This material can be procured made into a "set of cables" without extra cost.
1	Car-lighting equipment.

CONTROLLERS.

Under this heading are included all that type of appliance used for starting and stopping the motors and controlling the speed of the same. As almost all the old forms of rheostat with different steps have been abandoned for the so-called *series-parallel* controller, it is not necessary to describe any other here, nor will any detailed description of those now in use be attempted.

But one form is now in general use, viz., the *magnetic blow-out* type, made by the General Electric Company and used also by the Westinghouse Electric and Manufacturing Company.

The principle of the magnetic blow-out type was first developed by Prof. Elihu Thomson, i.e., that an electric arc in a strong magnetic field is blown out of line and extinguished or cut in two. This fact is taken advantage of in the controller of the General Electric Company by using a strong electro-magnet to extinguish the arcs formed at the contact-points, when the circuits are broken. The construction is shown in the cut of series-parallel controller, Form K2, following.

Controllers are now made in so many forms and varieties that it is impossible to give more than a few of the combinations which are practically the same everywhere in the United States.

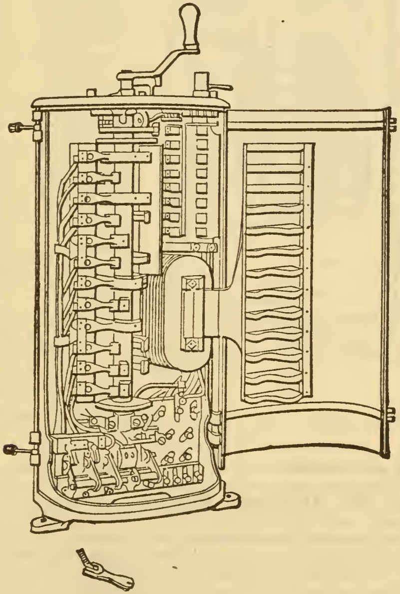


Fig. 102. Series-Parallel Controller, Form K2.
General Electric Company.

Used also by the Westinghouse Electric and Manufacturing Company, and others.

The General Electric Company manufactures controllers for all conditions of electric railway and power service. They are divided for convenience in designation into five general classes, each designated by an arbitrary letter.

Type B Controllers may be of either the series parallel or rheostatic type, but always include the necessary contacts and connections for operating electric brakes.

Type K Controllers are of the series parallel type and include the feature of shunting or short circuiting one of the motors when changing from series to parallel connection.

Type L Controllers are also of the series parallel type, but completely open the power circuit when changing from series to parallel.

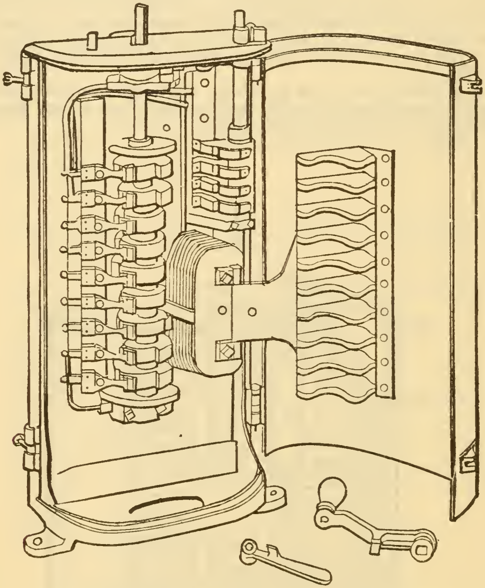


Fig. 103. "R" Type of Rheostatic Controller.

Type R Controllers are of the rheostatic type and are designed to control one or more motors by means of resistance only.

The Type M Control System developed by the General Electric Company with particular reference to the operation of motor cars in trains, is also suitable for operation of large equipments, where the size and weight of a cylinder type controller are objectionable.

This system of control consists essentially of a number of electrically operated switches called "contactors" that close the various power and motor circuits, and which are in turn controlled by small master controllers which are called upon to carry only the current for the operating coils of the contactors. The motors are reversed by electrically operated reversing switches also controlled by the master controller. Where equipments are operated together in trains, the control circuits are connected between adjacent cars by suitable couplers and the operation of the contactors and reversers on all the cars in the train are controlled simultaneously from any master controller on the train.

Series Parallel Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
K–2	Two 40 h.p. Motors.	5 Series. 4 Parallel.	For motors using loop or shunted field only.
K–4	Four 30 h.p. Motors.	5 Series. 4 Parallel.	For motors using loop or shunted field only.
K–6	Two 80 h.p. Motors or Four 40 h.p. Motors.	6 Series. 5 Parallel.	
K–10	Two 40 h.p. Motors.	5 Series. 4 Parallel.	
K–11	Two 60 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–10 but has connecting wires and blow-out coil of larger capacity.
K–12	Four 30 h.p. Motors.	5 Series. 4 Parallel.	Similar to K–11 but has reversing switch arranged for four motors.
K–13	Two 125 h.p. Motors.	7 Series. 6 Parallel.	
K–14	Four 60 h.p. Motors.	7 Series. 6 Parallel.	
K–27	Two 60 h.p. Motors.	4 Series. 4 Parallel.	Similar to K–11 but is arranged for operation on metallic circuit, having contacts for opening both sides of the circuit.
K–29	Four 40 h.p. Motors.	6 Series. 5 Parallel.	Similar to K–6 but is arranged for operation on metallic circuit, having contacts for opening both sides of the circuit.
K–31	Four 30 h.p. Motors.	4 Series. 4 Parallel.	Similar to K–27 except has reverse switch arranged for four motors.
K–32	Two 40 h.p. Motors.	4 Series. 4 Parallel.	Similar to K–27 except has connecting wires and blow-out coil of smaller capacity.
L–2	Two 175 h.p. Motors.	4 Series. 4 Parallel.	
L–3	Four 150 h.p. Motors.	8 Series. 7 Parallel.	
L–4	Four 100 h.p. Motors.	4 Series. 4 Parallel.	Similar to the L–2 but with additional reversing switch parts for four motors.
L–7	Four 200 h.p. Motors.	9 Series. 6 Parallel.	

Electric Brake Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
B–3	Two 40 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Superseded for general use by the B–13.
B–7	Two 100 h.p. Motors.	6 Series. 5 Parallel. 6 Brake.	Has separate brake handle.
B–8	Four 60 h.p. Motors.	6 Series. 5 Parallel. 7 Brake.	Has separate brake handle.
B–13	Two 40 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Supersedes the B–3 from which it differs in that the braking connections are such as to render the skidding of the car wheels practically impossible.

Electric Brake Controllers.—*Continued.*

Title.	Capacity.	Controlling Points.	Remarks.
B–18	Two 40 h.p. Motors.	4 Series. 4 Parallel. 6 Brake.	Similar to B–3 but arranged for rheostatic braking only.
B–19	Four 40 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–8, having separate handles for power and brake. Supersedes B–6.
B–23	Two 60 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to the B–13 but has connecting wires and blow-out coil of larger capacity.
B–29	Two 60 h.p. Motors.	5 Series. 4 Parallel. 7 Brake.	Similar to B–23 but has separate brake handle.

Electric braking is made little use of owing to the fact that it adds considerably to the heating of the motors. The conditions are such that the motors are already over-taxed and the use of brake controllers necessitates an increase in the size of motor required. Air-brakes are in almost universal use on the heavier cars owing to their smaller expense of installation.

Rheostatic Controllers.

Title.	Capacity.	Controlling Points.	Remarks.
R–11	One 50 h.p. Motor.	6	For motors using shunted field for running points only.
R–14	Two 35 h.p. Motors.	5	Very short and specially adapted to mining locomotives. Motors connected permanently in parallel.
R–15	Two 80 h.p. Motors.	6	Motors connected permanently in parallel.
R–16	Four 40 h.p. Motors.	5	Similar to R–15 but has reversing switch arranged for four motors. Motors connected permanently in parallel.
R–17	One 50 h.p. Motor.	6	
R–19	Two 50 h.p. Motors.	6	Similar to R–17 but has reversing switch arranged for two motors. Motors connected permanently in parallel.
R–22	Two 50 h.p. Motors.	5	Similar to R–14 but has connecting wires and blow-out coil of larger capacity.
R–29	Four 25 h.p. Motors.	6	Similar to R–19 but has reversing switch arranged for four motors. Motors connected permanently in parallel.
R–37	Two 50 h.p. Motors.	5	Similar to R–22 but has extra contacts on the reversing switch for connecting the motors either in series or parallel.
R–38	Two 35 h.p. Motors.	5	Similar to R–37 but has connecting wires and blow-out coil of smaller capacity.
R–48	Four 75 h.p. Motors.	8	
R–55	Two 150 h.p. Motors.	7	Has series parallel reversing switch same as R–37. It is specially adapted to mining locomotive service.

These controllers are used with single motor equipments or for locomotive work where the speed is very low, as in yard shifting service.

DIMENSIONS OF CONTROLLERS.

	Type K. Fig. 104.												Type L. Fig. 105.		
	K-2	K-4	K-6	K-10	K-11	K-12	K-13	K-14	K-27	K-29	K-31	K-32	L-2	L-3	L-4
A	35 1/16	35 1/16	38 3/4	33 3/16	33 3/16	33 3/16	39	38 7/8	35 1/16	38 3/4	35 1/16	35 1/16	40 7/8	45 1/2	40 7/8
B	7 5/16	7 5/16	8 1/2	7 5/16	7 5/16	7 5/16	10	10	7 9/16	8 1/2	7 9/16	7 9/16	10 7/8	13	10 7/8
C	2 7/8	2 7/8	3 3/4	2 7/8	2 7/8	2 7/8	5 3/4	5 3/4	3 1/8	3 3/4	3 1/8	3 1/8	7 3/4	6 1/8	7 3/4
D	4 1/2	4 1/2	4 5/8	4 5/8	4 5/8	4 5/8	...	...	4 5/8	4 5/8	4 5/8	4 5/8	...	...	...
E	1	1	1	1	1	1	...	...	1	1	1	1	...	...	...
F	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	...	...	3 1/2	3 1/2	3 1/2	3 1/2	...	...	...
G	43 1/2	43 1/2	47 1/16	42 1/4	42 1/4	42 1/4	46 11/16	46 9/16	44 1/8	47 1/16	44 1/8	44 1/8	48 1/4	53 3/4	48 1/4
H	29 7/8	29 7/8	33 3/16	28 15/16	28 15/16	28 15/16	...	...	29 7/8	33 3/16	29 7/8	29 7/8	...	...	...
K	25 3/8	25 3/8	28 11/16	24 7/16	24 7/16	24 7/16	...	...	26 3/8	28 11/16	26 3/8	26 3/8	...	...	...
L	16 5/8	16 5/8	16 1/2	16 5/8	16 5/8	16 5/8	19	22 3/4	16 5/8	16 1/2	16 5/8	16 5/8	25 1/8	28 7/8	25 1/8
M	17 1/2	17 1/2	17 1/16	17 1/2	17 1/2	17 1/2	20	23 3/4	17 1/2	17 1/16	17 1/2	17 1/2	27 13/16	29	32 9/16
O	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	8 3/4	8 3/4	5 3/4	5 3/4	5 3/4	5 3/4	...	5 11/16	...
P	8	8	8	8	8	8	9 1/2	9 1/2	8	8	8	8	9 1/2	13	9 1/2
R	8 3/16	8 3/16	9 1/16	8 3/16	8 3/16	8 3/16	11	11	8 3/16	9 1/16	8 3/16	8 3/16	11 5/8	14	11 5/8
S	...	...	...	...	...	...	...	...	...	...	...	...	18 5/8	...	18 5/8
U	5 1/4	5 1/4	4 1/4	5 1/4	5 1/4	5 1/4	4	4	5 1/4	4 1/4	5 1/4	5 1/4	...	3 1/4	...
V	7 7/16	7 7/16	6 11/16	7 7/16	7 7/16	7 7/16	10 3/4	10 3/4	7 7/16	6 11/16	7 7/16	7 7/16	...	15 1/8	...
W	6 11/16	6 11/16	5 11/16	6 11/16	6 11/16	6 11/16	5	8 3/4	6 11/16	5 11/16	6 11/16	6 11/16	...	9	...
X	4 5/16	4 5/16	4 11/16	4 5/16	4 5/16	4 5/16	5 1/2	5 1/2	4 5/16	4 11/16	4 5/16	4 5/16	...	10	...

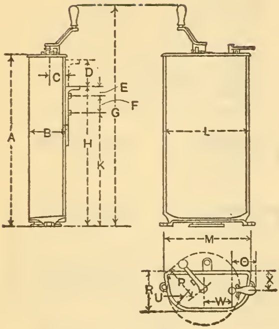


FIG. 104. Type K.

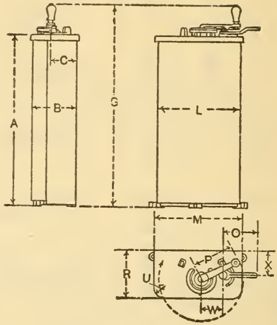


FIG. 105. Type L.

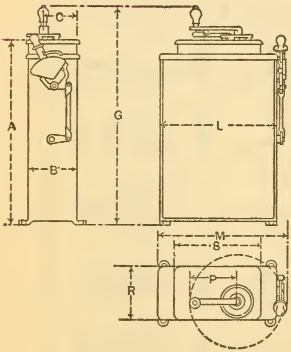


FIG. 106. Type B.

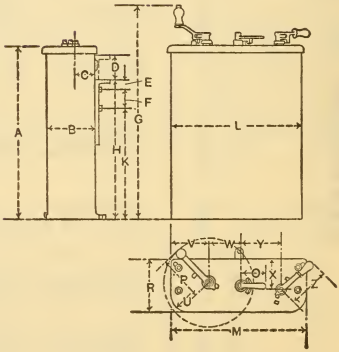


FIG. 107. Type R.

Diagrams for Dimensions of Controllers.

DIMENSIONS OF CONTROLLERS.

	Type B. Fig. 106.								Type R. Fig. 107.							
	B–3	B–7	B–8	B–13	B–18	B–19	B–23	B–29	R–11	R–14	R–15	R–16	R–17	R–19	R–22	R–37
A . .	36 1/16	36 13/16	42	38	36 1/16	36	38	38 5/16	33 3/16	21 3/16	33 3/16	29 3/16	33 3/16	33 3/16	21 3/16	21 5/16
B . .	8 1/8	10 1/4	11 1/4	9	8 1/2	9 7/16	9	9	7 5/16	7 5/16	7 5/16	7 5/16	7 5/16	7 5/16	7 5/16	7 5/8
C . .	3 11/16	4 3/8	5 3/8	4 1/4	3 11/16	3 13/16	4 1/4	3 3/4	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	3 3/16
D . .	4 5/8	...	...	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	...	...	...	4 5/8	4 5/8	...	...
E . .	1	...	...	1	1	1	1	1	1	...	...	...	1	1	...	...
F . .	3 1/2	...	...	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	...	...	...	3 1/2	3 1/2	...	...
G . .	44 9/16	45 1/4	50 7/16	46 1/2	44 9/16	44 3/8	46 1/2	46 11/16	41 11/16	28 1/8	41 11/16	37 11/16	41 11/16	41 11/16	28 1/8	29 3/4
H . .	30 9/16	...	...	30 5/8	30 9/16	29 3/16	30 5/8	30 5/8	28 15/16	...	...	...	28 15/16	28 15/16	...	...
K . .	26 1/16	...	...	26 1/8	26 1/16	24 11/16	26 1/8	26 1/8	24 7/16	...	...	...	24 7/16	24 7/16	...	...
L . .	19	27 3/8	28 3/8	21 1/2	19	25	21 1/2	21 1/2	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8
M . .	19 5/8	28 1/8	29 1/8	22 1/8	19 5/8	25 3/4	22 1/8	22 1/4	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2
O . .	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	6 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4
P . .	9	9	9	9	9	8	9	8	8	8	8	8	8	8	8	8
R . .	8 13/16	11 1/8	12 1/8	9 3/8	8 13/16	9 7/8	9 3/8	9 11/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16
U . .	6 1/2	4 3/8	4 3/8	5 1/2	6 1/2	5 1/2	5 1/2	5 1/2	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	4 7/16
V . .	9 5/16	7 3/4	7 3/4	12 7/8	9 5/16	6 5/8	12 7/8	6 5/8	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16
W . .	6 1/4	6 3/4	6 3/4	5	6 1/4	5 13/16	5	5 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16
X . .	4 7/16	6 5/8	6 5/8	5 5/16	4 7/16	5 1/16	5 5/16	4 7/8	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 1/4
Y . .	...	8 3/8	9 3/4	...	...	8 7/16	...	5 1/16	...	...	...	...	...	...	...	...
Z . .	...	8 3/4	8 3/4	...	...	8 3/4	...	8 3/4	...	...	...	...	...	...	...	...

MOTOR COMBINATIONS

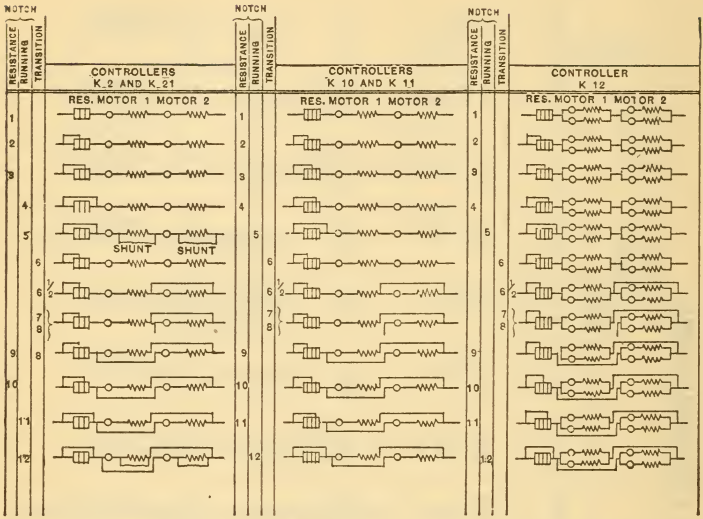


FIG. 108.

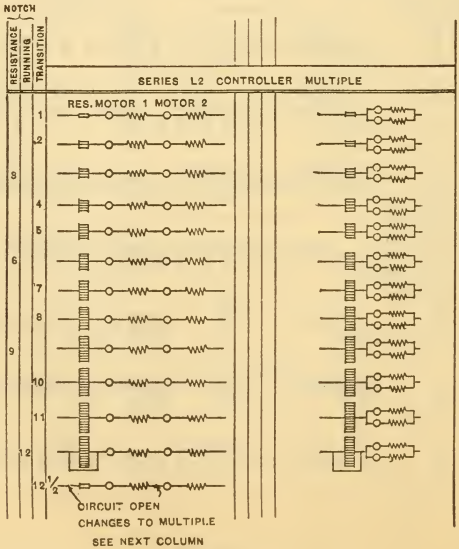


FIG. 109.

THE SPRAGUE GENERAL ELECTRIC MULTIPLE UNIT CONTROL.

The multiple unit control is designed primarily for the operation of motor cars in trains. Motor cars and trail cars may be coupled in any combination and the whole operated as a unit from any controller on the train. The system may also be used to advantage on individual equipments and locomotives.

The control apparatus for each motor car may be considered as consisting essentially of a motor controller and a master controller.

The former comprises a set of apparatus, — usually located underneath the car, — which handles directly the power circuits for the motors, connecting them in series and parallel and commutating the starting resistance in series with them. This motor controller is operated electrically and its operation in establishing the desired motor connections is controlled by the motorman by means of the master controller. The latter is similar in construction to the ordinary cylinder controller and is handled in the same manner, but instead of effecting the motor combinations directly, it merely controls the operation of the motor controller.

The latter consists of a number of electrically operated switches, or "contactors" which close and open the various motor and resistance circuits, and an electrically operated "reverser" that connects the field and armature leads of the motors to give the desired direction of movement of the car. Both the contactors and reverser are operated by solenoids, the operating current for which is admitted to them by the master controller.

In addition to the motor and master controllers, each motor and trail car is equipped with train cable consisting of nine or ten individually insulated conductors connected to corresponding contacts in coupler sockets located at each end of the cars. This train cable is connected identically on each motor car to the master-controller fingers, and the contactor and reverser operating coils; and the train cable is made continuous throughout the train by couplers between the cars, connecting together corresponding terminals in the coupler sockets.

All wires carrying current supplied directly from the master controller form the "control circuit;" those carrying current for the motors, form the "motor" or "power circuit."

Inasmuch as the motor controller operating coils are connected to this control train line, it will be appreciated that energizing the proper wires by means of any master controller on the train, will simultaneously operate corresponding contactors on all the motor cars, and consequently establish similar motor connections on all cars.

In case the "power" circuit is momentarily interrupted for any reason, the system of control provides for the immediate restoration of the motor and resistance connections, which were in effect immediately preceding such interruption. Should the motorman remove his hand from the operating handle of the master controller, the current will immediately be cut off from the entire train, thus diminishing the danger of accident in case the motorman should suddenly become incapacitated. The system must be supplied with a potential of at least 300 volts to insure successful operation.

The approximate total weight of control equipments, exclusive of supports is as follows:

Aggregate H.P. of Motors.	Weight of Equipment in Pounds.
125	1500
250	2000
400	3000
500	4500
800	5000

The approximate weight of the apparatus for each trail car, which included train cable, coupler sockets and connection boxes, is 100 pounds.

The position of the handle on that master controller which the motorman is operating always indicates the position of motor-control apparatus on all cars. The motor controller which handles all the heavy arcing is located underneath the car.

Apparatus.

Contactors.—The contactors are the means of cutting in and out the various resistance steps, of making and breaking the main circuit between trolley and motors and of changing from series to parallel connection.

Each contactor consists of a movable arm carrying a renewable copper tip which makes contact with a similar fixed tip, and a coil for actuating this arm when supplied with current from the master controller. The contactor

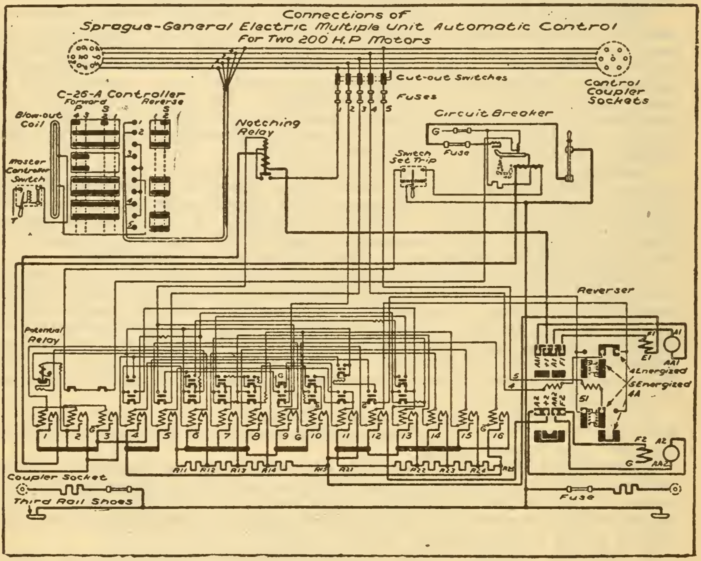


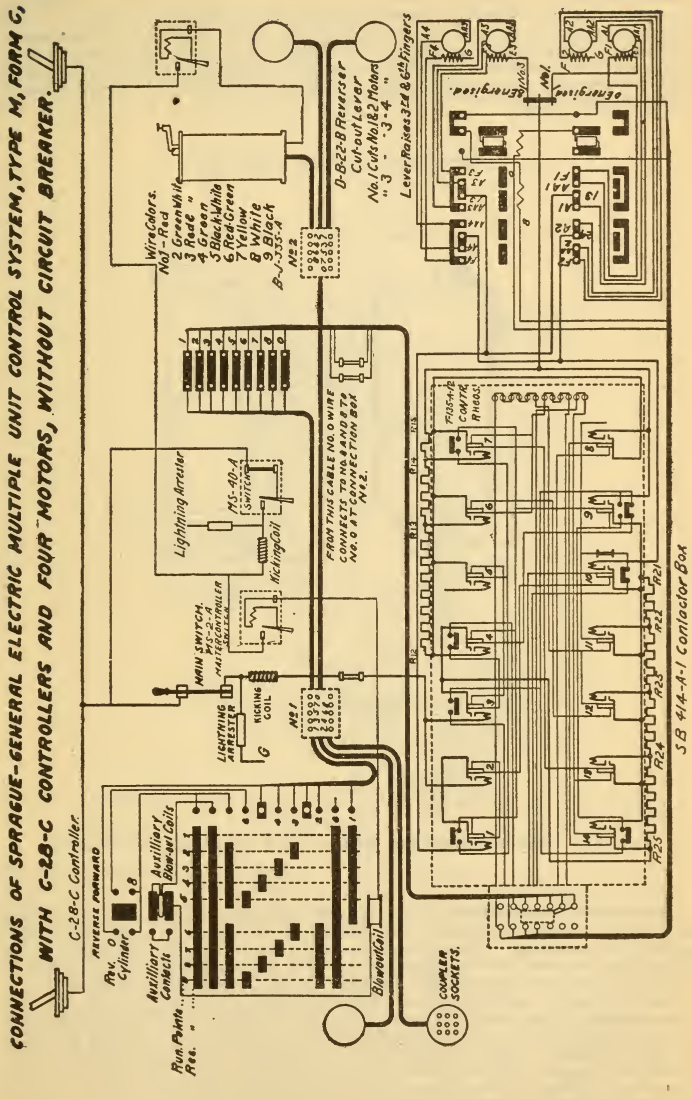
FIG. 110.

is so designed that the motor circuit is closed only when current is flowing through its operating coil; and gravity, assisted by the spring action of the finger, causes the arm to drop and open this circuit immediately, when the control circuit is interrupted.

In order to save space and eliminate interconnections as much as possible, several contactors are mounted on the same base. The contactors should preferably be located under the car, and boxes are therefore supplied which facilitate installation, protect the contactors from brake-shoe dust and other foreign material, and provide the necessary insulation.

Reverser.

The general design of the reverser is somewhat similar to that of the ordinary cylindrical motor-reversing switch with the addition of electromagnets for throwing it to either forward or reverse position. In general construction, the operating coils are similar to those used on the contactors, but in order to secure reliability of action the coil is given full line potential. The reverser is provided with small fingers for handling control-circuit connections and when it throws, the operating coil is disconnected from ground and is placed in series with a set of contactor coils, thus cutting the



CONNECTIONS OF SPRAGUE-GENERAL ELECTRIC MULTIPLE UNIT CONTROL SYSTEM, TYPE M, FORM C, WITH C-28-C CONTROLLERS AND FOUR MOTORS, WITHOUT CIRCUIT BREAKER.
C-28-C Controller
Wire Colors.
No. 1 - Red
2 Green White
3 Red
4 Green
5 Black-White
6 Red-Green
7 Yellow
8 White
9 Black
B-J-335-A
No. 2
0-B-22-B Reverser
Cut-out Lever
No. 1 Cuts No. 1 & 2 Motors
Lever Raises 3rd & 6th Fingers
Lightning Arrester
MS-40-A
Kicking Coil
MAIN SWITCH
MS-2-A
MASTER CONTROLLER SWITCH
LIGHTNING ARRESTER
KICKING COIL
No. 1
FROM THIS CABLE NO. 0 WIRE CONNECTS TO NO. 8 AND 8 TO NO. 0 AT CONNECTION BOX No. 2.
T-135-A-12
CONTR. RHEOS.
Energised.
Auxilliary Blow-out Coils
Auxilliary Contacts
Reverse Forward
Rev. Cylinder
Run. Points
Res.
Blowout Coil
COUPLER SOCKETS.
SB 414-A-1 Contactor Box

Fig. 111.

operating current down to a safe running value. These coils are protected by a fuse, which will open the circuit if the reverser fails to throw. If the position of the reverser does not correspond to the direction of movement indicated by the reverse handle on the master controller, the motors on that car cannot take current. While the motors are taking current the operating coil is energized, and the electrical circuits are interlocked to prevent possibility of throwing.

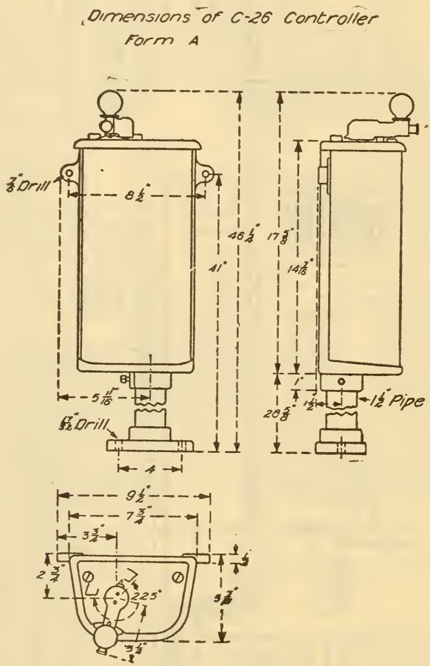


FIG. 112. Master Controller Sprague G. E. Multiple Unit System.

Master Controller.—The master controller is considerably smaller than the ordinary street-car controller, but is similar in appearance and method of operation. Separate power and reverse handles are provided, as experience has led to the adoption of this arrangement in preference to providing for the movement of a single handle in opposite directions.

An automatic, safety, open-circuiting device is provided, whereby, in case the motorman removes his hand from the master-controller handle, the control circuit will be automatically opened by means of auxiliary contacts in the controller, which are operated by a spring when the button in the handle is released. This device is entirely separate and distinct in its action from that of the main cylinder. Moving the reverse handle either forward or backward makes connections for throwing the reverser to either forward or backward position. The handle can be removed only in the intermediate or off position. As the power handle is mechanically locked against movement when the reverse handle is removed, it is only necessary for the motorman to carry this handle when leaving the car.

When the master controller is thrown off, both line and ground connections are cut off from the operating coils of important contactors, and none of the wires in the train cable are alive.

The current carried by the master controller is about 2.5 amperes for each equipment of 400 horse-power or less.

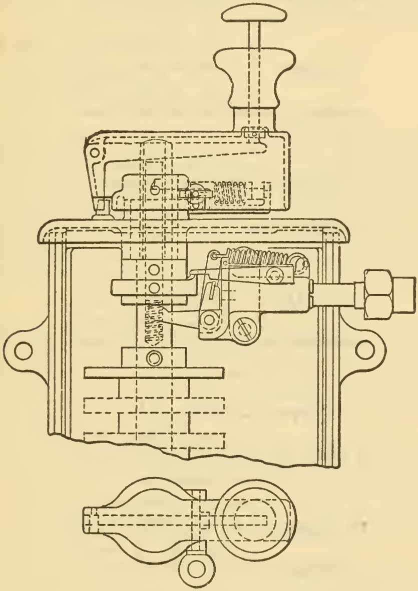


FIG. 113. Details of Top of Master Controller Sprague G. E. Co., Multiple Unit System.

Master Controller Switch. — A small enclosed switch with magnetic blow-out is used to cut off current from each master controller; and it is supplied with a small cartridge fuse enclosed in the same box. When this switch is open all current is cut off from that particular master controller which it protects.

Bridge Connection. — A noteworthy feature of the control is the method of accomplishing the series-parallel connection of the motors. This is by the so-called "Bridge" method of connections, which are so arranged that the circuit through the motors is not opened during the transition from series to parallel and substantially the full torque of both motors is preserved at all times, from the series to the full parallel connection. This connection does away with any serious falling off in the rate of acceleration which is sometimes noticed when the motor circuit is interrupted during transition from series to parallel in other methods of control. The "Bridge" connection is therefore particularly adapted to high rates of acceleration which can thus be sustained throughout the accelerating period without causing discomfort to passengers.

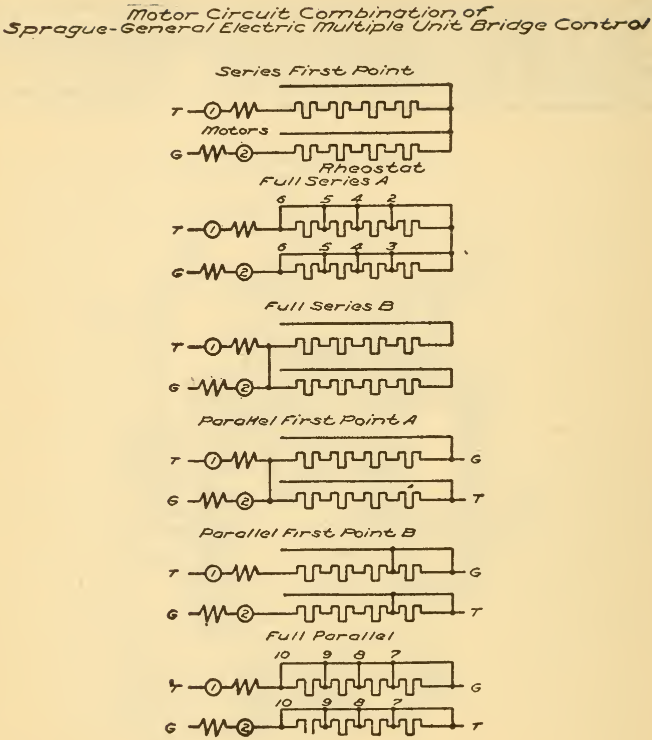


FIG. 114.

WESTINGHOUSE UNIT SWITCH SYSTEMS OF MULTIPLE CONTROL.

The system of multiple unit control developed by Westinghouse Electric and Manufacturing Company employs a combination of electromagnetic and pneumatic devices to produce a method of controlling from a single point a single car or train of cars, all or part of which are equipped with motors. It is applicable alike to alternating and direct-current motors, and to double and quadruple equipments. It may be arranged for either automatic or non-automatic acceleration and for operation with or without a train bus line.

The complete equipment comprises apparatus pertaining to the main control system, which operates the motors on each independent car; the auxiliary control system, which consists of the electric circuit which actuates and controls the various devices but is entirely separate and distinct from the main motor control system; and a number of safety devices and attachments which protect the apparatus and safeguard its operation.

Main Control. — The active element of the main control system is made up of the following apparatus:

A group of unit switches which regulate the supply of current to the motors.

A set of resistances or an auto-transformer which is used in connection with the unit-switch group to control the supply to the motor.

A line switch which controls the main supply of current to the unit-switch group.

A reverse switch which governs the direction of car movement.

Auxiliary Control. — The auxiliary control system derives its operating energy from a storage battery which forms part of each car equipment, and actuates the main control through the intervention of compressed air drawn from the brake supply. It comprises the following apparatus:

The master controller.
The train line.
The line relay switch.
The series limit switch.
The control cut-out switch.

The auxiliary control regulates the operation of the main control by the action of the master controller which governs the circuits connecting the storage battery mains and the valve magnets which regulate the air supply to the switches of the main control system. By the admission of air to the operating cylinders of the switch group, the motors are connected in the desired combinations.

Switch Group. — The switch group consists of a number of powerful circuit-breakers mounted in a common frame and assembled with their air cylinders in such a manner that when a valve magnet is energized the air will be admitted to the cylinder, forcing the piston forward and closing the switch.

The switch contacts consist of two heavy L-shaped pieces of hard-drawn copper which close the circuit first at the tip and then roll and slide on each other, finally resting at the heel under the full air pressure. The switches are opened by the action of powerful springs. As their normal position is open, any failure of the air supply or interruption of the circuit is accompanied by the immediate opening of all switches. A magnetic blow-out assists in the breaking of the arc.

Resistance or Auto-transformer. — The main control resistance consists of a suitable number of grids mounted in frames and so connected to the unit switches that they regulate the current flowing through the motors as the switch group advances through its cycle of operation.

With a single-phase alternating-current railway equipment an auto-transformer may be used in place of a resistance to regulate the voltage supplied to the motors.

Line Switch. — The line switch comprises a group of switches — one for each motor of a double equipment or each pair of a quadruple equipment — connected each in circuit with its motor and carrying the current of that circuit alone. Their construction is similar to that of the units forming the switch group, except that each has an independent magnetic circuit for the magnetic blow-out and is provided with an automatic trip which opens and renders inoperative the auxiliary control whenever the current in the blow-out coil becomes excessive, allowing all the switches of both the line switch and switch group to drop out.

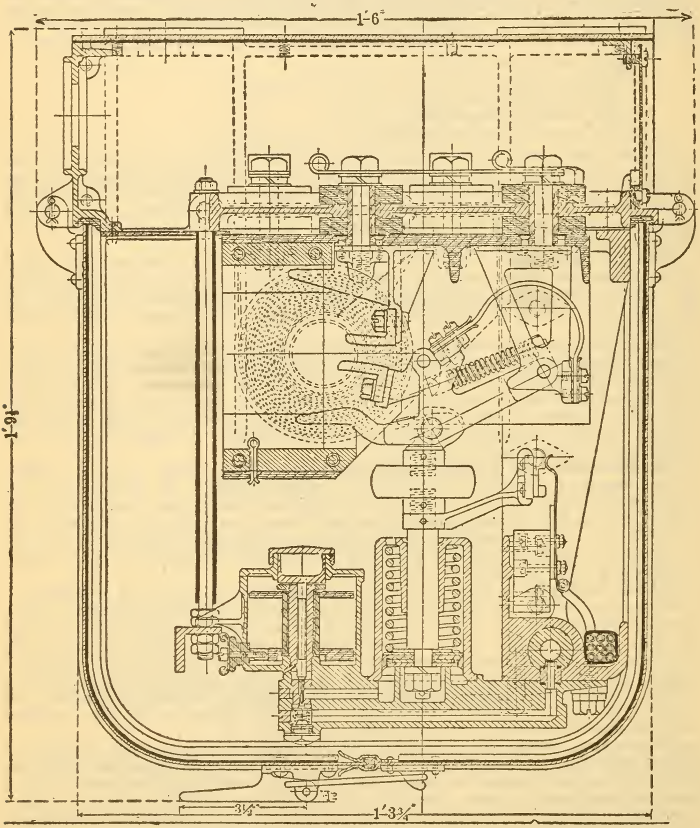
Reverse Switch. — In the direct-current reverse, an insulating block carrying two sets of metal strips arranged to make contact with stationary fingers is operated forward and back in a straight line motion by a pair of pneumatic pistons which form part of the auxiliary control. The operating cylinders are governed by magnet valves which are interlocked with those of the switch group in such a way that the reverse can be thrown only when the main control circuit is open.

The reverse for alternating-current equipment is of the drum type.

Main Switch and Fuse. — As an additional safeguard a switch and fuse may be introduced in the main line to open the circuit in case the automatic overload trip should fail, or if a ground or short circuit should occur on any unprotected portion of the main control system. When it is open the connection between the third-rail shoes or trolley and the main control apparatus is broken.

Master Controller. — The master controller consists of a movable drum and stationary contact fingers. The handle is brought to the central or "off" position by the action of a spring which is compressed by motion of the handle in either direction and is always returned to this position when the operator releases the controller handle. When it is desired to arrest the operation of the car or train at intermediate points, the controller handle is simply moved off the contact, opening the circuit and preventing a further advance of the unit switches.

Interlock Switches.—The interlock switches which form part of the auxiliary control system consist of spring contact fingers sliding on segments



SECTION PNEUMATIC UNIT SWITCH

FIG. 115.

and are electrically connected with the magnet valves in such a manner that the closing of one energizes the valve magnet of the switch next succeeding, producing an automatic progressive action which provides a uniform acceleration with a practically constant motor current.

Train Line.—The train line consists of seven small wires which extend through the entire train, together with the junction boxes, connector sockets and jumpers. It connects the several portions of the auxiliary control system to the storage batteries by which the operating current is supplied. The potential of these circuits is about 14 volts.

Electrical connection between cables of adjoining cars is formed by means of sockets permanently mounted on the ends of the cars and a jumper which consists of a pair of plugs connected by a short piece of cable.

Motor Control Cut-out Switch.. — To cut any motor out of service a control cut-out switch is provided with each equipment. It consists of a wooden drum with copper segments which make contact with fingers arranged on either side and forming part of the auxiliary control.

Series Limit Switch. — Regulation of the motor current during acceleration is accomplished by a small switch in the auxiliary control circuit governing the progressive action of the unit switches, through the coil of which passes current of one motor, so that the switch is opened and the progressive action of the switch group arrested whenever the current exceeds a pre-determined limit. When the current again falls below this limit, the switch closes by gravity and the progressive action of the switch group is continued.

Line Relay. — To protect the motors from an abnormal rush of current in case the main line circuit is suddenly reestablished after interruption, a line relay is introduced in the controlling system and arranged to open the unit switches in case of failure of the line supply, but is held closed unless the main current is interrupted. This action takes place on each car individually, so that if the current supply is interrupted on any car the switch group on that car will be cut out independently of all other cars in the train, and if the current supply is restored while the master controller is in a running position, the line relay will restore the battery connection of the control circuit and the switch group will then pass through its cycle under the control of the limit switch and again supply current to the motors.

Storage Batteries. — The current which operates the magnet valves of the control system is supplied by a storage battery in duplicate, each consisting of seven cells. The potential of this controlling current is about 14 volts. One battery is on charge by connection in series with the air compressor or the car lighting system while the other is in service.

The batteries on each car are connected in common leads which are carried through the entire train as positive and negative of the train line. The batteries of the several cars are therefore connected in parallel, and the negative side is also connected to one side of the magnet valves on each car, making the demand on the batteries more or less local.

Line Switch Cut-out and Overload Trip Reset. — Two small knife switches located within easy reach of the operator are so connected that when the first is open the line switches throughout the train cannot be closed, so that no current can be taken from the line, but the switch group may be operated through its cycle for the purpose of test or to "buck" the motors and effect a sudden stop in an emergency.

The second or overload trip reset switch is normally held open by a spring. When it is closed, with the master controller in the "off," or "semi-off," or coasting position, any trip that may be open will be reset.

Bus Line. — That the current supply to every car may be continuous, even though the trolley or third-rail shoes of any car be not in contact with the feeding circuit, a bus line is sometimes used throughout the train, connected from car to car by jumpers, plugs and sockets.

Some of the Advantages Claimed.

A control power wholly independent of the line power and voltage.

Safety secured by the impossibility of short circuits, the line power control being local to each car.

Absence of trouble with control circuit contacts.

Low potential train line, practically eliminating train line trouble and short circuits of the control system.

Great power at the switch contacts, made available by the use of compressed air, which secures greater carrying capacity and permits the use of powerful springs which insure operation of the switches under all conditions.

Effective circuit-breaking devices with powerful magnetic blow-outs.

Absolute independence in the regulation of the current input of each car.

A simple motor cut-out switch.

Automatic return of the main control to the "off" position if the current supply of any or all cars fails, and automatic return to action when the current is restored.

A main control which is not brought into action by the auxiliary control when current is cut off.

A main control which may be operated when the power is off for the purpose of test or to stop the train in an emergency.

APPROXIMATE RATES OF DEPRECIATION ON ELECTRIC STREET RAILWAYS.

(Dawson.)

Buildings	1 to 2 %	Feeder cables	3 to 5 %
Turbines	7 " 9 "	Lighting and current meters	8 " 10 "
Boilers	8 " 10 "	Cars	4 " 6 "
Dynamos and Engines, belted plants	5 " 10 "	Repair shop and test-room fittings	12 " 15 "
Belts	25 " 30 "	Motors	5 " 8 "
Large, slow-speed steam engines	4 " 6 "	Rotary transformers	8 " 10 "
Large, slow-speed direct-driven plants	4 " 8 "	Boilers and engines	6 " 10 "
Stationary transformers,	5 " 6 "	Spare parts	1½ " 2 "
Storage batteries in central stations	9 " 11 "	Track work	7 " 13 "
Trolley line	4 " 8 "	Bonding	6 " 10 "
		On remaining capital expenditure	4 " 6 "

If interest rate is 5 per cent, and plant has to be renewed at the end of 20 years, 3 per cent of original outlay must be reserved annually to provide for renewal.

DEPRECIATION OF STREET RAILWAY MACHINERY AND EQUIPMENT.

Rates Stated by Chicago City Railway in "Street Railway Journal," Dec., 1898.

Power-Station. Engines, 8 per cent; Boilers, 8 per cent; Generators, 3 per cent; Buildings, 5 per cent.

Cable Machinery. Cable machinery, 10 per cent; Cables, 175 per cent.

Roadbed. Rails, 5.5 per cent; Ties, 7 per cent.

Paving. Granite, 5 per cent; Cedar blocks, 16 per cent; Brick, 7 per cent; Asphalt, 7 per cent; Macadam, 6 per cent.

Cars. Car bodies, 7 per cent; Trucks, 8 per cent.

Rolling Stock. Armatures, 33 per cent; Fields, 12 per cent; Gear cases, 20 per cent; Controllers, 4 per cent; Commutators, 33 per cent.

Wiring and other electrical equipment, 8 per cent.

Line Equipment. Iron poles, 4 per cent; Wood poles, 8 per cent; Insulation, 12 per cent; Trolley-wire, 5 per cent; Trolley insulation, 7 per cent; Bonding, 8 per cent.

All based upon renewals and per cent of wear.

CAR HEATING BY ELECTRICITY.

Test on Atlantic Avenue Railway, Brooklyn.

Cars.			Temperature F.		Watts Consumed.
Doors.	Windows.	Contents, Cu. ft.	Outside.	Average in car.	
2	12	850½	28	55	2295
2	12	850½	7	39	2325
2	12	808½	28	49	2180
2	12	913½	35	52	2745
4	16	1012	7	46	3038
4	16	1012	28	54	3160

TRACK RETURN CIRCUIT.

It goes without saying that the return circuit, however made, whether through track alone or in connection with return feeders, should be the best possible under the circumstances. Few of the older roads still retain the bonds and returns formerly considered ample and good enough.

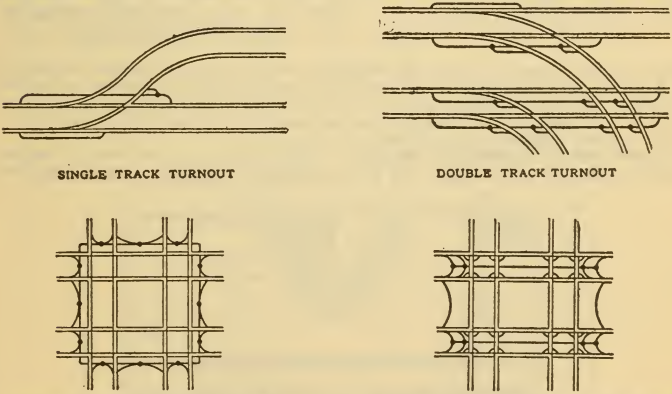
Electrolysis and loss of power have compelled many companies to replace bonds and return circuits by much better types. The British Board of Trade paid especial attention to the return circuit in the rules gotten out by them (see page 781), and many American railroads would have been much in pocket to-day if such rules had been promulgated in the United States at the beginning of the trolley development.

With few exceptions the practice of engineers has been to connect the rail joints by bonds, both rails of a track together at intervals, and both tracks of a double-track road together. To this has sometimes been added track return wires laid between the rails, and in other cases return feeders from sections of track have been run to the power house on pole lines or in ducts underground.

The writer favors the full connection return with frequent insulated overhead return feeders where there may be danger from electrolysis of water and gas pipes; in fact, ample return circuit has been proved time and again to be the only preventive of that trouble.

On elevated railways where the structure is used for the return, the ends of abutting longitudinal girders are likewise bonded together at the expansion joints. Tests have shown that the riveted joints, where well riveted, have a conductivity nearly equal to that of the girder itself, hence it is not necessary to bond them. The return circuit of the New York Subway is designed for an extreme drop of five volts.

Careful and continuous attention should be given to bonds from the moment cars are started on a line.



SINGLE TRACK TURNOUT — DOUBLE TRACK TURNOUT

CROSSING OF TWO ELECTRIC ROADS — CROSSING OF ELECTRIC AND STEAM ROADS

FIG. 116. Showing Cable Connections for Bonding Around "Special Work."

Dr. Bell gives the following ratios of track return circuit to overhead system as being average conditions.

Let R_1 = resistance of track return circuit, and
R = resistance of overhead system.

Then

$R_1 = .1$ to $.2R$. Exceedingly good track and very light load.
$R_1 = .2$ to $.3R$. Good track and moderate load.
$R_1 = .4$ to $.6R$. Fair track, moderate load.
$R_1 = .2$ to $.3R$. Exceptional track and large system.
$R_1 = .3$ to $.7R$. Good track, large system.
$R_1 = .7$ to $1.0R$. Poor track, large system.

In exceptional cases track resistance may exceed that of overhead system.
It is sometimes assumed that $R_1 = .25R$, but this is rather better than usual.

Under ordinary conditions $R_1 = .4R$ is nearer correct.

If formula for copper circuit = c.m. = $\frac{11\ I\ Dist.}{E}$ then for $R_1 = .4R$, the constant 11 should be increased to between 14 and 15 in order that copper drop may bear correct proportion to that of the ground return.

Type of Bonds.

(By F. R. Slater.)

Bonds are divided into two general classes, (1) those which are fastened to the surface of the rail or girder to be bonded, commonly called "soldered" bonds, and (2) those having terminals with a shank which is expanded into a hole in the rail or girder to be bonded, commonly called "riveted" bonds. In both classes that portion which is attached to the rail is called the terminal, the remainder the body of the bond.

Soldered Bonds. — These are formed in various ways but in general by a series of thin strips of annealed copper bent in the form of an

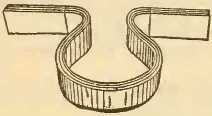


Fig. 117. Soldered Bond.

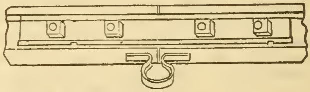


Fig. 118. Bond Attached to Base of Rail by Soldering only.

arch for the greatest degree of flexibility, with a pair of feet or terminals to provide contact surface. The strips of each foot are soldered or welded together, making a solid terminal, while the intermediate strips of the arch are free and unattached to each other so that they can readily take up vibrations. Figs. 111 and 112 illustrate this type.

Shawmut Soldered Bond. — This bond is constructed of copper laminations .023 inch thick, the ends separately tinned, clamped together

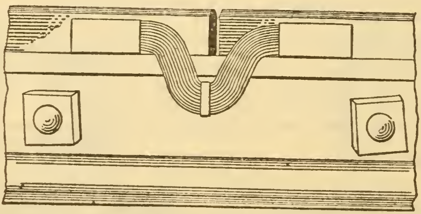


Fig. 119. Soldered Bond Applied to Head of Rail.

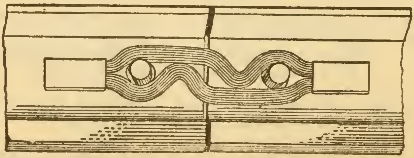


Fig. 120. Soldered Bond Applied inside of Angle Bar.

and dipped, then covered with a tinned wrapper, thus insuring perfect union when heated, and the form of construction assuming a great degree of flexibility.

In applying soldered bonds too much care cannot be exercised. The rail must be cleaned perfectly at the point of application and then tinned. The bond is then clamped in position and heat applied to both feet at once by means of a double burner gasolene torch, the solder being applied with zinc chloride flux.

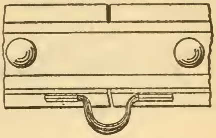


Fig. 121. Soldered Bond Applied to Base of Rail.

Bonds can be applied to the ball, web, or base of a rail, and each of the feet of the bond should be able to withstand a mechanical strain of two thousand pounds shearing stress, the electrical resistance not exceeding that of more than three feet of the rail to which it is applied.

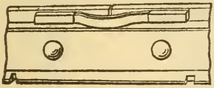


Fig. 122. Soldered Bond Applied to Head of Rail.

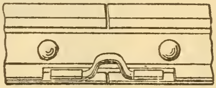


Fig. 123. Soldered Bond Applied to Flange of Rail.

Figure 124 shows the result of tests made on three sizes of soldered bonds 250,000 cm., 370,000 cm., and 640,000 cm., to determine at what current the bond would melt off. The rise in temperature at the terminals and center of the bond is given. The 640,000 cm. bond melted off at 5,500 amperes, melting both at the terminal and at the arched portion. The great difference in the heating of the two terminals of the 370,000 cm. was due to the imperfect soldering of one of them.

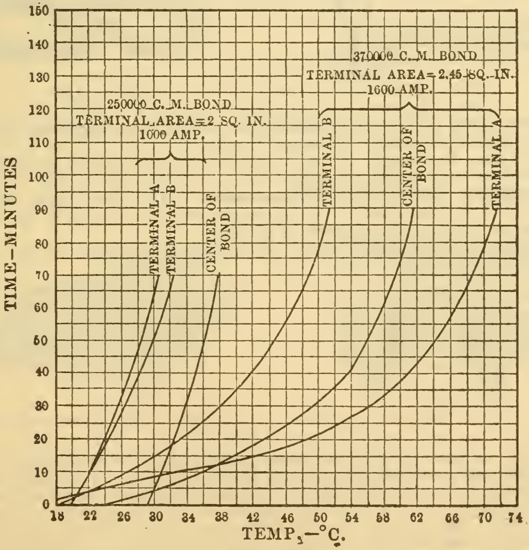


Fig. 124.

Riveted Bonds. — These are formed of a length of wire or cable having a copper terminal pressed or welded to its ends. Solid wire bonds of this type break easily from track vibration if short, and are used most largely for connecting around special work. This type of bond is subdivided into several styles, according to the way the shank of the terminal is fastened into the hole in the rail.

1. Bolt Expanded Terminal. — In this one the shank of the terminal is made with a hole through its center. Through this hole is passed a steel bolt which is threaded on one end and has a beveled shoulder

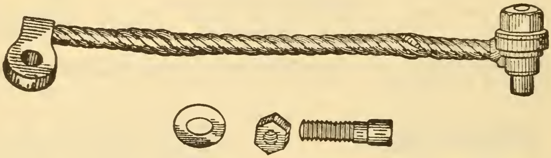


Fig. 125.

on the other. After the shank is fitted into the hole, it is expanded by pulling the bolt through the terminal by means of a nut, the tapered shoulder expanding the shank into the hole. This is shown in Fig. 125.

2. Pin Expanded Terminal. — In this type the terminal is made with a hole through the center of the shank which is fitted into the hole it is to occupy and a beveled steel pin is driven through its center, expanding the shank to a tight fit. This is shown in Fig. 126.

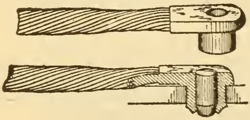


Fig. 126.

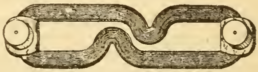


Fig. 127.

These two types are used principally for bonding the channel rails of the conduit system of electric railways.

In both types the shank of the terminal should practically fit the hole before the pin or bolt is driven in.

3. Machine Riveted Terminals. — In this type the shank of the terminal is made solid and is compressed into the hole by means of mechanical or hydraulic pressure (Fig. 127).

Terminals of bonds should never be riveted by hammer as the shank is

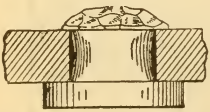


Fig. 128. Poorly Riveted Terminal.

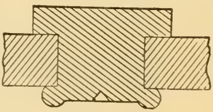


Fig. 129. Well Riveted Terminal.

not properly expanded into the hole (Fig. 128). An imperfect contact increases the resistance besides making the bond liable to further deterioration by reason of the accumulation of moisture between the shank and the hole. By means of the compressor the back of the terminal is first held securely against the face of the rail, then the shank of the terminal is expanded, forcing the soft metal back toward the base, making a uniform contact throughout the thickness of the rail, filling the hole so completely as to fill even the tool marks of the drill, and moreover, greatly increases the area of contact between the bond and the rail on account of the button head caused by the compressor (Fig. 129). This contact surface is an essential feature, and the efficiency of the bond depends upon this connection being made in the best possible manner.

Tests show that it takes twice the power to turn the compressed terminal in its hole that it does to turn the pin-driven terminal. As the only resistance against turning is the friction between the copper in the terminal and the sides of the hole, the compressed terminal must have much the superior contact.

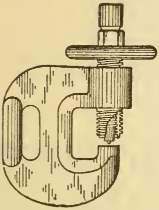
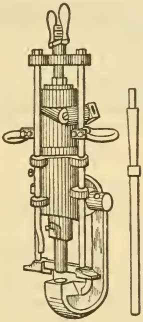


FIG. 130.



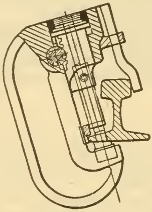


FIG. 131.

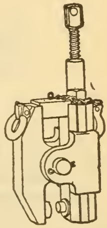


FIG. 132.

Figures 130 and 132 show respectively the double-screw and hydraulic compressors which have been successfully used on bonds in the web of the rail, and Fig. 131 shows a hydraulic compressor used successfully for putting bonds in the base of the rail.

The requirements for a good bond are:

1. Terminal should be made as an integral part of the stranded or body portion, in such a manner as to form practically a molecular union and thereby introduce a minimum resistance between the two.

2. Its terminal should be so proportioned as to have contact surface with the rail sufficient to carry the same amount of current as the body portion of the bond.

3. Its body portion should be so constructed as to possess sufficient flexibility to withstand all vibrations to which it may be subjected, such as

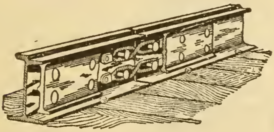


FIG. 133.

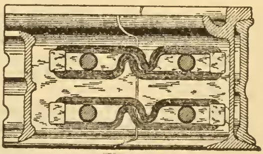


FIG. 134.

hammer blows, of passing car wheels on the track, and expansion and contraction of the rails due to temperature variations.

4. A method of applying the bond which will insure the permanency of the contact with the steel and reduce depreciation to a minimum.

In all cases it is desirable to have the bonds as little exposed as possible both for appearances, and to prevent their being stolen. This is particularly true of those in the return circuit. Bonds should also be made as short as possible to make their cost a minimum. For these reasons it is highly desirable that the bonds be placed under the splice plates whenever possible. In new installations standard splice plates are now procurable which have ample space between their inner surfaces and the rail to allow for the bonds, and in changing over old installations the saving in the initial cost of the bonds and the saving from loss by theft will go far towards paying for new splice plates.

With the idea of placing the bonds under the splice plates, manufacturers have designed them in suitable shapes, either by flattening the strands,

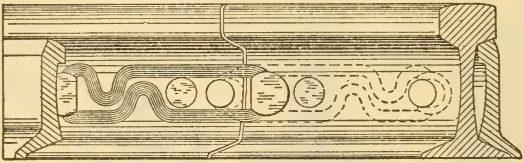


Fig. 135.

or the use of flat wires in the strands. Figures 133 and 134 show girder rails with bonds under the splice plates, and Fig. 135 shows a standard "T" rail similarly bonded.

Resistance of Bonds. — The total resistance of a bond is composed of three factors, the resistance of the copper in the bond, the resistance between the body of the bond and the terminal, and the contact resistance between the terminal and the rail. The following table gives the resistance of some of the more common sizes of bonds used:

Size of Bond.	Length of Bond.					
	5″	6″	7″	8″	9″	10″
0	.000047	.000056	.000064	.000072	.000081	.000089
00	.000039	.000046	.000052	.000059	.000053	.000072
000	.000033	.000038	.000043	.000048	.000053	.000059
0000	.000028	.000032	.000036	.000040	.000044	.000048

For any given size of bond the only variable factor in its resistance with the length is the resistance of the copper in the bond, the other two factors remaining constant. Hence the resistance of different sizes can be plotted as is done in Fig. 136, using resistance in ohms and length in inches as ordinates.

At least $\frac{1}{4}$ inch extra length of short bonds should be allowed for extreme contraction of rails due to changes in temperature, and bonds shorter than 9 inches are liable to excessive breakage due to vibration.

The most common practice has been to have the bond holes drilled at the rolling mills. Hence, when it is desired to do the bonding, the holes are rusty and will need to be reamed out until clear and bright. The cost of having the holes drilled at the mill at the current price ($1.00 per ton of rail) usually amounts to about 20 cents per hole, and the reaming to about 5 cents per hole — a total of 25 cents per hole, while if the holes are drilled just as the bonding is done, they will cost about 7½ cents each, including tools and supervision. Punched holes cost about 4 cents each. These costs will vary with conditions and rates of wages, the above being based on $2.00 for a day of eight hours. There is no material disadvantage in drilling the holes with oil.

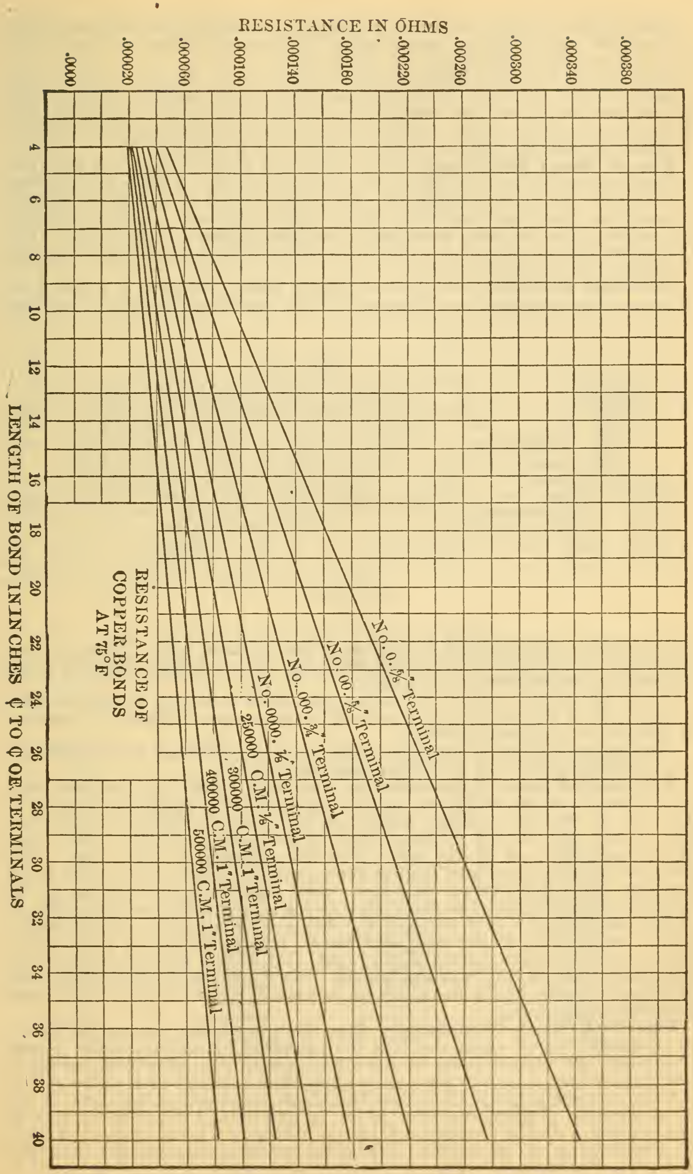

RESISTANCE IN OHMS
.0000
.000020
.000060
.000100
.000140
.000180
.000220
.000260
.000300
.000340
.000380
LENGTH OF BOND IN INCHES ℄ TO ℄ OF TERMINALS
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
RESISTANCE OF COPPER BONDS AT 75° F
No. 0. ⅝" Terminal
No. 00. ⅝" Terminal
No. 000. ¾" Terminal
No. 0000. ⅞" Terminal
250000 C.M. ⅞" Terminal
300000 C.M. 1" Terminal
400000 C.M. 1" Terminal
500000 C.M. 1" Terminal

Fig. 136.

Care should be taken to see that the holes are free from all moisture, as its presence greatly reduces the efficiency of the bond, hence bonding should never be done during damp or wet weather.

After the holes have been properly prepared the surface of the metal directly around the hole should be reamed so as to provide a bright, clean surface for the base of the terminal on the one side, and the button head, when riveted, on the other. If the shank of the terminal becomes oxidized or dirty it should be cleaned before being put into the rail.

Third Rail Bonding.—The practice in third rail bonding has been to bond the rail slightly in excess of its conductivity, in order to make the rail nearly a uniform conductor. In order to accomplish this it has been necessary to bond the base of the rail as well as the web. Special malleable iron splice plates are used which allow sufficient space for the bonds. Fig. 137 shows the bonding of the third rail of the Interborough Rapid Transit Company (New York Subway).

Welded Joints. — On many systems where the rails are imbedded they are made practically continuous by the use of welded joints, and but

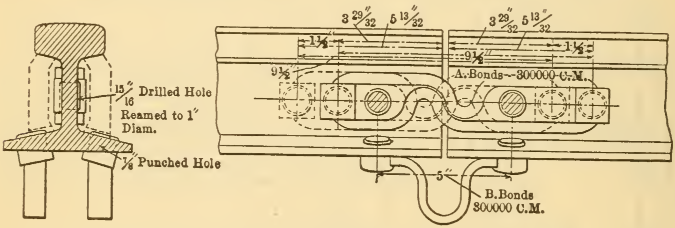


FIG. 137.

little trouble is experienced by broken joints or bent rails. These are not practicable on third rails or track rails that are not embedded and thus exposed to all temperature changes.

In the electrically welded system an iron plate is welded across the joint on each side of the rail web by means of heavy current of electricity applied by special low voltage machinery.

The cast weld joint is simply a large lump of steel cast about the joint in a mould after the rail ends have been cleaned.

Voynow Joint.—(*Street Railway Journal.*) The Voynow joint consists of what may be called two special channel bars which are riveted to the ends of the rail. These plates are not made to fit the fishing section of the rail; on the contrary, spaces are left under the head, tram and around the foot of the rail. The flat surfaces of both sides of the rails and of the joint bars having been previously cleaned by sand-blast, these spaces are filled with molten zinc, which enters into and fills out all the irregularities of the rolled surfaces, thus giving a continuous bearing throughout the whole length and width of the flanges of the plates. The adhesion of the molten zinc to the rails and plates, together with the body-bound rivets, holds the joint permanently tight, and at the same time prevents expansion, thus making rails continuous. As the rail ends and inside of the plates are cleaned to the metal by sand-blast, the joint is also of the best, electrically considered.

Thermit Rail-Welding. — The thermit process is a purely chemical operation, based upon the fact that metallic aluminum, under proper conditions, will reduce many of the other metals from their compounds to their simple form; as, for instance, if aluminum is mixed with oxide of iron and the mixture is ignited, the aluminum will unite with the oxygen of the oxide, forming aluminum oxide (which is commercial corundum), leaving the iron free. As the process of reduction liberates a great amount of heat, the temperature of the mixture during the reaction rises rapidly (to about 5000° F.), changing the iron to a molten low-carbon steel. Expressed in chemical terms, the equation, according to which the reaction takes place, would be $Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$. This is the process utilized in welding rails. The oxide of iron is mixed with powdered aluminum in the right proportion, and introduced into a crucible lined with magnesia, or with material obtained from a previous fusion. In order to set off the contents of the crucible, a small quantity of ignition powder (barium peroxide and pulverized aluminum) is put in a small heap on top of the mixture, and is ignited by means of a match or red-hot iron rod. The reaction propagates itself quickly through the whole mixture, with the result that in a few seconds the whole charge is a mass of white-hot fluid material. The contents of the crucible have separated into two layers, the molten metal reduced by the aluminum being at the bottom and the molten aluminum oxide above it.

In the application to rail-welding, a cone-shaped crucible, with magnesite lining, is mounted on a tripod over the joint to be welded, a properly prepared iron sand clay mould having been previously clamped around the joint. The conical crucible has a hole in the bottom, and before the operation a small iron rod or pin is placed in this hole with its end projecting several inches below the crucible. Above the head of the pin in the bottom of the crucible is first carefully fitted an asbestos washer, and on top of this is placed a solid circular metal washer to hold it in place. About 15 pounds or 20 pounds of powdered aluminum and oxide iron are then poured into the crucible. This mixture is known as "Thermit," and is furnished properly mixed and ready for use in small bags by the manufactures. On top of the mixture is placed a quantity of ignition powder, about enough to cover a 50-cent piece. When all is ready, a match is applied to the powder and a conical cover with a central opening is hastily placed on the crucible. In a few seconds the reaction commences, and within thirty seconds the contents of the crucible become a seething, boiling mass of molten metal. As soon as the reaction has reached its height, a man strikes the pin projecting from the bottom of the crucible with a rod or small shovel, driving the pin upward, thus freeing the hole and allowing the molten metal to flow down into the mould around the joint, depositing a mass of metal around the joint and welding the ends of the rails into one piece.

Resistance of Track Rails.

The resistance of the commercial steel track rails is about thirteen times that of copper. On this basis the following table of resistances of rails is computed.

Weight of Rail.	Sectional Area Sq. Inch.	Equivalent Cir. Mils of Copper.	Resistance per Mile Ohms.
45	4.4095	431,883	.13074
50	4.8994	479,884	.11766
55	5.4874	536,034	.10502
60	5.8794	575,505	.09806
65	6.3693	623,887	.09051
70	6.8592	671,825	.08404
75	7.3491	719,380	.07844
80	7.8392	767,763	.07354
85	8.3291	814,873	.06922
90	8.8190	863,766	.06537
95	9.3089	911,767	.06193
100	9.7988	1,072,068	.05883

$$\text{Area in cir. mils} = \frac{1{,}000{,}000 \times \text{weight per yard}}{10.2052 \times .7854}.$$

$$\text{Equivalent cir. mils of copper} = \frac{\text{Area in cir. mils}}{13}.$$

EXPERIMENTS FOR DETERMINATION OF THE RELATIVE VALUE OF RAILS AND BONDED JOINTS.

(W. H. Cole.)

Fifteen rails were used, giving three joints for each of the five different classes, and in making the tests and observations an average of the results for the three rails of its class was given. Micrometer calipers were used in measuring the wear of the rails each month, three different measurements were made at each place, and an average was calculated from these three measurements, viz.:

A. At a point at or near the gage line.
B. At a point in the center of the tread.
C. At a point near the outside of the rail.

The joints that were bonded were fished with standard fish plates, bolted with eight 1-inch bolts, screwed up tight; the rail ends butting each other were laid, fished and bonded in the maximum heat of the day, and immediately covered and paved around them.

No. 1. Three joints fished as above and bonded around the fish plates with standard Chicago bonds No. 00 B. & S. gage, two bonds to each joint.

No. 2. Bonded with "Crown" concealed bonds, with two bonds of a section equal to two No. 00 copper B. & S. gage, and the fish plates bolted over them.

No. 3. No. 2 plastic bonds, made by Harold P. Brown, and carefully installed according to instructions, by a man formerly experienced in this work.

No. 4. Three joints welded by the Falk process.

No. 5. Three joints welded by the Goldschmidt thermit process.

The rails were laid continuously so the same cars passed over the same section containing the different types of joints. The subjoined tables give the results, from which the writer has arrived at the following conclusions:

That for electric street railways under average traffic conditions, rails should give a life of about forty years if the joints are made continuous, and are composed of

Carbon	.55 to .58
Silicon	.10 or under
Phosphorus	.08 or under
Sulphur	.06 or under
Manganese	.83 or under

Ingredients of Rails Under Test.

Carbon.	Soft.	Medium.	Hard.
Carbon	.284	.572	.591
Silicon	.061	.235	.057
Phosphorus	.105	.052	.098
Sulphur	.065	.078	.060
Manganese	.784	.981	.830
	1.299	1.918	1.636
Iron	98.701	98.082	98.364
	100.000	100.000	100.000

Note. — Metalloids ignored.

The following would be the electrical efficiency and loss at the beginning and end of the first year:

Class of Joint.	Electrical Per Cent Efficiency at Beginning of Year.	Electrical Efficiency at End of Year.	Per cent below Equal Section of Rail.
Chicago bonds	89.51	74.43	29.57
Crown bonds	86.71	73.72	26.28
Plastic bonds	89.72	77.84	22.16
Falk cast weld	101.16	86.53	10.44
Goldschmidt thermit weld	101.14	100.39	100.39 +

BOARD OF TRADE REGULATIONS.

For Great Britain.

Regulations prescribed by the Board of Trade under the provisions of Section —— of the —— Tramways Act, 189—, for regulating the employment of insulated returns, or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on gas or water pipes, or other metallic pipes, structures, or substances; and for minimizing, as far as is reasonably practicable, injurious interference with the electric wires, lines, and apparatus of parties other than the company and the currents therein, whether such lines do or do not use the earth as a return.

Definitions.

In the following regulations :

The expression "energy" means electrical energy.

The expression "generator" means the dynamo or dynamos or other electrical apparatus used for the generation of energy.

The expression "motor" means any electric motor carried on a car and used for the conversion of energy.

The expression "pipe" means any gas or water pipe, or other metallic pipe, structure, or substance.

The expression "wire" means any wire apparatus used for telegraphic, telephonic, electrical signaling, or other similar purposes.

The expression "current" means an electric current exceeding one-thousandth part of one ampere.

The expression "the company" has the same meaning or meanings as in the —— Tramways Act, 189—.

Regulations.

1. Any dynamo used as a generator shall be of such pattern and construction as to be capable of producing a continuous current without appreciable pulsation.

2. One of the two conductors used for transmitting energy from the generator to the motors shall be in every case insulated from earth, and is hereinafter referred to as the "line"; the other may be insulated throughout, or may be insulated in such parts and to such extent as is provided in the following regulations, and is hereinafter referred to as the "return."

3. Where any rails on which cars run, or any conductors laid between or within three feet of such rails, form any part of a return, such part may be uninsulated. All other returns or parts of a return shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below the limit laid down in Regulation 7.

4. When any uninsulated conductor laid between or within three feet of the rails forms any part of a return, it shall be electrically connected to the rails at distances apart not exceeding 100 feet, by means of copper

strips having a sectional area of at least one-sixteenth of a square inch, or by other means of equal conductivity.

5. When any part of a return is uninsulated it shall be connected with the negative terminal of the generator, and in such case the negative terminal of the generator shall also be directly connected, through the current-indicator hereinafter mentioned, to two separate earth connections, which shall be placed not less than twenty yards apart.

Provided that in place of such two earth connections the company may make one connection to a main for water supply of not less than three inches internal diameter, with the consent of the owner thereof, and of the person supplying the water; and provided that where, from the nature of the soil or for other reasons, the company can show to the satisfaction of an inspecting officer of the Board of Trade that the earth connections herein specified cannot be constructed and maintained without undue expense, the provisions of this regulation shall not apply.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electromotive force not exceeding four volts shall suffice to produce a current of at least two amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

No portion of either earth connection shall be placed within six feet of any pipe, except a main for water supply of not less than three inches internal diameter, which is metallically connected to the earth connections with the consents hereinbefore specified.

6. When the return is partly or entirely uninsulated, the company shall, in the construction and maintenance of the tramway (*a*), so separate the uninsulated return from the general mass of earth, and from any pipe in the vicinity; (*b*) so connect together the several lengths of the rails; (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point; and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfill the following conditions, viz.:

(1.) That the current passing from the earth connections through the indicator to the generator shall not at any time exceed either two amperes per mile of single tramway line, or 5 per cent of the total current output of the station.

(2) That if at any time and at any place a test be made by connecting a galvanometer or other current indicator to the uninsulated return, and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanche cells connected in series, if the direction of the current is from the return to the pipe, or by interposing one Leclanche cell, if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (1) is complied with, the company shall place in a conspicuous position a suitable, properly connected, and correctly marked current indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the company to permit him at reasonable times and intervals to ascertain by test that the conditions specified in (2) are complied with as regards his pipe.

7. When the return is partly or entirely uninsulated, a continuous record shall be kept by the company of the difference of potential during the working of the tramway between the points of the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential exceeds the limit of seven volts, the company shall take immediate steps to reduce it below that limit.

8. Every electrical connection with any pipe shall be so arranged as to admit of easy examination, and shall be tested by the company at least once in every three months.

9. Every line and every insulated return or part of a return, except any feeder, shall be constructed in sections not exceeding one half of a mile in length, and means shall be provided for insulating each such section for purposes of testing.

10. The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily, before or after the hours of running, when the line is fully charged. If at any time it should be found that the leakage current exceeds one-half of an ampere per mile of tramway, the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within twenty-four hours. Provided, that where both line and return are placed within a conduit this regulation shall not apply.

11. The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile. A test of the insulation resistance of all such cables shall be made at least once in each month.

12. Where in any case in any part of the tramway the line is erected overhead and the return is laid on or under the ground, and where any wires have been erected or laid before the construction of the tramway, in the same or nearly the same direction as such part of the tramway, the company shall, if required to do so by the owners of such wires or any of them, permit such owners to insert and maintain in the company's line one or more induction coils, or other apparatus approved by the company for the purpose of preventing disturbance by electric induction. In any case in which the company withhold their approval of any such apparatus, the owners may appeal to the Board of Trade, who may, if they think fit, disdispense with such approval.

13. Any insulated return shall be placed parallel to, and at a distance not exceeding three feet from, the line, when the line and return are both erected overhead, or 18 inches when they are both laid underground.

14. In the disposition, connections, and working of feeders, the company shall take all reasonable precautions to avoid injurious interference with any existing wires.

15. The company shall so construct and maintain their systems as to secure good contact between the motors, and the line and return respectively.

16. The company shall adopt the best means available to prevent the occurrence of undue sparking at the rubbing or rolling contacts in any place, and in the construction and use of their generator and motors.

17. In working the cars the current shall be varied as required by means of a rheostat containing at least twenty sections, or by some other equally efficient method of gradually varying resistance.

18. Where the line or return or both are laid in a conduit, the following conditions shall be complied with in the construction and maintenance of such conduit:

(*a*) The conduit shall be so constructed as to admit of easy examination of, and access to, the conductors contained therein, and their insulators and supports.

(*b*) It shall be so constructed as to be readily cleared of accumulation of dust or other débris, and no such accumulation shall be permitted to remain.

(*c*) It shall be laid to such falls, and so connected to sumps or other means of drainage as to automatically clear itself of water without danger of the water reaching the level of the conductors.

(*d*) If the conduit is formed of metal, all separate lengths shall be so jointed as to secure efficient metallic continuity for the passage of electric currents. Where the rails are used to form any part of the return, they shall be electrically connected to the conduit by means of copper strips having a sectional area of at least one-sixteenth of a square inch, or other means of equal conductivity, at distances apart not exceeding 100 feet. Where the return is wholly insulated and contained within the conduit, the latter shall be connected to earth at the generating station through a high resistance galvanometer, suitable for the indication of any or partial contact of either the line or the return with the conduit.

(*e*) If the conduit is formed of any non-metallic material not being of high insulating quality and impervious to moisture throughout, and is placed within six feet of any pipe, a non-conducting screen shall be interposed between the conduit and the pipe, of such material and dimensions as shall provide that no current can pass between them without traversing at least six feet of earth; or the conduit itself shall in such case be lined with bitumen or other non-conducting damp-resisting material in all cases where it is placed within six feet of any pipe.

(*f*) The leakage current shall be ascertained daily before or after the hours of running, when the line is fully charged, and if at any time it shall be found to exceed half an ampere per mile of tramway, the leak shall be localized and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is localized and removed within 24 hours.

19. The company shall, so far as may be applicable to their system of working, keep records as specified below. These records shall, if and when required, be forwarded for the information of the Board of Trade.

Daily Records.

Number of cars running.
Maximum working current.
Maximum working pressure.
Maximum current from earth connections (*vide* Regulation 6 (1)).
Leakage current (*vide* Regulation 10 and 18 *f*.).
Fall of potential in return (*vide* Regulation 7).

Monthly Records.

Condition of earth connections (*vide* Regulation 5).
Insulation resistance of insulated cables (*vide* Regulation 11).

Quarterly Records.

Conductance of joints to pipes (*vide* Regulation 8).

Occasional Records.

Any tests made under provisions of Regulation 6 (2).
Localization and removal of leakage, stating time occupied.
Particulars of any abnormal occurrence affecting the electric working of the tramway.

Signed by order of the Board of Trade this ________day of_______189___

____

Assistant Secretary, Board of Trade.

CALCULATING THE OVERHEAD CONDUCTING SYSTEM OF ELECTRIC RAILWAYS.

Dr. Louis Bell gives the following steps as the best to be followed in entering upon the calculation of the conducting system of a trolley road:

Extent of lines.
Average load on each line.
Center of distribution.
Maximum loads.
Trolley wire and track return.
General feeding system.
Reinforcement at special points.

It must be said at once that experience, skill, and good judgment are far better than any amount of theory in laying out the conducting system of any road.

Much depends upon the character of the *load factor*, i.e., the ratio of average to maximum out-put; and this, varying from .3 to .6, can only be judged from a study of the particular locality, the nature of its industries and working people, the shape of the territory, and the nature of the surrounding country.

Map out the track to scale, noting all distances carefully, and dot in any contemplated extensions, so that adequate provision may be made in the conducting system for them. Note all grades, giving their length, gradient, and direction. Divide the road into sections such as may best suggest themselves by reason of the local requirements, but such as will make the service under ordinary conditions fairly constant.

The average load on each section will depend, of course, upon the number of cars, and the number of cars upon the traffic. This can only be arrived at by a comparison with similar localities already equipped with street railway, and even then considerable experience and keen judgment of the general nature of the towns are necessary in arriving at anything like a correct result.

If the road has been correctly laid out as to sections, the load on each will be uniform and may be considered as concentrated at a point midway in each section. Now, if a street railway were to be laid down on a perfectly level plain where the cost of real estate was the same at all points, and wires could be run directly to the points best suited; then it would only be necessary to locate the center of gravity of the entire system, and build the power station at that point, sending out feeders to the center of each section. Unfortunately for theory, such is never the case; and cost of real estate, availability of the same, convenience of fuel, water, and supplies will govern very largely the selection of a location for the power-house. Even when all the above points necessitate the placing of the power-house far from the center of gravity of a system, it may be possible to use such center as the distributing point for feeder systems, and even where this is not possible, it is well to keep in mind the center, and arrange the distributing system as nearly as possible to fit it.

All this relates, however, to preliminary determinations for the system as determined at the time, and in large systems will invariably be supplemented by feeders, run to such points as the nature of the traffic demands. A baseball field newly located at some point on the line not known to the engineer previous to the installation, will require reinforcement of that particular section; and often after a road has been running for some time, the entire location of traffic changes, due to change in facilities, and feeder systems then have to be changed to meet the new conditions, so that after all, location of the center of distribution depends largely on judgment.

The maximum current will rise to four or five times the average where but one or two cars are in use; will easily be three times the average on roads of medium size, while on very large systems it may not be more than double the average. If speeds are maintained on heavy grades the maximum is still further liable to increase.

Another point to be considered in connection with maximum load is the location, not only of heavy grades, but of parks, ball-grounds, athletic fields, cemeteries, and other such places for large gatherings of people that are liable to call for heavy massing of cars, many of which must be started practically at the same time, and for which extra feeder, and in some cases extra trolley capacity, must be provided.

Having determined the average current per section of track, the maximum for the same, and the extraordinary maximum for ends, park locations, etc., as well as the distances, all data are obtained necessary for the determination of sizes of feeders.

The selection of the proper size of trolley wire is somewhat empirical, but the size may be governed by the amount of current that is to be carried. It is obvious that with given conditions the larger the trolley wire the fewer feeders will be necessary, and yet with few feeders the voltage is liable to vary considerably. In ordinary practice of to-day No. 0 B. &. S. and No. 00 B. &. S. gauge, hard-drawn copper are the sizes mostly in use, the latter on those roads having heavier traffic or liable to massing of cars at certain localities. On suburban roads using two trolley wires in place of feeders, 0000 B. & S. gauge will probably be best.

Track return circuit has been treated fully in a previous chapter (see page 771); and all that is needed to say here is, that some skill in judgment is necessary in settling on the value of the particular track return that may be under consideration, in order to determine the value of the constant to be used in the formula for computing the size of wire or overhead circuit. In ordinary good practice this value may be taken as 13, 14, or 15, according as the bonding and rail dimensions are of good type and large.

It is quite obvious that the current-carrying capacity of the feeder must be taken into consideration, in spite of any determination of drop; and this can be found in the chapter on *Conductors*. Sizes of conductors are also governed to some extent by convenience in handling, and it is found that 2,000,000 cm. is about the largest that can be safely handled for underground work, while anything larger than 500,000 cm. for overhead circuits is found to be difficult to handle.

CONTINUOUS CURRENT FEEDERS LOAD DETERMINATION.

The first step towards determining the load is to draw a train diagram from the proposed time-table or schedule of trains. Such a diagram, having as abscissæ the length of the line and as ordinates the hour of the day, shows in a graphic form the course of every train and the number of trains on the line at any time. The stops may be omitted if they are very short compared to the runs, but in any case it is usual to show the course of each train by a straight line over each run, variations of speed being ignored unless of considerable duration and magnitude. An example of such a train diagram is given in Fig. 138, in which each train is indicated by a special kind of line in order to illustrate how it travels to and fro. The load at any time is estimated by counting how many train curves cut the line representing that particular time. Knowing the average amperes per train the total amperes are easily estimated for any time of day and may be plotted in the form of a load diagram. The average value of amperes for this purpose is obtained by plotting the curves of current for each run and adding the ampere hours of all these runs. The total ampere hours divided by the total number of hours occupied by the runs, is the average current taken by a train.

The method of plotting the current curves is described on page 667.

Economical Design of Feeders.—The investment in a system of feeders may be expressed as an initial cost, or as an annual interest or percentage thereof. The value of the kilowatt-hours lost in the feeders is most conveniently expressed as an annual expense. The sum of these two annual items is the total annual expense of the feeders. If the cost of feeders be proportional to the amount of copper and if the energy loss be computed for exactly the same part of the system as the first cost expense, the total cost will be a minimum when the interest and energy items are equal. This is known as Kelvin's Law. Unfortunately the conditions which are necessary for the correct application of this rule are not usually met with in practice. The cost of conductors is seldom proportional to the amount of copper owing to the existence of such items as cost of manufacture, installation and insulation. When, however, it is desired to find the most economical size of feeder to connect to a trolley wire or contact

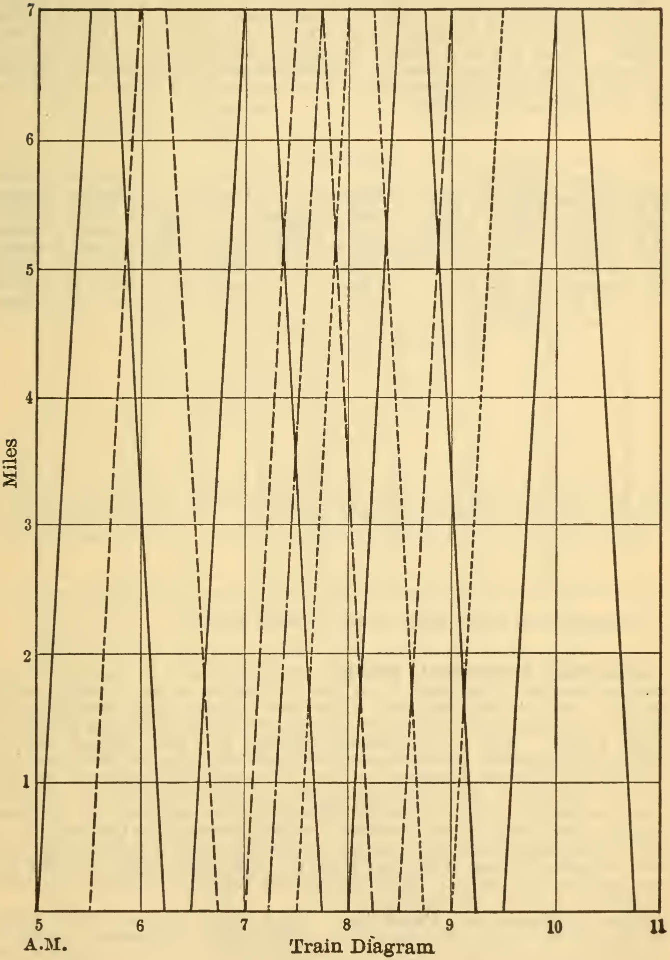


Fig. 138.

rail, the total energy loss in the combined system is more important than the loss in the feeder wires alone, so that in this case it is advisable to make a minimum the sum of the energy loss in the whole system and the interest and depreciation on part of the system, and the most economical case must be worked out by trial. A table showing how to do this is given herewith and should be used in connection with that on "Distribution of Copper," which is given below. In the former table the system of most economical distribution (Case 3) of the latter table, is assumed to be used, but this is not necessary, and is not even applicable if there is no drain of current from the conductors.

Volts drop to end of line V.	Kw.-hrs. lost per annum with R.M.S. current $5.2\,aV$	Annual cost of energy at n cents per kw.-hrs. $\$.052\,naV$.	Total C.M.-feet $\frac{4}{9}.k.\frac{aL^2}{V}$	Existing conductors C.M.-Ft.	Extra C.M.-Ft. reg.'d	Feet of . . . C.M. cable req.'d	Total cost of new cables	Interest maintenance and depreciation on cable at . . . %	Total annual expense, sum of third and last items.

a = square root of the mean of the currents squared.

Limiting Potential Drop.— The total drop in the positive and negative feeders is regulated by several conditions some of which, unfortunately, may be contradictory. The line voltage must always be high enough to supply current for starting a car on an up-grade, and to keep the lights bright. For a multiple-unit system, the line voltage must be sufficient to operate the contactors and air compressors with certainty. The General Electric Company's type *M* system of control should have at least 300 volts. The permissible drop is also influenced by considerations of economy, and in grounded feeders is often required not to exceed a certain limit fixed by law, this limit varying according to the locality. In England the maximum drop allowed in the grounded conductors is seven volts, whereas in most American cities no limit at all exists, it being only necessary for the railway company to take whatever precaution may be requisite to prevent electrolytic trouble.

Two Classes of Feeders.— Any direct current feeder system consists of two parts, the conductors which carry the current to the line and the line conductors (trolley wire) which serve as contact media to convey current to the cars. One set of conductors may be so designed as to fulfil these two functions, or the lines from the power station may be quite distinct from the contact rail or wire. In this latter case, the conductors from the power station carry the same current along their entire length, so that problems relating to drop, etc., may be treated by Ohm's Law. The contact conductors in either the first or second case mentioned above require somewhat different treatment owing to the fact that the current depends on the distribution of cars on the line.

Various arrangements of feeder and contact conductors are shown in Figs. 139, 140, 141, 142, and 143. Fig. 139 shows the simple ladder system in which the feeders and trolley wire are joined at intervals so as to form vir-

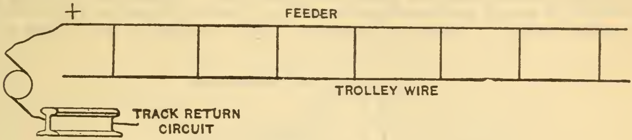


FIG. 139.

tually a single conductor. In its best form the cross section of the feeder is tapered according to the rules given below. Fig. 140 shows a modification of the last scheme. In this case the trolley wire is cut into sections, so that while losing the extra conductivity of the continuous trolley, each section

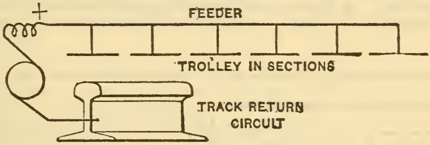


FIG. 140.

may be cut out in case of trouble without depriving the remainder of the system of current. Each section may be protected by a fuse and switch or a circuit breaker, but it is a disadvantage to have such apparatus scattered along the line. Fig. 141 shows a system where the current leaves the

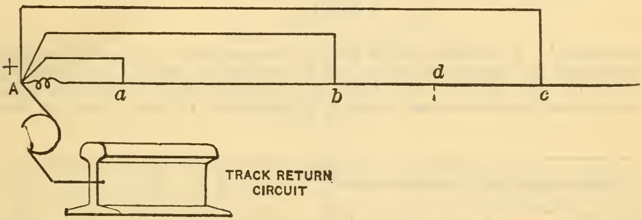


FIG. 141.

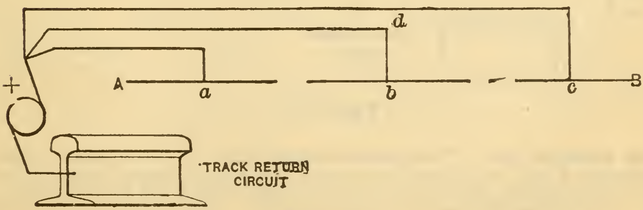


FIG. 142.

station by several lines, thereby enabling a number of small circuit breakers to be used instead of the large one required by the other systems. It, however, has the disadvantage of being uneconomical in copper, as the long lines carry very little of the load near the generators. The system shown in Fig. 142, is in many respects ideal from an operating standpoint, but it is very uneconomical in copper and energy. Each section of the trolley wire

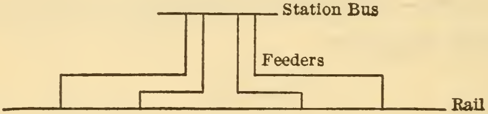


FIG. 143.

or third rail may be controlled by a circuit breaker in the power station thus giving the operators complete control in case of overload, short-circuit, or accident of any kind. It is also quite advantageous to replace a large circuit breaker by a number of small ones where thousands of amperes have to

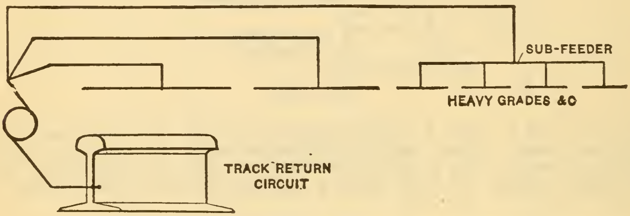


FIG. 144.

be transmitted. A combination of the last two systems is where the sections are connected by switches which can be opened in case of accident, but are normally kept closed. Fig. 143 shows a system that is useful for negative return conductors in cases where it is important to keep down the drop

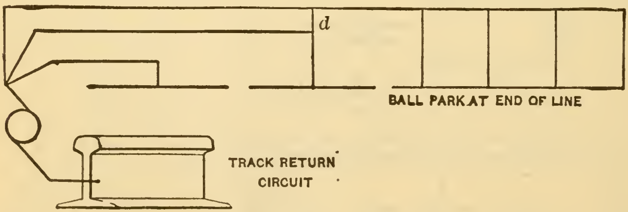


FIG. 145.

in the grounded rails. The numerous taps drain off the current in their neighborhood and so prevent the current in the rails being great at any point. The drop of potential in these insulated feeders will be considerable, but in the grounded ones it will be very little. This is in some cases more economical and certainly more simple than a "negative booster."

CALCULATION OF DIMENSIONS OF CONDUCTORS.

The problem of determination of the proper size of conductors to be used in distributing the current for an electric railway is somewhat complicated by the fact that the load is moving or changing its location all the time, and more so by the always changing condition of the resistance of the ground return, due to load, to track bending, condition of the earth return, and nearness of water and other underground pipes. Owing to this changing condition of the ground return part of the circuit it is necessary to assume some arbitrary value for it, in comparison with that of the overhead or insulated portion. The resistance of the ground return is seldom as high as that of the overhead part, nor is it often as good as .25 of that value; these values change with the load and track conditions, and it is now most universal to use the factor 14 as a number which represents the value of both overhead and return conductor, in place of 10.8, the resistance per mil-foot of copper, and that value is therefore used in the formulæ for calculating the sizes of overhead conductors, and has been found to produce good results in practice.

Let d = distance from switchboard to end of conductor.
CM = cir. mils area of the conductor.
V = drop in volts at far end of line.
I = current.
W = watts.
E = volts at switchboard.
10.8 = resistance of arc mil-foot of commercial hand drawn copper wire at 20° C or 68° F.
14 = resistance factor, including track return.
% = per cent expressed as a whole number, as 10 or 20.

Then for plain feeders between switchboard or other source of supply and the attaching point to the system,

$$CM = \frac{14 \times d \times I}{V}.$$

$$CM = \frac{1400 \times d \times I}{\% \times E}.$$

$$CM = \frac{1400 \times d \times \text{watts}}{\% \times E^2}.$$

$$V = \frac{14 \times d \times I}{CM}.$$

$$V = \frac{\% \times E}{100}.$$

The above formulæ can be used for nearly all practical determinations of feeder and other conductor sizes, but must always assume the load to be concentrated at one point or center. For other formulæ for calculation of the size of conductors see chapter on conductors.

Distribution of Current. — It is usual to assume the drain of current from the contact conductor to be uniform, so that the current at any section is given by the ordinates of a straight line sloping down from the power station. The error in this assumption is decreased on account of the motion of the cars as this causes the load to act as if more distributed.

Distribution of Copper — As the feeders carrying the same current along their entire length can be treated by the simple formulæ shown above, it is only necessary to consider those along which there is a uniform drain of current. Four typical cases are shown in the table with their respective formulæ for circular mils, C.M. ft., watts lost, and potential drop. The following abbreviations are used.

Where conductors of iron or aluminum are used it is best to reduce them to equivalent sections of copper.

The volts drop given by the formulæ are from the far end of the line; in order to get the drop from the power station, the values obtained by the formulæ must be subtracted from V.

Uniform Drain of Current.

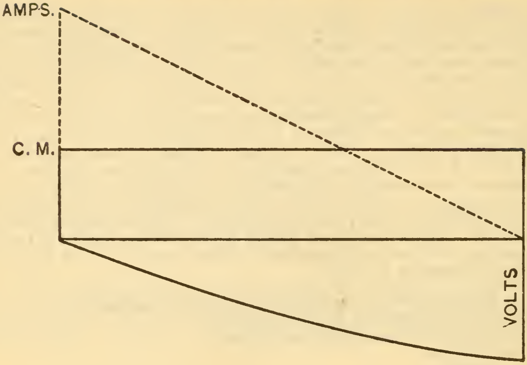


FIG. 146. Case 1.

Conductor Uniform.

$$C.M. = \frac{10.8 \times I \times l}{2\,V}. \qquad \text{Watts lost} = \frac{2}{3} IV.$$

$$C.M.\ \text{ft.} = \frac{10.8 \times I l^2}{2\,V}. \qquad \text{Volts drop} = \frac{10.8 \times I \times d^2}{2 \times C.M. \times l}.$$

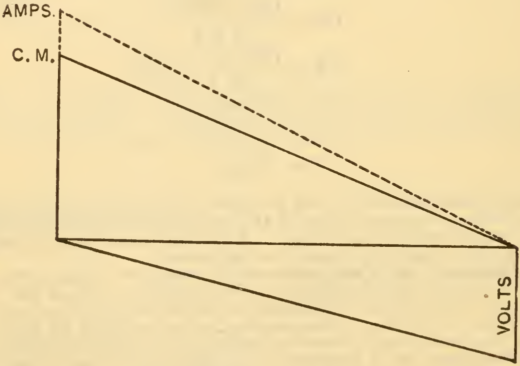


FIG. 147. Case 2.

Conductor Uniformly Tapered.

$$C.M. = \frac{10.8 \times I \times d}{V}. \qquad \text{Watts lost} = \frac{1}{2} IV.$$

$$C.M.\ \text{ft.} = \frac{10.8 \times I \times l^2}{2\,V}. \qquad \text{Volts drop} = \frac{10.8 \times I \times d}{C.M.}.$$

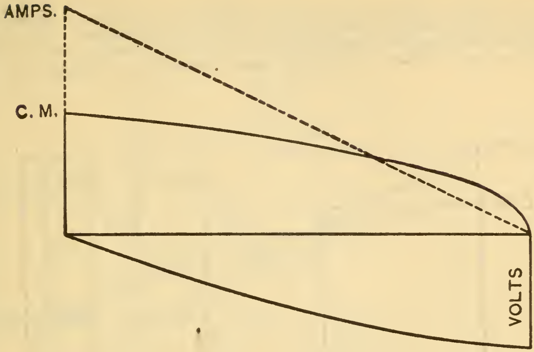


FIG. 148. Case 3.

Conductor Most Economically Tapered.

$$C.M. = \frac{2 \times 10.8 \times I \times \sqrt{l} \times \sqrt{d}}{3\ V}. \qquad \text{Watts lost} = \frac{3}{5} IV.$$

$$C.M.\ \text{ft.} = \frac{4 \times 10.8 \times I \times l^2}{9\ V}. \qquad \text{Volts drop} = V \times \sqrt{\frac{d^3}{l^3}}.$$

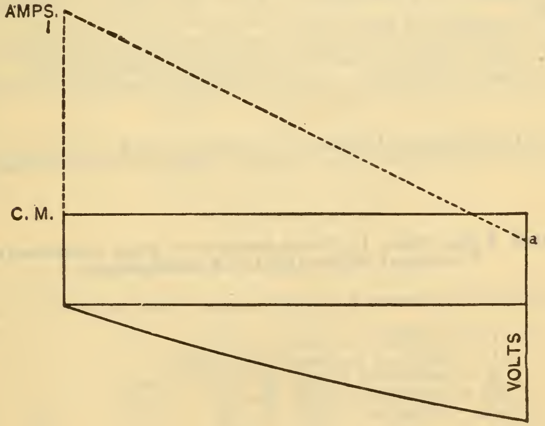


FIG. 149. Case 4.

Conductor Uniform. Current I at Station and i at Distant End.

$$C.M. = \frac{10.8 \times (I + i)\ l}{2\ V}. \qquad \text{Watts lost} = \frac{10.8 \times l \times (I^2 + Ii + i^2)}{C.M. \times 3}.$$

$$C.M.\ \text{ft.} = \frac{10.8 \times (I + i)\ l^2}{2\ V}. \qquad \text{Total drop, } V = \frac{10.8 \times l \times (I + i)}{C.M. \times 2}.$$

In case 3, the formula for C.M. gives the most economical distribution of copper to produce a certain drop V to the far end of the line. It is, of course, impossible to get this exact arrangement in practice as conductors of definite size must be used. The conductors are, therefore, arranged in steps of

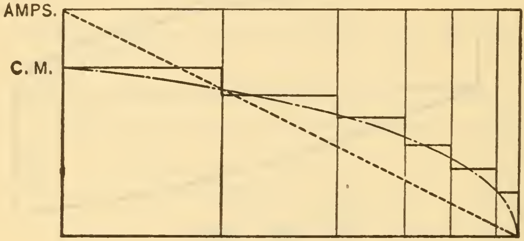


FIG. 150.

decreasing area as shown in Fig. 150, each of which may be treated as an example of case 4.

Miscellaneous Formulæ. — *Watts lost, assuming uniform drain of current.*

Watts = amperes per foot × area of "Drop" curve in volt-feet.

Potential drop in uniform conductor with any distribution of current.

Volts = ohms per foot × area of current curve in ampere-feet.

Most economical distribution of copper with any distribution of current.

Cross section of copper proportional to $\sqrt{\text{current}}$.

NOTE.— Do not connect trolley wire to feeder too close to power line or sub-stations, as if done this will cause frequent opening of circuit breakers.

Drop and Loss, etc., in Line between Two Substations of Unequal Potential. Assumptions.

One train moving between S.S. with constant speed and constant current.

I = current per train.
L = distance between sub-stations.
R = resistance of line per mile of track.
E_1 = potential of S.S. No. 1.
E_2 = potential of S.S. No. 2.

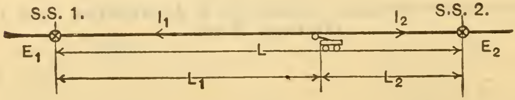


FIG. 151.

Maximum Drop at Train.

$$\left.\begin{matrix} D_{max\ 1} \\ D_{max\ 2} \end{matrix}\right\} = \frac{IRL}{4} \pm \frac{E_1 - E_2}{2} + \frac{(E_1 - E_2)^2}{4IRL}.$$

$$\left.\begin{matrix} I_1 \\ I_2 \end{matrix}\right\} = \frac{I}{2} \pm \frac{E_1 - E}{2RL}.$$

$$\left.\begin{matrix} L_1 \\ L_2 \end{matrix}\right\} = \frac{L}{2} \pm \frac{E_1 - E_2}{2IR}.$$

Average Drop at Train.

$$\left.\begin{matrix} D_{ave\ 1} \\ D_{ave\ 2} \end{matrix}\right\} = \frac{IRL}{6} \pm \frac{E_1 - E_2}{2}.$$

$$\left.\begin{matrix} I_1 \\ I_2 \end{matrix}\right\} = \frac{I}{2} \pm \frac{E_1 - E_2}{RL}.$$

Average Loss between S.S.

$$\text{Loss}_{ave} = \frac{I^2RL}{6} + \frac{(E_1 - E_2)^2}{RL}.$$

IMPEDANCE OF STEEL RAILS TO ALTERNATING CURRENT.

The impedance of iron or steel conductors to alternating currents is a complicated phenomenon which varies with the frequency of the current flowing with the area and the shape of the perimeter of the cross section and the permeability; and the permeability depends upon the current in the conductor; therefore statements of the impedance of iron or steel conductors to alternating currents convey little true meaning without a statement of all the conditions named above. Owing to the complexity of these conditions it is practically impossible to compute the values which must therefore be determined by experiment.

Following are tables showing the results of experiments upon steel track rails.

Experimental Determination of Impedance of Steel Rails.

(A. H. Armstrong, G. E. Co.)

45-pound Rail.

Measured cross section — 4.26 square inch. Perimeter — 15.875 inches. Direct current resistance of 180 feet — .00371 ohm.

Cycle	Amps.	Volts	Power Factor	Impedance	Watts	Eff. Res.	React.
25	223.2	4.18	.834	.01875	776	.0156	.0103
25	332	6.75	.852	.0203	1910	.01735	.0106
25	438	8.85	.864	.0202	3350	.01747	.0102
40	223.2	5.37	.826	.0241	990	.0199	.0136
40	332	8.8	.876	.0265	2560	.0233	.0129
40	438	11.47	.889	.0262	4450	.0232	.0120
60	223.2	6.88	.850	.0308	1308	.0262	.0162
60	332	11.06	.901	.0334	3305	.0300	.0145
60	438	14.46	.877	.0330	5550	.0289	.0158

60-pound rail.

Measured cross section — 6 square inches. Perimeter — 18.75 inches. Direct current resistance of 180 feet — .00185 ohm.

Cycles	Amps.	Volts	Power Factor	Impedance	Watts	Eff. Res.	React.
25	296	6.32	.826	.0213	1545	.01765	.0120
25	398	8.64	.849	.0217	2920	.01841	.01145
25	622	11.73	.861	.0189	6280	.01625	.00961
40	296	7.95	.896	.0268	2110	.0241	.0119
40	398	10.98	.871	.0276	3800	.0240	.01355
40	622	15.4	.870	.0248	8340	.02155	.0122
60	296	10.13	.901	.0343	2700	.0308	.0149
60	398	13.74	.916	.0345	5010	.0317	.0138
60	622	19.15	.869	.0308	10350	.0268	.01525

80-pound rail.

Measured cross section — 7.77 square inch. Perimeter — 21.5 inches. Direct current resistance of 180 feet — .002035 ohm.

Cycles	Amps.	Volts	Power Factor	Impedance	Watts	Eff. Res.	React.
25	392	6.1	.796	.01555	1905	.0124	.0094
25	620	10.01	.756	.0162	4700	.01225	.0106
25	820	12.83	.834	.01565	8760	.0130	.00863
40	392	7.61	.816	.0194	2440	.0159	.0112
40	620	12.98	.837	.0209	6720	.0175	.001145
40	820	17.35	.866	.0212	12300	.0183	.0106
60	392	10.15	.863	.0259	3430	.0223	.0131
60	620	17.03	.898	.0275	9460	.0246	.0121
60	820	21.65	.853	.0264	15150	.0225	.0138

Experiment on Interworks Tracks of Westinghouse E. & M. Co.

"In order to determine the drop in voltage in a circuit composed of a trolley wire and a pair of track rails and to determine also the effect of the addition of a feeder, the following tests were made on the Westinghouse Interworks Railway, in March, 1905. The section of the road selected was 4000 feet long and consisted of 1200 feet of double catenary construction and 2800 feet of single catenary construction. The trolley wire was No. 000 and the track rails were 70 pounds. The trolley wire was 24 feet above the track on the double catenary portion and 22 feet on the single catenary. The messenger cable consisted of $\frac{7}{16}$-inch stranded steel cable. A No. 0000 feeder was located approximately 3 feet above and 8 feet to the side of the trolley wire, as indicated in sketch (Fig. 152).

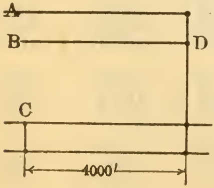


Fig. 152.

With the end of the trolley wire grounded to the track and an alternating current of 25 cycles applied at the points *B*, *C*, the following results were obtained, with the aid of the No. 0000 feeder used as a voltmeter lead.

Amperes	Total volts B − C	Volts A − B	Volts A − C	Total Impedance B − C	Power Factor
50	23.5	15.5	8	.47	.646
100	46.2	....	....	.465	.637
150	68.5	45	22	.456	.639
200	89.6	63.2	29.5	.448	.63
300	138.4	97	44	.448	.62
			Average	.457	.634

On direct current the average resistance of the total circuit B–C was .248 ohm; of the portion B–D, .219 ohm; and of the portion C–D, .0266 ohm.

It will be seen from the above that the drop in voltage in this circuit, composed of trolley and track, was 45.7 volts per 100 amperes and that approximately two-thirds of this was due to the trolley wire and one-third due to the rails.

In the second set of tests, current was supplied to the No. 0000 feeder and trolley wire in parallel and with 25 cycles alternating current, the following results were obtained.

Total Amps.	Amperes in trolley	Amps. in feeder	Voltage	Impedance	Power Factor
100	51.5	48.5	32.5	.325	.553
150	72.7	77.3	48.4	.323	.544
200	95.3	104.7	63.2	.316	.54
			Average	.321	.542

On direct current the resistance of this circuit was .1298.

It will be seen from these results that the addition of the No. 0000 feeder, which reduced the resistance from .248 ohm to .1298 ohm, or nearly cut it in half, reduced the drop with alternating current from 45.7 volts per 100 amperes to 32.1 volts per 100 amperes or only about one-third.

This indicates that for single-phase railways the most economical use of copper is to place it in the trolley wire only and to so locate the feeding points that proper voltage will be obtained.

In general, with a circuit consisting of No. 000 trolley and a pair of 70-pound rails, the drop in voltage with 25 cycle alternating current is approximately 60 volts per 100 amperes per mile, but only from 60 to 65 per cent of this voltage represents a loss of energy.

With the alternating current system using a trolley and track return, there is an inductive drop in the trolley and rails, with an additional loss in the latter case due to eddy currents and hysteresis. Measurements made upon the Ballston line indicate an apparent trolley resistance of 1.3 times the ohmic resistance, and a rail resistance 6.55 times the ohmic resistance.

Comparative A. C. and D. C. Resistance Trolley and Track, Per Mile of Circuit.

	D.C. Resistance	A.C. Resist. 25 Cycles	Ratio $\frac{A.C.}{D.C.}$
	Ohms.	Ohms.	
Two trolleys in series	.318	.417	1.31
One trolley and double track	.167	.259	1.55
Two trolleys and double track . . .	.088	.155	1.76
Double track alone	.0174	.114	6.55

The impedance of an electric railway conducting system consisting of a trolley wire overhead, placed in some sort of location above the two track rails, is a still further complication, and this impedance comprises the resistance and reactance of the trolley wire, and if of catenary construction, the messenger wires; the resistance and inductance of the rails; the inductance of the circuit bounded by the rails and the trolley wire, and the mutual inductance of the currents in the two rails. The calculation of this impedance is therefore hardly possible and in all cases its value must be determined by experience.

TESTS OF STREET RAILWAY CIRCUITS.

The following tests are condensed from an article by A. B. Herrick in the *Street Railway Journal*, April, 1899.

The following instruments will be required:

A barrel water rheostat to take say 100 amperes.
A voltmeter reading to 600 volts.
A voltmeter reading to 125 volts.
An ammeter reading to say 150 amperes.
A pole long enough to reach the trolley wire, with a wire running along it having a hook to make contact.

Use one generator at the station, and have the attendant keep pressure constant.

Test for Drop and Resistance in Overhead Lines and Returns.

The car containing the above equipment of instruments is run to the end of the section of conductor which it is desired to test, where a line circuit-breaker divides the sections.

The instruments are then connected as shown in Fig. 153.

It is clear now that if the switch G be closed, current will flow through the rheostat and be measured by the ammeter. We now have the trolley and feeder B for a pressure wire back to the station, and the reading of voltmeter C therefore gives the drop between the station and the point A in the feeder and trolley carrying the load. Voltmeter D shows the drop across the rheostat; and if the sum of readings C and D be deducted from the station pressure, the difference will be the drop in the ground return.

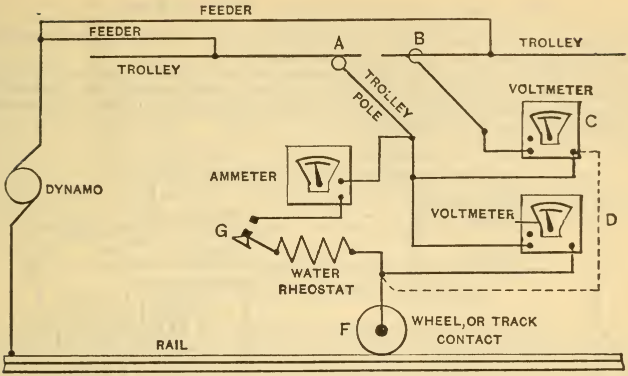


FIG. 153.

The station pressure can be taken by changing the lead of voltmeter C down to F as shown by the dotted line.

The drop on A and its resistance having been found, the trolley-pole can be swung around and the same data be determined for the circuit B.

To Read the Ground Return Drop Directly.

Open the station switch on that feeder that is being used as pressure wire, and ground the feeder to the ground bus through a fuse for safety.

Connect the instruments as shown in the following cut; then when the switch G is closed and current flows, the drop from A to F read on voltmeter C will be the drop in the ground return from F to X.

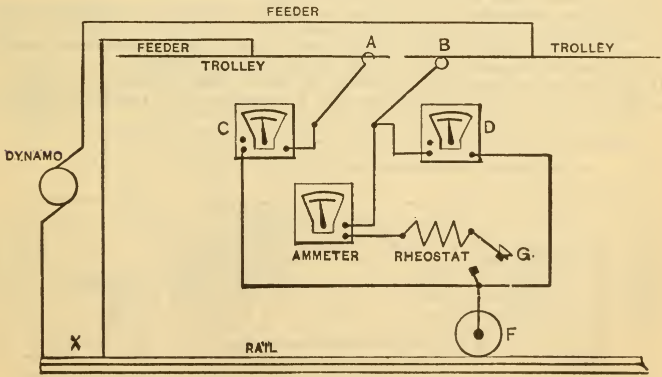


FIG. 154.

To Determine Drop at End of Line.

For use on double-track lines only, unless a pressure wire can be run to the end of line from the last line circuit-breaker.

Break all cross connections from feeder to trolley-wire for one track, as at *n*; connect this idle trolley to the next one back toward the station, as at C, then make the tests as in the two methods described above, connections being shown in the following cut.

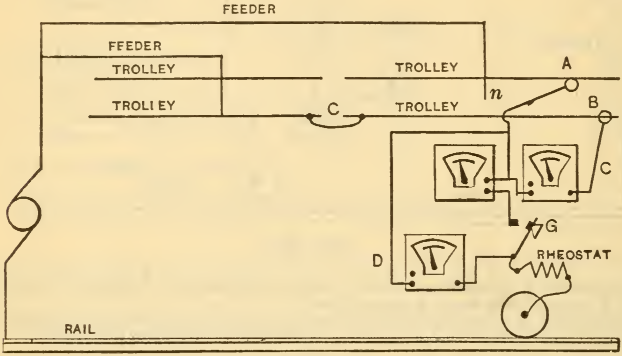


FIG. 155.

To Determine the Condition of Track Bonding, and the Division of Return Current through Rails, Water or Gas Pipes, and Ground.

The cut below shows the connections for this test as applied to a single track, or to one track of a double-track road.

Ground the feeder A at the station, or rather connect it to the ground bus through a fuse. Then connect the track at C to A by the pole E through the ammeter M. The drop between points F and D will be the drop through the rail circuit between C and D, due to the current flowing.

If connection be made to a hydrant, or other water connection, and to a gas-pipe, as at X, still retaining the rail connection at C, more current will

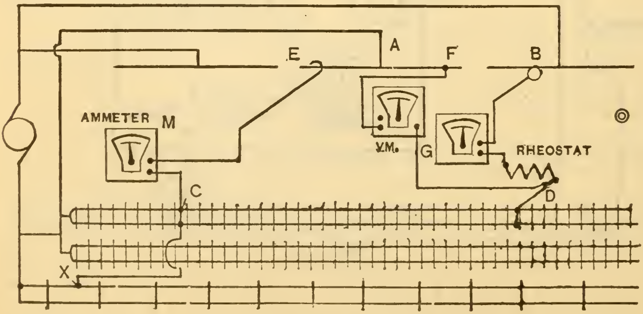


FIG. 156.

flow through ammeter M, due to providing the metallic return through A for the water-pipe, and the first reading of the ammeter M is to the second reading as the resistance of the water-pipe is to that of the rail return, and the current returning to the station will distribute itself between the two paths in proportion to the readings mentioned. If ammeter G be read at the same time, the difference between its reading and the sum of the other two readings will be the amount of current returning by other paths than the rail and water-pipe. If C is near the station it may be necessary to break the ground connection between rails and bus, so that all current may return over the metallic circuit A.

To determine condition of bonds, move the contact C back towards D, and the decrease in drop as shown by the *vm.* will be very nearly proportional to the length of track, except where a bad or broken bond may be located, when the change will be sudden.

TESTING RAIL BONDS.

It is not commercially practicable to measure the exact resistance of rail joints, as such resistance is small under ordinary circumstances, and all the conditions vary so much as to prevent accurate measurement being made. The resistance of rail joints is therefore measured in terms of length of the rail itself, and there are numerous instruments devised for the purpose, nearly all being based upon the principle of the wheatstone bridge, the resistance of the rail joint being balanced against a section of the rail, as in the following diagram.

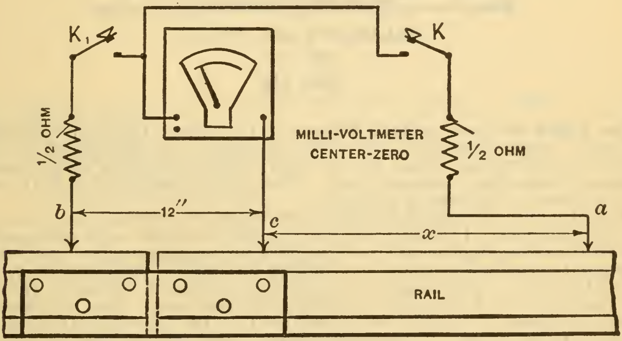


FIG. 157. Diagram of Method of Testing Rail Joints.

A Weston or other reliable milli-voltmeter, with the zero point in the middle of the scale, is the handiest instrument for making these tests. The points b and c are fixed usually at a distance of 12 inches apart, the point a is then moved along the rail until there is no deflection of the needle when both switches are closed. The resistance of the joint or the portion between the points b and c is to that of the length, x, inversely as the length of the former is to that of the latter, all being in terms of the length of rail, or,

Let

$x =$ distance in inches between points a and c,
$y =$ distance between the points c and b,
$v =$ resistance of joint in terms of length of rail,

then,

$$v = \frac{x}{y},$$

and if $x = 36$ inches and $y = 12$ inches,

then

$$v = \frac{36}{12} = 3 \text{ times its length in rail.}$$

Another scheme for testing rail joints is pointed out by W. N. Walmsley in the "Electrical Engineer," December 23, 1897.

In the following cut, the instrument is a specially designed, double milli-voltmeter, both pointers having the same axis, and indicating on the same scale.

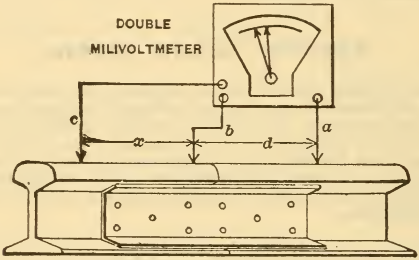


FIG. 158.

The points ab are at a fixed distance d, the point c being movable along the rail. Points a and b are set on the rail astride the joint, as shown ; the point c is then moved along the rail until the pointers on the instrument coincide, indicating the same drop. Then the resistance of x is the same as d, in terms of the size of rail used.

Harold P. Brown has devised an instrument for testing rail joints with little preparation. It consists of two specially shielded milli-voltmeters of the Weston Company's make, put up in a substantial wooden case, the top of which is made up in part of two folding legs which, when unfolded, cover six feet of rail. These legs form one length, which is divided by slots into two lengths, one of one foot, the other five feet long. The instrument is placed alongside the track in such position that the leg rests on the rail, and the joint to be tested is between the ends of the shorter branch or leg, while five feet of clear rail are included between the ends of the longer leg.

The instrument terminals are connected to small horseshoe magnets, that fit into the slots in each leg, and when rested on the rail always make the same pressure of contact, the poles being amalgamated and coated with a special soft amalgam, called Edison Flexible Solder.

With the five feet of rail as a shunt, the instrument will read to 1500 amperes.

There are several separate resistance coils and binding-posts supplied for different sizes of rail in common use, so that the dial of the milli-voltmeter needs but one scale.

The second milli-voltmeter measures the drop around the one foot of joint, and has coils so arranged to permit of reading .15, 1.5, 15. volts.

A reading of the current value is taken from the five feet of rail, and a simultaneous reading of the drop across the joint and one foot of rail is also made. The resistance of the latter is then found by ohm's law,

$$R = \frac{E}{I}.$$

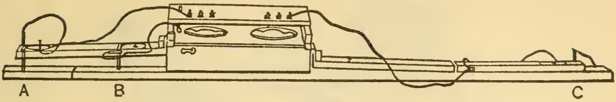


FIG. 159. Brown's Rail-bond Testing Instrument.

Street Railway Motor Testing.

Barn test for efficiency : —

Put a double-flange pulley on the car axle for the application of a prony brake, pour water inside the pulley to keep it cool. Use common platform scale, as shown in cut.

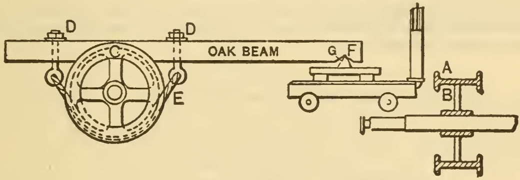


FIG. 160.

Then let $D =$ distance from center of axle to point on scales in feet, measured horizontally.

$\pi = 3.1416$,
$R =$ revolutions per minute,
$E =$ voltage at motor,
$I =$ amperes at motor,
$T =$ force applied to balance scales, in pounds.

$$\text{Then B. H. P.} = \frac{2\pi D R T}{33{,}000}.$$

$$\text{B. H. P. at 500 volts} = \frac{\left(2\pi DR \times \frac{500}{E}\right) T}{33{,}000}.$$

$$\frac{EI}{746} = \text{E.H.P. supplied to motor.}$$

$$\frac{500\ I}{746} = \text{E.H.P. supplied to motor at 500 volts.}$$

$$\text{Efficiency of motor} = \frac{\text{B.H.P.}}{\text{E.H.P.}} \times \frac{\text{B.H.P. at 500 volts}}{\text{E.H.P. at 500 volts}}.$$

Draw-bar Pull and Efficiency Test Without Removing Motor from Car.

Rig up lever as shown in cut, being sure the fulcrum *A* is strong enough to stand the pull. Posts, as shown, make good fulcrum ; have turn buckle *F* for taking up any weakness.

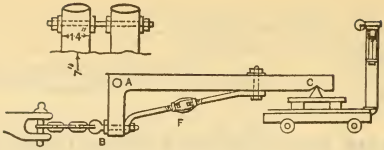


FIG. 161.

Let D = diameter of car wheel in feet.
π = 3.1416,
T = force on scale in pounds,
L = length of long arm of lever,
$L_{\prime}$ = length of short arm of lever,
R = revolutions per minute.

Place a jack-screw under each side of the car, and lift the body until there is only friction enough between wheels and rail to keep the speed of revolutions down to the normal rate.

Then

$$\text{Draw-bar pull} = T\frac{L}{L_{\prime}},$$

and

$$\text{B.H.P.} = \frac{T\frac{L}{L_{\prime}} D \pi R}{33{,}000}.$$

and the efficiency is the same as before,

i.e. $$\frac{\text{B.H.P.}}{\text{E.H.P.}} = \text{efficiency}.$$

Mr. A. B. Herrick has devised a testing-board for street-railway repair shops that will greatly assist in making all inspection tests, and which is described in the "Street Railway Journal" for January, 1898, pages 11 and 12.

Testing Drop in Railway Circuits. — For this test use can be made of any car that is in good order, and it should be carried out after the last car is in the barn, and the track is clear. Run the car over the line starting from the point nearest the power house, making the test at any points that may be selected. The following cut No. 162 shows the arrangement of instruments.

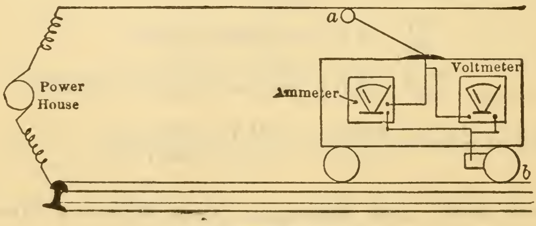


FIG. 162.

E = drop a to b without load, and in clear dry weather this should be same as at the switchboard. In wet weather or with poor insulation the drop without load may be considerable.

E_1 = drop a to b taken with the brakes set and the controller on the first notch.
I = amperes of current under conditions E_1.
$E - E_1 = e$ = drop in circuit due to current I.
$R = \frac{e}{I}$ = resistance of entire circuit of trolley wire; feeders, and rail returns.
R_1 = resistance of feeders and trolley wire as calculated from their known dimensions.
$R - R_1$ = resistance of the return circuit.

FAULTS AND REMEDIES.

Car Will not Start:

a. Turn on lamps; if they burn, trolley and ground wires are all right and current is on line.

b. If lights die down when controller is thrown on, trouble may be poor contact between rails and wheels, or car may be on "dead" track.

c. If car works all right with one controller, fault may be open circuit, or poor contact in the other. Throw current off at canopy, or pull down the trolley and examine the controller.

d. See that both motor cut-outs are in place.

e. Fuse may be blown; throw canopy switch and replace.

f. See that motor brushes are in place and intact, and make good contact.

g. Car may be standing on "dead" or dirty rail; in either case connect wheels to next rail by wire. It is better to open canopy switch while connecting wire to wheels, or a shock may be felt.

h. Ice on trolley wheel or wire will prevent starting.

Sparking at Commutator Brushes:

a. Brushes may be too loose; tighten pressure spring.

b. Brushes may be badly burned or broken, and therefore make poor contact on the commutator. Replace brushes with new set, and sandpaper commutator surface smooth.

c. Brushes may be welded to holder, and thus not work freely on commutator surface.

d. Commutator may be badly worn and need renewing.

e. Commutator may have a flat bar, or one projecting above the general surface; commutator must then be turned true in lathe.

f. Dirt or oil on commutator may produce sparking; clean well.

Flame at the commutator may be produced by:—

a. Broken lead wire or coil, producing a greenish flame, and burning two bars usually diametrically opposite each other. If left too long the two bars will be badly burned, as will also the insulation between.

Temporary relief can be had by putting a jumper of solder or of small wire across the burned bar, connecting the two adjacent bars to each other; one jumper is enough.

b. A short-circuited field coil, or a field coil improperly connected, will produce flare at commutator. Short-circuited coil can be found by voltmeter test across terminals showing drop in coil. Wrong connection can be detected by pocket compass.

Incandescent Lamps sometimes burn out or break. Replace with new ones. If they do not burn when switch is on,

a. Examine each for broken filament.

b. Examine for poor contact in socket.

c. Examine switch for poor contact or broken blades.

d. Examine each part of circuit, switches, line, and sockets with magneto, which will locate opening. The wire may be broken at ground or trolley connections.

Brakes Fail to Operate:

In great emergency only, throw controller handle to *off*, reverse reversing-switch, and turn controller handle to first or second notch.

In sliding down grades, or when there is time, proceed as follows :
a. Throw controller handle to *off* point.
b. Throw canopy switch *off*.
c. Reverse reversing-switch.
d. Throw controller handle around to last notch. Both methods are more or less strain on the motors, but the second is somewhat less so than the first.

Grounds: Either on field or armature coils will nearly always blow fuse; it can then be tested out.

Bucking: When running along smoothly, a car will sometimes commence jerky, bucking motions, and should be thoroughly examined at once. It may be due to a ground of field or armature that may short-circuit one or the other, either fully or intermittently. Injured motor may usually be located by smell of burning shellac, and can be cut out at the controller, and the car run in with the good motor.

Mud and water splashing on commutator will sometimes produce bucking, and often a piece of wire caught up from the track may do the same.

Miscellaneous Note.

Experiments show that four arresters per mile of trolley wire are plenty for safety.

Green wooden poles should not be painted for at least a year after they are set, as the paint will peal off and not give good results.

Loose ornamental joint caps frequently used on iron or steel poles collect moisture and rust out the pole.

Wiring Diagrams for Lighting Circuits on Street Cars.

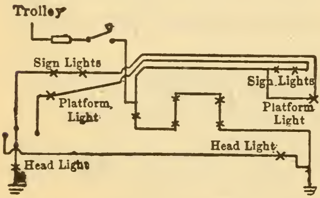


FIG. 163. Diagram for two Circuits Headlights, Platform Lights and Sign Lights Interchangeable.

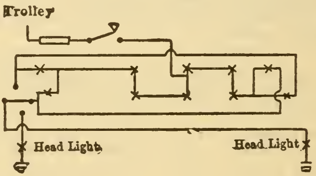


FIG. 164. Diagram of Wiring to permit use of 32-p. Headlight.

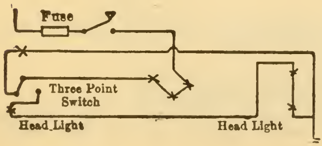


FIG. 165. Diagram of Wiring where Headlights are placed on Hoods.

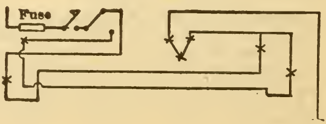


FIG. 166. Same as above but three-point Switch located on Trolley End of Car.

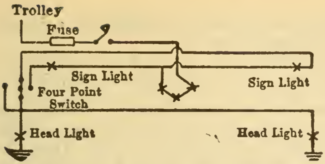


FIG. 167. Diagram of Wiring for five-light Circuit with four-point Switch for Headlights and Platform Lights.

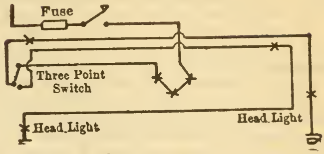


FIG. 168. Same as above except three-point Switch.

Special Methods of Distribution.

For cases requiring excessively large currents carried a considerable distance, or for ordinary currents carried excessive distances, it is usually economy to adopt some special method; and among those most commonly mentioned are: the three-wire system, the booster system, the substation system.

Three-Wire System. This system, patented some time ago by the General Electric Company, has been seldom used, and where used has met with little success, owing to the difficulty met in keeping the system balanced.

The diagram below will assist in making the method plain. Two 500-volt generators are used, as in the lighting system of the same type. The rail return is used as the neutral conductor; and if both trolley wires could be made to carry the same loads, and to remain balanced, then the rail return

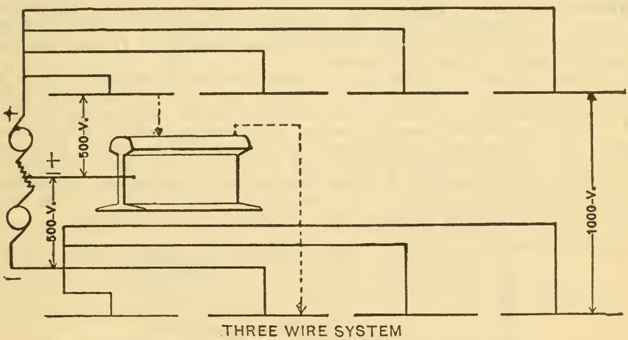


FIG. 169. Three-Wire System.

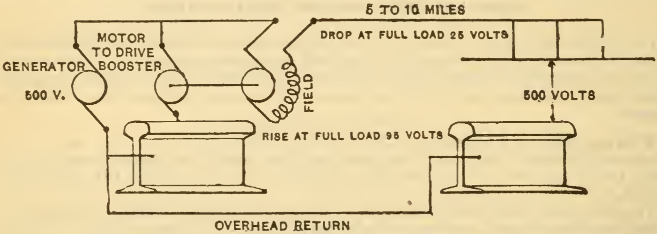
would carry no current, and no trouble would occur from electrolysis. The overhead conductors could also be very much smaller, as currents would be halved, and the full voltage would be practically 1000.

A balanced three-wire system has been proposed and is in limited use abroad in which the car carries two trolley poles, making contact with both trolley wires. The motor equipment is in duplicate, thus each set of motors is fed from 600 volts making the current through the return practically zero, and the whole equipment forming a balanced three-wire system in itself. This system is the only practical three-wire system and offers some advantages for transmitting large amounts of power over considerable distances.

The Booster System. — Where current must be conveyed a long distance, say five to ten miles, and be delivered at 500 volts, it is hardly good economy to install copper enough to prevent the drop; and if the voltage of the generator be raised sufficiently to deliver the required voltage, the variations due to change of load will be prohibitive.

In such cases a "booster" can be connected in series with the feeder, and automatically keep the pressure at the required point, as long as the generator delivers the normal pressure.

The "booster" is nothing more than a series-wound dynamo, connected so that all the current of the feeder to which it is attached flows through both field and armature coils, and the voltage produced at the armature terminals is added to that of the line, and as the voltage so produced is in proportion to the current flowing, it will be seen that the pressure will rise and fall with the current. This is now used in many instances, both in lighting and for railway feeders, and especially in feeding storage batteries, and has met with entire success. The following cut is a diagram of the connections.



BOOSTER SYSTEM
FIG. 170.

Return Feeder Booster. — Major Cardew, Electrical Engineer for the Board of Trade, some time ago devised a method of overcoming excessive drop in track return circuits by the use of insulated return feeders, in series with which he placed a booster.

The booster draws current back toward the station, adding its E.M.F. to that in the feeder. Cardew used a motor generator, the series field of which was separately excited by the outgoing feeder for the same section of road. Thus the volts "boosted" were in direct proportion to the current flowing. H. F. Parshall, in adopting the return feeder booster for some of his work in England, used a generator in place of the motor generator of Major Cardew, exciting the field by the current flowing out on the trolley feeder, thus producing volts in the armature in proportion to the current flowing. The following diagram shows Parshall's arrangement.

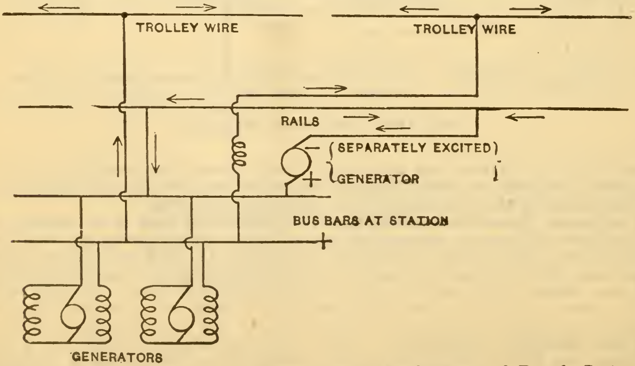


FIG. 171. Modification of Major Cardew's System of Track Return Booster for Preventing Excessive Drop in Rail Return Circuits.

Electric Railway Booster Calculations.

(*H. S. Putnam.*)

The following method of calculating the size and characteristics of electric railway boosters, and the graphic representation of the results will be found useful.

A^1, A^2, A^3, A^4, etc., = load in amperes at various points along the line. These loads should be taken from schedule, and should ordinarily represent an average maximum condition.

R^1, R^2, R^3, R^4, etc., = feeder resistance (including trolleys) to the corresponding load points.

Σ = drop in volts to the point at which it is proposed to feed into the system with the booster.

V = allowable volts drop in feeder system with the booster in circuit.

I = amperes in booster.

E = volts boost.

$p = \frac{E}{I}$ = ratio of volts boost to amperes boosted.

Rb = resistance of booster feeder.

R = resistance of feeder system to point selected for the booster feed.

Then assuming that all the load beyond the point at which it is proposed that the booster should feed into the system is concentrated at the latter point,

$$\Sigma = A^1 R^1 + A^2 R^2 + A^3 R^3, \text{ etc. } -A^b R.$$

$$I = \frac{\Sigma - V}{R}.$$

$$Rb = \frac{V}{I} + p.$$

$$E = I \times p.$$

$$p = Rb - \frac{V}{I}.$$

These equations give the necessary data to determine the required size and ratio of the booster and its feeder. In case it is desired to install a negative booster, the same method is followed.

In case the load is uniformly distributed over the line, or is assumed as distributed in that manner, the voltage drop at any desired point on the line is found from the equation:

$$\Sigma = \frac{(2\,L - d + 1)\,dIR}{2},$$

in which L = total length of line in feet.

d = distance to point selected.

I = amperes per foot.

R = resistance of feeder system per foot.

If desired these units can be expressed in 1000 feet or miles or any other unit of distance.

When the drop to the end of the line is desired, this equation becomes:

$$\Sigma = \frac{L^2 + L}{2}\,IR.$$

It is often desirable to represent these calculations graphically. Special cases are shown in Figs. 172, 173 and 174, in which the potential diagram is shown for different conditions and schedules. In the preparation of these diagrams it will be found convenient to plot the schedule and feeder and return resistances on the same sheet. In Fig. 172 it is seen that a negative booster is not required though one is included. Fig. 173 shows a system in which a booster is used at either end. Fig. 174 illustrates a different and more severe operating condition than shown in Fig. 173.

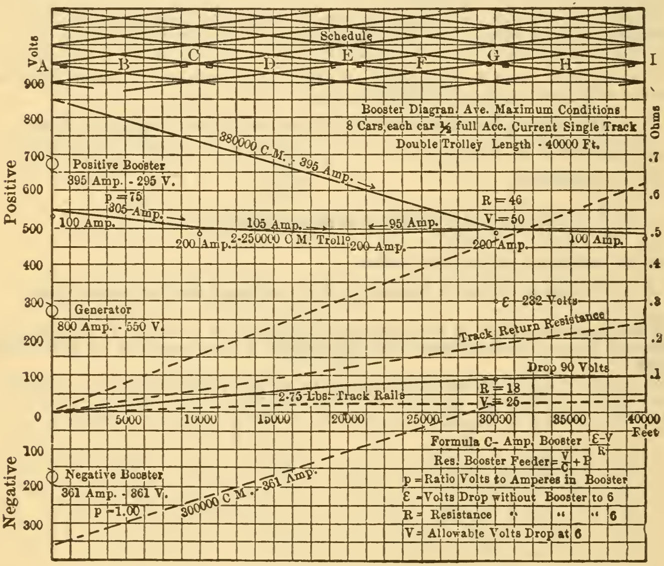


Fig. 172.

Kelvin's Law can be applied to the booster distribution as well as to other methods of distribution. In most cases, however, it will be found that the voltage requirements will govern. The question as to whether a booster, more feeder copper or a sub-station shall be employed, is one which must be determined from the annual charges against the investment and the cost of the power lost in each method. In calculating the cost of the power lost, the load factor must be considered.

In selecting a booster care must be exercised that its overload capacity shall be sufficient to take care of the maximum operating condition which occasionally arises in any system where boosters are likely to be employed, namely, when all the cars are accelerating at once. As such occasions may be rare, it is only necessary that the voltage shall be maintained above the minimum voltage at which contactors will operate, if such contactors are employed, that the booster motor shall carry such overload, and that the machines shall properly commutate at the overload current.

By varying the value of "*p*" the ratio of the volts of boost to the amperes boosted, the size of the booster feeder and the amount of power lost in the booster system is changed. By Kelvin's Law the annual charges on the booster feeder and booster should equal the annual cost of the power lost in the booster system.

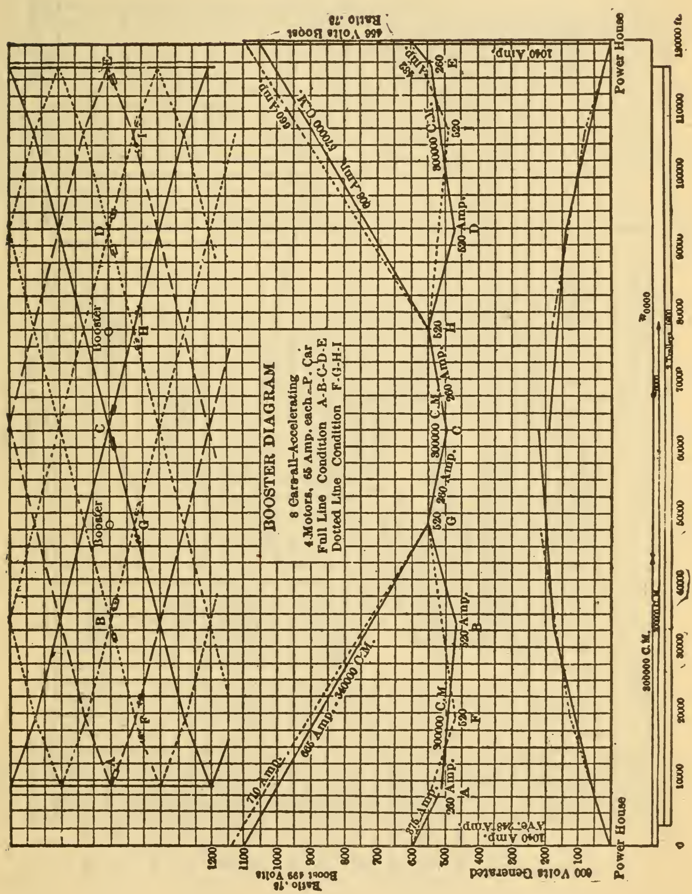

BOOSTER DIAGRAM
8 Cars-all-Accelerating
4 Motors, 65 Amp. each - P. Car
Full Line Condition A-B-C-D-E
Dotted Line Condition F-G-H-I
Power House
Power House
600 Volts Generated
Boost 499 Volts
Ratio .78
466 Volts Boost
Ratio .78

FIG. 173.

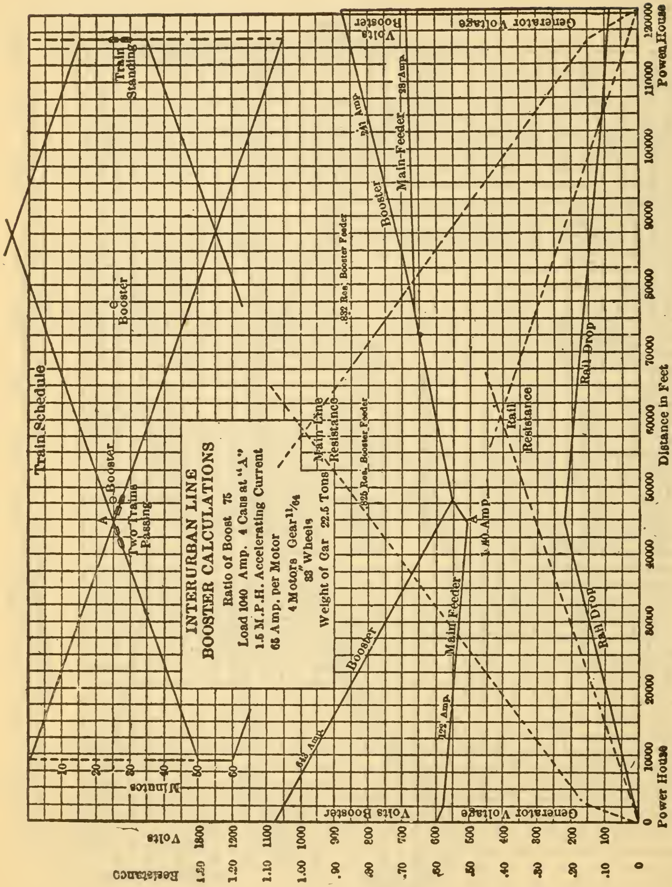

INTERURBAN LINE
BOOSTER CALCULATIONS
Ratio of Boost 75
Load 1040 Amp. 4 Cars at "A"
1.5 M.P.H. Accelerating Current
65 Amp. per Motor
Weight of Car 22.5 Tons
Train Schedule
Two Trains Passing
Train Standing
Booster
Main-Feeder
Main Line Resistance
Rail Resistance
Rail Drop
Volts Booster
Generator Voltage
Minutes
Volts
Resistance
Distance in Feet
Power House

FIG. 174.

Series Boosters for Railway Service. — The amount of variation allowable in the voltage characteristic of a series booster for 500-volt railway service is an important factor in its design, as it largely determines the amount of material required and therefore the cost. The actual voltage characteristic of commercial series boosters is not a straight line but a curve, which at partial load will be above the theoretical line as shown in the accompanying diagram. The amount of variation from the straight line is principally affected by the saturation of the magnetic circuit; if the saturation is high, the variation of the voltage characteristic will be great. By increasing the amount of iron in the magnetic frame and therefore keeping the saturation low, the voltage characteristics can be made to more nearly approximate a straight line; but, obviously, a machine so designed is more costly than a booster having a voltage characteristic departing further from a straight line. These facts are particularly important in cases where high voltage boosters are used, as may be seen from the following example:

In the accompanying diagram of a 200-kilowatt, 400-volt booster, the potential at half load is 240 volts, that is, 40 volts, or 10 per cent of the full

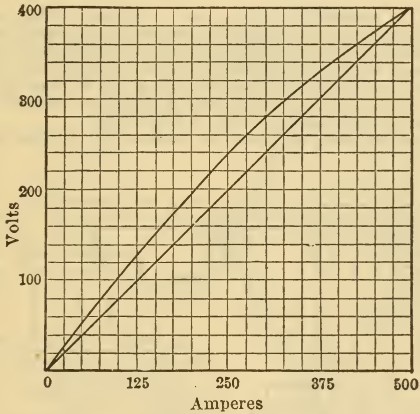


FIG. 175. Characteristics of a 200-Kw. 400-Volt Booster.

load voltage, higher than a theoretical straight line characteristic. Had less iron been used in the magnetic circuit the potential at half load would have been higher, and estimating an instance of 320 volts, the potential would be 120 volts too high, or, at 695 volts, assuming a generator potential of 575 volts. This high voltage might burn out the car lights and would increase the speed and subject the motors to a severe strain.

While a straight line characteristic is not essential, the variation from a straight line must be kept within reasonable limits.

Unless otherwise specified, the voltage characteristic variations of all series boosters of different potentials should not exceed the following values at partial current load and at constant speed:

Full Load Voltages of Boosters.	Maximum Variation of Full Load Voltage at Partial Load.
50 to 100 volts	20 per cent
100 to 150 volts	15 per cent
150 to 250 volts	12½ per cent
250 to 500 volts	10 per cent

Temperature. — After a run of twenty-four hours at full rated volts and amperes, the temperature of no part of the machine should be more than 40° C. above the temperature of the surrounding air, provided the conditions of ventilation are normal and the temperature of the surrounding air does not exceed 25° C. If the temperature of the surrounding air differs from 25° C., the observed rise in temperature is to be corrected by one-half per cent for each degree centigrade that the temperature of the surrounding air differs from 25° C.

The booster should be capable of standing an overload of 25 per cent of the full load ampere and volt capacity of the machine for one-half hour; and as this corresponds to the 25 per cent voltage overload, the overload capacity in kilowatts will be about 50 per cent. The boosters should be capable of standing a momentary overload of 50 per cent of the rated capacity in amperes at full load or about 100 per cent in kilowatt rating.

SUB-STATION SYSTEM.

Where traffic is especially heavy, and a railway system widespread, it is now the practice to use one large and economical power station with high-pressure generators, now invariably polyphase alternators, and to distribute this high-pressure alternating current to small sub-stations centrally located for feeding their districts, and there changing the current by means of static transformers and rotary converters into continuous current of the requisite pressure, in the case of railways 550 to 600 volts.

The following diagrams will assist in making the system plain.

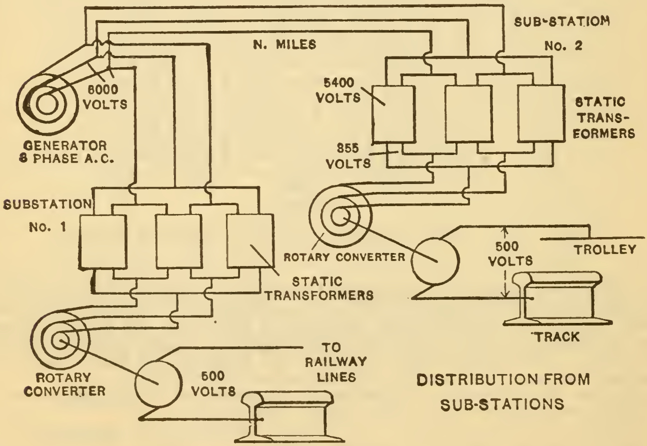


FIG. 176.

The universal use of rotary converters has led to many similar designs of sub-stations. It is customary to install the rotaries in buildings designed for the purpose and Figs. 178 and 179 show a typical station in plan and elevation. As each sub-station is in reality a complete supply station, it is necessary to install suitable protective devices for both high-tension alternating

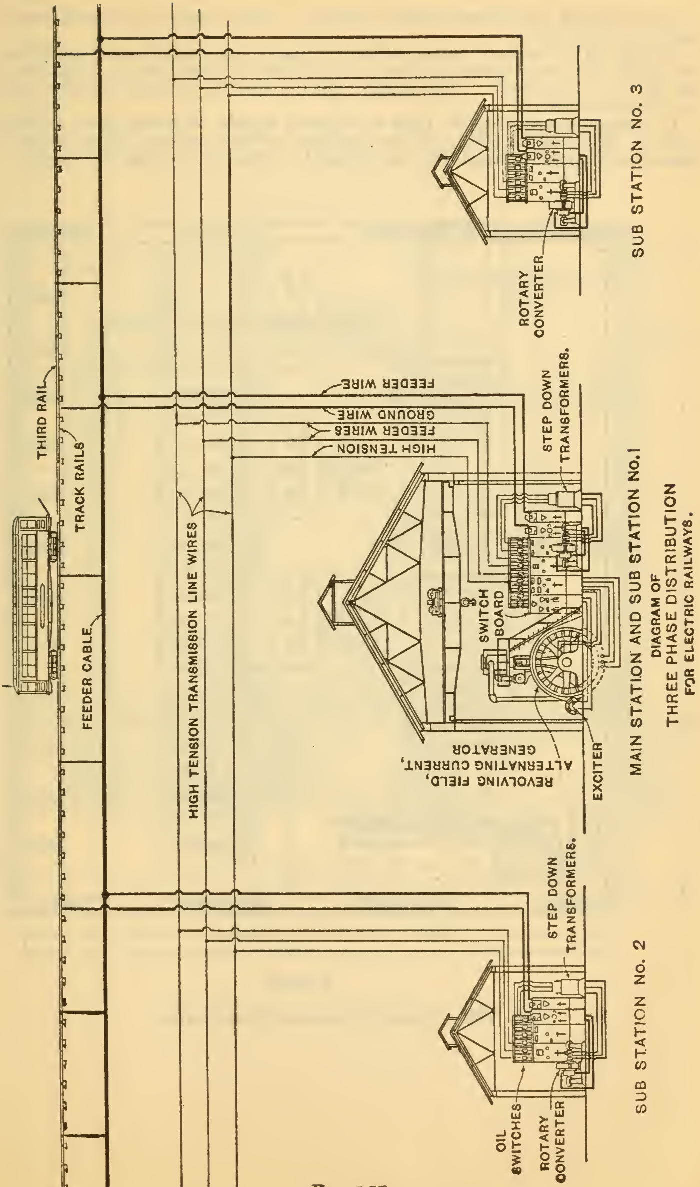

THIRD RAIL
TRACK RAILS
FEEDER CABLE
HIGH TENSION TRANSMISSION LINE WIRES
FEEDER WIRE
GROUND WIRE
FEEDER WIRES
HIGH TENSION
STEP DOWN TRANSFORMERS.
ROTARY CONVERTER
SUB STATION NO. 3
SWITCH BOARD
REVOLVING FIELD, ALTERNATING CURRENT, GENERATOR
EXCITER
MAIN STATION AND SUB STATION NO.1
DIAGRAM OF
THREE PHASE DISTRIBUTION
FOR ELECTRIC RAILWAYS.
STEP DOWN TRANSFORMERS.
OIL SWITCHES
ROTARY CONVERTER
SUB STATION NO. 2

FIG. 177.

current and 600 volts direct-current circuits. The necessary connections are shown in Fig. 180.

In Fig. 181 is shown a cross section of one of the latest types (1907) as developed for the United Railways and Electric Company of Baltimore, by Mr. L. B. Stillwell. This station has an unusually large capacity for one center of load.

In designing sub-stations, their equipment should be based upon taking care of the maximum load of the stations, while a central power station operating through rotaries may be designed to take the average load only.

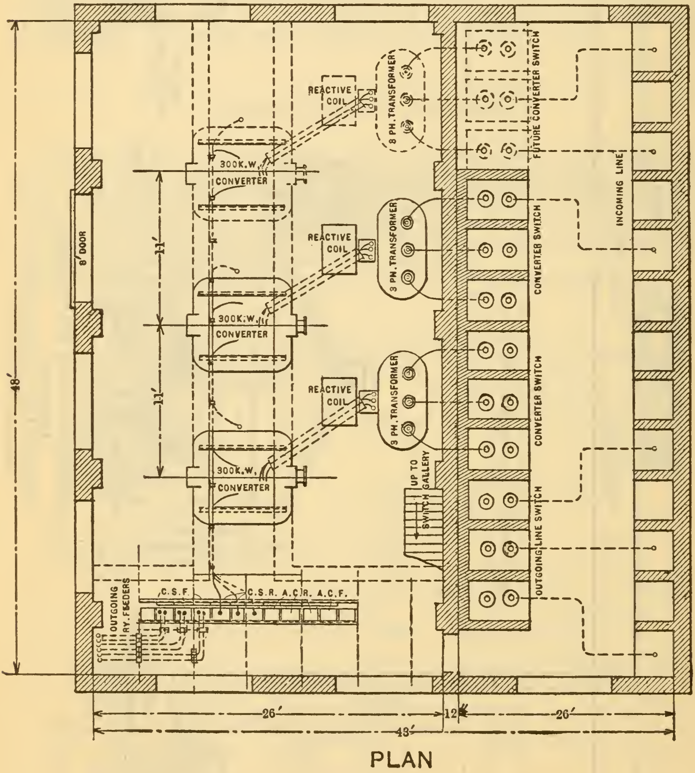


FIG. 178. Rotary Converter Sub-Station.

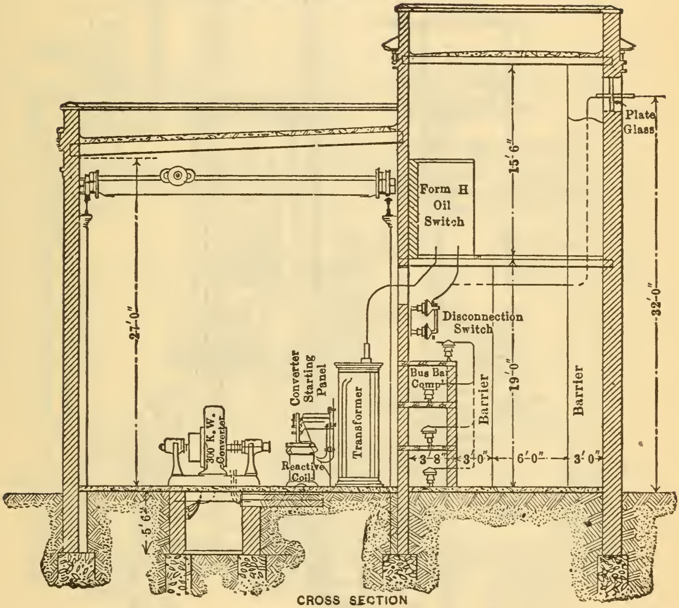


FIG. 179. Rotary Converter Sub-Station.

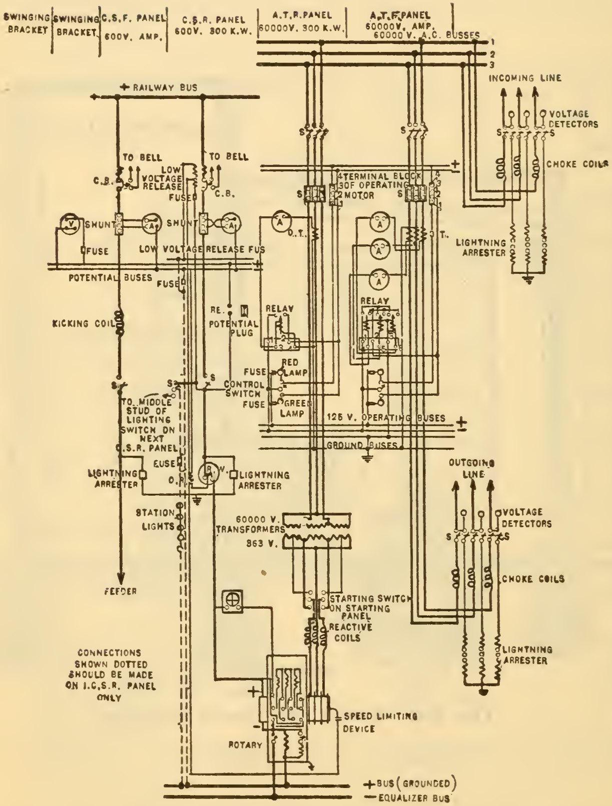


FIG. 180. Diagram of Connections for Proposed Rotary Converter Sub-Station.

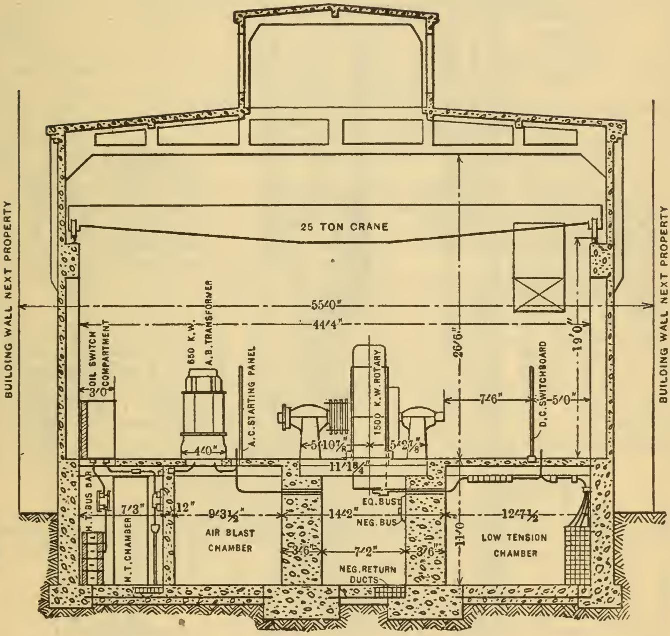


FIG. 181. Cross section of typical large sub-station (1907) 12,000-kilowatt 13,000-volts alternating current, 575-volts direct current. L. B. Stillwell, Engineer.

Portable Sub-Stations. — Many roads have a heavy traffic on certain lines for a portion of the year only, thus making it hardly feasible to expend a large sum in a permanent sub-station. For such cases, the portable sub-station has been designed, consisting of a box car containing step-down transformers, rotary converter and all necessary protecting devices. Such a sub-station can be run out on any line having a transmission system connected up, and put into service in a very short time. It therefore forms a reserve sub-station. A plan, elevation and diagram of connection, of a typical portable sub-station is shown in Fig. 182.

A portable sub-station having as high as 1000-kilowatts capacity is in use, see *Street Railway Journal*, November 4, 1905 and June 23, 1906.

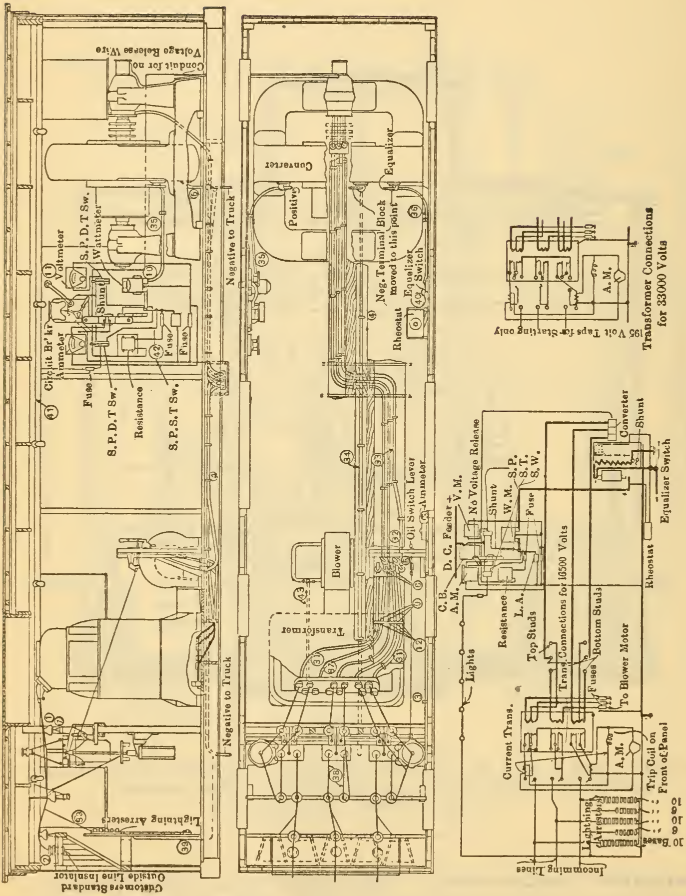


FIG. 182. Portable Sub-Station.

THIRD RAIL SYSTEMS.

(By F. R. Slater.)

For certain classes of electric railways, such as elevated, interurban and underground, a steel conductor insulated from and alongside the track, commonly called the third rail, is much used in place of the copper overhead trolley wire.

This conductor is easily installed, cheaply maintained, presents a large surface area for conducting and collecting the current, and is, therefore, particularly suitable for high speed and heavy service. With costs calculated on the basis of equal conductivity in rail and trolley wire, the third rail is the cheaper, except where the necessary trolley wire would be of considerable less conductivity than would be obtained with the smallest size of steel rail that would ordinarily be used. Even in such cases the lower cost of maintenance, together with the advantage of adaptability (particularly in the case of terminals, yards and very heavy high speed service), will frequently offset the higher first cost of the third rail and make it the preferable means of conducting the current from the power station to the car motor.

With the coming of the heavy high-speed service of the past few years, the resistance of standard "T" rails has been found to be so high, that rails of higher specific conductivity were sought, and specifications have been drawn, usually based on the fact that the conductivity of a metal is generally directly proportionate to its purity.

Resistance of Rails with Varying Composition. — Mr. J. A. Capp, of Schenectady, conducted a series of tests of steel for electric conductivity. He says in part: "In most cases the purity of the iron specified for such rails has been so high, that not only was it difficult to obtain, but the iron was also correspondingly high in price. One of the factors governing the choice between a third rail and a trolley wire is the relative price of steel and copper, allowance being made for the difference in conductivity. Hence a balance must be struck between high conductivity (which is equivalent to saying a high degree of purity or freedom from the usual metalloids associated with iron) and the cost of producing the steel of the composition necessary for the conductivity required.

. . . .

"Table XVII below states the electrical resistance and the chemical composition of 47 samples of steel, and Table XVIII similar data on 7 samples of wrought or refined iron:

Table XVII.—Electrical and Chemical Qualities of Steel for Third Rail.

Specific Resistance.		Conductivity.	Resistance.	Percentage Composition.						
Microhms per Cu. C.M.	Temp. °C.	Mathiessen Standard.	Copper = 1.	C.	Mn.	P.	S.	Si.	Total Not Fe.	P + S + Si.
23.798	26°	7.43	13.46	.444	.953	.059	.137	.139	1.732	.135
22.72	19°	7.58	13.20	.33	1.27	.09	.05	.05	1.79	.19
20.90	20°	8.27	12.12	.17	1.09	.09	.05	.004	1.404	.144
21.29	25°	8.27	12.09	1.40	.222	.01	.02	.082	1.734	.112
19.87	19°	8.65	11.55	.20	.95	.10	.08	.05	1.38	.23
19.80	19°	8.68	11.51	.43	.77	.10	.04	.066	1.406	.206
19.80	19°	8.69	11.51	.36	.80	.10	.04	.047	1.347	.187
19.81	20°	8.69	11.51	.22	1.08	.10	.05	.06	1.51	.210
19.69	19°	8.73	11.44	.74	.58	.043	.036	.20	1.599	.279
18.95	25°	9.29	10.76	1.61	.147	.015	.018	.092	1.882	.125
18.17	19°	9.47	10.56	.41	.72	.039	.041	.11	1.32	.19
17.27	19°	9.96	10.04	.36	.87	.08	.09	.04	1.44	.21
17.10	19°	10.06	9.94	.37	.73	.09	.04	.06	1.29	.19
17.10	19.5°	10.06	9.94	.23	.80	.016	.033	.016	1.095	.065
16.96	19°	10.14	9.86	.30	.95	.063	.01	.01	1.333	.083
16.95	19.5°	10.14	9.86	.29	.99	.084	.01	.01	1.384	.104
16.32	19°	10.55	9.48	.23	.89	.058	.01	.005	1.193	.073
16.25	19.5°	10.59	9.44	.26	.83	.053	.01	.004	1.157	.067
16.21	20°	10.62	9.42	.28	.65	.083	.06	.05	1.123	.193
16.09	19°	10.69	9.36	.22	.68	.077	.07	.05	1.097	.197
16.09	19°	10.69	9.36	.16	.66	.074	.030	.014	.938	.118
11.13	26°	15.883	8.98	.098	.485	.085	.158	.022	.848	.165

Table XVII.—*Continued.*

Specific Resistance.		Conductivity.	Resistance.	Percentage Composition.						
Microhms per Cu. C.M.	Temp. °C.	Mathiessen Standard.	Copper = 1.	C.	Mn.	P.	S.	Si.	Total Not Fe.	P + S + Si.
15.32	19°	11.24	8.90	.33	.49	.068	.05	.02	.958	.138
14.57	19.5°	11.82	8.46	.31	.45	.10	.04	.026	.926	.166
14.49	20°	11.88	8.42	.25	.41	.10	.04	.03	.83	.17
14.73	23.5°	11.88	8.42	.144	.46	.09	.08	Tr.	.774	.17
14.62	23.5°	11.96	8.36	.188	.48	.09	.08	Tr.	.83	.17
14.15	19°	12.17	8.22	.22	.56	.024	.34	Tr.	.838	.058
14.03	19°	12.26	8.16	.192	.57	.024	.34	Tr.	.82	.058
13.86	19°	12.41	8.06	.16	.48	.091	.04	.01	.781	.144
13.83	19.5°	12.44	8.04	.10	.55	.08	.05	.024	.804	.154
13.80	19°	12.57	8.02	.14	.41	.11	.05	.009	.719	.169
13.67	19°	12.58	7.95	.23	.48	.024	.01	.023	.767	.057
13.64	19°	12.61	7.93	.24	.57	.029	.01	.003	.85	.042
13.90	24°	12.63	7.92	.10	.25	.04	.02	.05	.46	.11
13.31	19°	12.92	7.74	.25	.37	.04	.03	.018	.708	.088
13.30	19.5°	12.94	7.73	.23	.49	.024	Tr.	.004	.748	.028
13.27	19°	12.97	7.71	.19	.37	.09	.05	.01	.71	.15
13.25	19°	12.99	7.70	.27	.41	.024	.01	.001	.715	.035
13.18	19°	13.05	7.66	.28	.28	.027	.034	.04	.661	.111
13.18	19°	13.05	7.66	.07	.40	.08	.07	.013	.633	.163
13.07	19°	13.16	7.60	.28	.42	.022	.04	.008	.770	.07
12.87	20°	13.27	7.48	.16	.38	.08	.04	.009	.669	.129
12.73	20°	13.52	7.40	.15	.45	.011	.033	Tr.	.644	.044
12.69	19°	13.55	7.38	.19	.21	.025	.04	.034	.499	.099
12.53	19°	13.74	7.28	.215	.22	.051	.113	. . . .	.599	.164
11.01	19°	15.63	6.40	.05	.19	.054	.059	.03	.383	.143

Table XVIII. — Wrought or Refined Iron.

Specific Resistance.		Conductivity.	Resistance.	Percentage Composition.						
Microhms per Cu. C.M.	Temp. °C.	Mathiessen Standard.	Copper = 1.	C.	Mn.	P.	S.	Si.	Total Not Fe.	P + S + Si.
13.80	25.5°	12.78	7.82	.15	.068	.13	.02	.15	.518	.30
13.82	26°	13.37	7.48	.15	.064	.036	.02	.13	.400	.186
13.10	26°	13.50	7.41	.16	.074	.12	.027	.10	.481	.247
12.54	25.5°	14.07	7.11	.08	. . .	.13	.008	.024	.242	.162
11.92	25.5°	14.80	6.76	.17	.027	.074	.022	.077	.370	.173
10.82	24°	16.21	6.17	.058	.10	.014	Tr.	.012	.184	.026
10.80	25.5°	16.34	6.12	.16	.018	.049	.011	.015	.252	.075

"A study of the tables shows that manganese preponderates in influencing the resistance of steels and that for lowest resistivity this element must be present in very small quantity, much smaller than is usual in merchant or structural steels. While all the other elements must be present only in very small percentages, so great is the preponderance of the influence of manganese that they may be tolerated in quantities which the steel makers would consider reasonable, without unduly increasing the resistance."

Resistance of Steel. Variation with Manganese.

(Carbon from 0.17 to 0.23 Per Cent.)

Sample Number.	Manganese.	Resistance. Copper = 1.	Carbon.	P + S + Si.
	Per Cent.		Per Cent.	Per Cent.
2	1.09	12.12	0.17	0.144
4	0.95	11.55	0.20	0.23
7	1.08	11.51	0.22	0.210
13	0.80	9.94	0.23	0.065
16	0.89	9.48	0.23	0.073
19	0.68	9.36	0.22	0.197
25	0.48	8.36	0.188	0.17
26	0.56	8.22	0.22	0.058
27	0.57	8.16	0.192	0.058
31	0.48	7.95	0.23	0.057
35	0.49	7.73	0.23	0.028
36	0.37	7.71	0.19	0.15
43	0.21	7.38	0.19	0.099
44	0.22	7.28	0.215	0.164

Resistance of Steel. Variation with Manganese.

(Carbon from 0.27 to 0.33 Per Cent.)

Sample Number.	Manganese.	Resistance. Copper = 1.	Carbon.	P + S + Si.
	Per Cent.		Per Cent.	Per Cent.
1	1.27	13.20	0.33	0.190
14	0.95	9.86	0.30	0.083
15	0.99	9.86	0.29	0.104
18	0.65	9.42	0.28	0.193
21	0.49	8.90	0.33	0.138
22	0.45	8.46	0.31	0.166
37	0.41	7.70	0.27	0.035
38	0.28	7.66	0.28	0.111
40	0.42	7.60	0.28	0.070

Resistance of Steel. Variation with Carbon.

(Manganese from 0.15 to 0.28 Per Cent.)

Sample Number.	Carbon.	Resistance. Copper = 1.	Manganese.	P + S + Si.
	Per Cent.		Per Cent.	Per Cent.
3	1.40	12.09	0.222	0.112
9	1.61	10.76	0.147	0.125
33	0.10	7.92	0.25	0.11 ·
38	0.28	7.66	0.28	0.111
43	0.19	7.38	0.21	0.099
44	0.215	7.28	0.22	0.164
45	0.05	6.40	0.19	0.143

To determine the influence of carbon in the above table, those steels have been selected which have manganese constant at from 0.15 to 0.30 per cent, with carbon as the principal variable.

Resistance of Steel. Variation with Carbon.

(Manganese from 0.4 to 0.49 Per Cent.)

Sample Number.	Carbon.	Resistance. Copper = 1.	Manganese.	P + S + Si.
	Per Cent.		Per Cent.	Per Cent.
21	0.33	8.90	0.49	0.138
22	0.31	8.46	0.45	0.166
23	0.25	8.42	0.41	0.17
24	0.144	8.42	0.46	0.17
25	0.188	8.36	0.48	0.17
28	0.16	8.06	0.48	0.144
30	0.14	8.02	0.41	0.169
31	0.23	7.95	0.48	0.057
35	0.23	7.73	0.49	0.028
37	0.27	7.70	0.41	0.035
39	0.07	7.66	0.40	0.163
40	0.28	7.60	0.42	0.070
42	0.15	7.40	0.45	0.044

Resistance of Steel. Influence of Carbon.

(Results of M. Le Chatelier.)

Resistance.		Composition.		
Microhms.	Copper = 1.	C.	Mn.	Si.
		Per Cent.	Per Cent.	Per Cent.
10	5.78	0.06	0.13	0.05
12.5	7.22	0.20	0.15	0.08
14	8.10	0.49	0.24	0.05
16	9.25	0.84	0.24	0.13
18	10.40	1.21	0.21	0.11
18.4	10.64	1.40	0.14	0.09
19	11.00	1.61	0.13	0.08

Resistance of Steel. Variation with Carbon. Results of Barrett, Brown and Hadfield. Temperature 17° C.

Sample Mark.	Resistance.		Composition.		
	Microhms. per Cu. C.M.	Copper = 1.	Carbon.	Manganese.	Silicon.
			Per Cent.	Per Cent.	Per Cent.
1392G	19.1	11.19	1.23	0.14	0.12
1392L	17.6	10.31	1.09	0.32	0.17
1392A	17.9	10.49	0.85	0.32	0.17
1392B	17.2	10.07	0.84	0.18	0.20
1392I	16.7	9.78	0.83	0.25	0.06
1392H	16.1	9.43	0.78	0.10	0.10
1166A	13.4	7.85	0.14	. . . .	0.08

RESISTANCE OF STEEL.

Compiled by H. N. Latey.

C. Greater than .50%.

C.	Mn.	Si.	P.	S.	R. Cu. = 1	Authority.	Remarks.
.535	.592	.201	.051	.059	11.30	Parshall	T Rail.
.568	.608	.204	.053	.061	11.40	"	"
.588	.632	.214	.056	.065	11.50	"	"
.610	.650	.220	.062	.071	12.90	"	"
.740	.580	.200	.043	.036	11.40	G. E. Co.	
.780	.100	.100	. . .	. . .	8.50	Barrett	Bar.
.830	.250	.060	. . .	. . .	8.87	"	"
.840	.180	.200	. . .	. . .	9.36	"	"
.840	.240	.130	. . .	. . .	9.25	Chatelier	
.850	.320	.170	. . .	. . .	9.55	Barrett	Bar.
.900	.200	Tr.	.040	.030	9.78	G. E. Co.	
1.000	.580	.490	. . .	. . .	13.00	Barrett	Bar.
1.090	.320	.170	. . .	. . .	10.10	"	"
1.210	.210	.110	. . .	. . .	9.25	Chatelier	
1.230	.140	.120	. . .	. . .	10.20	Barrett	Bar.
1.250	.620	.460	. . .	. . .	13.70	"	"
1.400	.140	.090	. . .	. . .	10.64	Chatelier	
1.400	.222	.082	.010	.018	10.76	G. E. Co.	
1.610	.130	.080	. . .	. . .	11.00	Chatelier	
1.610	.147	.092	.015	.018	10.76	G. E. Co.	
.780	3.810	.630	. . .	. . .	25.70	Barrett	Bar.
1.200	7.000	.630	. . .	. . .	32.40	"	"
1.230	13.000	.630	. . .	. . .	37.10	"	"
1.500	15.25	.630	. . .	. . .	38.55	"	"
1.540	18.50	.630	. . .	. . .	40.10	"	"
1.660	11.50	.630	. . .	. . .	35.80	"	"

RESISTANCE OF STEEL.

C. LESS THAN .50%.

C.	Mn.	Si.	P.	S.	R. Cu. = 1	Authority.	Remarks.
.028	Tr.	.070	.004	.005	5.96	Barrett	Iron bar, annealed.
.028	Tr.	.070	.004	.005	6.06	"	Iron bar, not annealed.
.030	.036	.140	.004	.005	6.38	"	Iron bar.
.045	.200	Tr.	.040	.030	6.58	G. E. Co.	" "
.050	.180	.020	.013	.011	6.68	Barrett, G.E.	" "
.050	.180	.020	.004	.005	6.60	Barrett	" "
.050	.190	.030	.054	.059	6.50	. . . . .	T Rail, U. R. Co., London.
.058	.100	.012	.014	Tr.	6.17	G. E. Co.	Bar, Swedish iron.
.060	.130	.050	. . .	. . .	5.78	Chatelier	
.070	.400	.013	.080	.070	7.66	G. E. Co.	
.080	Tr.	.024	.130	.008	7.11	"	Staybolt iron.
.090	Tr.	.011	.015	.030	6.58	"	
.090	.210	.020	.030	.050	7.43	Campredon	Wire, 3 M.M. diam.
.100	.240	.020	.040	.050	7.74	"	" " "
.100	.250	.050	.040	.020	7.92	G. E. Co.	
.100	.260	.020	.040	.060	8.00	Campredon	Wire, 3 M.M. diam.
.100	.310	.020	.050	.050	8.16	"	" " "
.100	.400	.020	.040	.070	8.67	"	" " "
.100	.550	.024	.080	.050	8.04	G. E. Co.	
.110	.350	.030	.060	.060	8.41	Campredon	Wire, 3 M.M. diam.
.110	.490	.030	.060	.060	9.08	"	" " "
.120	.330	.030	.050	.070	8.30	"	" " "
.120	.400	.020	.070	.070	8.74	"	" " "
.140	Tr.	.080	.004	.005	7.43	Barrett	Bar.
.140	.410	.009	.110	.050	8.02	G. E. Co.	
.144	.460	Tr.	.090	.080	8.42	"	T Rail, A.E.& C.Ry.
.150	.064	.130	.036	.020	7.48	"	Bar, reinforced iron.
.150	.068	.150	.130	.020	7.82	"	Bar, reinforced iron.
.150	.450	Tr.	.011	.033	7.40	"	
.160	.018	.015	.049	.011	6.12	"	Bar, Norway iron.
.160	.074	.100	.120	.027	7.41	"	Bar, refined iron.
.160	.380	.009	.080	.040	7.48	"	
.160	.480	.010	.091	.040	8.06	"	
.160	.660	.014	.074	.030	9.36	"	
.170	.027	.077	.074	.022	6.76	"	Bar, spec. ref. iron.
.188	.480	Tr.	.090	.080	8.36	"	T Rail, A.E.& C.Ry.
.190	.210	.034	.025	.040	7.38	"	
.190	.370	.010	.090	.050	7.71	"	
.192	.570	Tr.	.024	.340	8.16	"	
.200	.150	.080	. . .	. . .	7.22	Chatelier	
.200	.500	.130	.004	.005	8.42	Barrett	Bar.
.200	.950	.050	.100	.080	11.55	G. E. Co.	T Rail.
.215	.220	. . .	.051	.113	7.28	"	
.220	.560	Tr.	.024	.340	8.22	"	
.220	.680	.050	.077	.070	9.36	"	
.230	.490	.004	.024	Tr.	7.73	"	
.230	.480	.023	.024	.010	7.95	"	
.230	.890	.005	.058	.010	9.48	"	
.230	.800	.016	.046	.033	10.06	"	
.240	.570	.003	.029	.010	7.93	"	
.250	.370	.018	.040	.030	7.74	"	
.250	.410	.030	.100	.040	8.42	"	

RESISTANCE OF STEEL—*Continued.*

C. LESS THAN .50%.

C.	Mn.	Si.	P.	S.	R. Cu. = 1	Authority.	Remarks.
.260	.830	.004	.053	.010	9.44	G. E. Co.	
.270	.410	.001	.024	.010	7.70	"	
.280	.280	.040	.027	.034	7.66	"	
.280	.420	.008	.022	.040	7.60	"	
.280	.650	.050	.083	.060	9.42	"	
.290	.990	.010	.084	.010	9.86	"	
.300	.950	.010	.063	.010	9.86	"	
.310	.450	.026	.100	.040	8.46	"	
.330	.490	.020	.068	.050	8.90	"	
.360	.800	.047	.100	.040	11.51	"	
.360	.870	.040	.080	.090	10.04	"	T Rail.
.370	.730	.060	.090	.040	9.94	"	"
.378	.550	.181	.040	.041	10.80	Parshall	"
.410	.720	.110	.039	.041	10.56	G. E. Co.	
.430	.770	.066	.100	.040	11.51	"	
.446	.568	.188	.046	.044	11.10	Parshall	T Rail.
.490	.240	.050	. . .	. . .	8.10	Chatelier	
.080	3.500	.130	. . .	. . .	17.28	Barrett	Bar.
.150	5.400	.130	. . .	. . .	19.65	"	"
.150	15.400	.130	. . .	. . .	37.80	"	"
.160	10.100	.630	. . .	. . .	37.10	"	"
.170	1.090	.004	.090	.050	12.12	G. E. Co.	T Rail.
.220	1.080	.060	.100	.050	11.51	"	"
.240	1.000	.130	. . .	. . .	13.70	Barrett	Bar.
.260	13.000	.130	. . .	. . .	35.80	"	"
.320	5.15	.130	. . .	. . .	21.75	"	"
.330	1.27	.050	.09	.05	13.20	G. E. Co.	T Rail.
.360	4.00	.130	. . .	. . .	16.70	Barrett	Bar.
.360	4.75	.130	. . .	. . .	17.10	"	"
.410	2.25	.130	. . .	. . .	17.00		"

For a satisfactory third rail, the lowest possible resistance (from 6 to 6.5 times that of copper?) is not necessary; and the great cost of making such extremely pure steel is not warranted. Assuming, then, that a rail made from steel having a resistance not greater than eight times that of copper (13.8 microhms at 20° C.) would be desirable, the figures tabulated seem to indicate that the following extreme composition would be permissible:

	PER CENT.
Carbon up to	0.2
Manganese up to	0.4
Phosphorus up to.	0.06
Sulphur up to	0.06
Silicon up to	0.05

This composition, however, would be extreme, and any overstepping of bounds might result in too great resistance; therefore, for resistance up to eight times that of copper, the specified analysis should be:

	PER CENT.
Carbon not to exceed	0.15
Manganese not to exceed	0.30
Phosphorus not to exceed	0.06
Sulphur not to exceed	0.06
Silicon not to exceed	0.05

This latter composition is one which could be made easily in any open-hearth furnace, and it should present no difficulty in rolling to a shape suitable for conductor rails, such as that shown (Fig. 183). In fact, steel of this composition has been successfully rolled into sheets as thin as 0.014 in., and was for a long time a standard product of a large sheet-mill.

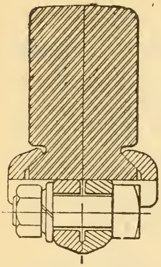


FIG. 183. Cross Section of a New Conductor Rail, Designed by Mr. W. B. Potter.

A section of a conductor-rail has been designed by Mr. W. B. Potter, Chief Engineer of the Railway Department of the General Electric Co., which, when 2.5 in. wide by 4 in. high, will weigh about 98 lb. to the yard. This shape, which is shown in Fig. 189, may be easily rolled in any merchant-bar mill heavy enough to attempt sections of this weight. A dovetail at the bottom provides an easy means of securing by fish plates of special forms, and any of the common forms of bond may easily be applied.

The Manhattan Railway Company (Elevated) and the Interborough Rapid Transit Company (Subway), of New York City, both purchased their rails upon specifications as to their chemical composition. Each rolling was analyzed, and the resistance of several samples measured.

Following are the analyses and specifications:

	MANHATTAN.		INTERBOROUGH.	
	Specifications.	Analysis.	Specifications.	Analysis.
Weight of rail . . .	100 lbs.	. . . .	75 lbs.	. . . .
Area of cross section	9.8 sq. in.	. . . .	7.4 sq. in.	. . . .
Carbon	.10	.098	.08–.15	.161
Manganese	.55	.485	.50–.70	.561
Phosphorus	.10	.085	.10	.091
Sulphur.	.08	.158	.05	.055
Silicon	.03	.022	.05	Trace
Specific resistance (microhms) . . .	. . . . . .	15.883	. . . . . .	14.99
Temperature of test.	. . . . . .	26° C.	. . . . . .	23° C.
Conductivity . . .	. . . . . .	11.13%	. . . . . .	11.68%
Resistance — Copper = 1	8.31	8.98	8.37	8.56
Equivalent of copper, C.M.	1,500,000	1,389,000	1,125,000	1,100,000

Location of Third Rail.— The location of the third rail with reference to the track rails has been different for each road using it. The Pennsylvania, Long Island, New York Central and Interborough Rapid Transit railroads have agreed upon a location which will not interfere with the passage of any of their rolling stock, either freight or passenger. This location is as follows: "The third or conductor rail shall be located outside of and parallel to the track rails so that its center line shall be 27 inches from the track gauge line and its upper face 3½ inches above the top of the track rail."

Relative Location of Third Rail on Different Railway Systems.	From Top of Third Rail to Top of Track Rail.	From Track Gauge Line to Center of Third Rail.
General Electric Railroad, Schenectady .	3″	28″
Met. West Side Elevated, Chicago	$6\frac{1}{4}$″	$20\frac{1}{8}$″
Lake Street Elevated, Chicago	$6\frac{1}{2}$″	$20\frac{1}{8}$″
South Side Elevated, Chicago	$6\frac{3}{4}$″	$20\frac{1}{8}$″
Northwestern Elevated, Chicago.	$6\frac{1}{2}$″	$20\frac{1}{8}$″
Brooklyn Elevated, Brooklyn	6″	$22\frac{1}{4}$″
Manhattan Elevated, New York	$7\frac{1}{2}$″	$20\frac{3}{4}$″
Albany & Hudson, New York	6″	27″
Boston Elevated, Boston	6″	$20\frac{3}{8}$″
Aurora, Elgin & Chicago, Ill.	6 5-16″	$20\frac{1}{8}$″
Columbus, Buckeye Lake & Newark, Ohio	6″	27″
Columbus, London & Springfield, Ohio . .	6″	27″
B. & O. R.R., Baltimore	$2\frac{3}{4}$″	24″
N.Y., N.H. & H. R.R., Connecticut . . .	$1\frac{1}{2}$″	Center
Central London, England	$1\frac{1}{2}$″	Center

THIRD RAIL INSULATORS.

The requirements for a third rail insulator are:

(*a*) That it shall have sufficient strength to carry the weight of the rail and not crush under the vibration of passing trains.

(*b*) That its insulating body shall be made of a thoroughly vitreous material, practically impervious to heat and moisture, and having its exposed surface well glazed.

(*c*) That its resistance shall, when wet over its entire surface, be 1 megohm at least.

(*d*) That it have a drip edge between the rail and ground.

(*e*) That the portion upon which the rail rests shall allow free movement of the rail, laterally and longitudinally to allow for expansion and contraction, and vertically to allow for depression of ties during the passage of trains.

(*f*) That it must be capable of easy and quick renewal.

Those here illustrated show the two general types which have been most widely used (Fig. 184 and Fig. 185). Fig. 184 consists of a metal base surrounded by an insulating body of vitreous material to which are clamped the clips which hold the rail. Fig. 185 is practically the same, except that in place of the clips clamping the insulating body there is a metal cap setting over it, having ears which may or may not be bent over the rail.

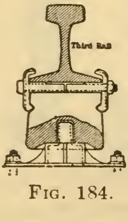


Fig. 184.

Fig. 185.

These insulators are usually placed 10 feet apart, except on sharp curves, where they are generally placed on 5-foot centers in order to keep the rail up to gauge, to allow for the expansion and contraction. The rail is usually anchored at the two center insulators, any movement being taken up at the joints where a sufficient distance has been left between rails for the purpose. This is either done (1) by making the portion of the insulator upon which the rail rests in such way that it may be bolted to the web of the rail, or (2) by making the portion of the insulator upon which the rail rests with a lug that fits into a slot punched in the bottom flange of the rail.

Where the shoe or current collector leaves the third rail at the ends on straight track and at the side at switches and crossovers, suitable inclines must be provided, because the shoes normally hang lower than the top of the third rail. (See Fig. 186.)

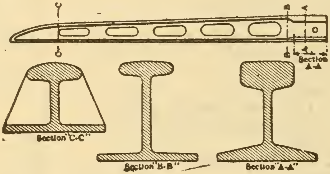


Fig. 186.

Third Rail Shoe. — These shoes are of practically but two types viz., the link shoe and the slipper shoe.

The link shoe is shown in Fig. 187, and is attached to the coil spring seat of the truck, and the shoe proper is suspended by two links from the yoke

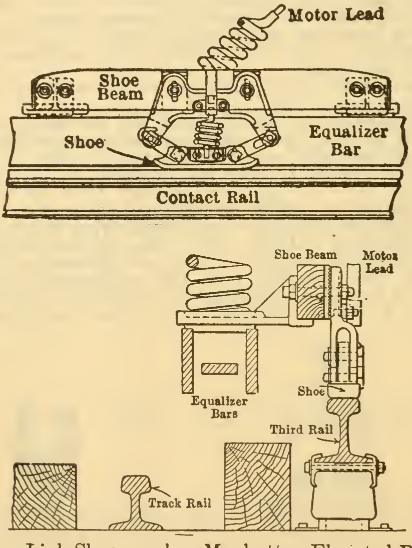


Fig. 187. Link Shoe, used on Manhattan Elevated Railway.

which is in turn bolted to castings on the shoe beam. This type of shoe is not entirely satisfactory because it has a tendency for the shoe to ride on its nose when the speed is high, and does not permit of adequate protection of the rail from the weather.

The slipper shoe shown in Fig. 188 is also carried from the shoe beam, which in turn is fastened to the spring seat. This type of shoe is quieter

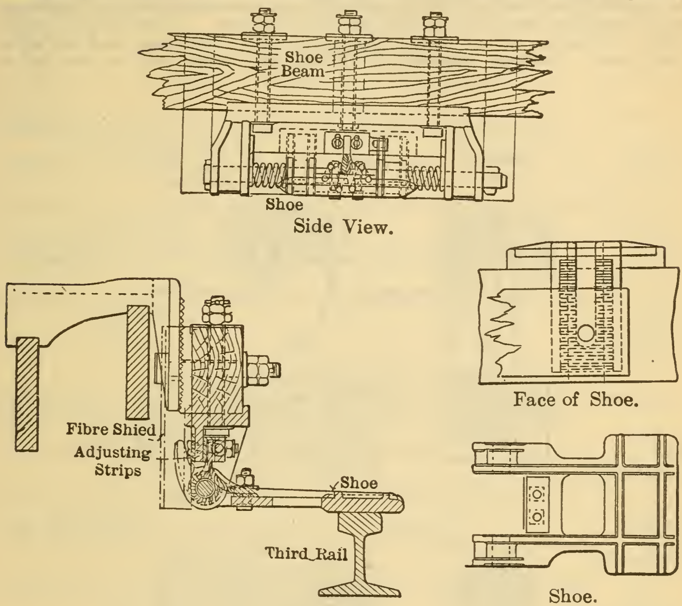


FIG. 188.

sparks less under heavy currents and allows of the use of a top guard, usually a plank or wide channel section of light steel. (See Fig. 189.)

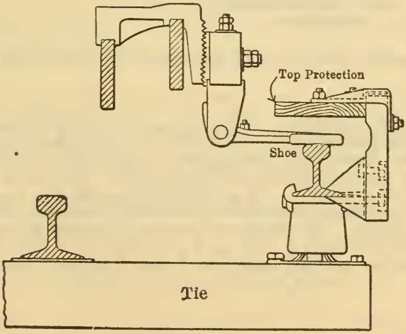


FIG. 189.

Direct metallic connection is maintained from the shoe to the motor in the types of shoes shown, by copper terminals bolted to both yoke and shoe, these two being connected to each other and to the motor by extra flexible copper leads.

New York Central Third Rail. — This arrangement of contact rail is the joint invention of W. J. Wilgus and Frank J. Sprague, and as will be noted in the illustration, is supported every eleven feet by iron brackets, which hold the insulation blocks by special clamps. These blocks, which are in two pieces, are six inches long by $\frac{3}{4}$ inch in thickness, and are interchangeable. Between supporting brackets the upper part of the rail is

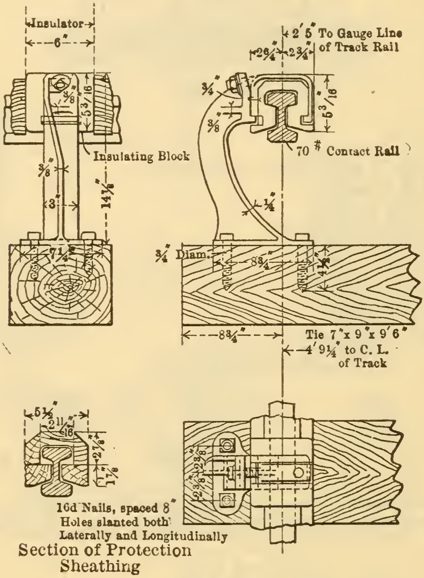


FIG. 190. Details of Third Rail Construction, New York Central R.R.

covered by wooden sheathing, which is applied in three parts and nailed together. At the joints where the third rail is bonded, and at the feeder taps, the wooden sheathing is mortised. This rail is given a little play in the insulators for expansion and contraction, except at certain central points, where it is anchored. It weighs 70 pounds per yard; is of special section and composition; and has a resistivity between seven and eight times that of copper. The under or contact surface is placed $2\frac{3}{4}$ inches above the top of the service rail, and its center is 4 feet $9\frac{1}{4}$ inches from the center line of the service track, or 2 feet 5 inches from the gauge line of the near rail.

APPROXIMATE ESTIMATED COST OF ONE MILE OF SINGLE TRACK OF PROTECTED THIRD RAIL.

(W. B. POTTER.)

6-INCH CHANNEL IRON PROTECTION.

5260′ 75-lb. 3″ × 2½″ conductor rail at $43 per ton (66 tons) . .	$2,840.00
528 Reconstructed granite insulators, clamps and lag screws at 40 cents per set	211.00
352 No. 0000 GE 9″ Form B bonds at 38 cents	134.00
	$3,185.00
5280′ 31½-lb. 6″ channel iron guard for conductor rail at $45 per ton (27.71 tons).	$1,248.00
792 Malleable-iron guard supports at 36 cents	286.00
176 Malleable-iron fish plates and bolts at 25 cent	44.00
	$1,578.00
Approximate labor for installation, including drilling rails and channels.	900.00
Total cost	$5,663.00

8-INCH CHANNEL IRON PROTECTION.

5280′ 75-lb. 3″ × 2½″ conductor rail at $48 per ton (66 tons) . .	$2,840.00
528 Reconstructed granite insulators, clamps and lag screws at 40 cents per set	211.00
352 No. 0000 GE 9″ Form B bonds at 38 cents	134.00
	$3,185.00
5280′ 48-lb. 8″ channel iron guard for rail at $45 per ton (42.24 tons)	$1,900.00
792 Malleable-iron guard-rail supports at 36 cents	286.00
176 Malleable-iron fish plates and bolts at 25 cents	44.00
	$2,230.00
Approximate labor for installation, including drilling rails and channels.	900.00
Total cost	$6,315.00

8-INCH WOOD PROTECTION.

5280′ 75-lb. 3″ × 2½″ conductor rail at $43 per ton (66 tons) . .	$2,480.00
528 Reconstructed granite insulators, clamps and lag screws at 40 cents per set	211.00
352 No. 0000 GE 9″ Form B bonds at 38 cents	134.00
	$3,185.00
5280′ Ash plank 1½″ × 8″ at $48 (M board feet) in the rough, 5280 board feet	$253.00
792 Malleable-iron guard-rail supports for wooden guard plank at 39 cents	308.00
176 Malleable-iron fish plates and bolts at 25 cents	44.00
	$605.00
Approximate labor for installation, including drilling rails . . .	750.00
Total cost	$4,540.00

CONDUIT SYSTEMS OF ELECTRIC RAILWAYS.

Previous to 1893 many patents were granted on conduit and other sub-surface systems of carrying the conductors for electric railways, and hundreds of experiments were carried on; but it has been only since that year that capitalists have had the necessary courage to expend enough money to make a really successfully operating road. The work was put into the hands of competent mechanical engineers, who perfected and improved the mechanical details, and the electrical part of the problem was by that means rendered very simple.

The Metropolitan Street Railway Company of New York, and the Metropolitan Railroad Company of Washington, decided, in 1894, that, by building a conduit more nearly approaching cable construction, the underground electric system could be made a success. The former contracted for its Lenox Avenue line, and the latter for its Ninth Street line. The New York road was in operation by June, 1895; the Washington road by August of the same year; and they continue to run successfully. While modifications have been made in some details since these roads were started, yet the present construction is substantially the same. These roads were the first to avoid the almost universal mistake of spending too little and building unsubstantially where new enterprises are undertaken. The history, in these particulars, of the development of overhead trolley and conduit roads is to-day repeating itself in the third-rail equipment of branch and local steam roads.

The Metropolitan Railroad, in Washington, used yokes of cast iron placed on concrete foundations, and carrying the track and slot rails. The slot rails had deep inner flanges, with water lips to prevent dripping on conductors. The conductor rails were T bars 4 inches deep, 13 feet 6 inches long, 6 inches apart, and were suspended from double porcelain corrugated insulators filled with lead and mounted on cast-iron handholes. A sliding plow of soft cast iron collected the current. During the first few months of its operation there were but few delays, mostly due to causes other than electrical defects. Some trouble came from short-circuiting of plows, which was remedied by fuses on plow leads, and a water rheostat at the power-house. The flooding of conduits did not stop the road, although the leakage was 300 to 550 amperes. Under such circumstances the voltage was reduced from 500 to about 300. The average leakage on minus side, when tested with plus side grounded, was one ampere over 6,500 insulators. The positive side always showed higher insulation than the negative, possibly due to electrolytic action causing deposits on the negative pole.

The Lenox Avenue line of the Metropolitan Street Railway was the first permanently successful underground conduit line in the United States. The cast-iron yokes were similar to those used on their cable lines, placed 5 feet apart. Manholes were 30 feet apart, with soapstone and sulphur pedestal insulators located under each, carrying channel beam conductors, making a metallic circuit. At first the voltage was 350, but it was gradually raised to 500. The pedestal support was afterwards abandoned, and suspended insulators used every 15 feet, at handholes. At one time iron-tube contact conductors were tried, but they proved unsatisfactory.

The details of track construction for underground or sub-surface trolley railroads are essentially of a special nature, and are determined in every case by the local conditions and requirements. They belong to the civil engineering class entirely, and will not be treated here in any way other than to show cuts of the yokes and general construction.

The requirements of the conduit for sub-surface trolley conductors are first, that it shall be perfectly drained, and second, that it be so designed that the metallic conductors are out of reach from the surface, of anything but the plow and its contacts. Another requisite is that the conducting rails and their insulated supports shall be strong and easily reached for repairs or improvement of insulation.

The conducting rails must be secured to their insulating supports in such a manner as to provide for expansion and contraction. This can be done by fastening the center of each section of bar solid to an insulated support at that point, and then slotting the ends of the bar where they are supported on insulators. The ends of the bars will be bonded in a manner somewhat similar to the ordinary rail bonding.

The trolley circuit of the sub-surface railway differs from the ordinary overhead trolley system in that while the latter has a single insulated conductor, and return is made by the regular running rails, the former has a complete metallic circuit, local, and disconnected in every way from track return.

The contact rails must be treated like a double-trolley wire, and calculations for feeders and feeding in points can be made after the methods explained for overhead circuits and feeders earlier in this chapter. Feeders and mains are usually laid in underground conduits for this work, and the contact rails may be kept continuous or may be divided into as many sections as the service may demand, taps from the mains or feeders being made to the contact

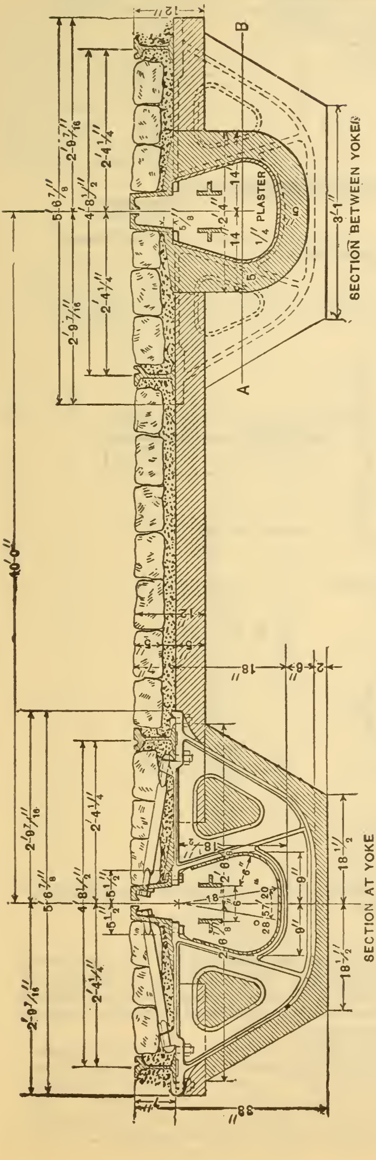


FIG. 191. Section of Conduit, Metropolitan Railroad, Washington, 1895.

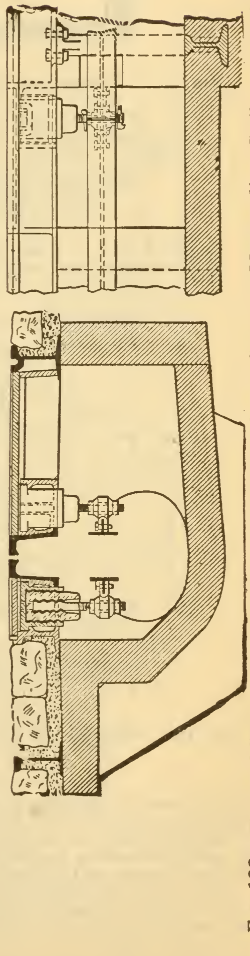


FIG. 192. Plan and Section of Conduit, showing G Conductor Support, Metropolitan Railroad, Washington, 1895.

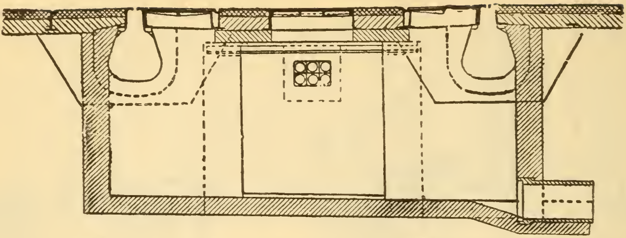


FIG. 193. Drainage at Manhole of Conduit, Metropolitan Railroad, Washington, 1895.

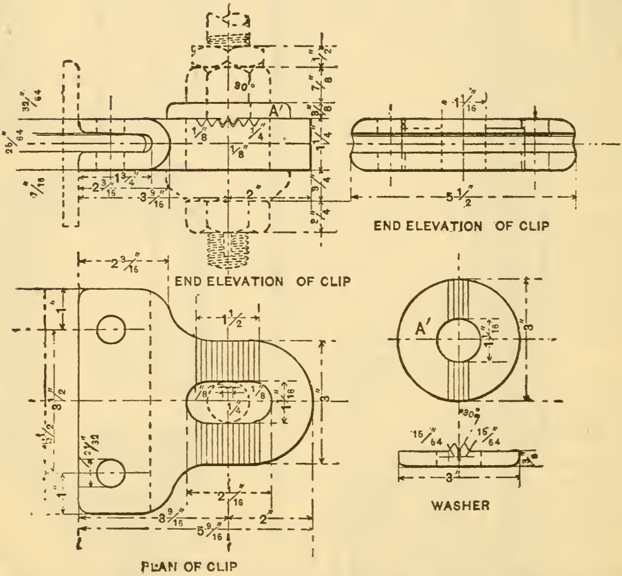


FIG. 194. Clip and Ear for Conduit, Metropolitan Railroad, Washington, 1895.

rails at such points as may be determined as necessary. All the insulated conductors should be of the highest class: may be insulated with rubber or paper, but should in any case be covered with lead. Especial care should be taken in making joints between the conducting rail and copper conductor so that jarring will not disturb the contact.

Other than the above few general facts it is difficult to say much regarding this type of electric railway, for it is so expensive to install that it can be used in but a few of the largest cities, and in every case will be special, and require special study to determine and meet the local conditions. The reader is referred to the files of the street railway journals for complete descriptions of the few installations of this type of electric railway.

Following are a number of cuts showing the standard construction of electric conduits as designed and built by the Metropolitan Street Railway Company, of New York. The system of railway may be said to use all the latest methods, including wire-carrying conduits along side or under the tracks, as will be seen by the next cut.

The porcelain insulator here shown for supporting the contact rails is very substantial in design and construction, and by its location at a handhole is easily reached for cleaning, repairs, and replacement. The *plow* has also received careful attention, and those now used as standard by the Metropolitan Company leave little to be desired.

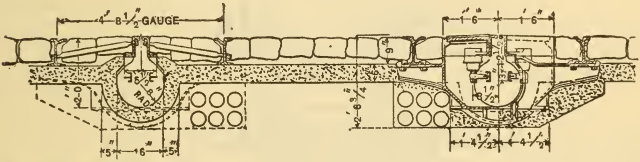


Fig. 195. Section of Conduit, Metropolitan Street Railway, New York. — Standard Work, 1897–98.

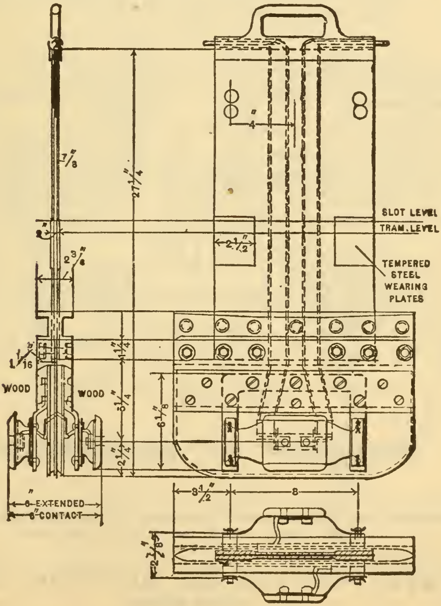


Fig. 196. Section, Side and End Elevation of Plow, Metropolitan Street Railway, New York. — Standard Work, 1897–99.

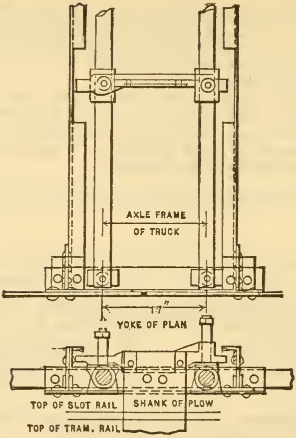


FIG. 197. Plan and Elevation of Plow Suspension from Truck, Metropolitan Street Railway, New York. — Standard Work, 1897–98.

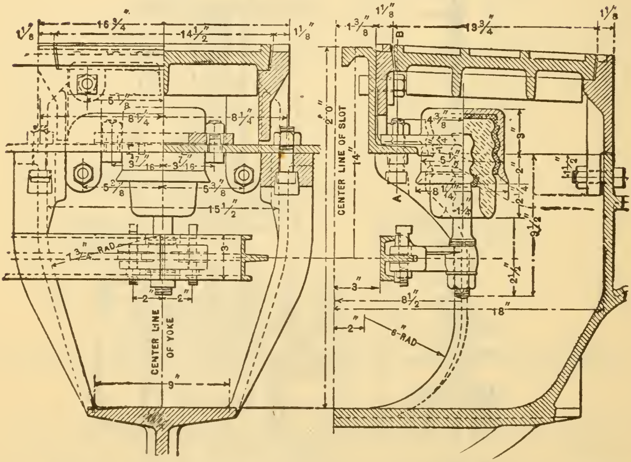


FIG. 198. Section and Elevation of Insulator, Metropolitan Street Railway, New York. — Standard Work, 1897–98.

SURFACE CONTACT OR ELECTRO-MAGNETIC SYSTEMS.

The development of surface contact systems began even earlier than the use of the overhead-trolley wire, and many patents have been issued on the same. Most of these failed through ignorance of the requirements, and timidity of capital in taking up a new device answers for others.

The Westinghouse Electric and Manufacturing Company and the General Electric Company finally took the matter up, and being equipped with vast experience of the requirements, and the necessary engineering talent and apparatus, have each developed a system that is simple to a degree, and is said to cost but half as much to install as the conduit system, and to offer advantages not known to that or other systems.

I quote as follows from a bulletin issued by the Westinghouse Electric and Manufacturing Company.

Some Advantages of the System.

No poles, overhead wires, or troublesome switches are employed. The streets, yards, and buildings are left free of all obstructions.

The facility with which freight cars can be drilled in yards and through buildings, without turning the trolley whenever the direction of a motor car or locomotive is reversed, and the absence of the necessity of guiding the trolley through the multiplicity of switches usually found in factory yards and buildings, is of great advantage, permitting, in fact, the use of electric locomotives where otherwise electricity could not be used.

The only visible parts of the system, when installed for street railway work, are a row of switch boxes between the tracks, flush with the pavement, and a double row of small contact buttons which project slightly above the pavement, and do not impede traffic in any way.

This system can be used in cities where the use of the overhead trolley is not permitted, and if desired the continuation of the road in the suburbs can be operated by the cheaper overhead system. It would only be necessary to have a trolley base and pole mounted on the car, the pole being kept down when not in use.

There are no deep excavations to make. The system can be installed on any road already in operation without tearing up the ties.

The cost is only about one-half that of a cable or open conduit road.

The insulation of all parts of the line, the switches, and the contact buttons is such that the possibility of grounds and short circuits is reduced to a minimum.

The system is easy to install, simple in operation, and reliable under all conditions of track and climate.

Finally, the system is absolutely safe. It is impossible for anyone on the street to receive a shock, as all the contact buttons are "dead" excepting those directly underneath the car.

Requirements.

In devising this system the following requirements of successful working were carefully considered.

The insulation must be sufficient to prevent any abnormal leakage of current.

The means for supplying the current to the car must be infallible.

The apparatus must be simple, so that inexperienced men may operate it without difficulty.

The system must operate under various climatic conditions.

Finally, absolute safety must be assured.

WESTINGHOUSE SYSTEM.

This system includes the following elements.

First. Electro-magnetic switches, inclosed in moisture-proof iron cases. Each switch is permanently connected to the positive main or feeder which is laid parallel to the track.

Second. Cast-iron contact plates or buttons, two in each group, placed between the rails and electrically connected to the switches. A separate switch is provided for each group of buttons.

Third. The conductor forming the positive main or feeder. This is completely inclosed in wrought-iron pipe, and is connected to the various switches.

Fourth. Metal contact shoes or bars, suspended from the car trucks; two bars on each car.

Fifth. A small storage battery carried upon the car.

The operation of the system is described as follows, and is illustrated by cuts making plain the text.

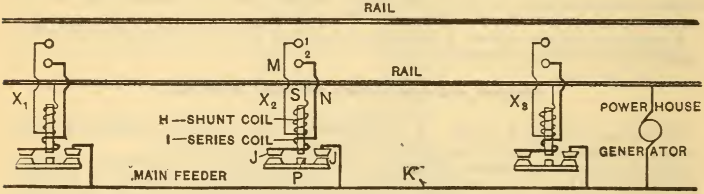


FIG. 199. Diagram of Switch Connections.

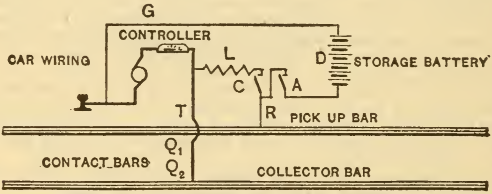


FIG. 200. Diagram of Car Connections.

Electro-magnetic switches, X_1, X_2, X_3., inclosed in water-tight casings, are installed at intervals of about 15 feet along the track to be operated. Each switch is provided with two windings, I and H, which are connected by the wires N and M to two cast-iron contact buttons, 1 and 2, which are mounted on suitable insulators and placed between the rails.

Each car to be operated on this system is provided with two spring-mounted T steel contact bars, Q_1 and Q_2, and a few cells of storage battery in addition to the usual controllers and motors. The contact bars are mounted at the same distance apart as the contact pins, 1 and 2, so that as the cars advance along the track the bars will always be in contact with at least one pair, as the length of the bar exceeds the distance between any two pairs by several feet.

Suppose a car is standing on the track over the switch X_2, the contact bars, Q_1 and Q_2, being then in connection with the buttons 1 and 2 respectively. The first step is to "pick up" the current, i.e., render the buttons 1 and 2 alive.

Switch A is first closed; this completes the circuit from the storage battery, D, through the wiring, R, contact shoe, Q_1, button No. 1, and shunt coil, H, to the ground. The current passing through H magnetizes the core, S, which in turn attracts the armature, P, closing the switch and establishing connection between the 500-V main feeder K, and button No. 2, through the contacts, JJ, coil I, and wiring N. Switch C is now closed and switch A opened; the switch X_2 is kept closed, however, by the current flowing from button No. 2 through bar Q_2, connection T, resistance L, connection R, bar Q_1, button No. 1, connection M, coil H to ground.

The car now proceeds on its way, current from the main passing through connection T, to the controller and motors. When the car has advanced a short distance the contact bars make connection with the pair of buttons connected to switch X_3. Current then passes from bar Q_1 through the shunt coil of this switch. The operation described above is then repeated. As soon as the bars leave the buttons 1 and 2, current ceases to pass through the coils I and H of switch X_2, and this switch immediately opens by gravity, leaving the buttons connected to it dead and harmless. As connection with the main has already been established through switch X_3, there will be a continuous flow of current from the feeder, and no flash will occur either at the button or the switch.

It will be observed that all the current passing to the car from the main through switch contacts J J passes through the series coil, I, holding the switch firmly closed and precluding all possibility of its opening while current is passing through the contacts, even should the circuit through coil H be interrupted. Although the act of "picking up the current" requires some time to describe, it takes in practice only a few seconds.

Two separate switches, A and C, are shown in the diagram; but in practice one special switch of circular form is provided, and the necessary combinations required for "picking up the current" are made by one revolution of the switch handle.

The battery need only be employed to lift the first switch; for after that has been closed, the contact shoes bridge the main voltage over from one set of pins to another, as described, thus closing the successive switches, without further attention from the motorman.

The battery is charged by leaving switches A and C closed at the same time.

The Switch.

Fig. 201 shows the general arrangement of switch, bell, and pan. The switch and magnet are mounted upon a marble slab, which is secured in the bell by means of screws to the bosses, B B.

The switch magnet, M, is of the iron-clad type. It is secured to the upper

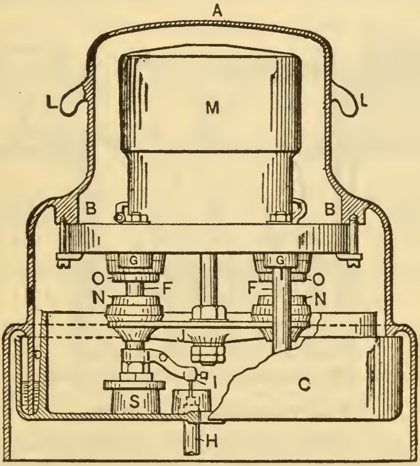


FIG. 201. Section of Switch, Bell, and Pan.

side of the marble base, and is provided with a fine (shunt) winding for the "pick up" current, and a coarse (series) winding through which the working current passes.

When magnetized the poles attract an armature attached to a bridge piece, J, each end of which carries a carbon disk, N. R, R, are guides for the bridge piece, J. Directly above each of the carbon disks, N, is a stationary disk, O, mounted upon a marble base. One of the disks, O, is permanently connected by means of one of the contact cups, G_1, as explained later, to the positive main cable, and the other, through the series coil and cup, G_2, to the positive contact button.

The pan, C, is provided with four bosses, S, to support the vertical split pins, F, which are insulated from the pan. These pins slide into receptacles, G, on the switch base. The pins, F, are provided with connectors, I, for the purpose of making connection with the several cables, H, which pass through the holes in the under side of the pan. The pan is completely filled with paraffine after the connections are made, thus effectually keeping out all moisture.

The object of the bell, A, and the pan, C, with the split pins, F, and the cups, G, is to provide a ready means of examination of the switch without disconnecting the wires. The bell can be lifted entirely free of the pan. In replacing it, it is only necessary to see that a lug, T, on the side of the cover, fits into a slide, U, on the frame. When in this position the split pins make connections with their corresponding cups, G.

The bell, A, is provided with lugs, L, to facilitate handling; and also a double lip, W. The inner portion of this lip fits into and over the annular groove, D, of pan C. This groove is filled with a heavy non-vaporizing oil. The outer portion of lip, W, prevents water from entering the groove. The object of the groove, D, and the lip, W, is to make a waterproof joint to protect the switch and cable terminals without the necessity of screw joints or gaskets. The bells are all tested with 25 pounds air pressure; they may be entirely submerged in several feet of water without affecting the operation of the system.

The Contact Buttons are made of cast iron. They are about 4½ inches in diameter, and, when installed on paved streets, project about five-eighths of an inch above the pavement and offer no obstruction to traffic. This is sufficiently high to enable the collector-bars to make contact, and at the same time to entirely clear the pavement. For open-track installations they are substantially mounted in a combination unit as described below.

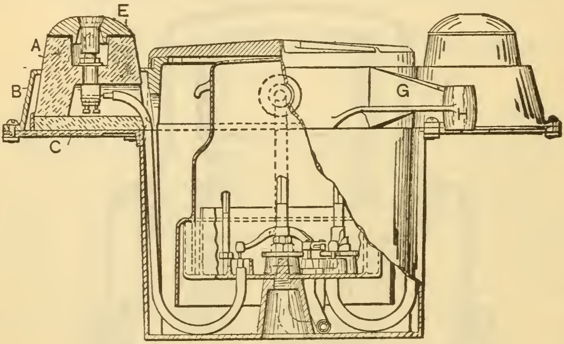


FIG. 202. Section of Combination Unit.

The Combination Units.

The bell and pan are entirely inclosed in a cast-iron switch-box. This box and the contact buttons are made into a complete unit as shown in Fig. 101. Each unit consists of three separate castings. The cylindrical cast-iron box, which incloses the switch, bell, and pan, is bolted into a recess provided for that purpose in the bottom of the spider-like structure, which is a separate casting, consisting of box rim, receptacles for the button insulators, and supporting arms. The removable lid is the third casting.

The insulators, A, Fig. 202, are made of a special composition, and are cemented into the tapered cups, B, and supported by the iron plates, C. The contact buttons, E, are mounted on top of these insulators and stand, when installed, about one inch above the rail.

The four arms, G, are secured to the ties by means of the bosses, H, thus reducing to a minimum the labor of leveling the boxes and avoiding the necessity of special ties.

Mains and Wiring.

The positive main or feeder is incased in a $1\frac{1}{4}$-inch iron pipe, and passes directly through each switch-box, and a tap is made to each switch, the switch-boxes being all connected by the iron pipe, as per cut below.

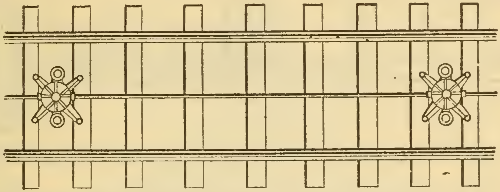


FIG. 203. Track Equipped for Track Return Circuit.

No additional wires are used to interconnect the coils or contacts of adjacent switches.

The Contact Bars are of steel, of ordinary T section. They are supported from the car trucks by two flat steel springs and adjustable links. These bars are inclined at the ends so that they may readily slide over the buttons and over any ordinary obstacle.

Insulated Return Line.

In case it is considered best not to use the rails as the return line, insulated mains for this purpose may be included in the system. It is only necessary to install another row of contact buttons, another collecting bar,

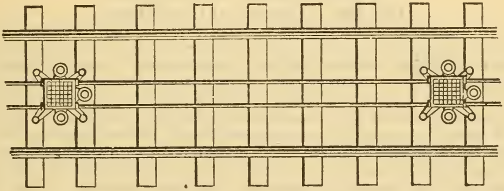


FIG. 204. Track Equipped for Insulated Return Circuit.

and to use double-pole switches. Fig. 204 illustrates an installation of this kind. For all ordinary work, however, the ground return is satisfactory.

Modifications of the System.

The description given on the preceding pages applies to the system as installed for yard and similar work. Modifications can be made and detail matters arranged according to the requirements of each case.

Street Railway Work.

The foregoing description applies to installations where the track is open (unpaved),and where it is unnecessary to make provision for traffic crossing the tracks except at certain points. For street railway work, the switch-boxes are preferable installed outside the track, while the buttons are placed between the rails and mounted on a light metal tie, as shown in Fig. 205.

The operation of the system is exactly the same as in open-track work. Connecting wires pass from the buttons under the tie to the switch-boxes. For double-track work the switches are installed between the two tracks, and the boxes may be built to hold two switches, one for each track.

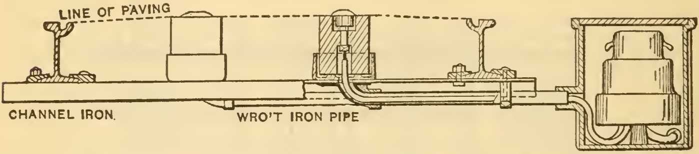


FIG. 205. Section of Track Equipped for Street Railway Service.

When, as is sometimes necessary, the buttons are placed in a single row, it is necessary that the "pick-up" current should be of the same voltage as that of the main circuit, and consequently the car-wiring indicated in Fig. 206 is used, instead of that shown in Fig. 200.

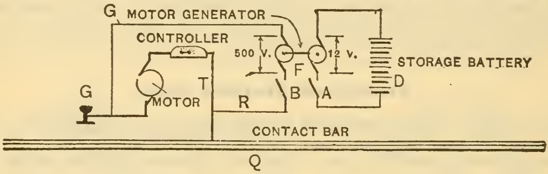


FIG. 206. Diagram of Car-Wiring.

Referring to Fig. 206, the method of "picking up" the current is as follows: Switch A is first closed; this completes the circuit from a storage battery D, through a small 500-volt motor-generator F, which immediately starts. As soon as it is up to speed, which only requires a few seconds, switch B is closed; current then passes from F through the wiring R, to contact shoe Q, and then through the switch magnet, as explained on page 538. Switches A and B are then opened, thus stopping the motor-generator, which need only be used to operate the first switch. The successive switches are closed, as described on page 842.

This arrangement of a high-voltage "pick-up" may also be used advantageously with two rows of buttons where the track is liable to be obstructed by mud or snow.

Sectional Rail Construction.

For suburban railway or similar service two light rails may be substituted for the two rows of contact buttons, as shown in Fig. 207. The cars are then equipped with contact shoes instead of bars. These rails are insulated from the ground, and may also be insulated from each other wherever desirable, thus breaking them up into sections, which are each controlled by a single switch. The sections may be made of any desired length to suit the conditions. For example, between stations they may be 500 or more feet long, while near stations or crossings, where anyone is liable to come in contact with the rail, the length of a section may be reduced to 50 feet or less. The electrical operation of two-rail installations is the same as when two rows of buttons are used. The sectional switches along the tracks are entirely under the control of the motorman, and the rails may be rendered "dead" at any moment should occasion arise.

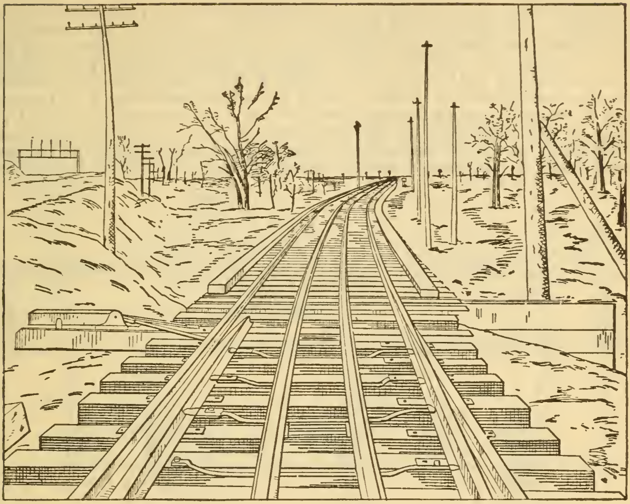


FIG. 207. Sectional Rail Installation.

GENERAL ELECTRIC SYSTEM OF SURFACE CONTACT RAILWAY.

Following is a description of the surface contact system, as developed by the General Electric Company, and practical application of it has been made at Monte Carlo, and at the company's works at Schenectady. The description is from a report made by W. B. Potter, Cf. Eng. of the Railway Department, and written by Mr. S. B. Stewart, Jr.

In the operation of electric cars, by the closed conduit surface plate contact system of the General Electric Company, the current is collected for the motor service by means of two light steel shoes carried under the car, making contact with a series of metal plates, introduced along the track between the rails, automatically and alternately energized or de-energized by means of switches grouped at convenient places along the line; the method of the switch control being such that in the passage of the car, in either direction, it is impossible for any plate to become alive except when directly under the car body.

In ordinary street car practice, the contact plates are spaced approximately ten feet apart, positive and negative plates being staggered, as shown in Fig. 208, which admits of but three plates ever being covered at any one time by the shoes, which are so designed as not to span more than two plates of the same polarity.

In grouping the switches it is customary to locate them either in vaults constructed between or near the tracks, or in accessible places along the side of the street, the location and spacing of groups and number of switches in each group being based upon a comparative cost between the style of vault or other receptacle, and the amount of wire with ducts between the contact plates and their corresponding switches.

The main generator feeder is carried to each vault or group, and auxiliary feeders from it are distributed to each switch, the track rail being utilized for the return circuit.

The operation or performance of this system can be readily traced out by reference to Fig. 208. It will be seen that the current in its passage to the motor from the positive generator conductor passes to contact A of switch No. 2 through the carbons on its magnet armature (which has been lifted by the energized coil G) to contact plates B and C, through the contact shoe D to the controller and motor, coming out at contact shoe E to the contact plate F, when it passes through the coil of the automatic switch G, energizing it and returning by the track-rail H; thus maintaining contact at switch No. 2 armature carbons as long as the shoes remain on the contact plates C and F. It should now be noted that contact plate B is energized

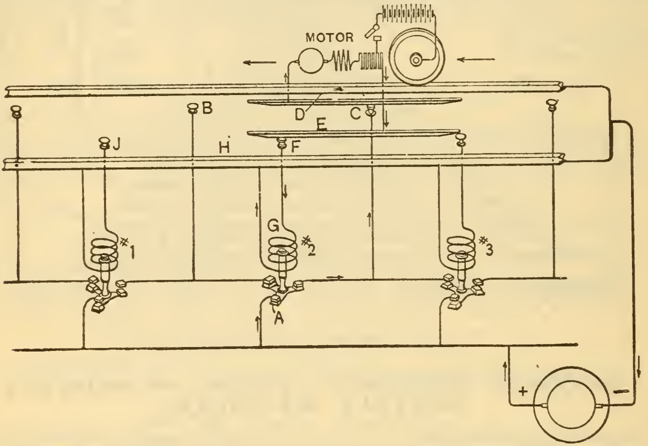


FIG. 208. Diagram of Connections for Surface Contact Railway Plate System, General Electric Co.

as stated above. As the car proceeds, the shoe D spans the plates B and C, thereby keeping the coil of switch No. 2 energized after shoe has left plate C, and until shoe E comes in contact with plate J, which immediately energizes coil No. 1, thus making the preceding contact plate energized, preparatory to the further advance of the car. It will be noted in the above description of the performance of the system, that we have assumed switch No. 2 on Fig. 208 as closed; it should therefore be understood that an auxiliary battery circuit is necessary in starting or raising a first switch, preparatory to its armature being held in contact position by the generator current, which current energizes the preceding contact plates consecutively as described above.

The battery current is brought into the automatic switch circuit momentarily during the period of first movement of handle of the controller in starting a car, the transition of the controller cylinder also bringing the generator current in connection with the battery for a short period of time, thus replenishing the elements sufficiently to operate the switches. The battery is also used to supply current for lighting the car, the generator circuit being disconnected while the car is at rest.

Surface Contact Plates.

The surface contact plates are made of cast iron, with wearing surfaces well chilled, designed to be leaded into cast-iron seats in such a manner that they are thoroughly secure, but can be readily removed by special tongs for the purpose. The seat is imbedded in a wooden or composition block set into a cast-iron box, the latter being spiked or screwed to the tie. A brass terminal is fastened to the seat for the reception of the connecting wire from the switch. See Fig. 209.

As stated above, the plates are usually located 10 feet apart for straight line work, but somewhat closer on curves, depending upon the radius of the curve and length of contact shoe. The negative and positive contact plates are staggered with a uniform angular distance between them, situated not less than 10 inches from the track rails.

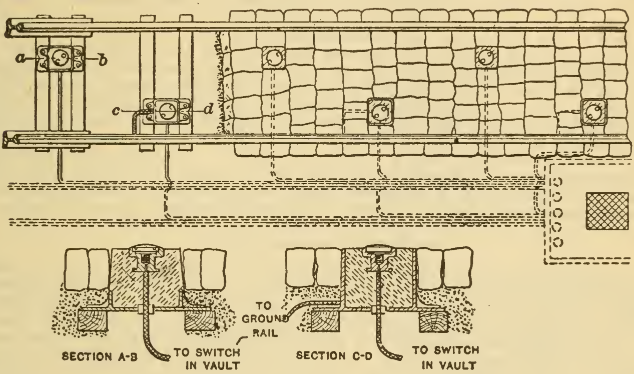


FIG. 209. Plan and Section of Track, Monte Carlo, Europe. General Electric Company's Surface Contact System, 1898.

Surface Contact Switch.

The automatic switches are constructed on the solenoid principle, the armature or core of which is employed in closing the contacts as shown in

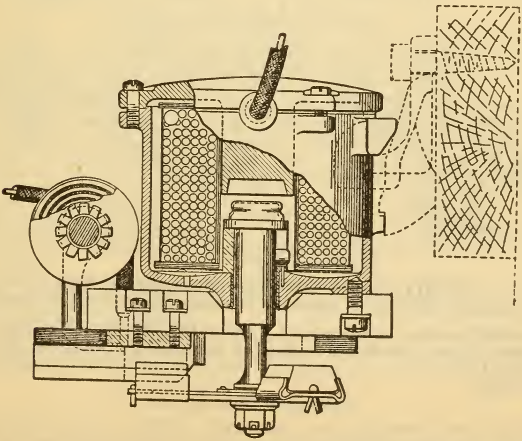


FIG. 210. Automatic Switch for Open Conduit, Surface Plate Contact System.

Fig. 210. The end of the armature core is provided with a pressed sheet-steel carbon-holder, for the purpose of supporting the carbon contacts which are held in place by bronze clips and cotter pins which can easily be removed. The pressed-steel carbon-holder can also be detached with little trouble by removing the end holding it to the core. Copper plates are secured to the slate base for contact surfaces and the attachment of feeder-wires. The wire of the solenoid is wound on a copper spool and placed in a bell-shaped magnet frame, and a pole-piece, slightly recessed to receive the end of the armature core when the switch is in a closed position, is attached to the top cover, and extends part way down through the winding. The recess in the armature increases the range of the magnet, making the attraction uniform except at the point of contact where the power increases rapidly, thus securing an excellent contact. A blow-out magnet coil is connected in series with the feeder current, and so situated that the influence of its poles is used to rupture any arc that might be formed while the switch is opening; however, this blow-out magnet is used simply as a precautionary device, as under ordinary conditions there is no arcing, the succeeding automatic switch closing the circuit before it is opened by the preceding one. Each vault or group of switches should be provided with cut-outs or an automatic circuit breaker to protect them in the event of short circuits.

Surface Contact Shoes.

The contact shoes are made of "T" steel of light section, the suspension for which is an iron channel beam extending longitudinally with the truck frame directly under the motors, with a substantial wooden cross-arm attached to each end for the shoe-supporting casting, the shoes being attached to these supporting castings by a spring equalizing device for maintaining the shoes at the proper height, and also for making them flexible enough to meet any slight variations in the contact plates and track rails. The shoes when in their correct position should never drop over one-fourth inch below the surface contact plates, and are designed so that they may raise three-fourths of an inch or more above them. See Fig. 211.

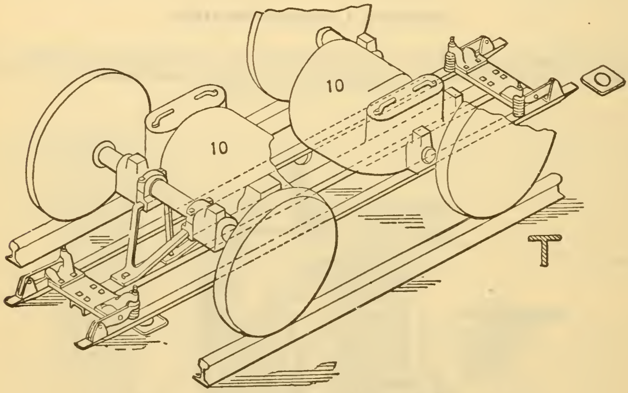


FIG. 211. Collecting Shoes, Monte Carlo, Europe.
General Electric Company's Surface Contact System, 1898.

A screw adjustment is provided to lower the shoes as they wear away, or to take care of any other discrepancies due to wear of parts, etc.; if they are allowed to drop too low they will interfere with rail crossings, causing short circuits.

Storage Batteries.

It requires for closing the first automatic switch when starting, and for lighting the car approximately, ten storage battery elements capable of 35 amperes rate of discharge for five hours.

The batteries are only slightly exhausted in making the initial connections through the automatic switch, as it only takes approximately 15 amperes momentarily to perform this work, the battery is immediately recharged by current which has passed through the motors. The battery serving as a rheostatic step, this momentary charging does not represent any extra loss of energy.

The circuit connections of the battery are accomplished in the controller and require no attention on the part of the motorman.

Car Lighting.

The amount of recharging derived from the motor circuits is sufficient to operate the automatic switches, but where lighting of the car is done from the same battery, an additional recharge is required.

Assuming that 10 20-volt lamps are used for lighting a car, the batteries will need to be recharged every night about five hours, at an approximate rate of 25 amperes.

It is customary to run leads from both the positive and negative terminals of the batteries to charging-sockets attached to the under side of one of the car sills in a convenient place for connection to the charging-wire.

A small generator of low potential (30 volts) driven by a motor or other method is required for supplying current for recharging the batteries where the desired low-potential current is not accessible, and the wiring from the charging source should be run to a location in the car-house most convenient for connections to the battery sockets. These locations may be fixed either in the pits or on posts at the nearest point to where the cars will be stationed, and there should be flexible lead wires attached to plugs for connecting to the battery circuit on the car. In wiring the car-house for the battery connections, it would be found convenient to designate the polarity of the various wires either by different colored insulation or tags, and the plugs at the ends of the flexible leads should be marked plus and minus to avoid mistakes in making connections with the car battery receptacle.

Motors and Controllers.

The motor and controller equipment used with the surface plate contact system is standard apparatus as ordinarily employed for electric car service, with the exception that provision is made in the controller for cutting in and out the storage battery while starting the car.

Care of Apparatus.

As success in the operation of the contact plate system depends largely on the care of the apparatus, a few general remarks on the subject will not be out of place here.

Care should be taken that the contact plates are kept clean, and they should be frequently inspected, the roadbed being well drained. Any small quantity of water temporarily standing over the tracks, however, would do little harm, as the leakage through the water would not be sufficient to create a short circuit, although this condition should not be allowed to exist any length of time.

The automatic switches should be carefully inspected and all cast-iron parts thoroughly coated with heavy insulating paint, and a test for insulation or grounds be made frequently, and all the parts kept clean and free from moisture.

The contact shoes, in order to prevent leakage, should have their wooden supports well protected with a coating of an insulating paint, and should also be occasionally cleaned.

The storage batteries should be properly boxed and should have the cus tomary care which is necessary to keep them in good working order.

DETERIORATION OF UNDERGROUND METALS DUE TO ELECTROLYTIC ACTION.

REVISED BY A. A. KNUDSON, *Electrical Engineer.*

IN view of the different phases and effects of electrolytic action herein presented, it seems essential, where a clear insight of the subject is desired, that a reference to the *causes* which underlie the principles of such action should first be given.

To this end the following is abstracted from the *Report of the Electrical Bureau of the National Board of Fire Underwriters, Pamphlet No.* 5, *dated August*, 1896, viz: This deals with early discoveries and represents the gist of opinions given by several authorities on this subject at that time. The balance of this article is treated in a purely practical manner.

Recent reports show that the destructive effects of electrical currents on subterranean metal pipes are becoming sufficiently marked in many parts of the country to seriously interfere with the service the pipes are intended to perform.

Underground water mains have broken down, because of faults unquestionably due to electrolytic action; and smaller service pipes have been weakened to such an extent as to break at critical moments, when excess pressure is put upon them at intervals during a fire. Measurements show that conditions unquestionably exist in nearly every district in the United States covered by a trolley road, which are favorable for destructive action on the subterranean metal work in the vicinity, and pipes taken up in many of these districts show unmistakable signs of harmful effects. The general nature of this action, and the causes which bring it about, are too often seen to need elaborate description. Briefly it may be compared to the action which takes place in an electro-plating bath.

The current which enters the bath through the nickel or silver metal suspended therein, flowing through the bath and out through the object to be plated, ultimately brings about the destruction of the suspended piece of metal. Similarly, the current from a grounded trolley system flowing through the earth in its course from the cars back to the generating station selects the path of least resistance,* which is generally for the whole or a part of the way the underground mains, and at points where it leaves the pipes to reach the station the iron of the pipe wastes away until at points the walls become too thin to withstand the pressure of the water, and a breakdown ensues. The difference of potential necessary to bring about this action is very small, — a fraction of a volt, — and consequently in all districts where potential differences are found between water-pipes and the surrounding earth, such actions can be assumed to be taking place, for dampness, and the salts necessary to produce electrolysis, are present in all common soils.

Whenever, then, a reading is shown by an ordinary portable voltmeter registering tenths of a volt with the positive binding-post in electrical connection with a water-pipe or hydrant, and the negative binding-post in electrical connection with an adjacent lamp-post, car track, or metal rod driven in the earth, electrolytic action will be found upon examination to be taking place at that point which will ultimately result in the destruction of the water-pipe, provided that the resistance of the soil is sufficiently low to conduct current.

Referring to the diagram shown in Fig. 1, it is seen that the current will pass from the generator out over the trolley line, through the motor to rail, back to the power house. There are obviously two paths open for the

* The correct statement would be that the current follows the law of divided circuits taking all paths offered, rails, earth, pipes, etc., in inverse proportion to their respective resistances.

current. One a return through the rail, the other a return through the earth and any existing gas-pipes, water mains, or other metallic structures that may be in its path in the earth. The current flowing through these two paths in parallel is plainly inversely proportional to the resistance of these two paths. Therefore, in a general way the current will leave the rails at A, flowing into the water-pipe at B, and will again leave the water-pipe at C and enter the rails. Here, then, is an electric current flowing between metallic structures that may be called electrodes at places in the return path from the motor to station. All that remains, then, to promote electrolytic action is the presence of some solution which will act as an electrolyte.

Observation has shown that the earth, especially in the larger cities, contains a large percentage of metallic salts in solution, which will readily act as electrolytes upon the passage of electric current. It can be seen, then, referring to this diagram, that if there exists in the ground sufficient moisture of some metallic salt, electrolytic action will take place between the electrodes A and B, and between the electrodes C and the rails. In the earlier electric roads the positive terminals of the generators were connected to ground. This arrangement of the polarity of the street railway has a tendency to distribute the points of danger on water-pipes, gas-pipes, cable-sheathing, or any other underground metallic structure throughout a large and extended territory. By reversing the polarity of the railway generator,

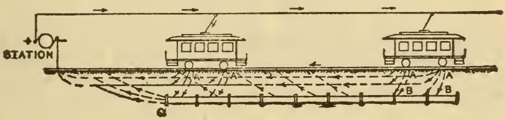


FIG. 1.

bringing the positive terminal to line and negative to ground, the points where the current leaves these metallic structures will be brought much nearer the power station, and will be localized in a much smaller area.

From the electric railway standpoint, the prohibitive expense of the requisite addition of copper to make a complete circuit is advanced, together with the impracticability of a double-trolley system that is apparently a necessary concomitant of the metallic return; and these arguments have a certain weight. There is no question but that the complete metallic return is in the beginning a more expensive installation, but per contra few railway companies have any idea of the energy now expended in returning the energy delivered by the power station through the poor conductivity of the average railway track with its surrounding earth.

Destructive Effects. — In the process of electrolysis upon underground pipes there are two distinct phases of action considered as follows: *A*, the *lateral effect* which is most common, illustrated by Figs. 2, 3, 4 and *B*, the *joint effect* as shown in Fig. 6.

A. Where the current is leaving a cast iron main and passing into the soil the iron is usually removed in spots, causing pittings of varied size and depth, and in aggravated cases, furrows and holes. The pittings are small at first, being 1-16 to $\frac{1}{8}$ inch in depth and varying in diameter at the surface from $\frac{1}{4}$ to 1 in.; those more advanced are from $\frac{1}{4}$ to $\frac{1}{2}$ in. or more in depth, with correspondingly larger surfaces.

When a section of cast iron pipe containing such pittings has been removed from the soil and exposed to the sun, the graphitic carbon and impurities, of which the pittings are filled, become dry and hard and drop out or are easily removed. In appearance they are flat, or nearly so, at the surface of the pipe and oval in depth, as in Fig. 2.

These are $\frac{3}{4}$ of the actual size and shape taken from a pipe. In weight they are about the same as dry wood of equal dimensions.

Where electrolytic action has been severe and the main has burst. the most of these impurities will have become detached or washed out by the force of escaping water, and the spots and holes are plainly revealed. Fig. 3 is an example of severe action and represents a section of a 6-in. cast iron water main taken from a street in Brooklyn, N. Y. The water from this

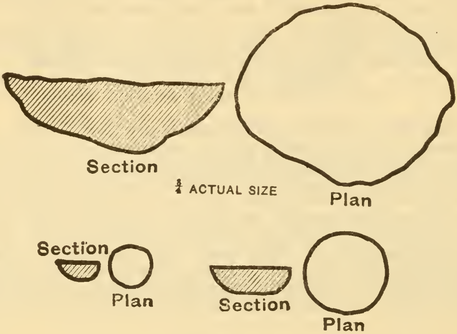


FIG. 2.

leak escaped into a canal, did not appear on the street, and the leak was only discovered by accident. The length of time the water was running to waste is not known. Fig. 4 is a 6-in. section from Reading, Pa. Fig. 5, also from Reading, Pa., replaced Fig. 4 and failed again in about one year.

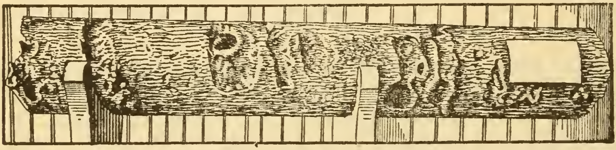


FIG. 3. Section of 6-inch Cast Iron Water Main Destroyed by "Electrolysis," removed from Wallabout Place, East of Washington Avenue, Brooklyn, N. Y., January 21, 1903.

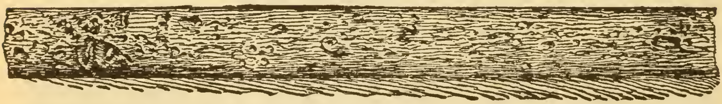


FIG. 4.

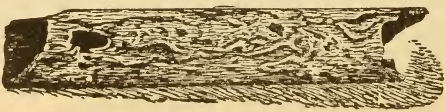


FIG. 5.

B. Joint Effect. — This is caused by electric currents flowing through or along the pipes lengthwise, and by reason of resistance at the joints, electrolytic action takes place. Resistance is caused partly by the coating of asphalt varnish upon both the inside and outside of the pipe, making a partial insulation; and partly by corrosion due to the continued presence of water upon the inside, and moisture upon the outside. In such case the current shunts the joint, the damage occurring at points where it leaves, causing pittings in the iron close to the lead, softening of the lead, resulting in leaks. Fig. 6 — the spigot end of a cast iron pipe — shows cause of a leak through disintegration of the iron near the lead of the joint; the furrow of pittings — between chalk-marks — extend half way around the pipe; the left end of the pipe softened three-eighths of an inch deep was cut with a pocket knife. The *extent* of joint damage depends upon the strength of current flowing in a given time.

The action upon wrought iron or steel pipes differs somewhat from that upon cast iron. In the reduction of wrought iron by the process, there is

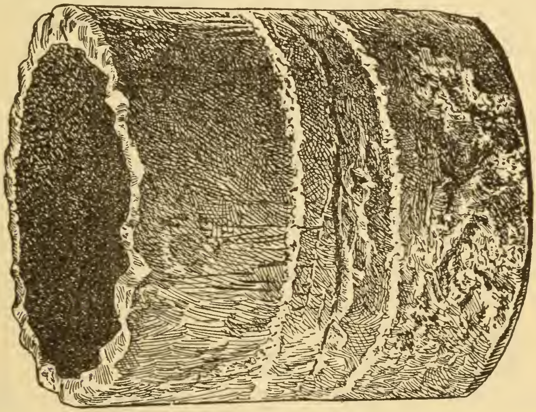


Fig. 6.

a seamy, or shredded appearance, with but little residual carbon. Upon steel such as the base of steel rails, or rail chairs (the latter now little used), the effect is a melting away of the metal, leaving sharp edges at their bottom portions. This effect is found where rails are positive to pipes.

The action upon lead service pipes, or lead covering upon cables, is somewhat similar to that upon cast iron so far as pittings and furrows are concerned, but instead of the graphitic residue there is left in the pittings and the surrounding soil a whitish matter consisting of the oxide or residue of lead.

Increase of Current Flow upon Mains due to Bonding Same to Rails or to Negative Conductors.

Measurements in different cities under varying conditions show the increased flow of current through mains after bonding the mains to the rails, from four to ten times above the normal at points near the bonds, in some cases very much higher. In one case where 5 amperes maximum was found flowing through a 6″ main a temporary connection with ammeter and leads was made between main and P. H negative with result of over 150 amperes. The flow in excess of normal is generally less as the distance is increased from a bond.

The following tables represent actual measurements made in different cities. Measurements made near the bonds, except in No. 3, Table 1.

Table I.

No. of Test.	Flow in Amperes.		Notes.
	Normal.	Connected.	
1	21.0	41.7	
2	21.0	60.2	3 bonds.
3	30.5	4.3	3000 ft. from bond.
4	5.0	128.0	In negative district 5 miles from P.H.
5	6.0	32.0	Geneva, Switzerland.
6	11.5	37.5	
7	80.0	125.0	
8	27.7	45.1	
9	9.8	30.5	
10	6.6	10.5	

Table II.

Three Cases Difference of Potential in Average Volts.

	Normal.	Connected.
No. 1	5.25	0.25
No. 2	1.5	0.3
No. 3	10.0	2.5

In one city examined by the writer two water mains in front of a power house were connected by copper cables directly to the negative bus bar of the switchboard. The estimated amount of current flowing by this path was found at times to be over 1000 amperes; a very much smaller flow has been known to damage the joints of mains.

Current Movements upon Underground Mains. — The flow of current upon underground mains is proportional to the traffic upon the car lines. When railway traffic is heavy mornings and evenings more current output is required at the power house than during hours of light loads. Such changes are faithfully reflected by current flowing in the mains. This is illustrated in curve sheet, Fig. 7, where the load line of a 24-hour log of a power house is shown, and directly above it is placed the line of current strength flowing through a 36-inch water main. It will be noticed that the rise and fall of current strength upon the water main takes place at the same hours of the twenty-four as the load changes at the power house. This effect is more or less common in all cities where electric railways with the usual ground return prevail.

Many instances of railway currents flowing through and across waterways have been discovered, where, as is often the case, the power house is located upon the banks.

One instance of such action was discovered at Bayonne, N.J., November, 1904. At that time current was supplied from the power house in Jersey City, five miles from the central part of Bayonne. The city is nearly surrounded by salt water. Mains in streets near the shore and in salt marsh

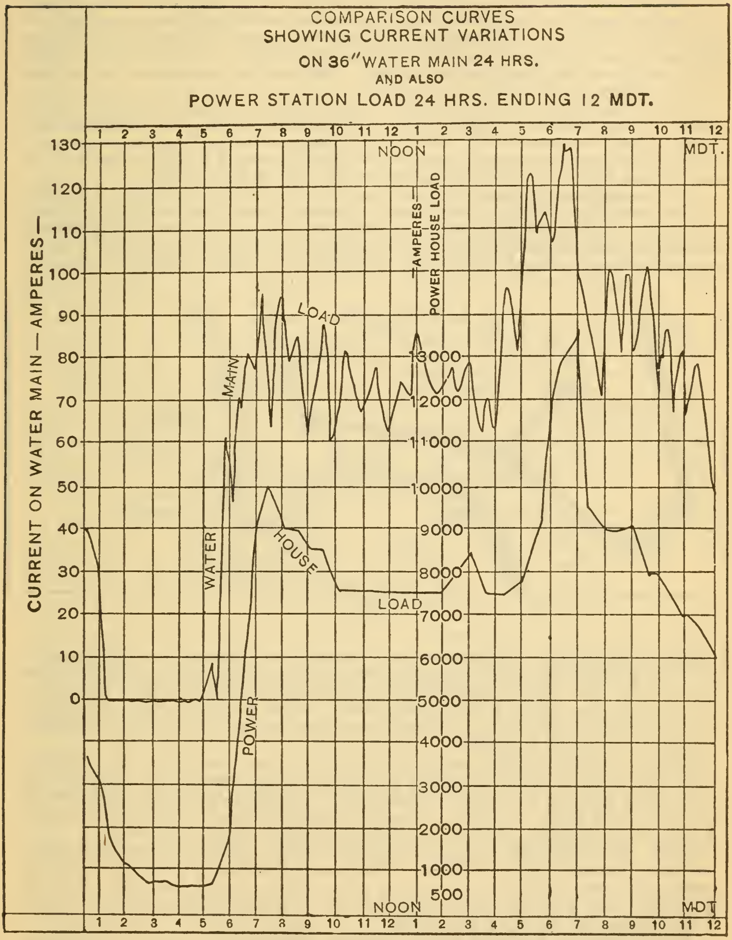

COMPARISON CURVES
SHOWING CURRENT VARIATIONS
ON 36″ WATER MAIN 24 HRS.
AND ALSO
POWER STATION LOAD 24 HRS. ENDING 12 MDT.
CURRENT ON WATER MAIN — AMPERES —
AMPERES — POWER HOUSE LOAD
NOON
MDT.
WATER
MAIN
LOAD
POWER
HOUSE
LOAD
130
120
110
100
90
80
70
60
50
40
30
20
10
0
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
500
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

FIG. 7.

have been destroyed by the returning railway currents delivering at such grounds, causing a heavy loss in piping property to the city by electrolysis. There was no point in the city where mains were positive to the rails; the flow was from rails to mains, thence to shore and to power house. A similar case was discovered by the writer in 1906 during a survey in the city of Toronto, Canada, where mains adjacent to the shore of Lake Ontario, 2 to 4 miles distance from the power house, were badly damaged. The conditions in Bayonne have been changed by the placing of a sub power station in that city.

Such returning currents usually enter the power house through pipes used for condensing. Cases have been found where much damage has been caused to apparatus in the steam plant.

Other current movements may be cited where metal bridges cross a river as in map, Fig. 8, as was discovered in the city of New York.

The power house is located near the Navy Yard, in Brooklyn. A portion of the returning currents, as shown by arrows, flows over the New York and Brooklyn Bridge to Manhattan, thence north to the new Williamsburg Bridge by way of underground mains, subway structures and other metals, and passes over that bridge back to Brooklyn, thence through mains, to

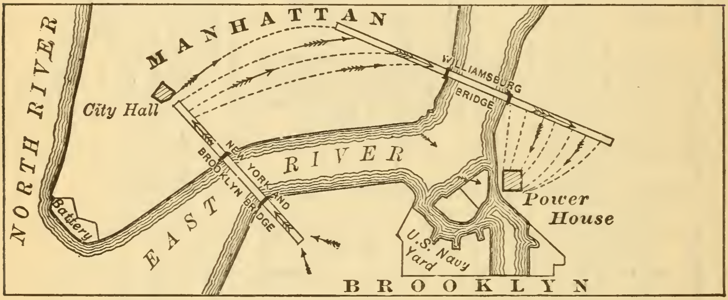


FIG. 8.

rails and negatives, to power house. In this case damage may be expected at three points, viz., where currents leave bridge metals on the Manhattan side, where they leave pipes to enter Williamsburg bridge, where they leave same bridge for pipes on Brooklyn side. When the two bridge structures are connected in Manhattan as proposed, then there will be further changes in this direction of current.

Before the new bridge was built, these currents recrossed through the river bed, *leaving* mains all along the docks on the Manhattan side, for the river, and leaving *the river* for mains or other metals along the docks of the Brooklyn side. Traces of these currents have been found as far north as 23d St., a distance of over two miles from the Brooklyn Bridge.

Since the Williamsburg Bridge has been built, nearly all traces of these currents flowing north of it have disappeared, showing that the mass of metal composing the structure acts as a "short circuit" or path of lower resistance and now carries practically all of the returning currents flowing from Manhattan back to Brooklyn.

Electrolytic Effects upon Water Meters. — This is a comparatively recent discovery, and is due to the location in which many meters are placed. Those found damaged by electrolysis in one city examined have in every case been taken from pits in the cellar bottoms of dwellings, stores, stables, and near water fronts, where tide water had access.

The meter pits in many cases are constructed of boards at the bottom and sides, with a loose fitting wooden cover; this pit, being the lowest point in a cellar, acts as a catch basin and collects the drainage when water is present, partially or wholly submerging the meter very often in stagnant water.

The quality of such liquid makes a convenient electrolytic for any current of electricity. Railway or other current passing to the meter through the service pipes, and out of the meter into this liquid, in time causes a rupture of the thin iron shell of the small sizes where the top is iron.

The actual weight of iron lost through electrolysis by a 4-inch meter located in a ferry house and subject to tide water was in about six years 15 pounds. This meter was near a power house where the p. d. at times reached 25 volts, with mains positive to rails. These severe electrical conditions have since been modified by the railway company improving their track return.

Meters constructed of bronze have had holes eaten through their base where resting on damp soil in cellars. Such grounds often attract trolley current through the service pipes.*

Danger from Fire or Explosions. — Currents entering buildings which contain explosives, through water or gas mains, are dangerous owing to sparks when gas mains are separated or the cross-connecting and disconnecting of pipes containing current, by movable metals is made.

The usual course of such currents is to enter a building on one pipe and pass out upon another when a cross-connection is made between the two systems anywhere inside of a building. When the connection is broken the spark appears, and it may appear at any point in the building, possibly in the presence of explosives.

Bonding the pipes together where they enter the building has proved effective as a temporary remedy in some cases. As no two cases are alike, no particular rule can be laid down as a remedy. Where the conditions are considered dangerous the services of a specialist should be engaged.

Electrolysis in Steel Frame Buildings. — While no instance of serious damage to a steel structure through the disintegration of supports caused by electrolytic action can be cited, still this question is now receiving attention by architects and others, and methods for safeguarding against such corrosive effects are being applied. One such instance of protection is the new *New York Times* building. In one of their publications the following is stated in reference to this structure:

"The danger that in case of the steel frame rusting the disintegration of electrolysis would hasten the process of dissolution so much as to make structures of this kind prematurely unsafe through the destruction of their supports, was recognized in time to permit of ample safeguarding in the case of the steel frame of the *Times* Building.

"It is axiomatic that columns to which moisture has no access will not be impaired by rusting, and that those effectually insulated from vagrant electrical currents will not be affected by electrolysis. The first consideration was to keep the basements dry; hence the thorough waterproofing and draining of the retaining walls already described, which was also carried under the floor of the pressroom, occupying the great area of the sub-basement. As a further safeguard, all the steel members up to the street level are incased in Portland cement mortar to the minimum thickness of three-fourths of an inch. This is effectual protection against rust deterioration. Under these conditions electrolytic disintegration is deemed impossible, but the probability of its occurrence in even microscopic degree is rendered still further remote by as perfect insulation as can be provided. There is sufficient grounding to relieve any electrical tension which may exist in any part of the steel frame by drawing off the current at points where electrolytic action cannot be set up. This also makes it lightning-proof to the extent to which it is possible to impart that quality to a building."

For results of experiments by the writer upon metals in concrete, see February, 1907, Proceedings of the A.I.E.E. in a paper entitled "Electrolytic Corrosion on Iron or Steel in Concrete," discussion in April number.

Current Swapping.— The transfer of currents between the tracks of different companies through underground routes, often by way of mains, is of frequent occurrence, particularly if the lines parallel even for a short distance.

This is more noticeable at the terminus of suburban lines, but also prevails in cities.

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* Case illustrated in abstract of the writer's report for Providence, R.I. in *Water and Gas Review*, N.Y., March, 1907.

One case in a city where the termini of two different lines were but a few feet apart, showed upon measurement a heavy delivery at times, leaving tracks of one company for tracks of another, soil conditions continually wet, consequently a large percentage was flowing through soil and the water mains. Another case near suburban terminals of two railway lines about 600 feet of 6-inch water main with a number of service pipes were practically destroyed by electrolysis; the main acted as an intermediate conductor; the pipes were destroyed under the tracks of one road *by the currents from the other*. An attempt to remedy was made by bonding the two tracks together. This method cut the potential difference between mains and rails from 6.7 volts down to about 2 volts. After six months' standing no further breaks in the mains have occurred. This plan was considered of value in affording temporary relief, but is not now of importance as the tracks of the two lines have been joined by new tracks in a cross street.

Current swapping is more frequent than generally supposed, and is caused largely by local conditions, such as swamps, rivers or other waterways to which a company's tracks connect and are grounded, offering paths which attract their own as well as foreign currents. In the case cited of damaged mains, the flow was *from newly constructed tracks*, seeking grounds on another road where rails were in wet soil. Usually, however, the cause is due to opposite reasons, viz., currents seeking a track return of lower resistance.

A well-constructed road bed on suburban lines will often avoid such opportunity for grounds, and current swapping.

Alternating-Current Electrolysis.

The possibility of damage to underground structures by alternating currents has been investigated by several authorities both in this and foreign countries. As no actual damage has yet been discovered so far as known to the writer, these investigations are necessarily confined to laboratory experiments. The following abstracts from a few papers give a fair idea of what is known of the subject, and where further information may be obtained.

The Ultimate Solution of the Electrolysis Problem by S. P. GRACE, paper before the Pittsburg, Pa., Branch A.I.E.E., read December 12, 1905:

"Our many hundreds of laboratory tests have shown us that the electrolysis to be expected from alternating currents is by no means negligible, and that while it is far less than that encountered with direct currents, in practice we should anticipate that it is only a question of time until its action would destroy many millions of dollars of underground metallic structures."

From transactions of the Farady Society, Volume I, February, 1906, Part 4. *Alternating-Current Electrolysis as shown by Oscillograph Records*, by W. R. COOPER, M.A.B. Sc., read October 31, 1905:

Photographic reproductions of oscillograph records are given illustrating results of his investigations. The author also gives results of several other investigators of this subject.

From transactions of the Farady Society, Volume I, August, 1905, Part 3. *Alternate Current Electrolysis* by PROF. ERNEST WILSON, paper read July 3, 1905:

The author gives results upon different metals at different frequencies and in different solutions, and begins by saying, "It is well known that if an alternate current be passed between metal electrodes in an electrolyte, electrolysis may take place."

The Electrolysis Problem from the Cable Manufacturers' Standpoint, by H. W. FISHER, paper before A. I. E. E., Pittsburg, Pa. Branch, read December 12, 1905:

"My experiments have not been very comprehensive, but I have found under certain conditions, destructive electrolytic action may occur with alternating currents operating at a frequency of 60 cycles per second.

The solution I employed for the electrolyte was water containing common salt and salammoniac, all of which may occur in and around duct systems. I found that with a current density of 0.1 ampere per sq. in. of lead, there was no electrolytic action.

Amperes per sq. in. of Surface.	Lead Destroyed per Ampere, per hour, per sq. in.
3.04	.004 Grammes.
11.8	.136 "
17.9	.237 * "

. . . . . . with a frequency of 25 cycles per second, the alternating current action would probably be greater than shown by my tests." This latter statement agrees with Prof. Wilson's tests above referred to, where he says, "It will be seen from the table that the total diminution in weight, which was equally distributed between the two plates, in a given cell is nearly twice as great at low frequency as it is at high frequency."

Remedies. — Several methods have been suggested for counteracting the evil effects of electrolysis.

The insulated metallic circuit.

The underground, known as the "slotted conduit," has been in successful practical use in the borough of Manhattan, city of New York, some ten years, and for a still longer time in the city of Washington, D. C.

The double overhead trolley has been in successful practical use in the suburbs of the city of Washington for some years, and in the city of Cincinnati, Ohio, since 1889, and more recently has been established in the city of Havana, Cuba.

Both outgoing and return conductors of either construction are insulated; where there is no connection to the rails or ground the currents which propel the cars are confined to their respective conductors, consequently no damage to underground metals is possible.

Improved Track Return.

Next to the double trolley, this method is probably the best, although a modification of the trouble.

In some cities a large amount of copper for returns has been placed for this purpose, as well as heavy double bonding at the rail joints. The expense involved in providing copper returns sufficient to give a fair degree of protection to mains, would in most cases be considered unnecessary by the railway companies, unless compelled by law.

Bonding Mains to the Track Circuit.

This has been done in some cities for the purpose of protecting a positive area where electrolysis was found to be acute; usually this is near a power house. Some effects of such bonding have been mentioned.

While this may protect from injury the immediate area where such connections are made, it is likely to aggravate joint corrosion by the increased flow which has been pointed out.

Meters. — A remedy for exterior electrolysis upon meters is to place them in iron or other receptacles under a sidewalk where they will be free from liquids or damp soil. Such methods are used in the cities of Cleveland, Ohio; Richmond, Va.; and Louisville, Ky. Official reports show in such case they are in no danger from electrolysis, or from freezing, and are easily accessible for reading, and removing when desired.

Insulating Joints in Mains. — This is a further attempt at remedy, and much attention has been given to this phase of the subject by railway companies in Boston, Mass., with the Metropolitan Water Works coöperating.

The Metropolitan Official Report dated January, 1905, contains much information on this and other attempts to stop the current action which

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* In this case a large hole was eaten through the lead, and the surface exposed to electrolytic action was nearly a square inch.

was causing great damage to their mains. Several insulated joints have been set, and are found to be fairly efficient in arresting the flow of current through a main. Usually, however, it is at the expense of diverting flow into other mains.

In one case an experiment was tried of two joints in a 48-inch main, one insulated with wood and the other with rubber. A measurement made when the writer was present showed the one with wood insulation than that of the rubber after six months' use.

The following sketch will illustrate the tests.

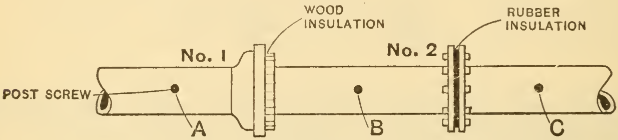


Fig. 9.

Ammeter test between A and C gave 60 to 110 amperes, representing the flow if there were no joints. Between A and B, flow passing through No. 2 (rubber) 0.6 to 1.0 ampere. Between B and C, flow passing through No. 1 (wood) 0.1 ampere. This reading should not be taken as the true value for all cases owing to varying conditions. The efficiency of either one for stopping current was in this particular case very good.

Fig. 10 represents a pair of insulated joints ready to place in a 6-inch main. They are made up of wood slats driven in the hubs; a flange of wood rests at

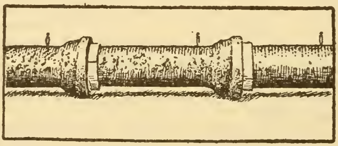


Fig. 10.

the bottom of the hub. The three screw posts are for wires which are led to the surface for testing efficiency of each joint.

Fig. 11 shows the same joints connected in the main at the bottom of the pit, and wires run to ammeter. Before the pit was filled in, wires were run through small pipe to the surface of the street, the ends being secured by cap, for future testing.

A test with low reading ammeter failed to show any sign of current passing through either joint, when first set. After two years one joint shows leak of 0.1 ampere; the other perfect, short circuit around both joints shows 5 amperes.

A water pressure of 110 lbs. to the square inch was put on this main, and neither joint leaked. Two joints were used in case one failed, and to provide opportunity for testing efficiency of either one.

Experience in Boston is, joints of wood are preferable to those of rubber, on the ground of expense, and equally efficient for stopping current flow.

Surface Insulation. — Wrapping a 48-inch main with burlap saturated with asphalt cement applied hot, is another attempt to stop electrolytic action near a power house.

After two years' trial, results show, after careful examination, this method to be unsuccessful, and it has been abandoned. This class of insulation has long been known by electricians to be *no protection to metals where subject to continual moisture.*

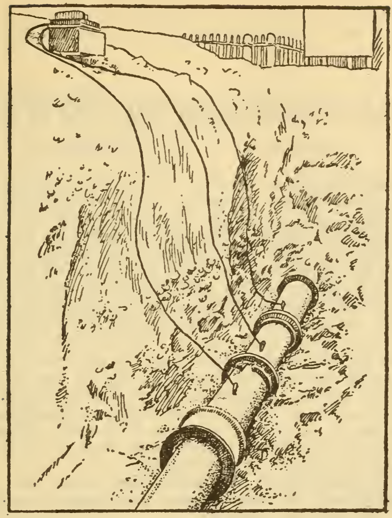


FIG. 11.

Summary.

1. The *tendency* of return currents on long lines five to ten miles from a power house is to leave the tracks near a terminus and seek "grounds." This may be by way of other tracks, by way of underground mains, or by water routes. Recent tests show that a very good return construction will not wholly prevent such diversion of currents.

2. Low spots in a company's road bed, where rails are in contact with wet soil, offer an attractive outlet for their own, or foreign, currents.

3. Bonding rails to mains always invites heavier flow of currents to the mains, with corresponding increase of damage at joints.

4. All establishments manufacturing or carrying explosives should be often examined, particularly if contiguous to electric railways, and if metal pipes of any kind pass to them the passing of straying currents into and through such establishments is quite possible and oftentimes dangerous.

5. Protection of metal foundations of important structures, such as tall office buildings, bridges, etc., from electrolytic action should be well considered before their construction and occasionally tested after construction.

6. **Current Swapping.** — The cause for current swapping between railway tracks should be sought out and removed where possible, especially in cities or towns where underground mains are likely to be included as conductors to their detriment. In one case bonding of tracks of two companies together afforded relief.

7. **Insulated Joints** in water mains have proven effective to stop current flow in some cases, but often at the expense of diverting it to other mains.

8. No complete cure for electrolysis has been discovered where the grounded return is in use.

TRANSMISSION OF POWER.

REVISED BY F. A. C. PERRINE.

THE term "*Transmission of Power*," as used by electrical engineers, has come to have a conventional meaning which differentiates it from what must be considered its full meaning. Any transmission of electric current, for whatever practical purpose, whether for lighting, heating, traction, or power-driving, must of course be a transmission of power; but the conventional meaning of the term as now used by electrical engineers and others eliminates many of these objects, and is held to mean simply the transmission of electric current from a more or less distant point or station to a center from which the power is distributed, or to power motors at different points in a factory or other installation. While the distances over which electric current is transmitted for arc lighting in some large cities and in many small places far exceed the length of line of the ordinary or average power transmission, yet the former is never alluded to as transmission of power. The same condition obtains with traction, the transmission of current covering miles of territory, and yet it is only alluded to as power transmission when the current is transmitted from a central point to various sub-stations from which it is distributed.

Many engineering features of *transmission of power* will be found treated under the separate heads in their respective chapters, and the following is a short *résumé* of the subject matter.

Building.

Structural conditions and material.

Motive Power.

Water power: Turbines, etc.
Steam power: Boilers and appliances.
Engines and appliances.
Shafting and pulleys.
Belting and rope drive.

Generators.

Dynamos: Direct current.
Alternating current.
Double current.

Transmitting Appliances.

Switchboards.
Transformers, step up.
Rotaries.
Cables and pole lines.
Conduits, etc.

Distributing Appliances.

Sub-stations and terminal houses.
Transformers, step down.
Switchboards, high tension and secondary.
Rotary converters.
Direct current motors.
Synchronous motors.
Induction motors.
Frequency changers.
Distributing circuits.

Much has been written regarding the relative values of the different methods of transmitting power, and comparison is often made between the following types, i.e.,

a. Wire rope transmission.
b. Hydraulic transmission, high pressure.
c. Hydraulic transmission, low pressure.
d. Compressed air transmission.
e. Steam distribution for power.
f. Gas transmission.
g. Electrical transmission.

All of the first six methods listed have so many limitations as to distance, efficiency, adaptability, elasticity, etc., that electricity is fast becoming the standard method. The matter of efficiency alone at long distances is one of the best arguments in its favor, and we take from Prof. Unwin's book, "Development and Transmission of Power," the following table of the efficiencies such as have been found in practice.

System.	Per Cent Efficiency at	
	Full Load	Half Load
Wire rope	96.7 *	93.4 *
Hydraulic high pressure	55	45
Hydraulic low pressure	50	50
Pneumatic	51	44
Pneumatic reheated virtual efficiency . .	75	64
Electric	73	65

For short distances out of doors, transmission by wire rope is much used both in the United States and Europe, and where but few spans are necessary, say less than four, it is obvious that the efficiency is very high.

Hydraulic transmission is in considerable use in England, but except for elevator (lift) service is in little use in the United States.

Pneumatic transmission is in wide use in Paris, but not so for general distribution in the United States, although for shop transmissions for use on small cranes and special tools is making good progress, the principal usage being for the operation of mining drills, hoists and pumps.

Electrical transmission is so elastic and so adaptable to varied uses, and has been pushed forward by so good talent, a not small factor, that its progress and growth have been simply phenomenal. In one place alone, that of traveling cranes for machine shops, it has revolutionized the handling of material, and has cheapened the product by enabling more work to be done by the same help. Indeed the great increase in size of units which is such a distinguishing characteristic of modern engineering has been rendered possible by the capacity of the electric traveling crane for lifting great weights.

Electric Power Transmission may be divided into two classes, i.e., long distance, for which high tension alternating current is exclusively used; and local or short distance transmission, for which either direct current or polyphase alternating current are both adapted, with the use of the former largely predominating owing perhaps to two factors: *a*, the much earlier development of direct current machinery, and *b*, to the fact that a large number of manufacturers are engaged in the building of direct current machinery. Both types of current have their special advantages, and engineering opinion is, and will probably remain, divided as to which has the greater value.

* Per span.

Long distance transmission is now accomplished by both three-phase three-wire, and by the two-phase four-wire systems, with the former predominating for the greatest distances, owing to economy of copper.

Every case of electric transmission presents its own problem, and needs thorough engineering study to decide what system is best adapted for the particular case.

Limitations of Voltage.— While 10,000 volts pressure was used with some distrust for a time previous to 1898, since that time voltages up to 70,000 volts have been and are still in use with substantial satisfaction, and plants using voltages of 80,000 and 100,000 are under construction.

Properly designed glass or porcelain insulators, made of the proper material and tested under high pressure conditions, cause little trouble from puncture or leakage. The latter is its own cure, for the reason that the leakage of current over the surface of the insulator dries up the moisture. Dry air, snow, and rain-water are fairly good insulators, and offer no difficulties for the ordinary high voltages. Dirt, carbon from locomotive smoke, dust from the earth, and such foreign material that may be lodged on the insulators, are sure to cause trouble. In the West and some sections of the East many insulators are broken by bullets fired by the omnipresent marksman.

At the lower voltages glass makes a satisfactory insulator, as the eye can make all necessary tests; but it is so fragile that porcelain is more commonly used. It is not safe to accept a single porcelain insulator without a test with a pressure at least twice as great as that to be used.

Mr. Ralph D. Mershon of the Westinghouse Electric & Manufacturing Company made a long series of tests at Telluride, Col., on the high-pressure lines in use there. With a No. 6 B. & S. copper wire he found that at 50,000 volts there will be a brush discharge or leakage from one wire to the next that can be seen at night, and makes a hissing noise that can be heard a hundred feet or more. This brush discharge begins to show at about 20,000 volts, on dark nights, and increases very rapidly, as does also the power loss at 50,000 volts and higher. This loss depends upon the distance apart of the conductors and their size. For these reasons, wires should be kept well apart and be of as large size as other properties will allow.

The wave form of E.M.F. used also influences the brush discharge, being the least in effect for sine wave curves of E.M.F., and being much increased by the use of the sharp, high forms of curve.

In regard to the frequency to be adopted for power transmission, one has to be governed by the case in hand, and the commercial frequencies available at economical cost.

SPECIAL FEATURES OF DESIGN DUE TO TRANSMISSION LINE REQUIREMENTS.

While the general requirements for the design of a power plant and line for long distance power transmission are practically similar and theoretically identical with those for other electrical installations, at the same time special features are important. These are due to the character of service required, the size of the plants, high voltage, and location of the plants. The general features of design have already been considered in this book, and a short resumé is given on page 864. Below, attention is called to special requirements to be considered in power transmission installations.

Buildings.—Transmission generation stations are commonly located in relatively inaccessible locations, and the size of unit is therefore limited, whereas the total capacity of the station may be great and the current is transmitted at high potential.

Transportation and labor conditions must be carefully studied, as the neglect of this precaution may readily involve an underestimate of no less than 25%, and has often so resulted in estimates otherwise correct. This is especially true as regards the use of patented or special building construction, which might result in savings where competent workmen are to be had, but which actually result in excessive cost where the amount of work to be done is not sufficient to import men familiar with the type of construction.

Roofing. — The buildings should be entirely fireproof, and whereas this is easily taken care of by avoiding wood altogether in the interior construction, supports and walls of the building, a mistake is often made in choosing a roofing which must be laid upon planks. Such construction has frequently resulted in disastrous fires at power plants otherwise indestructible.

Heating. — Where temperatures do not fall to less than 10° F. the waste of energy from the machines is commonly sufficient for heating; where lower temperatures are encountered, special provisions must be made for heating. Boilers for steam- or water-heating fired in cellars accessible from the outside of the building only are the best.

Outlets for High-Tension Wires. — In buildings where the temperature falls below freezing, sewer pipes with large openings for high-tension wire outlets should not be used on account of the excessive draft through these openings. A number of systems for high-tension wire outlets are described in *Transactions of American Institute of Electrical Engineers*, Vol. 22, p. 313; Vol. 23, p. 578; Vol. 25, p. 865. Special methods for carrying out some of these plans have been designed and are described in the catalogues of the porcelain insulator manufacturers.

Lightning Arrester Protection. — Arresters should be considered as belonging to the line and not to power house, and lightning arresters should not be installed in the power house itself, but in a separate neighboring enclosure especially erected. Arresters are to be considered as a means for preventing line disturbances entering the power house in any manner.

Separating Generator and Transformer Rooms. — The only reason for attempting to separate generator and transformer rooms is on account of the oil contained in the transformers which may become the source of fire hazard. If, however, the oil transformer is properly enclosed, separate buildings are unnecessary. See *Transactions of American Institute of Electrical Engineers*, Vol. 23, p. 171.

Auxiliary Buildings. — No estimate on an isolated transmission power house is complete which does not include houses for the married employees, a central mess house with reading room, assembly room and offices, and stables for the accommodation of horses. Unless these features are properly taken care of, it will be difficult to retain satisfactory employees and to operate the plant economically and continuously.

MOTIVE POWER.

Water Power. — Load factor and total capacity are closely related in questions of design and revenue.

The effect of yearly load factor on revenue is shown by the curves below.

By reducing all yearly load rates to a K.W.H. basis we are enabled, through the use of these curves, to determine the total revenue to be derived when we know the total yearly K.W.H. that any variable water supply may sell when applied to the operation of any set of variable loads, and hence the value to the plant of an annual storage.

In variable loads there is a variation in the daily load factor as well as in the annual load factor.

STORAGE RESERVOIRS.

Apart from Plant. — These reservoirs serve to aid in properly supplying variable annual load factor, but on account of plant distance, cannot take care of daily variation in load factor.

Adjacent to Plant. — When a daily variation of load factor is to be met, revenue may be increased by reservoirs near the plant that may be called upon for conserving water flowing at low power periods and delivering it at peaks, which cannot be done by distant storage.

Auxiliary Power. — The value of any plant should be based, not upon the total maximum or minimum capacity, but upon the K.W.H. salable, and in obtaining the maximum K.W.H. capacity it is often possible to increase this by auxiliary machinery to be used at the low water periods or at periods of customer's peak. Neglecting the study of this factor often results in estimates of plant value unnecessarily low.

Auxiliary power may be obtained from steam, water, or gas, as is obtainable at the most satisfactory cost, not necessarily the lowest price. The most satisfactory cost is that which yields the greatest annual K.W.H. output from the total plant at the lowest cost.

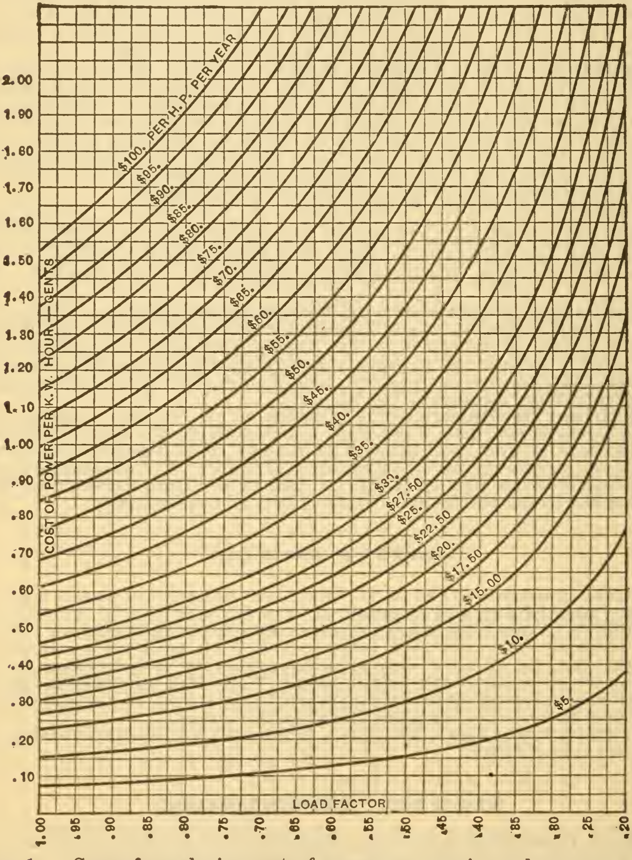


FIG. 1. Curve for reducing cost of power per maximum horse-power per annum in dollars to cost per kilowatt-hour in cents at various load factors.

Ditches, Canals and other Conduits. — Construction of open ditches is generally the cheapest method where water is to be carried a long distance over ground fairly uniform and capable of being made tight. Ditches are distinguished from canals mainly by size; the term "canal" being applied to large open water carriers, and is particularly applied where the sides and bottom are reinforced for reducing friction or maintaining the structure. Where ground is of such character as induces leakage, or where surface evaporation is excessive, it is necessary to carry water through pipes or through enclosed conduits. In such case the conduit is run full and under pressure, which means that the top of the conduit must always lie below the hydraulic gradient. Economy in construction is obtained by running close to the hydraulic gradient and concentrating the fall near the power house.

Pipe Lines or Penstocks. — Pipe lines near the power house, where a rapid fall greatly exceeding the slope of the hydraulic gradient is allowed for useful head, are generally called penstocks. Such lines are built at as rapid a fall as possible and constructed of various thicknesses or strengths to conform to the increased water pressure.

Fish Ladders. — In all streams where there are any fisheries or where the government is introducing spawn or small fish, the law requires the use of fish ladders, which must be included in the estimate on any such plant. No standard type of ladder has ever been permanently adopted, and the construction must depend upon the character of fish they are intended to serve. Salmon will go up ladders requiring jumps of from two to four feet; but smaller fish, shad, trout, etc., must be provided with ladders with jumps not over one foot. These ladders consist of flume boxes rising from the river to the point above the dam, each box rising slightly above the preceding one from the river, and each allowing a relatively quiet flow near the dam into the next one.

Effect of Silt on Storage. — Most streams carry more or less silt, and have been known to carry as high as 13 tons of silt per second foot of water per day. Under such circumstances the capacity of the storage is often reduced, and where such conditions are encountered, only a small proportion of the total storage area can be relied upon, unless special means are provided for removing the silt. Dams will fill less rapidly with silt if the surplus water during floods is carried off through the bottom of the dam rather than over the crest.

Choice of Head. — It is an error to subdivide heads which are not more than 2,000 feet in height, since pipe can be readily obtained to handle 2,000 feet head, and sub-division of the head not only increases the cost of installation, but also the cost of operation. This is true, not only for high heads, but for low, as the building of a high dam in place of two low ones more than doubles the available storage. Exception to this is when relatively constant load is to be operated, in which case the increase of storage does not increase the total yearly K.W.Hs., and the cost of the high dam, which is about double that for two low dams, is unwarranted. Here, as always, the construction of the plant should depend upon the total yearly K.W.Hs. salable, without especial reference to the total yearly K.W.Hs. available for sale, unless it may definitely be shown that the surplus yearly K.W.Hs. salable at the time of construction can be increased by reason of having a greater available quantity of energy.

Estimate of Water. — Excepting at the head waters of streams or where an actual gauging is obtainable, it is unwise to estimate any stream in the United States at a minimum greater than .25 per second foot per square mile of drainage area. In the east and south this minimum is produced by the summer drought, which is also true on the Pacific Coast. In the west and north this minimum is produced by the cold winter weather when the streams are frozen and flow diminished below that of any other period of the year. The best estimate of water flow can be obtained where accurate gaugings have been made by a careful and experienced government office. Even these must be modified by a study of the local conditions and of the rain fall. Where gaugings for a considerable period of time are not obtainable, an approximate estimate of the water flow can be obtained by a study of the rain fall and then compared with gaugings in a similar locality, though the extreme minimum cannot be obtained in this manner, and a minimum considerably below that indicated by the rain fall should be taken.

Coal Power. — Coal power for transmission is only practical in one or two conditions: First, where waste coal is obtainable ; and secondly, where inaccessible coal can be marketed by transmission. Coal is primarily a domestic fuel and material for chemical reduction. Its continued use for power is only a question of relatively few years, excepting where coal can be obtained which is not adapted to other purposes, or where it cannot readily be made available by other means. As an auxiliary power material it is well adapted for supplementing the deficiencies of water power plants, or for handling the peaks of loads, thereby enabling a greater total yearly K.W.H. output from any given installation.

GENERATORS.

Frequencies. — This subject is much confused at the present time. Twenty-five cycles has been a standard frequency for power work as it is well adapted to use of the present type of synchronous rotary converter. It has never been well adapted to lighting work or to the induction motor, and at the present time, with the strong development of single-phase railroad working, it is a questionable frequency for that service. A frequency of 60 cycles is perfectly adapted to all lighting needs, motor-generator sets for conversion to direct current, and for inductor motor converters, as well as the newer types of synchronous rotary converters. The effect of increasing the impedance of the line at 60 cycles has not given added trouble over that found when low frequencies are used, excepting in the case of lines delivering over 10,000 K.W. In any case of transmission the frequencies must be determined by the market to be served, both for the immediate future and the distant future, where power is available to contemplate increased development. A choice of frequency different from 60 cycles must be well warranted by the circumstances, or not adopted.

Voltage. — Direct generation of high voltage should not be contemplated, excepting where the present and future market can be reached at not over 500 volts per mile. When direct generation is not contemplated, standard 2300 volt generation is to be preferred, unless the plant to be installed contains great capacity, in which case 6600 volt generation is preferable.

Regulation. — Close regulation for inductive loads should at all times be preferred, but in large stations, where the load is relatively steady, it should be remembered that a change to 1,000 K.W. on a 10,000 K.W. machine represents only one-tenth the variation of what the same change in load means in a 1,000 K.W. machine.

Speed. — High speed is always preferable in power houses for transmission work. It should be remembered, however, that for impulse wheels the correct speed of the wheel buckets is about one-half spouting velocity of the water, and in consequence, all machinery should be installed to allow a speed practically equal to full spouting velocity of the water when the load goes off.

For turbine wheels the speed is approximately 70%, the spouting velocity of the water, and for no load does not increase more than 50%.

Size of Units. — While large sized units are preferable, units should not be chosen which are greatly underloaded for long periods of the day, nor should units be adopted which do not allow the installation of at least one spare at the maximum load.

Use of Direct Current. — In the United States direct current to-day is practically unused. In Europe it is somewhat used in Italy and Switzerland. The success obtained by the use of direct current where it has been employed, and the recent developments in the design of direct current machines warrants its future employment, but as direct current is only used in constant current circuits the line loss is constant, and is only warranted where there is constantly flowing a surplusage of water which cannot be conserved.

TRANSMITTING APPARATUS.

Switchboards. — For transmission plants which run to very high line voltage, it is preferable, even in comparatively small stations, to install the high tension oil switches in such a manner as will not tend toward the destruction of the plant should they fail and burn. The lower tension generator switches may be installed in the line of generator leads without attempting to bring the generator leads to one central point for re-distribution of the current from that point. These provisions can be carried out by means of the installation of centrally located distant control switches, while keys or switches are installed for operating the high and low tension switches, without bringing any current above 120 volts to the operating board.

TRANSFORMERS.

Single or Multi-Phase. — In large installations multi-phase transformers reduce the number of units to be taken care of and the complexity of the wiring. In the smaller installations they involve a greater proportion of spare units. Accordingly multi-phase transformers are to be considered preferable to single phase, excepting where their size calls for too much added machinery in the spare units.

Protection against Fire. — A large majority of the transformers used in transmission plants to-day are oil filled. Experience seems to indicate that this does not increase the fire hazard, excepting in so far as this is due to the presence of a large quantity of oil. When oil can be kept cool and within the cases of the transformers it does not increase the fire risk. It may be kept cool by circulating water rapidly through the cooling coils in the transformers, though a separate enclosure of each transformer within a space where water may be sprayed on the outside of the case, or the enclosure filled with water, is a surer means than that of relying on the circulating pipes, whenever any serious accident has occurred. Accordingly transformers should be enclosed where water can readily flow on them without damaging the remainder of the machinery. Transformers through which the oil is circulated and the oil cooled outside the transformers constitute a greater fire hazard than those in which the water circulating coils are immersed in the oil within the case.

Another way is to provide a large tank into which the oil from the transformers may be drained in case of fire.

POLE LINES.

Right of Way. — For high tension work private rights of way are to be preferred and result in final economy in operation. Rights of way adjacent to steam railroads result in difficulty with the insulation on account of the coal smoke and are not to be sought. It is not generally practical to obtain a right of way so wide that in case the pole or tower line fall it will fall entirely within the right of way. Width of from 50 to 100 feet is entirely practical, provided the additional right is given to cut diseased trees within an additional 50 feet on either side of the right of way.

Character of construction has already been described under the following headings: Wood poles, towers, cross-arms, pins, insulators, attachment of insulators.

STORAGE BATTERIES.

REVISED BY LAMAR LYNDON.

Theory and General Characteristics.

Elements. — The form of storage battery now in general use is that in which the electrodes are of sponge lead (Pb) and lead peroxide (PbO_2) which, when immersed in dilute sulphuric acid, form a voltaic couple. Its action differs in no wise from that of the ordinary primary battery, except that when it has given out all the energy that the chemicals present enable it to supply, instead of having to put in new chemicals, the cell can be regenerated or brought back to its original condition by passing current into it in a direction opposite to that in which the flow took place on discharge. Obviously, there are many combinations which can be used as storage batteries, but with the exception of the lead-sulphuric acid battery, none has proven commercially practical, unless it be possibly the Edison battery, which has lately appeared. This battery has for one of its electrodes, nickel oxide, and for the other, finely divided iron or iron sponge, these being immersed in a solution of sodium hydrate. Up to the present, however, these cells have not been used for power work, and therefore the discussion will be confined to the lead battery.

The plate on which the lead peroxide is carried is termed the positive plate, and the lead sponge plate is termed the negative, the reason being that on discharge, current flows from the lead peroxide plate and returns to the battery via the lead sponge plate. The condition, however, is the opposite of this inside the cell, as the current flows from the lead sponge plate to the lead peroxide plate. Therefore, considered as a voltaic couple, the lead sponge plate is the positive; considered as a source of electric current, however, the lead peroxide plate is the positive, since it is from this electrode that the current flows out.

Theories. — The first and oldest theory is that on discharge hydrogen, which is released at the lead peroxide plate (PbO_2), combines with some of the oxygen in the peroxide, forming water, and reducing the oxidization of the PbO_2 by one molecule of oxygen, bringing it to a state of lead oxide, or PbO. At the sponge lead plate, oxygen is released (these released gases coming, of course, from the electrolytic decomposition of the water in the electrolyte), and this oxygen (O) combines with the sponge lead (Pb), and oxidizes it, causing it also to become lead oxide (PbO). Thus the two plates tend to approach the same chemical composition. If lead oxide (PbO) be immersed in sulphuric acid, it will be chemically attacked, independently of any current flow, and change into lead sulphate, the chemical reaction being

$$PbO + H_2SO_4 = PbSO_4 + H_2O.$$

Thus the active material on both the plates tends to approach the condition of lead sulphate.

On charge, the reverse condition takes place, the hydrogen being released at the negative plate and the oxygen being released at the positive, the hydrogen reducing the oxide in the negative plate and carrying it back to its original condition of sponge lead, and the oxygen at the positive increasing the oxidization of the positive plate and returning it to its condition of lead peroxide, PbO_2.

The later theory is that the plates do not pass through the intermediate stage of being changed to lead oxide, but, on discharge, change directly from their respective states to that of lead sulphate. This theory is doubtless the correct one, for the reason that in the *chemical* change from lead oxide to lead sulphate, heat is released, which represents lost energy, and if this energy loss should take place it would be impossible to get from the storage battery a large proportion of the amount of energy which might have been put into it on charge.

The foregoing is set forth by the following reversible equation, which shows the action that takes place:

$$\xleftarrow{\text{charge}}$$

$$
\begin{array}{ll}
(1) & PbO_2 + H_2SO_4 = PbSO_4 + H_2O + O \\
(2) & Pb + H_2SO_4 = PbSO_4 + H_2 \\
\hline
(3) & = (1) + (2) = PbO_2 + Pb + 2\,H_2SO_4 = 2\,PbSO_4 + 2\,H_2O.
\end{array}
$$

$$\xrightarrow{\text{discharge}}$$

The first equation shows the reactions which take place at the positive plate; the second shows those which occur at the negative; and the sum of these two, the third, is the combined effect and is the fundamental equation of the storage battery. Reading from left to right the reactions are those which take place on discharge, while read from right to left the reactions are those which take place on charge.

Change in Electrolyte. — The reversible equation of the storage battery shows that some of the SO_3 in the sulphuric acid (which may be looked on as being made up of $H_2O + SO_3$) goes into chemical combination with the plates on discharge, and a definite amount of SO_3 is abstracted from the electrolyte from each ampere hour of discharge, and therefore the concentration of the electrolyte decreases and is lower at the end of discharge than at the beginning. The amount of SO_3 abstracted per 100 ampere hours is 298 grams, and therefore, with a given quantity of electrolyte and acid density, the final density at the end of discharge after a certain number of ampere hours has been taken out, can be computed.

The formula for computing the quantity of electrolyte required, when the initial and terminal densities are given is

$$X = \frac{1290 - 10.53\,d}{D - d}.$$

X = number of ounces avoirdupois of electrolyte per 100 ampere hours of discharge.
D = percentage of H_2SO_4 in the electrolyte at the beginning of discharge.
d = percentage of H_2SO_4 in the electrolyte at the end of discharge.

For discharge other than 100 ampere hours, multiply the computed value of X by the actual discharge and divide by 100.

Also $$D = \frac{1290 + d\,(X - 10.53)}{X},$$

and $$d = \frac{1290 - XD}{10.53 - X}.$$

Sulphate. — Lead sulphate, which is a white substance, has no conductivity whatever, and if too much sulphate be allowed to form on discharge, it is difficult to bring the battery plates back to their original condition because the regenerating current cannot be made to flow through the sulphated masses. If the plates are only partially sulphated, the high conductivity of the active material with which the sulphate is mixed will afford a path for the current which can easily reduce the sulphate back to sponge lead or lead peroxide.

This is one of the reasons why discharge should never go beyond the point where the voltage per cell is 1.8 with normal outflowing current.

Change in Volume. — Another reason for avoiding overdischarge lies in the increase in volume of the active material when converted into lead sulphate. If too much of the active material be converted into lead sulphate, the increase in volume sets up strains in the plates, tending to buckle them, and causes the active material to crack or shed and fall away from the supporting grid, thus reducing the amount of available active material, the capacity of the plates, and shortening their life.

Voltage. — The voltage of lead peroxide against sponge lead in dilute sulphuric acid is about 2 volts, varying with the concentration of the acid. The actual voltage for any concentration may be computed by Streintz's formula: $E = 1.850 + 0.917\,(S - s)$, in which

E = E.M.F. of cell.
S = Specific gravity of the electrolyte.
s = Specific gravity of water at the temperature of observation.

In practice it is generally assumed as 2.05 volts, this being the E.M.F. on open circuit when the battery is fully charged; that is, both electrodes being free from any lead sulphate. As the battery discharges, the voltage gradually decreases, so that when the battery is nearly discharged its voltage is less than at the beginning of discharge. The reasons for this will appear hereafter.

Appearance of Plates. — The battery plates are distinguishable both by their appearance and hardness, the peroxide plate being of a reddish brown or chocolate color and hard like soapstone, and the sponge lead plate is a grayish color, and can readily be cut into with the thumb nail.

Requirements. — Neither lead sponge nor lead peroxide possess any mechanical strength, and therefore in order to make them into suitable electrodes it is necessary that they be attached to a supporting plate or grid, and since lead is the only metal except the so-called "noble metals" which resists the action of sulphuric acid, the supporting grid is always made of it.

In order that a storage battery should work satisfactorily the current must be distributed equally over the surface of the plate and pass through, practically, all the molecules of the active material both on charge and discharge, and it is essential that batteries be so designed as to attain this condition; otherwise portions of the plate will be overworked and will disintegrate, while other portions may be left in good condition.

Types of Plates.

In the production of battery plates there are three general methods:

One is known as the Planté process, which consists in chemically or electrochemically forming sponge lead or lead peroxide directly on the surface of a lead plate, this active material being produced from the lead of the plate itself.

The second method consists in taking certain oxides of lead, principally litharge and red lead, and mechanically applying them to a previously prepared leaden grid — generally under pressure — and afterwards reducing these oxides to sponge lead or lead peroxide.

The third method, which is not much used now, is to prepare pellets of sponge lead or other lead compounds which may easily be reduced to sponge lead, placing them in a mould, and casting the supporting grid around them.

In the Planté type of battery the layer of active material produced is comparatively thin, and in order to obtain a sufficiently large quantity to give each plate a reasonable capacity, it is necessary that the area exposed be made as large as possible. This is accomplished by some method which raises grooves or webs in the plate, or by making up the plate of narrow ribbons of lead, which are folded backwards and forwards until an electrode is finally produced, the thickness of which is equal to the width of the lead ribbon, the length and breadth of the plate being anything that may be desirable.

The comparative value of these different types of batteries will be taken up after discussion of various characteristics of batteries in operation.

Capacity. — The unit of storage battery capacity is the ampere hour, that is, the ability to discharge one ampere continuously for one hour.

The capacity is dependent on the rate of discharge; the temperature; the quantity of active material present; the quantity of electrolyte in the cell, and the exposed surface of the plate.

Theoretically, .135 oz. of active material per negative plate, with .156 oz. per positive or .291 oz. for both electrodes will, in the presence of sufficient electrolyte, give a discharge of one ampere hour. In practice about

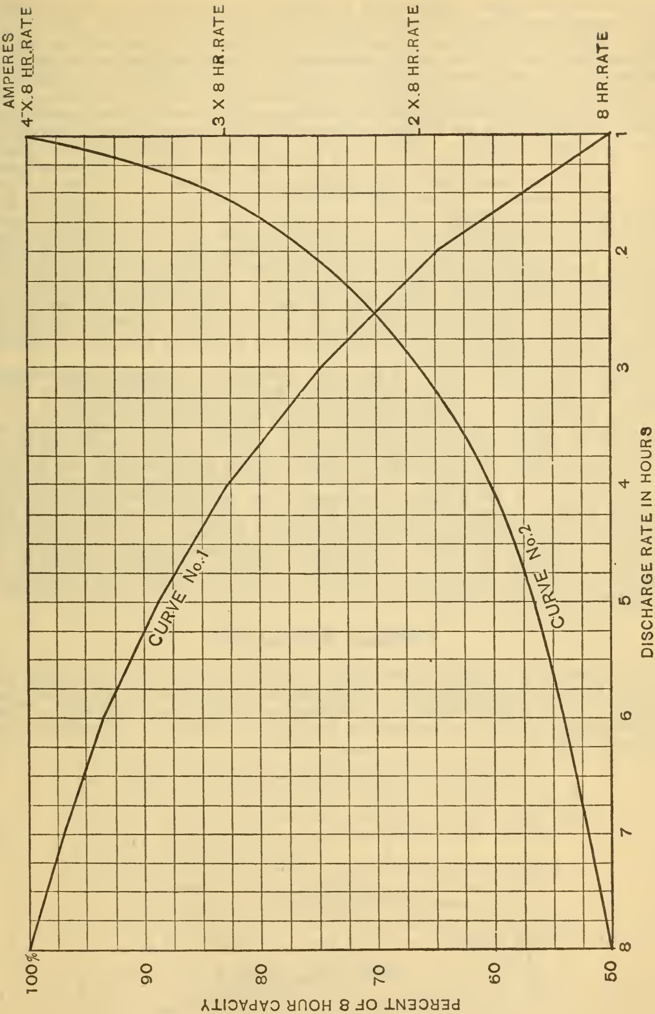


Fig. 1.

five times this much, or 1.45 oz. for both plates, is required. The reason of this is that the active material is not completely reduced, the discharge being stopped before the point of zero voltage is reached, and the gradual formation of sulphate as discharge proceeds, tends to close up the pores and prevent access of the electrolyte to the mass of active material.

The capacity increases with increase in temperature, being about 1 per cent for each degree Fahrenheit increase in temperature. Theoretically, the ampere hour capacity of a battery should not vary with the current rate. If a battery discharge continuously 100 amperes for 8 hours, giving 800 ampere hours at this rate, theoretically it should discharge 800 amperes for one hour. As a matter of fact, however, the ampere hour capacity of a battery decreases rapidly with increase of rate of current flow. The reason for this decrease in capacity is due to several causes, the most important one being that as discharge proceeds, the active material begins to turn into lead sulphate. The volume of the lead sulphate is very much greater than the volume of the active material from which it is formed, and since the action takes place most rapidly on the surface of the plates where they are in contact with the electrolyte, the formation of the sulphate also takes place most rapidly at the surface, and this increase of volume tends to fill up the pores of the plate and prevent access of the electrolyte to the active material which lies beyond this shielding layer. If the discharge rate be very rapid, the masking layer of sulphate is rapidly built up, and the shielding effect takes place more quickly. In a battery discharged at a low rate the formation of this sulphate layer is so slow that the electrolyte can reach the innermost portions of the porous active material, the chemical action takes place more thoroughly, and a greater amount of current can therefore be taken out.

Curve No. 1 shown in Fig. 1 gives the variations in capacity with varying rates of discharge in percentages of the eight-hour rate, and curve No. 2 shows the increase in *amperes* output with increased discharge rates.

Thus if a battery have a capacity of 400 ampere hours, it will discharge 50 amperes continuously for eight hours. If the total capacity be taken out in one hour, the discharge rate will be 200 amperes, and the ampere hours will be 200, this being 50 per cent of the eight-hour rate as indicated by the curve. If the ampere hour capacity of the battery at the eight-hour rate be known, its capacity at any other rate can be determined from this curve, or if its capacity at any rate be known its capacity at the eight-hour rate can be also determined. The curve is an average, and applies approximately to nearly any type of battery, although different characters of batteries will give different curves, but none of them will depart materially from that shown in the figure.

Voltage Variation.

As stated, the voltage depends on the character of the electrodes and the density of the electrolyte. The available potential at the battery terminals is further dependent on the internal resistance of the cell. These facts explain the drop in voltage as discharge proceeds, as indicated by the curves in Fig. 2.

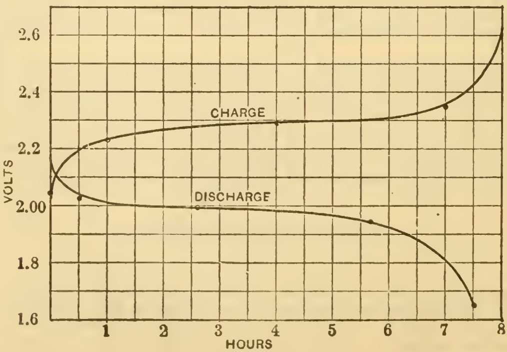


FIG. 2.

The electrodes gradually change from pure active material to a mixture of active material and sulphate; the formation of the sulphate increases the resistance from the surface of the electrodes to their conducting grid, thereby increasing the internal resistance, and the surface layer of sulphate prevents access of electrolyte to the interior pores of the active material, and the small amount of electrolyte imprisoned in these pores has its SO_3 rapidly abstracted from it, greatly reducing its concentration and therefore the voltage of the cell. To this cause nearly all of the fall in voltage may be attributed.

Electrolyte.

The resistance of the electrolyte varies with the density of the acid, being a minimum when 30 to 35 per cent of the mixture is acid, and increasing if a greater or less percentage of acid be present.

Parts of the plate surface may do more than their share of the work if the plates be very long and the containing tanks deep, this condition arising from a difference in the density of the electrolyte at the top and bottom of such tanks. The containing cells should therefore never be deeper than 20 inches, unless some artificial means of acid circulation be used, such as compressed air introduced into the bottom of the tank through small rubber tubes. With such circulation the electrolyte density is maintained constant in different portions of the tank, and the plates will then be worked at equal current densities over their entire surfaces.

Conductivity also changes with the temperature, being greater for increase of temperature. The table on page 1229 under caption "Electrochemistry" shows the changes in electrolyte resistance with variations in density and temperature.

The density of electrolyte in storage batteries should never exceed 1.200 when the batteries are fully charged, and there should be ten pounds or more of electrolyte per 100 ampere hours of battery capacity on a basis of the eight-hour rating. The final density at the end of discharge with this quantity of acid and 1.200 initial density, will be about 1.134.

In motor car batteries about four pounds of electrolyte per 100 ampere hours is sufficient, and because of the small amount of acid present the initial density must be higher. If the initial density be 1.265 at beginning of discharge it will, with this amount of acid, fall to about 1.137 at the end of discharge. Since there is a definite change in density for a given amount of discharge taken from a cell, the density of the electrolyte is one of the best indications of the state of charge of a battery, provided, of course, that no internal discharge, due to local action, takes place. If, when the cell is charged, it shows a density of 1.200 and when discharged 1.130, the difference, .07, represents the total change. If at any time the density is 1.165, just one half the amount of capacity has been taken from the cell. In order that these observations may be reliable, however, it is necessary to stir the electrolyte well, so that the density is the same all through the tank; also if the discharge has taken place at a high rate, the cell must stand for an hour or more before the electrolyte will completely diffuse so that the density readings are correct.

The electrolyte must be made of either distilled or rain water, mixed with pure brimstone acid. Ordinary city or well water will, in all probability, ruin the batteries, and pyrites acid will most certainly do so.

The electrolyte should always be tested to discover if harmful impurities are present, which are platinum, iron, chlorine, nitrates, copper and acetic acid.

The tests for these are as follows:

Platinum. — A complete test for this substance can only be made by an experienced chemist with proper appliances. A good rough test for traces of platinum is to pour electrolyte into a cell and note if gassing takes place on open circuit. If it does, and continues for some time, it is an indication of the presence of platinum, and the suspected electrolyte should then be sent to a chemist for analysis. Never use chemically pure sulphuric acid which has been refined in platinum stills.

Iron. — Take a sample of the electrolyte and neutralize with ammonia. Boil a small portion with hydrogen peroxide, which process will change whatever iron may be present into the ferric state. Add ammonia or caustic potash solution until the mixture becomes alkaline. Iron will be indicated by a brownish red precipitate which will then form.

Chlorine. — Take a small sample of the electrolyte, add a few drops of nitrate of silver solution of concentration of twenty to one. A white precipitate will indicate chlorine. This precipitate will be redissolved by addition of ammonia, and can be re-precipitated by the addition of nitric acid.

Nitrates. — Place some of the electrolyte in a test tube, and add strong ferrous sulphate solution. Then carefully pour down the side of the tube a small amount of chemically pure concentrated sulphuric acid, so that it forms a layer on top of the liquid. If nitric acid be present it will be shown by a stratum of brown color, which will form between the electrolyte and concentrated acid.

Acetic Acid. — Add ammonia to a sample of electrolyte until it becomes neutral, then add ferric chloride (Fe_2Cl_6). A red color will indicate the presence of acetic acid, which may be confirmed by the addition of hydrochloric acid, which will bleach the mixture.

Local Action. — Certain metallic impurities present in the electrolyte may be, on charge, carried over to the negative plate, and the hydrogen there evolved will turn these impurities into pure metal. The condition then exists of the sponge lead plate having a different metal attached to it, and in electrical connection therewith, and the two immersed in electrolyte. If the voltage of such a couple is sufficiently high to decompose the electrolyte, current will begin to flow, the whole acting as a short-circuited battery at the negative plate. This discharges the negative, either wholly or partially, according to the amount of metallic impurities which may be carried over, and it is then not in a proper condition to discharge in company with the positive plate when it is desired to take current from the cell. If this local action continues for some time the negative plate may be so far discharged that it will sulphate, and finally become worthless.

Cadmium Test.

The condition of the negative and positive plates can best be ascertained by measuring the voltage between the plate under examination and a small test electrode of cadmium. This cadmium should be covered

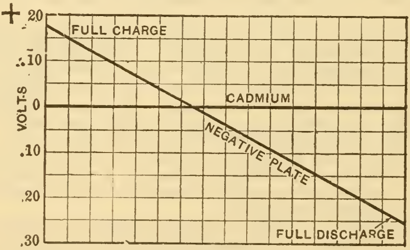


FIG. 3.

with rubber, perforated so that the test piece cannot come in contact with any of the battery plates or connections, though the electrolyte may freely penetrate to it.

When a cell is fully charged, showing a voltage of 2.5, the voltage between the negative plate and the cadmium should be from .16 to .2 volt. When discharge takes place, this voltage gradually reaches zero, after which a potential begins to rise in the opposite direction, gradually increasing with discharge. When the voltage, after passing through zero, reaches a value of .25 volt, the full amount of discharge has been taken from the negative plate, and the current should be cut off regardless of the potential of the cell.

Figure 3 shows the way in which the potential between the negative plate and the cadmium changes. The cadmium undergoing no discharge does not change, and its line of potential is therefore horizontal and unchanging, as indicated. The negative plate, however, is discharging, and its potential decreases so that, though it begins to discharge at a potential of .18 volt above the cadmium, it soon reaches a point at which it is the same as the cadmium, the voltage between them then being zero. As the potential of the negative falls further, a potential begins again to appear between the two, but, as is obvious, it is in the reverse direction, as the potential of the negative plate is now lower than that of the positive.

On charge, the voltage between the cadmium and the negative plate should be brought up to at least .17, even if continued overcharge after the cell has reached 2.5 volts is necessary to do it.

Batteries are so designed that the negative plates work through their proper range of potential with normal change in the cell E.M.F., but oversulphation, reduction in amount of active material, or, most of all, local action, will destroy this balance, and these cadmium tests are useful in keeping watch over the condition of batteries in service.

Polarization.

If the voltage of a battery on open circuit be a given amount, say 2 volts, and charging current is sent into it, it would be natural to assume that the potential rise at the battery terminals would be equal to the drop due to the internal resistance of the battery. It is found, however, to be very much greater than this amount — the actual internal resistance of large cells being practically negligible. This increase in drop, when current passes through a cell, comes from a phenomenon known as polarization, which is, in effect, the production of a counter E.M.F. which opposes the flow of current, and which always takes place whenever current passes from one electrode to another immersed in an electrolyte. This effect also opposes the flow of discharging current, and causes the voltage drop at the cell terminals, which is observable when current is taken from a battery. The principal polarizing agent is hydrogen, which may be considered as an electro-positive element. It always forms at the negative electrode and sets up an E.M.F. opposing current flow.

In cells of the same type the drop at any given time rate of charge or discharge is the same for any size of cell.

The Voltage Drop in cells of a given type is independent of the size of the cell, but varies with the state of battery charge and the rate of discharge. This drop is also fairly constant for various types of cells. The following table gives the fall or rise in voltage from the open circuit E.M.F. when discharge or charge takes place:

8-hour rate	.05 volt
6 " "	.065 "
4 " "	.09 "
3 " "	.11 "
2 " "	.14 "
1 " "	.2 "

Efficiency.

The efficiency of the storage battery, similarly to that of any other device, is the ratio of the watts output to the watts input. If current be taken out at a high rate, and a resulting small capacity be obtained, it does not follow that the efficiency has been lowered correspondingly, as it will be found that the amount of current required for succeeding charge will not be so great as if a lower rate of discharge had been used, and a greater amount of energy taken from the battery. In other words, there is a relation between the amount of energy derived on discharge and the amount of energy required on subsequent charge to bring the battery back to the condition at which the discharge began. The efficiency of batteries which discharge only a few moments and immediately after receive charge, that is, in which the charge and discharge fluctuate rapidly, and the net amount discharged from the battery in an interval of time is small, is about 90 to 92 per cent. Where used for power storage, a long continuous charge being sent into the battery and followed by a long continuous discharge, the efficiency is from 75 to 80 per cent.

The losses in a battery are made up of the I^2R, and the gassing at the end of charge, in which the constituent gases which are released by the action of the electric current do no chemical work on the electrodes, but escape into the air, the energy required for this dissociation being lost. There is also the further loss due to the counter E.M.F. of polarization, as has been explained.

Comparison of Planté and Pasted Electrodes.

Of the two types of cells mentioned, the Planté and the pasted, each has its particular place, and one is more suitable than the other for its particular class of work.

The *pasted* negative plate is, in general, the best type for nearly every class of work. *Pasted* positive plates are necessary in batteries where light weight is required, such as in automobile and train lighting batteries. They are also suitable for battery plants which receive long charge, store the energy and discharge over a considerable length of time, such as residence and isolated plants, and central lighting stations. The *Planté* positive is most suited to those conditions where the battery discharge takes place for short intervals at very high rates, such as regulation of railway and elevator loads, and also when prolonged overcharge is likely to occur frequently.

Charging.

In charging, the voltage gradually rises, as shown by the upper curve in Fig. 2, until about 2.5 volts are reached, when, at both the positive and negative plates, gases are rapidly released. Charge should always be continued until both plates gas freely. Full charge will also be indicated by the electrolyte density rising to its proper value.

The best way to charge is to send in current rapidly at the beginning and gradually decrease it until at the end of charge the current flow is very small. For instance, in charging a 1,000 ampere hour cell for eight hours, the average rate of flow is 125 amperes. The proper rates at which to charge this cell would be

250	amperes	for	1	hour
200	"	"	1	"
150	"	"	3	"
75	"	"	1	"
25	"	"	1	"

For rapid charging, when a battery has to be charged in four hours, the current should vary as follows:

40	per cent	of	total	1st	hour
25	"	"	"	2d	"
20	"	"	"	3d	"
15	"	"	"	4th	"

For quick charging in three hours the rates should be:

50	per cent	1st	hour
$33\frac{1}{3}$	" "	2d	"
$16\frac{2}{3}$	" "	3d	"

Whatever the rapidity of charge, never send a heavy current into a battery toward the *end* of charge. The rapid rates can only be used during the early part of charge.

In case of loss of electrolyte from the cells from evaporation or spraying, add only pure water to maintain its level, as the addition of normal electrolyte will gradually increase the density of that in the cells, because the added liquid merely takes the place of that which has been carried off as gas or lost from evaporation, which, in either case, is pure water only. High electrolyte densities tend to accentuate all the troubles that can befall a battery, and accelerate the formation of sulphate. The water should be introduced through a rubber hose or lead pipe extending nearly to the bottom of the cell, so that it will diffuse and mix with the electrolyte. If the water be poured in, it, being lighter than the electrolyte, will float and take a long time to diffuse with the liquid in the cell.

Removal from Service.

To take a battery out of commission it should first be fully charged, then given a good overcharge, and then discharged down to 1.7 volts per cell in the electrolyte, immediately after which the electrolyte should be drawn off, and either distilled or rain water put in the cells. The discharge should then be continued until the voltage comes down practically to zero. In most cases it is necessary to short-circuit the cells in order to get them down nearly to zero with pure water as the electrolyte. Discharging them in the water has no injurious effect, however, as no sulphate can form. Upon complete discharge the water should be poured out of the cells, and the plates thoroughly washed, generally by running water continuously through the cells. All water is then drawn off, and the plates may then stand for any length of time without injury. When the batteries are again to be used, it is only necessary to pour in the electrolyte and give a long overcharge.

Battery Troubles.

The principal troubles which are encountered in battery operation are loss of capacity, buckling, shedding of active material, sulphation and loss of voltage.

Loss of Capacity usually comes from clogging of the pores in the plate with sulphate which is not visible to the eye because the surface of the plate is maintained in proper condition but the interior portions of the active material have not been thoroughly reduced. This condition can be remedied by prolonged overcharge at low current rates, say about one-fourth the normal eight-hour charging rate.

Loss of Active Material will also reduce the capacity of a plate, and this takes place continuously, but slowly, in every storage battery, and may be considered as the normal depreciation. If the battery be overworked, however, and especially if discharge be carried too far, the amount of sulphate formed will so expand the active material as to cause it to crack or shed off very rapidly.

Buckling. — Under the action of unequal expansion of the two sides of the plate, or certain portions of the plate, the strains may distort it and cause it to assume a buckled shape, that is, bent so one side is concave and the other convex. This is due, in every case, to over-discharge on either the whole or some portion of the plate, and consequent over-sulphation and over-expansion. In certain battery plates, which are designed to allow this expansion, buckling cannot take place, but in most of them the active material is on an unexpanding framework, and over-discharge is therefore to be avoided.

Sulphation. — This is practically the cause of every storage battery trouble, and can only be avoided by stopping the discharge before the voltage of the cells has fallen too low, namely, at 1.8 volts per cell, with normal discharge current flowing, and by occasional boiling, that is, overcharge which should be given at intervals of about three or four weeks.

In giving this overcharge the battery should be fully charged at normal rates until it shows about 2.6 volts per cell. The current should then be decreased to about one-half its normal eight-hour rate, and the charge continued until the cells show about 2.65 volts, and about twenty minutes after this potential is reached. This will effectually reduce any sulphate which may have accumulated in the pores of the active material. A battery should never be allowed to stand idle or uncharged after discharge, as the plates will sulphate very rapidly. A charge should be started immediately after discharge, or as soon thereafter as possible.

Loss of Voltage. — It will frequently be found that one or more of a number of cells will show a lower voltage than the others. This generally occurs because of *loss in capacity*, so that a cell having this lower capacity, and in series with the main battery, would discharge the same amount as the other cells having a higher capacity, and in this way its voltage would drop more rapidly and always be lower than that of the other cells on discharge.

Testing.

There are two classes of storage battery tests. One is to determine whether a battery which has been installed meets the conditions of the specifications; the other is to determine all the constants of a battery as compared with others on the market, either for purposes of improving the product of the factory or determining its commercial value.

The first class of tests will not be gone into here, as they will be indicated by the conditions of the contract and specifications. In the second class of tests the following are the points to be determined:

1. Weight of complete cell.
2. Weight of the separate component parts, namely, elements, electrolyte, separators and containing cell.
3. Dimensions of component parts of the cell.
4. Rates of charge, maximum and normal.
5. Rates of discharge, maximum and normal.
6. Capacity at low, normal and rapid discharge rates.
7. Voltage curves of charge and discharge.
8. Internal *virtual* resistance.
9. Variation in density of electrolyte.
10. Loss on charge with time.

These are all determined by test and observation, and from them are deduced:

11. Charge and discharge rates per square foot of positive plate surface.
12. Charge and discharge rates per pound.
    (*a*) of complete cell.
    (*b*) of element.

13. Capacity per pound.
    (*a*) of complete cell.
    (*b*) of element.

14. Efficiency at various charge and discharge rates.

Weight of Complete Cell and Component Parts.

The weight of complete cell is of course found by means of the scales, and in order to determine the weight of the component parts the elements should be partly discharged, then removed from the electrolyte and dried with blotting paper, after which they are weighed. Do not keep the negative plates in the air any longer than necessary. The weight of the electrolyte is equal to the total weight, less that of the elements and jar.

Dimensions.

These are determined by usual measurements at the time when the cells are dismantled for weighing, and should include dimensions of separators, height of lower edge of plate above bottom of jar, clearances between adjacent plates and between interior of jar and plates. Also area of plate surfaces and of conducting lugs. This latter for the purpose of determining if current densities are within usual practice, namely, about 150 amperes per square inch. The cell may then be reassembled, given a prolonged overcharge, and connected up for testing.

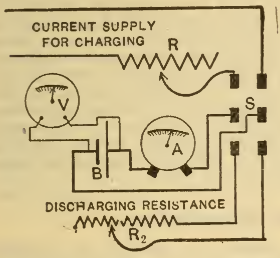


FIG. 4.

Connections for Testing.—Referring to Fig. 4, *R* is an adjustable resistance by means of which the current to the battery may be kept constant. *B* is the cell under test; *S* a D.P.D.T. switch; R_2 a variable resistance through which discharge takes place and is maintained at a constant value; *A* is a two-way reading ampere meter which measures both inflowing and outflowing current and *V* is a low-reading voltmeter across the cell terminals.

Rates of Charge and Discharge.

The charging rates are usually given by the manufacturers, but if without this data, six amperes per square foot of positive plate surface may be taken as a trial rate, and after a few charges and discharges may be determined by the length of time required to fully charge or discharge the cell. The eight hour is the standard normal rate. The maximum charge and discharge rates are usually taken as the one hour rate, although the current flow should never be so rapid on charge as to heat the cell more than 25° F. above surrounding atmosphere or cause excessive gassing.

Capacity at Various Discharge Rates.

These are determined on taking out a constant current on discharge at say, the eight hour, the four hour and the maximum rate, whatever the latter may be, and noting the length of time during which this discharge continues, the battery having been charged up to 2.5 volts before beginning discharge, and being cut off when a voltage of 1.8 is reached, except in the case of the maximum rate, when the voltage can be carried down to 1.70. Since the capacity will change with temperature, it is necessary to note the temperature, and keep it constant through any one determination.

Voltage Curves.

During charge and discharge — both of which should take place at the constant rate for testing — frequent observations should be made of the voltage across the cell terminals. From this the regular charge and discharge curves are plotted with voltages as ordinates and time as abscissæ.

Internal Virtual Resistance.

There are many methods of determining the internal *ohmic* resistance of a cell, but this has no bearing whatever on practice. Furthermore, it is not constant, but changes with the state of charge and discharge. What an engineer requires to know, is the drop at various discharge rates due to whatever internal effects may take place. The net result of all the factors, namely, internal ohmic resistance, polarization, increase in normal internal ohmic resistance, due to the passage of gases through the electrolyte, etc., are all included in the term, "Virtual Resistance." To determine this, note the voltage of the cell on open circuit. Then close the discharge switch quickly, allowing a heavy discharge current to flow. The voltmeter will immediately indicate a lower value than when the battery was open circuited. Read the voltmeter within four seconds after closing the discharge switch. The difference between the discharge voltage and the open-circuit voltage, divided by the amperes flowing on discharge, is equal to the virtual internal resistance. Several tests should be made at different rates of discharge, and also several tests in which charging current is sent into the battery; the rise in voltage above that on open circuit noted, and the difference between the open circuit and the observed charging voltage, divided by the inflowing current, will give the internal virtual resistance. Owing to the small changes it is difficult to get accurate results, and the average of a number of tests both on charge and discharge should be taken as the actual value.

Variation in Density of Electrolyte.

This should be noted as discharge proceeds, by reading the specific gravity on a regular flat bulb hydrometer immersed in the cell itself. At the end of charge the hydrometer should be allowed to stand in the acid for about four hours before taking the final specific gravity in order to allow the dilute acid in the interior pores to mingle with the main body of acid in the jar. If the gravity be taken without allowing this time to elapse it will be found higher than the actual gravity will be after complete diffusion.

Loss of Charge with Time.

This is determined by subjecting a battery to several cycles of charge and discharge, until its capacity becomes constant at the given rate. Knowing this capacity, if the cell be fully charged and set aside for several days and then discharged at the normal rate, the difference between its capacity when immediately discharged, and that after the interval of time has elapsed, shows the loss which may occur from leakage or local action. The cells should be kept perfectly dry and well insulated to prevent any leakage whatever when set aside.

Charge and Discharge Rates and Capacity.

These are computed from a knowledge of the dimensions and the charging rates, determined during the test.

Efficiency at Various Charge and Discharge Rates.

Efficiency is determined at the various charge and discharge rates by dividing the output on discharge by the input on charge. In all cases the *discharge* should precede the *charge* against which the ratio is to be taken, and in every case the cell should be brought back to its original condition on charge. In taking efficiency, if a charge be given and a discharge follow it, to compare these would give no reliable results, as it is the charge which succeeds a given discharge that bears the proper relation to it.

Failure to recognize this fact has been the cause of the extraordinary results which certain tests have shown, in which the efficiency has been over 100 per cent, though in most cases the erroneous method of comparing a charge with its succeeding discharge will give a result below the actual efficiency of the battery.

Erection of Batteries.

Storage batteries should always be installed in a cool room, which is well ventilated. The floor should be of cement, tiles or bricks, and it should slope slightly to one or more drains, so that water or electrolyte which is spilled or leaks may easily run off and the floor be kept dry.

All exposed iron work should be covered with some good acid-proof paint, and all exposed copper should have a coating of lead or tin, to prevent the corrosive action of acid fumes.

Provision should be made for easy and thorough inspection of the cells. They should therefore be accessible, and hand lamps connected to long, flexible conductors provided so that each cell may be inspected.

In the installation of large station batteries consisting of a number of large plates in lead lined tanks, it is usual to set these on 4 × 6 inch stringers which run underneath a row of cells. Four or more porcelain insulators are placed between the stringers and the cells, and in many cases it is usual to doubly insulate the cells by putting under each one a wooden framework which is the size of the bottom of the cell, above the stringers, resting it on insulators which are supported on the stringers. The cell rests on a second set of insulators which are in turn supported by the framework. The number of insulators depends on the size and weight of the cell to be supported. The positive plates in each cell are connected to the negative plates in the adjacent cell by burning each of the plates separately to the leaden bus bar, as shown in Fig. 5. In the smaller sizes of cells which

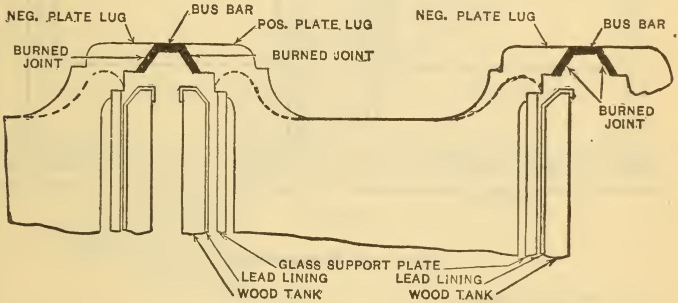


Fig. 5.

have lead lined tanks, they are generally set on a framework from twenty to twenty-four inches high and rest upon four insulators. The plates of each cell may be joined to those of the next succeeding cell either by burning to a common bus bar, as above mentioned, or by bolting together lead straps which form the cell terminals, the bolts and nuts being, of course, lead covered. If the containing vessels are glass jars, it is usual to set each of them in a shallow wooden box about 1½ inches deep and filled with fine, dry sand. The glass cell beds itself in this sand, giving an equal distribution of pressure over the bottom of the jar, and the sand also catches and absorbs such electrolyte as may be spilled or sprayed out with escaping gases. Each sand tray, as these are termed, rests upon four porcelain insulators, and the cells are placed on a framework in one or two tiers, as may be desired. Fig. 6 shows this method of installing.

Lead Burning. — The hydrogen flame has the special property of not oxidizing, or otherwise soiling the lead, and is therefore used for melting together two lead surfaces, notably that between cells and the sheet lead lining of the tanks.

Hydrogen gas is generated in a vessel from sulphuric acid and zinc. The gas is collected and passed through a water bottle to a burner, where it is mixed with air that has been forced into the burner by a pump or bellows, the mixture being ignited for the welding.

The use of this burner requires some skill and practice, especially in joining the edges of sheet lead, as it is very apt to burn away. All plate terminals, and all lead connections of any kind, must be scraped clean before connecting up.

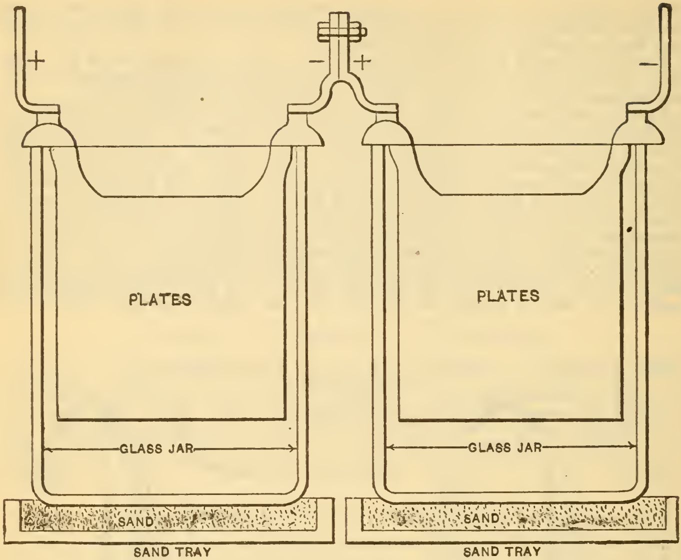


FIG. 6.

Uses of Batteries.

The principal uses are:

(1) For propelling electrically driven motor cars.
(2) For railway train lighting.
(3) As a substitute for the ordinary primary battery in telephone and telegraph work.
(4) To carry the load peak on a supply system.
(5) To carry the entire load during the periods of light demand, the generating equipment being shut down.
(6) To regulate the load on systems where the demand fluctuates widely.
(7) To act as an equalizer on three-wire systems in which the generators are connected across the outsides of the system and give a corresponding voltage.
(8) To reduce the amount of copper required for systems supplying variable loads.
(9) To insure continuous service.
(10) As auxiliaries to exciter dynamos in large alternating current stations.
(11) Combinations of any of above from (4) to (8).

The first three applications involve no special engineering knowledge.

(4) In case of a supply system on which the load rises greatly during certain hours of the day, as shown by the load curve *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, in Fig. 7, it is often advisable to install a battery to receive charge during the period of light load, as shown by the shaded area in which the heavy curve is the demand on the station and the light curve, the load on the generating equipment, the difference going into the battery; and to discharge in parallel with the generators during the heavy output on peak *d*, *E*, *e*, as shown by the cross-hatched area. Such a battery assists to

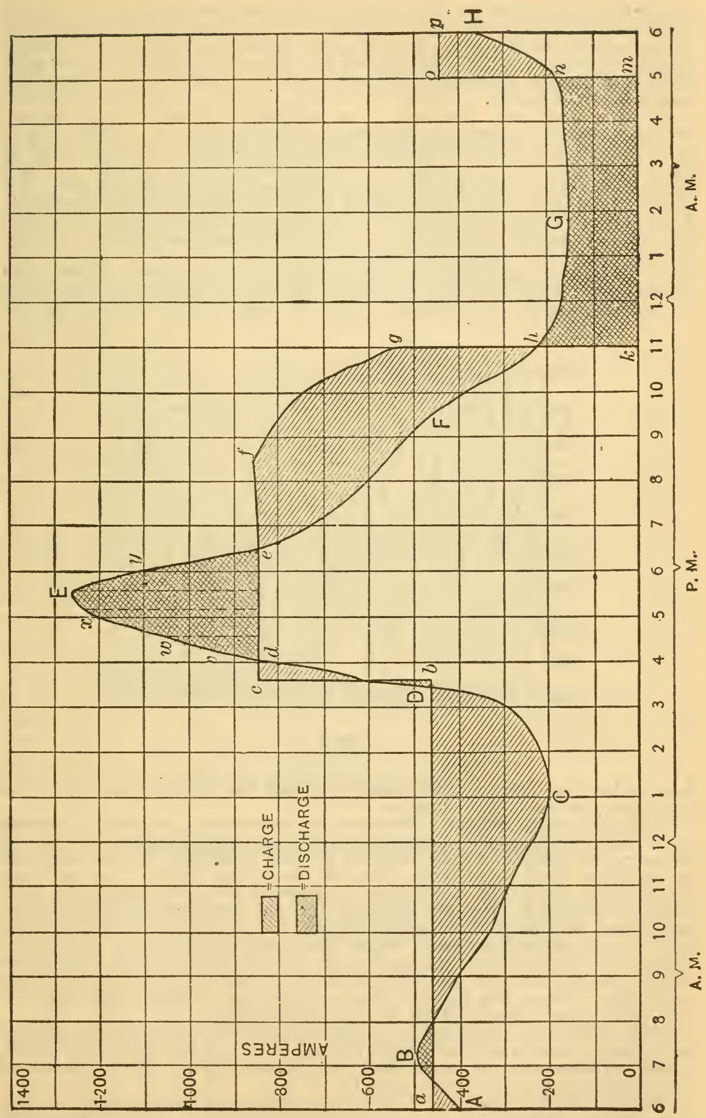

AMPERES
CHARGE
DISCHARGE
A. M.
P. M.
A. M.
1400
1200
1000
800
600
400
200
0

FIG. 7.

maintain a reasonably constant load on the dynamos, reduces the cost of the generating equipment, and is always ready to take up any excess load on the system, such as may come from a suddenly overcast sky or storm, without the loss of time necessary to fire up additional boilers and start additional engines, as would be the case if the entire load were carried by generating machinery.

(5) After the peak discharge is ended and the load on the system decreases below the generator capacity, the batteries may be fully charged by, say, midnight, and the entire plant shut down during the period of light load until, say, five or six A.M. This is also indicated in Fig. 7, where the shaded area *e*, *f*, *g*, *h*, *F*, represents charge put in after the peak discharge, while the cross-hatched area *h*, *k*, *m*, *n*, indicates battery discharge. If the battery is large enough to do this, the cost of the fuel and the depreciation, for the time of shut-down, are saved, and two shifts of station attendants only are required instead of three.

(6) In case of a system on which the load fluctuates rapidly and between wide limits, such as an electric railway or elevator load, the form of load diagram will be as shown in Fig. 8. Here it will be seen that the

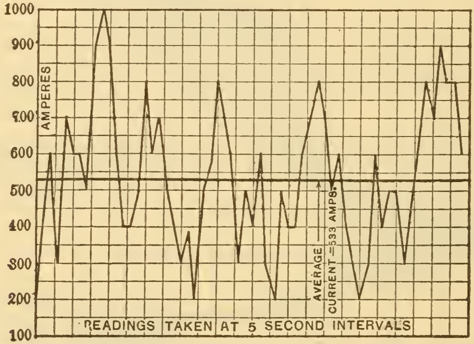


FIG. 8.

load varies from 200 to 1,000 amperes, though the *average* load taken over in diagram shown is 533 amperes.

If the system be without a battery the generating equipment, including steam plant generators and accessories, will have to be of sufficient capacity to carry the maximum load, and the moving machinery will be subjected to excessive shocks and strains due to the sudden loads. The fuel consumption is also much more than it would be if the engines could work under steady load. If a regulating battery be used, the generating equipment need only be great enough to supply the *average* load, as the battery will absorb all fluctuations. When the current required to supply the external circuit is small, the additional amount, supplied by a generator working under constant load, will go into the battery and be stored there as charge. When the external load exceeds the average generator output, the excess is furnished by the battery discharge.

Thus the battery maintains a constant load on the generating equipment regardless of the variations in the external load, and the attendant advantages of fuel economy, normal duty only on moving machinery, decreased depreciation and repairs, are realized.

(7) In three-wire systems, if the generators give a voltage equal to that between the outside mains, some forms of equalizer are necessary to prevent the unbalancing which may take place. If a battery be connected across the outsides with a sufficient number of cells in series to give an E.M.F.

equal to that of the system, and the neutral be connected to the middle of the battery, any excess of current flow, on one side of the system, will be supplied by discharge from the half of the battery connected across that outside and the neutral, while the half of the battery on the other side will receive an equivalent amount of charge. This is a widely used arrangement, as all the other advantages of storage batteries are obtained in addition to the balancing effect.

(8) In cases where current is transmitted over a considerable distance, and the load varies either at different periods of the day, such as a lighting load, or rapidly, as a railway load, a storage battery located far away from the station, near the point where the load comes on the system, may be made to maintain the voltage at periods of heavy load when the feeder drop would be excessive, and the useful potential too low for satisfactory service. This is accomplished by the discharge of the battery when the heavy load comes on, reducing the amount of current transmitted and therefore the drop. The battery is charged during the time of light load when sufficient current is transmitted to supply the load, and also charge the battery. In other words, the battery equalizes the load over the line, causing the continuous flow of average current, and reducing the cost of feed or copper.

In certain classes of rapidly fluctuating loads this effect is automatic and produced by slight changes in line drop, with small changes in the load over the line.

(9) To insure continuous operation of any electrical plant a storage battery is necessary. No matter what may happen to the generating part of an equipment, if a storage battery be connected to the system it will immediately take on the load and carry it a sufficient length of time to enable any quick repairs to be made and the machinery again started up.

(10) In large central stations where alternating current is generated and distributed to substations, and a large territory is dependent on the station supply, the failure of an exciting dynamo would cause a shut-down of possibly several minutes, which would be a serious mishap. To insure against this a storage battery is connected directly across the exciter bus bars. It does no work and is never of any real service unless failure of an exciter takes place, in which case the alternator field excitation is taken up without a break or interval. The insurance against stoppage, even for a moment, by means of the storage battery, is so thoroughly demonstrated that nearly all the large alternating current stations have added this equipment to their exciter systems.

(11) Combinations of (4) to (9) inclusive can be in part effected by a single battery, such as regulation of fluctuating load, discharging on peaks and carrying the night load alone, or equalizing on a three-wire system, carrying peaks on both sides of the system, and also carrying the light load alone. Many other combinations will suggest themselves to the engineer as the conditions to be met may require.

Methods of Controlling Discharge.

In Fig. 2 is shown the change in voltage of a cell when charging and discharging at the normal rate. In order to compensate for this variation, so that the E.M.F. supplied to the discharging circuit may be maintained constant or varied at will to meet external load conditions, the following methods of control are used:

(1) The number of cells in series may be altered by means of suitable switching mechanism.

(2) Counter cells, or cells connected in opposition to the main battery, may be included in the discharging circuit and the desired voltage obtained by varying the number of counter cells in this circuit.

(3) A variable resistance may be interposed in the main circuit to regulate the discharge.

(4) A dynamo-electric machine, termed a "booster," having its armature in series with the battery circuit, its field being variable at will as to either direction or magnitude, may be employed.

If any of the first three methods be employed, the total number of cells composing a battery must be such that at the end of discharge, with normal outflowing current, the sum of the voltages of all cells in series is equal to the voltage to be maintained on the supply circuit.

When discharging at normal rate, it is usual to stop discharge when the E.M.F. per cell has dropped to 1.8 volts.

End Cells and Switches.

As shown in Fig. 2 the E.M.F. at the beginning of discharge is 2.15 volts, and at this point on the discharge curve only 51 cells would be required to give 110 volts; as discharge continues and the E.M.F. falls, the number of cells in series must be increased accordingly, and at the end of discharge, when the cell voltage is 1.8, 61 cells are required in series to supply a 110-volt system, 10 of them being end or reserve cells. The whole 61 cells would be connected in a single series, a conductor being connected to each of the ten end cells and to suitable contacts on an end cell switch.

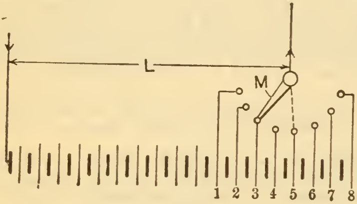


FIG. 9.

The voltage across the discharging circuit will be dependent upon the number of cells included in the circuit.

Figure 9 shows an arrangement of cells, all connected in series, a portion of these being end cells; the voltage when the moving arm *M* is in the position shown by the full lines will be that due to all the cells in the main battery, plus the voltage of the two end cells included by the arm. If now the arm be moved to the position shown in the dotted lines, the voltage across the mains *L* will be increased by the addition of the end cells 4 and 5. In switching from one end cell point to another the discharging circuit must not be opened, neither must the moving arm touch one contact before leaving the adjacent one, since the joining of two contacts will short-circuit the cells connected thereto.

In general, the form of switch for this purpose is essentially that shown in Fig. 10, where the moving arm is provided with a small advance arm, the two being insulated from each other but connected through the resistance *X*. The spacings of the two arms and contacts are such that when the main current carrying arm is squarely on an end cell contact, the advance or auxiliary arm touches no other contact, but in passing from one point to the next, the advance brush reaches the contact towards which the arm is moving, before the main brush leaves its contact; the resistance *X* between the two points prevents short-circuiting, and the current to the main circuit is never broken.

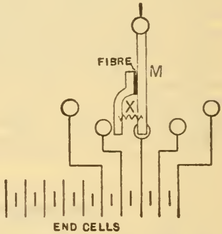


FIG. 10.

The conductors joining the end cells to the end cell switch contacts must be of the same sectional area as the conductors of the main circuit, for when any end cell is in use the conductor connecting it to the switch becomes a part of the main circuit. 1000 amperes per square inch, when the battery is discharging at the two-hour rate, is good practice.

End cell switches of small capacity are made circular; the larger sizes are, however, made horizontal in form, and both types may be either manually operated or motor driven.

End cell switches of large capacity are generally located as near the battery room as possible, to avoid the cost of running the heavy conductors, and when such switches are motor driven, the usual practice is to control their operation from the main switchboard.

Automatic end cell switches have been used more or less abroad, but have found little favor in this country. The controlling devices for such switches are so arranged as to make the switch automatically respond to changes in the discharging circuit.

Counter E.M.F. Cells.

Counter cells or counter electromotive-force cells are merely lead plates in an electrolyte of dilute sulphuric acid; they have no capacity but set up an opposing E.M.F. of approximately 2 volts per cell if current be passed through them.

In using these cells for controlling discharge, the total number of active cells in the battery will be the same as if the method of end cell control had been used. The counter cells represent an increase in equipment, the additional expense being 8 per cent or more.

Figure 11 shows the method of counter cell control; these cells are connected in opposition to the main battery, and conductors are run from each of the counter cells to points on a switch similar to an end cell switch. At the beginning of discharge all the counter cells are in circuit, acting in opposition to the main battery. As discharge proceeds and the battery voltage falls, the counter cells are gradually cut out of circuit.

Controlling discharge by counter cells is now nearly obsolete practice, and is scarcely ever to be recommended; the only advantage in this method of control is that the discharge throughout the battery is uniform, but this fact alone does not warrant the use of such methods on account of the additional expense involved, and the energy loss when discharging against counter cells is the same as if resistance had been interposed in the discharging circuit.

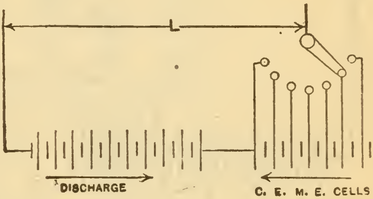


FIG. 11.

Resistance Control.

The discharge may be controlled by a variable resistance included in the discharging circuit. This method is not used unless the battery is of small capacity and the cost of energy low.

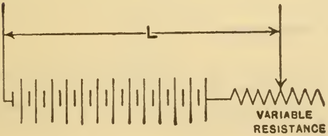


FIG. 12.

Figure 12 shows a diagram for resistance control. In small plants, where the available space for battery auxiliaries is limited — such conditions obtaining in batteries for yacht lighting and the like — the resistance control has some merit.

Boosters.

A booster consists of a dynamo electric machine, the armature of which is in the battery circuit, its E.M.F. being added to or subtracted from that of the battery to produce discharge or charge. This action of the booster, i.e., the direction and magnitude of its armature E.M.F., may be automatically or manually controlled.

The Shunt Booster.

As shown by the battery curves in Fig. 2 the maximum voltage per cell at the end of charge is 2.6 volts. As 61 cells are required for a battery operating on a 110-volt circuit, the total charging voltage required is 2.6 × 61 = 158.5 volts, or about 50 volts higher than the voltage of the supply circuit, and to fully charge the battery this additional voltage must be supplied by a booster or by an excess voltage in the charging generator.

Figure 13 shows the diagram of a simple charging booster. Its armature should be wound for the normal charging current, and have a maximum voltage equal to the difference between that of the supply circuit and the maximum charging voltage. The field is separately excited, either from the bus bars or the battery, and the voltage at the armature may be varied by the field rheostat.

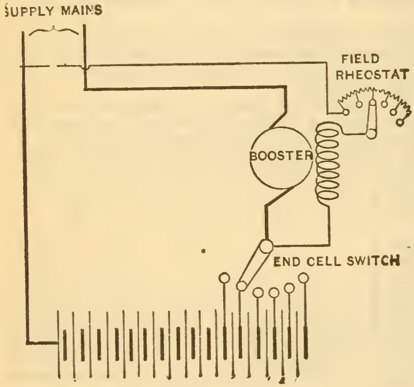


FIG. 13.

Instead of discharging through an end cell switch or resistance, the current through the booster field may be reversed and varied, so that the E. M.F. of its armature may oppose that of the battery, this E.M.F. being reduced as the battery voltage falls, the algebraic sum of the booster and battery E.M.F.'s being always equal to that of the supply circuit.

In this case, however, it is usual to put in fewer cells, the available voltage being taken as 2 volts per cell. On discharge when the voltage of all cells in series is greater than that of the supply circuit, the booster voltage is equal to the excess battery voltage over the supply circuit potential, and in opposition to the battery voltage: when the battery voltage becomes equal to that of the supply circuit the booster voltage is zero; when the battery voltage falls below that of the supply circuit, the booster voltage must then be in a direction to assist the battery, adding its voltage to that of the battery.

Automatic Boosters.

In batteries which are used for regulation on fluctuating loads, the changes from charge to discharge and *vice versa* are so rapid that the *state* of battery charge changes but little. The voltage of the battery, however, changes with these fluctuations, increasing with inflowing and decreasing with outflowing current.

In this respect the storage battery has much the same characteristics as a shunt wound generator: with increasing output the battery voltage falls, due to the drop caused by internal resistance and polarization; with decreasing output the voltage rises for the same reasons.

These voltage changes are approximately proportional to the rate of current flow causing them. The fluctuations coming with such rapidity and irregularity must be automatically compensated for by changes in booster voltage, which vary both in direction and magnitude with the direction and rate of current flow.

There are two generic types of automatic boosters, viz., the non-reversible and the reversible.

Non-Reversible Booster.

In installations where it is desired to supply both an approximately constant and a fluctuating load, from the same generators — such conditions obtaining in an office building or hotel, where it is necessary to supply lights and elevators from the same source of supply — the fluctuations in the power circuits must not interfere with the lighting circuits, and to prevent this, two sets of bus bars are provided. The generators are connected in the usual manner to one set of bus bars, and the lighting circuits are connected across these. Across the other set of bars are connected the circuits supplying the fluctuating load, and the battery is also connected directly across these power bars. The power bars are supplied with current from the lighting bars, a non-reversible or so-called "constant current" booster being interposed between the two, as shown in Fig. 14. Since this permits only a constant current to pass from the lighting bus bars, the load on the generator does not vary, although the load on the power busses may vary widely. The connections and operation of this system are as follows:

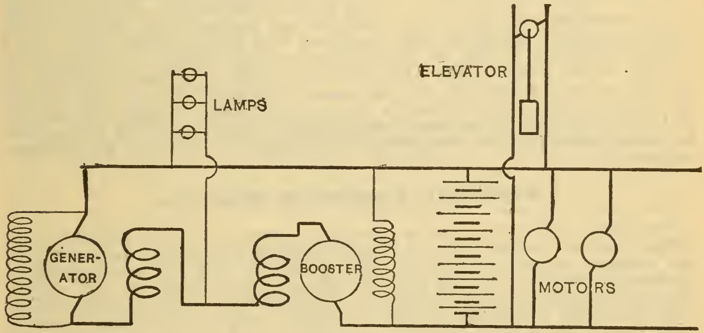


FIG. 14.

The booster armature and field are in series between one side of the lighting and power bus bars. A shunt field is also provided, which acts in opposition to the series field. This booster carries a practically unvarying current from the lighting to the power bus bars, regardless of the fluctuations of the external load, which current is equal to the *average* required by the fluctuating load.

Except under abnormal conditions, the shunt field always predominates, giving a voltage which is added to that of the lighting bus bars, so that the voltage across the power busses is always higher than that across the lighting by an amount equal to the booster voltage.

If an excessive load comes on the power circuits, the increased excitation of the series coil, due to a slight increase in current from the lighting to the power bus bars, lowers the booster voltage and consequently reduces the voltage across the power bus bars. The battery discharges, furnishing an amount of current equal to the difference between that required by the load and the constant current through the booster.

If the power load decreases below the normal value, the slight decrease in current in the booster series field increases the booster armature voltage, and the excess current goes into the battery. The booster therefore does not in reality give a constant current, but by proper design the variation may be kept within a few per cent.

Reversible Booster.

Figure 15 shows a diagram representing one form of booster for producing charge and discharge in accordance with variations in load, in which *S* represents a series field winding, and *f* a shunt field winding. The generator output passes through the series winding, and the current in the coil *S* is to remain practically constant. The shunt coil *f* produces a field which opposes the field produced by *S*, the resulting magnetization being, in direction and amount, the resultant of the two field strengths.

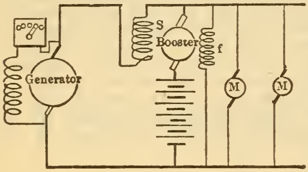


FIG. 15.

The adjustments are so made that when the normal generator current is passing through the series coil *S*, the shunt field just neutralizes its effect, and the resultant magnetization is zero. Since the open-circuit voltage of the battery is equal to that of the system, neither charge nor discharge takes place. With increased demand on the line, the slight increase in generator current in the coil *S* overpowers the shunt field, and causes an E.M.F. in the booster armature in such a direction as to assist discharge. If the external load falls below the average demand, the current in the coil *S* decreases slightly so that the shunt field predominates, producing a booster armature E.M.F. in a direction to assist charge. Although the voltage of the battery falls while discharging by an amount proportional to the outflowing current, the increased excitation due to this current through *S* is also proportional to it, and the booster voltage rises as that of the battery falls, their sum being always equal to that of the system. In other words, the booster serves to compound the battery for constant potential.

Externally Controlled Boosters.

The types of boosters before described, depend for their action on the differential relation of shunt and series coils, and produce a constant voltage change, to charge or discharge the battery, with a given change in generator current. This is not the desired relationship, as the voltage required to effect a given charge or discharge of a battery varies greatly with its state of charge and its condition. Also, such boosters require large frames for a given kilowatt capacity in order to accommodate the windings.

Recently, systems of external control have been devised, which make use of ordinary shunt-wound machines as boosters, the fields being regulated to produce the proper voltages for effecting charge or discharge, by an external device which is, in turn, controlled by small changes in generator current. So successful have these later forms been, that they have superseded the differentially wound boosters for both reversible and non-reversible control.

One form is that of Hubbard, in which the external controller is a small exciting dynamo. The general arrangement is diagrammatically shown in Fig. 16.

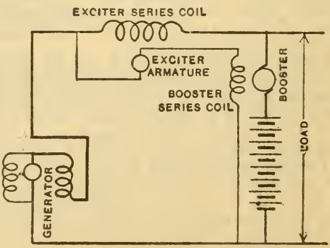


FIG. 16.

The exciter is provided with a single series coil, through which the station output or a proportional part thereof, passes; the armature of the exciter is connected to the exciting coil on the booster, and thence across the mains, as shown. With the average current passing through the field coil or the exciter, its armature generates an E.M.F. which is equal to that of the system, and in opposition to it. These two opposing E.M.F.'s balance, and no current flows in the booster field coils. With an increase in external load above the average, the tendency is for an increase to take place through the exciter series coil, augmenting its field strength and consequently the exciter armature voltage. This latter now being higher than that of the line, causes current to flow in the booster field coil, in such a direction as to cause an E.M.F. in the booster armature which assists the battery to discharge, and is of a magnitude to compensate for the battery drop occasioned thereby. When the load decreases below the normal, the current in the exciter field is decreased, and its armature voltage falls below that of the system. Current will now flow in an opposite direction in the booster field coil, generating an E.M.F. in the booster armature to assist charge. Since the exciter always generates a voltage in opposition to that of the line, this system is known in the trade as the Counter E.M.F. System.

Another type of externally controlled booster is that of Entz. The arrangement and connections are shown in Fig. 17.

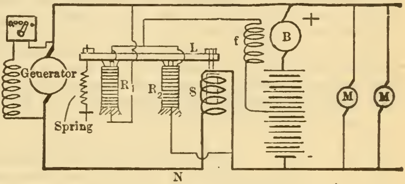


FIG. 17.

R_1 and R_2 are two resistances made up of piles of carbon plates. These resistances diminish greatly in value when subjected to pressure. L is a lever resting on the tops of the piles, R_1 and R_2, which is pulled downward to compress them, by the spring at one end and the electromagnet S at the other, as shown.

The magnet winding is in series with the current from the generator, and with normal output to the load M.M., the pressures of the spring and the magnet are so related that the resistance of R_1 equals that of R_2. The booster field has one terminal connected to the middle point of the battery, and the other terminal is connected to a wire which joins the upper ends of the two carbon piles.

The lower end of R_1 is connected to the positive side of the circuit, and the lower end of R_2 to the negative side.

The drop through R_1 plus R_2, i.e., from the positive to the negative side, is equal to the potential of the system, and therefore, when R_1 is equal to R_2 the drop through either is equal to one-half the potential of the system; hence the potential of the terminal of the field coil f, connected to the upper ends of the resistances, is midway between the potentials of the positive and negative mains.

Since the other terminal of coil f is connected to the middle point of the battery, its potential is also midway between the potentials of the positive and negative mains, from which it follows that when R_1 and R_2 are equal there is no difference of potential between the field coil terminals, consequently no excitation, and the booster potential is zero.

If the external load should increase, a small increase in generator current will cause a stronger magnet pull, decreasing the resistance of R_2 and increasing that of R_1. The drop through R_2 becomes much less than half the potential across the mains, and consequently there is a potential across the field winding f to cause current flow from the middle point of the battery, through the winding, through the diminished resistance R_2, to the negative main. This produces a booster E.M.F. in a direction to discharge the battery and cause it to assist the generator to supply the load demand.

Conversely, if the external load M.M. should decrease, the diminished pull of the magnet due to the slight decrease in generator current allows the spring pull to predominate, and the resistance of R_1 is decreased while that of R_2 is increased. The field f becomes excited by current flow from the positive main, through the diminished resistance R_1, through field f, to the middle point of the battery. This sets up an E.M.F. in the booster armature to charge the battery, the difference between the normal generator output and the load demand being thus absorbed.

Owing to the comparatively small change in the pressures which the magnet S exerts, and the thereby limited size of the carbon piles, this system is only directly applicable to small boosters. Where large machines are to be controlled, the booster has a small exciting dynamo, its field being controlled as above described.

Another form of externally controlled booster is that of Bijur and is shown diagrammatically in Fig. 18.

The booster field winding has one terminal connected to the middle point of the battery, the other terminal being connected to the wire joining the resistances R_1 and R_2. L is a lever carrying at either end a number of metallic contact points P_1 and P_2 which dip into troughs of mercury D_1 and D_2 when one end of the lever moves upward or downward. These points are connected to corresponding points on their respective resistances, and therefore all of the resistances connected to contact points which are immersed in the mercury are short-circuited. The points are of unequal length, being in a step formation, so that they gradually contact with the mercury as the lever is moved.

If more of the points P_1 than points P_2 are immersed in the mercury the resistance R_2 is less than R_1, more sections of it being short-circuited. Current will therefore flow from the middle point of the battery, through the booster field f and through resistance R_2 to the negative side of the system, exciting the booster field and producing a booster E.M.F. to charge the battery; while if more of the points P_1 are immersed the resistance R_1 becomes the smaller, and current then flows from the positive side of the

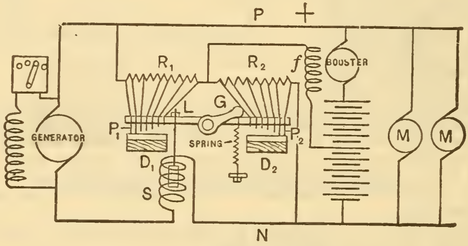


FIG. 18.

system through resistance R_1, through booster field f, to the middle point of the battery, the field excitation and the booster E.M.F. produced being in a direction opposite to the first described, and tending to discharge the battery.

When the resistances R_1 and R_2 are equal there is no potential to send current in either direction through the field coil f.

When the load on the external circuit is normal, the lever L is in a horizontal position, resistance of R_1 is equal to the resistance of R_2, no current flows through the booster field, the booster E.M.F. is zero, and no current passes into or out of the battery.

With increase of external load the pull of magnet S is strengthened by a small increase in generator current passing through the winding. This draws down the left end of lever L, overcoming the pull of the spring. The contacts P_1 are immersed to a greater or less degree in the mercury, thereby short-circuiting portions of R_1 and decreasing its resistance. This produces a current flow in the booster field to cause an E.M.F. to discharge the battery and assist the generator to supply the load demand.

A decrease in external load is attended by a slight diminution in generator current; magnet S is weakened, the pull of the spring predominates, resulting in a movement of the lever to immerse points P_2 in the mercury trough D_2 and thereby reduce the resistance of R_2, causing excitation of the booster field to produce an E.M.F. to send charge into the battery.

The essential difference between this form of regulator and other types is that the design provides for a condition of neutral equilibrium between the pull of the magnet and that of the spring for any position of the moving parts; that is, with a given current passing through S, the pull of the magnet balances the pull of the spring in any position of the lever L, consequently, the change in the generator current with change in external load is not proportional to the load but is a fixed amount. This variation is just sufficient to cause such a change in the pull of the magnet that the resulting unbalanced force overcomes the friction of the parts. The lever will begin to move and will continue to move until the current through S is restored to its normal value, which is accomplished by causing the battery to absorb or discharge current equal to the difference between the normal generator current and that supplied to the external load. The change in the resistances, being made by the immersion of the small contact points in mercury, offers no appreciable opposition to the movement of the parts and thus allows a continuous condition of neutral equilibrium to be maintained throughout the travel of the moving parts.

Obviously by providing externally controlled boosters with a single variable resistance, a non-reversible booster is produced, its action being in effect the same as that described under the heading "Non-Reversible Booster."

Comparison of Boosters.

Reversible boosters should be used where the average, total current to the fluctuating load is greater than the battery discharge current, and where the potential of the power bus bars must not fall off with increase in load. Electric railway and lighting plants having long feeders are examples of the systems to which reversible boosters are suited. Non-reversible boosters should be used where the average total load is less than the battery discharge current, and where a drop in the potential of the power bus bars is of advantage. Examples of such plants are hotel or apartment houses where electric elevators are operated from the lighting dynamos.

Boosters are usually driven by electric motors directly connected to them, though any form of driving power may be used. They are sometimes operated by engines or turbines.

Installations.

Figure 19 shows diagram of connections and Fig. 20 the switchboard of a battery equipment for a residential lighting plant. In the diagram, the voltmeter and voltmeter connections have been omitted. The bus bars on the battery panel are connected directly to the bus bars on the generator panel. In this installation the generators are run during the after-

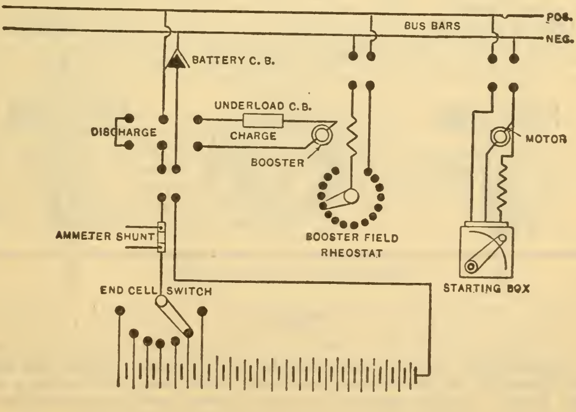


FIG. 19.

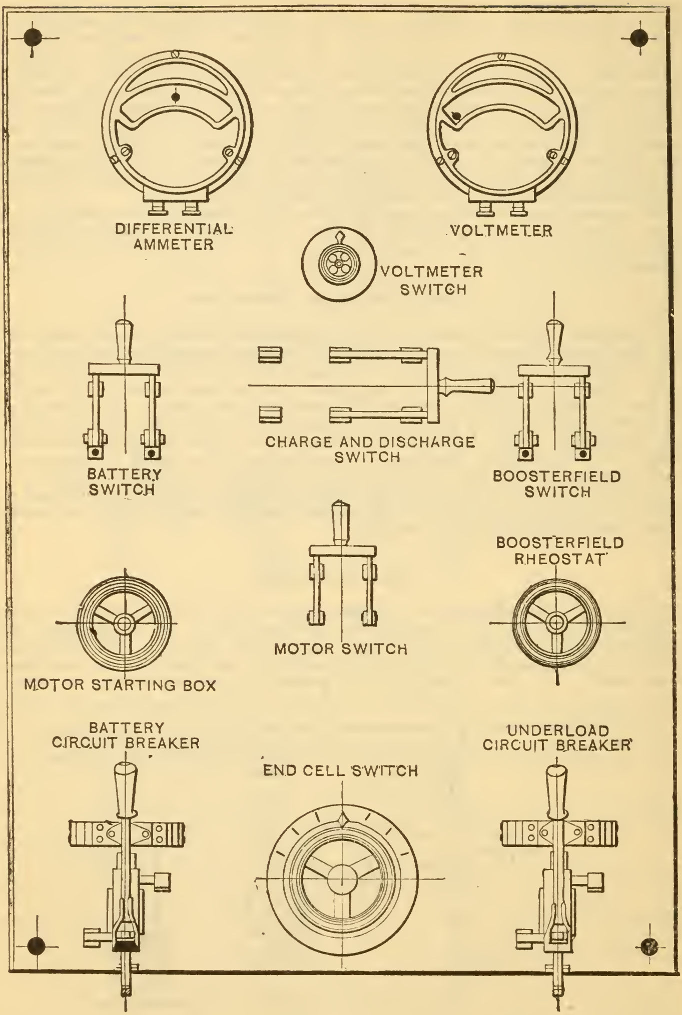


FIG. 20.

noon, charging the battery and supplying the load. When the battery is fully charged the generators are shut down and the battery carries the load alone. In this manner the plant gives continuous service, while the generators are run only from five to nine hours per day.

The bus bar voltage remains constant at all times, the battery voltage on discharge being regulated by means of an end cell switch. On charge, the E.M.F. above that of the bus bars, required to bring all cells up to full charge, is supplied by means of a motor driven charging booster, the voltage at the armature being suitably varied by changing the field excitation.

Figure 21 shows diagram of connections arranged for charging the battery in two parallel groups and discharging in series, the charge and discharge being controlled by variable resistances. In yacht lighting the limited space generally prohibits the use of a charging booster, and in such instances this method of charge and discharge control is the usual practice.

In case the generator from which the battery is charged has sufficient range in voltage to charge all cells in series, a charging booster is not

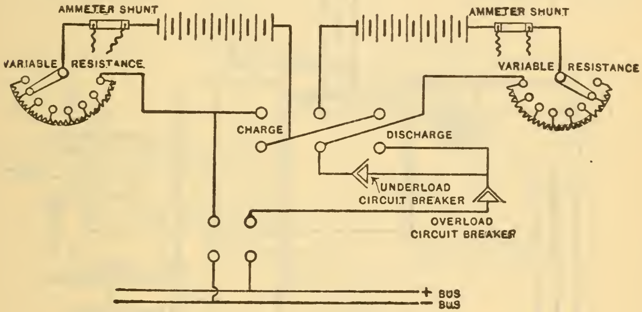


FIG. 21.

required, nor is it necessary to connect groups of cells in parallel, as the generator voltage may be varied as charge proceeds.

The diagram shown in Fig. 22 permits of charging the battery at one voltage and supplying lights at a different voltage. As may be seen, two end cell switches are required for this plant. The voltage of the supply circuit is adjusted by the number of cells in series on switch S_2, while S_3 is moved to cut out cells as they become fully charged. In this instance the end cells included between the contact arms of the two end cell switches must be of sufficient size to receive the charging current, plus the current to the supply circuit.

If the battery can be charged at times when the generator is supplying no other load, only one end cell switch is required.

Figure 23 shows a diagram of connections for a constant current booster system, in which the same generators supply a lighting and a power load, the battery being connected directly across the power bus bars. The diagram further provides for the battery to supply lights at such times as the generators may be shut down.

Three-Wire Systems.

In three-wire systems it is usual to put in two equipments, one on each side of the system. Figs. 24 and 25 show the general schemes of two different three-wire systems; the one shown in Fig. 24 consists of a complete battery equipment and charging booster on each side of the system. In this diagram the generators are connected to the outsides of the line, the neutral being taken from the battery. This makes a good arrangement. One side of the battery system will discharge a sufficient current to take up any unbalanced load.

Figure 25 is a battery three-wire system in which only one booster is used. The main battery is charged from the outsides of the system, and the booster forms a local circuit of the end cells and gives them the proper charge; the voltage of the system being high enough to charge the cells is the main battery. In the boosters shown in these diagrams the armatures only have been indicated, as in nearly every instance boosters on three-wire systems are merely charging machines, the fields being separately excited from the bus bars or from the battery.

Figures 26 and 27 show clearly the switchboard connections of a central station battery working on three-wire systems. It is obvious that the systems would work just as satisfactorily if the generators were of a poten-

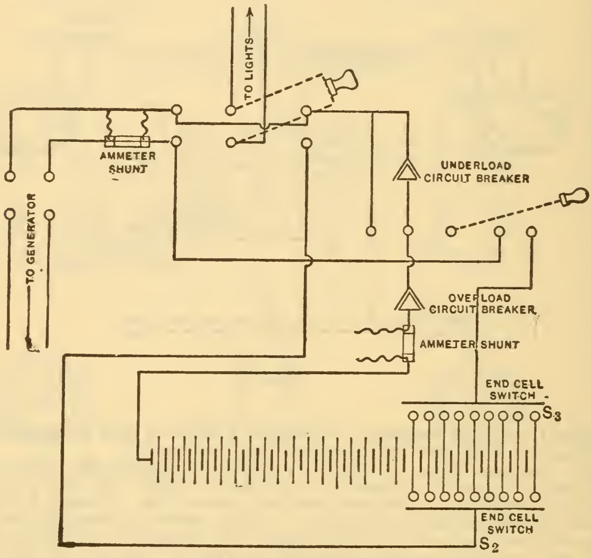


FIG. 22.

tial equal to that of the outsides, and connected directly across the system, as any unbalancing would be taken up by the batteries.

Battery Capacity.

In computing the capacity of a battery to give a certain discharge, it is necessary to take into account the fact that the capacity of a battery varies greatly with the rate of discharge. This variation in capacity can be computed from the curves, Fig. 1. Taking the eight-hour rating as a basis, it is seen that only 50 per cent of the ampere hour capacity is available at the one-hour rate of discharge. Therefore if 200 ampere hours be required at the one-hour rate, the normal ampere hour capacity must be $\frac{200}{50\%} = 400$ ampere hours. In a like manner the normal capacity required for any other rate may be obtained. In the case of a load curve such as

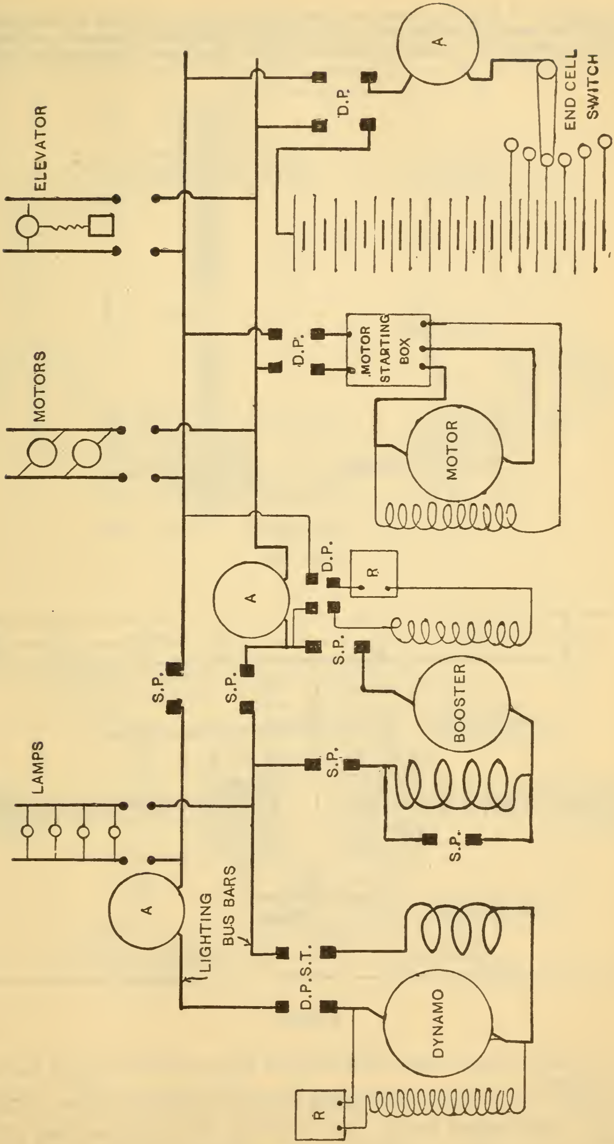

ELEVATOR
MOTORS
LAMPS
LIGHTING
BUS BARS
A
D.P.
END CELL SWITCH
MOTOR STARTING BOX
MOTOR
R
S.P.
BOOSTER
D.P.S.T.
DYNAMO

FIG. 23.

that shown in Fig. 7, when the peak *dEe* is to be carried by the battery, it will be seen that the rate of battery discharge changes continually. If the area of the peak be taken above the line of generation supply,

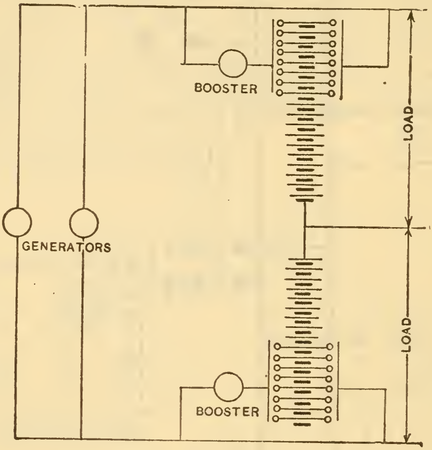


FIG. 24.

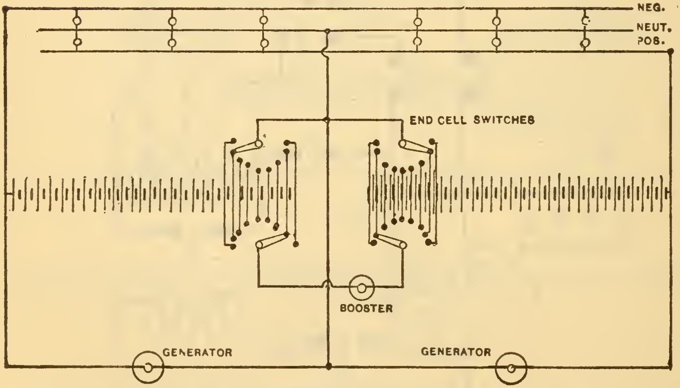


FIG. 25.

"*de*," it will be found equal to 550 ampere hours, and the time of discharge is 2.1 hours.

On a basis of the two-hour discharge rate, the size of battery required $= \frac{550}{64\%} =$ 860 ampere hours. This, however, is the average rate of discharge and on a basis of 860 ampere hours battery capacity. When the discharge takes place along the high portion of the peak at E the amperes supplied by the battery are 400, which is nearly the one-hour rate. To determine the actual capacity required to take care of the load indicated, assume a capacity greater than that necessary for the average rate of

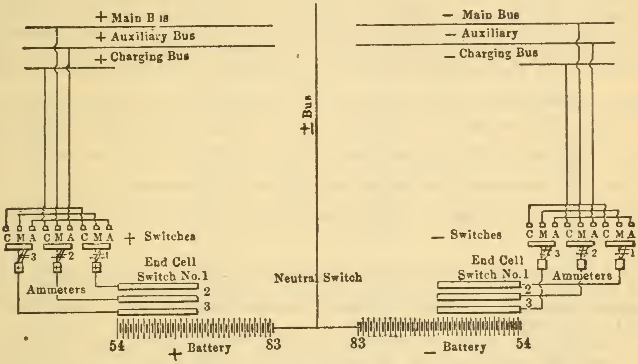


FIG. 26.

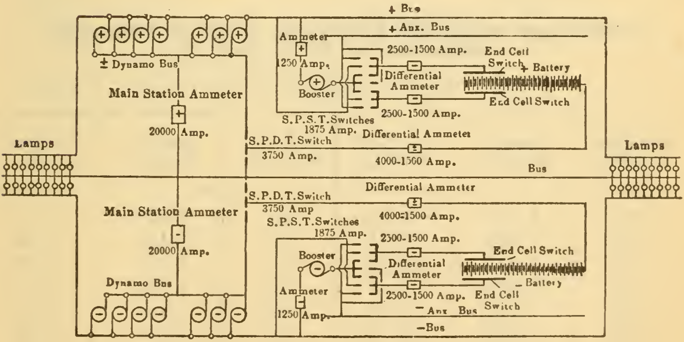


FIG. 27.

discharge. The portion of the load peak to be carried by the battery is divided into vertical divisions, as indicated by the dotted lines. The ampere hours of each strip, divided by the rate of discharge factor (from curves, Fig. 1), gives the ampere hours capacity, on a basis of the normal rate, required for that particular strip. The sum of all these capacities must be the capacity of the proper battery. If the assumed figure be too small or too large, a second computation must be made, based on a capacity again assumed, which is greater or less than that just taken according as the result of the first computation is too small or too large For instance, if peak E be divided vertically into areas V, W, X, Y, and a 900 ampere hour battery assumed as the proper size, the normal rate of discharge will be 112.5 amperes. The ampere hours of area V are 75, and the average discharge rate is 210 amperes. Dividing 210 by the amperes of normal discharge, the result is 1.86. Locating 1.86 on the right-hand scale of curve, Fig. 1, and moving horizontally to curve No. 2, and then downwards to the lower scale, it is seen that this corresponds to the 3¼-hour rate. The percentage of the normal capacity at the eight-hour rate, when the discharge takes place at the 3¼-hour rate, is shown by curve, Fig. 1, to be 76 per cent. The capacity required to cover strip V then is $\frac{75}{.76} = 99$ ampere hours. Similarly the ampere hours of strip W are 193, the rate of discharge 340 amperes, the factor $= \frac{340}{112.5} = 3.02$ corresponding to the 1½-hour rate. Percentage of eight-hour capacity, .58, and ampere hours $= \frac{193}{.58} = 333$.

In a like manner, the capacity required for area X is 269 ampere hours, and for Y is 237 ampere hours, the sum being 938 ampere hours. The assumed capacity is therefore nearly correct, and a 950 ampere battery will be the proper size in this case.

If the battery is also to be used for supplying the light load from 11 P.M. to 5 A.M., the capacity must be computed from the area h, k, m, n, which is 990 ampere hours. The rate of discharge is fairly constant, and extends over six hours. The percentage of normal capacity available at the six-hour rate of discharge is 94 per cent.

$\frac{990}{.94} = 1050$ = ampere hour capacity of battery required to carry the load given from 11 P.M. to 5 A.M.

Strength of Dilute Sulphuric Acid of Different Densities at 15° C. (59° F.)

(*Otto.*)

Per Cent of H_2SO_4.	Specific Gravity.	Per Cent of SO_3.	Per Cent of H_2SO_4.	Specific Gravity.	Per Cent of SO_3.
100	1.842	81.63	23	1.167	18.77
40	1.306	32.65	22	1.159	17.95
31	1.231	25.30	21	1.151	17.40
30	1.223	24.49	20	1.144	16.32
29	1.215	23.67	19	1.136	15.51
28	1.206	22.85	18	1.129	14.69
27	1.198	22.03	17	1.121	13.87
26	1.190	21.22	16	1.116	13.06
25	1.182	20.40	15	1.106	12.24
24	1.174	19.58	14	1.098	11.42

Ordinarily in Accumulators the densities of the Dilute Acid vary between 1.150 and 1.230.

Conducting Power of Dilute Sulphuric Acid of Various Strengths.

(*Matthiessen.*)

Specific Gravity.	Sulphuric Acid in 100 parts by Weight.	Temperature. C.°	Relative Resistances. Ohms per cubic centimeters.
1.003	0.5	16.1	16.01
1.018	2.2	15.2	5.47
1.053	7.9	13.7	1.884
1.080	12.0	12.8	1.368
1.147	20.8	13.6	.960
1.190	26.4	13.0	.871
1.215	29.6	12.3	.830
1.225	30.9	13.6	.862
1.252	34.3	13.5	.874
1.277	37.3	. . .	.930
1.348	45.4	17.9	.973
1.393	50.5	14.5	1.086
1.492	60.6	13.8	1.549
1.638	73.7	14.3	2.786
1.726	81.2	16.3	4.337
1.827	92.7	14.3	5.320
1.838	100.0	. . .	. . .

Conducting Power of Acid and Saline Solutions.

Copper (Metallic) at 66° F.	100,000,000.
Sulphuric Acid . . . . 1 Measure Water. . . . . 11 Measures (Equal to 14.32 parts by weight of Acid in 100 parts of the mixture), at 66° F.	98.0 approximate.
Sulphate of Copper, saturated solution at 66° F.	6.1 "
Chloride of Sodium, saturated solution at 66° F.	35.0 "
Sulphate of Zinc, saturated solution at 66° F. .	6.4 "

SWITCHBOARDS.

Revised by H. W. Young, B. P. Rowe and E. M. Hewlett.

The object of a switchboard is to collect the electrical energy in an installation, for the purposes of control, measurement and distribution.

In small stations this is accomplished by concentrating the energy at a single place. In the large modern stations this is often impractical, and it is, therefore, customary to concentrate only the control and measuring apparatus.

There are two general types of switchboards:

(1) **Direct-Control Panel Switchboards,** in which the switching and measuring apparatus is mounted directly on the switchboards.

(2) **Remote-Control Switchboards,** in which the main current carrying parts are at some distance from the controlling and measuring apparatus. This type may again be divided into two divisions, viz.: *hand-operated* remote-control, and *power-operated* remote-control apparatus. The best modern power-operated apparatus is electrically operated, although there are a few installations which have employed compressed air.

The above general types may both be sub-divided into Direct-Current and Alternating-Current Switchboards, and there are numerous and distinct classes in each subdivision.

It is customary to mount apparatus and switching devices for low-tension service up to and including 750 volts directly on the face of the switchboard panels unless provided with suitable insulating covers or is out of reach of the operator.

If the plant is of small capacity, the switching devices and conductors may be provided for on the rear of the panels. Heavy capacity plants from 2200 to 6600 volts, however, are invariably remote control, and nearly always electrically operated.

In all high-tension plants from 6600 to 33,000 volts the switchboard is invariably remote control, and if of heavy capacity it is invariably electrically operated. In large stations, for pressures above 33,000 volts, switchboards are invariably electrically operated remote control. In small capacity installations where the high-pressure service consists of only one or two incoming lines, which will not warrant expensive remote control switches, a set of simple fused circuit breakers or expulsion fuses are often installed and a switchboard dispensed with. Cut out switches are used, however, in addition, for disconnecting the lines.

Design of Direct-Control Panel Switchboards.—In designing buildings for control stations or isolated plants, the switchboard should be located in an accessible place, with plenty of room in front and rear. If care is taken in locating the various panels with respect to the machines and feeders to be controlled, much unnecessary expense and complication may be avoided.

If extensions to switchboards are expected, which is usually the case, panels controlling generators should be together at one end of the switchboard, and those controlling feeders at the other end. When total output panels are used, they are placed between the generator and feeder sections. It is advisable, however, in some special cases, in order to save copper in the busses and simplify the station wiring, to intermingle the generator and feeder switches although even in this case it is desirable to group the generator indicating devices together and likewise those of the feeders.

Unnecessary complications and extra flexibility being at the expense of simplicity are always to be avoided. For instance, in a majority of cases it would seem unnecessary to provide more than one set of bus bars.

Plainness, neatness, and symmetry in design should be aimed at, and nothing placed on the switchboard which has no other function than ornamentation.

Sufficient indicating and recording instruments should be used to determine if the machines are working efficiently, to obtain a record of the output of the feeders, to detect external or internal troubles, and to check with records obtained from outside sources. The degree of accuracy required in the switchboard instruments depends entirely upon the conditions involved, greater accuracy being required where power is bought or sold. Instruments which are accurate to within 2 per cent of the full scale deflection will generally fulfill all requirements.

Switchboards are now standardized, covering a large range of requirements, and standard panels are advisable for general use, although special conditions may usually be met with small modifications of the standards.

For ordinary direct-current switchboards, 4 feet is little enough behind the panels. In any case there should be a clear space between the connections on the panels and the wall of 2½ to 3 feet. For heavy direct-current work and most alternating-current work it is often necessary to have 6 to 8 feet behind the panels.

Hand-control panel switchboards may not be advisable in direct-current stations where capacities are large, and in such cases remote-control installations should be considered. It is likewise inadvisable to design switchboards of this class for heavy capacity alternating-current circuits of 2200 volts or upward, as the conductors for such service should be specially isolated.

It should be noted especially that heavy capacity conductors and switching devices for circuits of 4000 alternations and above should be avoided, on account of excessive heating to be met with due to eddy currents in the conductors. It is doubtful if satisfactory switching devices can be easily procured, which will carry currents of more than 3000 amperes at 7200 alternations or the equivalent, and such devices require special design and expense.

In locating switching apparatus it is usually assumed that dynamo leads come up from below, and feeder wires go out overhead except that underground feeders naturally go out below.

In order to avoid a very unsightly complication of wiring and apparatus on the rear of switchboards, it is best to locate series and voltage transformers apart from the switchboard on the incoming and outgoing cables, if at all possible, and to make all large rheostats operate with sprocket and chain, thus locating the rheostats separate also. Any extensive system of fuses to be supplied on the rear should preferably be provided for on a separate framework.

The material from which panels should be made varies with the service. Plain slate can be used for any panels where the potentials are not above 1200 volts. This slate may be either plain, or oil filled, or it may be given a black finish. The black enamelled slate is very satisfactory for use where oil is prevalent, but it shows scratches easily, and is not easily repaired if chipped. The most popular finish is the natural black oil finish slate, which may be made oil proof, and is a durable dead black. It is easily replaced when damaged.

For switch bases and panels not requiring finish, soapstone is often used as it is a better insulator than slate, the latter being liable to contain conducting veins. Such slate should be rejected.

Marble is largely used for switchboard panels because of its good insulating qualities. Many varieties are available, the most common being the white Italian, pink or grey Tennessee, and several varieties of blue Vermont marble. The colored marbles do not show oil stains as readily as the white varieties, and present a more pleasing appearance. The blue Vermont marbles are more uniform in coloring, and therefore easier to match; but if absolute uniformity in this respect is desirable, it is advisable that all panels be given a black marine finish, as it is often difficult to get new panels with exactly the same shades and markings as those it is desired to match, marble being a natural product.

Standard Central Station switchboard panels are commonly made 90 inches high, and composed of two or three slabs. The upper slab of a two-piece panel is usually from 60 to 65 inches high, the lower one being from 25 to 30 inches high. The General Electric Company's three-section panels are upper and middle sections 31 inches each and the lower section is 28 inches, the corresponding Westinghouse standard being 65 and 25 inches. The Westinghouse three-piece panel has an upper slab 20 inches high, middle slab 45 inches high and lower slab 25 inches, the 20-inch slab being provided primarily to permit circuit breakers to be directly mounted thereon, and allow of easy removal in case of substitution or repairs.

The General Electric Company also makes panels of any sizes up to 48 inches high and 1½ inches thick for isolated plants. Panels 48 inches high are mounted on 76-inch pipe supports, the Westinghouse standard for similar service being 48 inches high and 1¼ or 1½ inches thick as required.

Each panel is beveled ¼ to ½ inch all around the front edges, the dimensions being measured from the edges of the panel, and not across the face of the level.

Switchboard frames for very heavy panels are often made of channel iron tees or I-beams. The Central Station Switchboard frames are made of steel

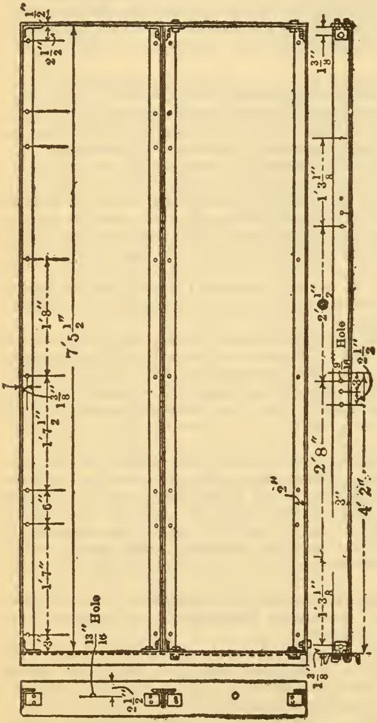


FIG. 1.

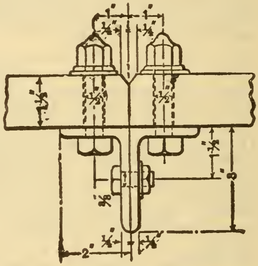


FIG. 2. Method of Joining Adjacent Panels.

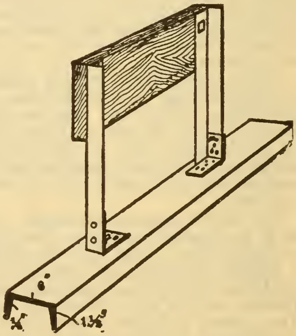


FIG. 3. Channel Foot for Switchboard Frame.

angle bars varying from 2¼ × 1½ × ¼ inches to 3 × 2 × ¼ inches or 1¼-inch gas pipe. The angle bars are supported in an upright position on a level strip which rests on the floor. This may be of slate, an inverted channel iron, or a hardwood plank.

The panels are bolted to the narrow web of the angle bars and the adjacent angles bolted together through their wide webs. (See Fig. 2.)

Another method used with panels which carry a moderate weight of apparatus is to make a frame of iron piping, secured to the panels by means of suitable iron supporting clamps.

The framework of all switchboards should be insulated from ground when used on systems of 600 volts or less. In high-tension alternating-current systems, it is necessary to ground all framework to carry off static discharges, and to insure safety to the operator, should he touch the framework. For securing the frame in a vertical position, rods are used with or without turnbuckles, or else angle iron braces.

As a general thing, alternating and direct-current panels should never be intermingled, especially when this involves the mingling of conductors on the rear.

It is recommended that illuminating lamps be omitted from the front of switchboards, and that the instruments be illuminated by lamps in front of the same.

The copper bars and connections on the rear of switchboards should be carefully laid out in order that the current may be carried economically and without overheating, and especially to prevent undue crowding and insure a neat and workmanlike appearance. The best practice requires that bus bars be not placed near the floor. Switches, circuit breakers and other apparatus are connected up with bare copper strap or insulated wire as occasion requires, bent in suitable forms. Where bus bars are not rigidly supported, it is not recommended, as a rule, to have long studs on the apparatus, projecting out far enough to connect to the busses, as the strain on the apparatus due to the weight of the busses may affect the adjustment of electrical contacts. Except for small switchboards the bus bars are usually supplied with insulated supports.

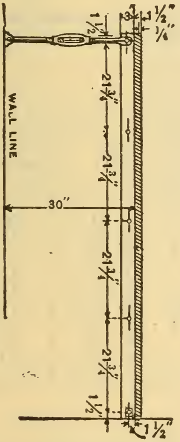


Fig. 4. Showing Method of Bracing Switchboard Panel to Wall.

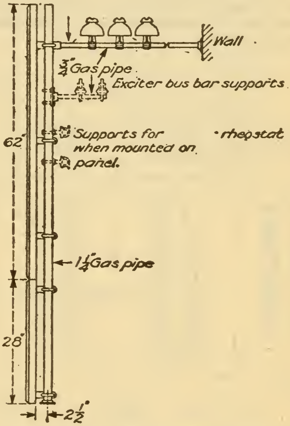


Fig. 5. Showing Gaspipe Framework.

Bare flat or round copper bars are now used almost universally for conductors on low-potential switchboards, the flat bar being usually preferred on account of ease in making connections and the facility with which additional capacity may be provided for. The prevailing thicknesses vary from $\frac{1}{8}$ to $\frac{1}{2}$ inches with widths proportioned to suit the capacity. The size of copper conductor is usually figured out on the basis of 800 to 1000 amperes per square inch of cross section. By properly laminating the bars, even very heavy currents may be provided for on this basis. Contact surfaces should be figured on a basis of 100 to 200 amperes per square inch according to the method of clamping, bolting, or soldering. Steel bolts are used in clamping. Care must be taken, however, with alternating-current circuits to see that iron clamping plates and bolts do not form complete magnetic circuits and cause undue heating, due to eddy currents set up in the iron.

Connections and apparatus for carrying current should be guaranteed to carry their normal current at a temperature rise not exceeding 30° C., above the surrounding air. Rolled copper should be used for conductors to secure the best conductivity, but it is often necessary to use copper or brass castings. As their conductivity is usually low, such materials should be avoided as much as possible. Where it is necessary to use castings they should be of new metal only and care should be taken to insist on a standard of conductivity for each piece where such a condition counts. The ordinary mixtures vary from 12 to 18 per cent according to mixture. A conductivity of 50 per cent may be considered high and sufficient, but it is not obtainable in a regular brass casting.

The following table from "Modern Switchboards," by A. B. Herrick, gives percentages of mixtures with resulting conductivity as compared with 100 per cent copper:

% Copper.	% Zinc.	Conductivity.	% Copper.	% Tin.	Conductivity.
98.44	1.56	46.88	98.59	1.41	62.46
94.49	5.51	33.32	93.98	6.02	19.68
88.89	11.11	25.50	90.30	9.70	12.19
86.67	13.33	30.90	89.70	10.30	10.21
82.54	17.50	29.20	88.39	11.61	12.10
75.00	25.00	22.08	87.65	12.35	10.15
73.30	36.70	22.27	85.09	14.91	8.82
67.74	32.26	25.40	16.40	83.60	12.76
	100.00	27.39		100.00	11.45

All minor connections to bus bars such as switch leads, feeder terminals, or any attachments whatsoever, whether clamped, bolted or soldered, should have ample contact surface contact rated at 100 amperes per square inch, and all round conductors should be cup-soldered to flat lugs leaving proper amounts of contact surface.

Cup-soldered connections should enter the sockets from two to three diameters. All permanent joints of this nature should be soldered, as required by the National Board of Fire Underwriters. Where it is essential to leave a joint that may be easily disconnected, the old style sleeve or socket with binding screws can be used, but the connections should enter from four to ten diameters to make a secure connection.

An exceedingly clever device to take the place of the connection referred to or to use in place of cup-soldering is the Dossert joint which is quickly and easily applied to the end of a wire or cable, and is so designed as to insure the full conductivity of the conductor to which it is applied.

The tables given below furnish the electrical constants of copper and aluminum bars which are most likely to be of use to the switchboard designer. The current which any given section may carry is calculated upon the basis of a load factor of 50 per cent, and the densities given are those which for average conditions of radiation would result in a temperature rise of about 10 degrees Centigrade. Where the load factor is to be 100 per cent, and it is desired to keep the heating within the above limits, the current densities must be halved.

The data given show in an interesting manner the relative values of copper and aluminum in switchboard construction.

Copper Bar Data.

The Cutter Company.

Size.	Amps.	Amps. per Square Inch.	Circular Mils.	Square Mils.	Ohms per Foot.	Weight per Foot.
1 × ¼ in. . . .	433	1732	318,310	250,000	.0000336	.97
1¼ × ¼ in. . . .	530	1696	397,290	312,000	.0000269	1.21
1½ × ¼ in. . . .	626	1669	477,465	375,000	.0000223	1.45
1¾ × ¼ in. . . .	725	1657	556,400	437,000	.0000192	1.70
1¼ × ⅜ in. . . .	676	1442	596,830	468,750	.0000179	1.82
1½ × ⅜ in. . . .	798	1418	716,200	562,500	.0000149	2.18
1¾ × ⅜ in. . . .	916	1395	835,600	656,250	.0000128	2.54
2 × ⅜ in. . . .	1035	1380	954,930	750,000	.0000112	2.92
2¼ × ⅜ in. . . .	1154	1367	1,074,300	843,750	.00000995	3.27
2½ × ½ in. . . .	1500	1200	1,591,550	1,250,000	.00000672	4.86
2½ × ⅝ in. . . .	1715	1097	1,989,440	1,562,500	.00000537	6.07
2 × ½ in. . . .	1222	1222	1,273,240	1,000,000	.00000840	3.89
No. 0000 B. & S.	267	1606	211,600	166,190	.0000505	.64
½ in. round . . .	305	1552	250,000	176,350	.0000428	.76
⅝ in. round . . .	426	1388	390,625	305,796	.0000273	1.18
¾ in. round . . .	560	1267	562,500	441,787	.0000190	1.71
1 in. round . . .	861	1096	1,000,000	785,400	.0000107	3.05

Aluminum Bar Data.

The Cutter Company.

Size.	Amps.	Amps. per Square Inch.	Circular Mils.	Square Mils.	Ohms per Foot.	Weight per Foot.
1 × ¼ in. . . .	347	1388	318,310	250,000	.0000534	.291
1¼ × ¼ in. . . .	424	1360	397,290	312,000	.0000428	.362
1½ × ¼ in. . . .	500	1334	477,465	375,000	.0000356	.435
1¾ × ¼ in. . . .	580	1327	556,400	437,000	.0000305	.507
1¼ × ⅜ in. . . .	530	1131	596,830	468,750	.0000285	.544
1½ × ⅜ in. . . .	638	1130	716,200	562,500	.0000237	.653
1¾ × ⅜ in. . . .	733	1117	835,600	656,250	.0000203	.762
2 × ⅜ in. . . .	830	1107	954,930	750,000	.0000178	.871
2¼ × ⅜ in. . . .	925	1096	1,074,300	843,750	.0000158	.980
2½ × ½ in. . . .	1200	960	1,591,550	1,250,000	.0000107	1.45
2½ × ⅝ in. . . .	1400	897	1,989,440	1,562,500	.00000855	1.81
2 × ½ in. . . .	980	980	1,273,240	1,000,000	.0000134	1.16
No. 0000 B. & S.	211	1266	211,600	166,190	.0000803	.193
½ in. round . . .	244	1260	250,000	176,350	.0000680	.228
⅝ in. round . . .	340	1108	390,625	305,796	.0000436	.355
¾ in. round . . .	448	1013	562,500	441,787	.0000302	.513
1 in. round . . .	690	880	1,000,000	785,400	.000017	.911

Circuit breakers, if required to open circuits carrying heavy loads, should be mounted at the top of the panels to give the arc plenty of room to rise without scorching the instruments or the panel, and to keep it above the attendant's head. Instruments should be mounted below the circuit breakers, while the lower portion of the panel should be utilized for switching devices.

Switches, circuit breakers and fuses are usually rated at their maximum continuous ampere capacity and for this reason care should be taken in selecting these devices. Take into account the one hour, two hour and three hour overload guarantee on the machines. Indicating instruments should have scales calibrated to read in excess of the overload guarantee of the machines to which they are to be connected. It is usually good practice to have the needle about in the middle of the scale at normal load, but a good reading should be obtained as low as one quarter load. Meters affected by stray fields should be kept away from the influence of connections carrying heavy currents.

Panel switchboards for small capacity stations for alternating-current circuits from 480 to 3300 volts are usually supplied with oil switches, mounted on the back of the panels, with handles for manual operation on the front. In large stations, however, these are usually replaced by remote-control switches.

Insulation Distances. — In high voltage switchboard work where there are bare conductors, safe distances must be maintained between the conductors and from the conductors to the switchboard structure. The striking distance through air may be somewhat less than the distance over surfaces. The air distance should not be less than two and one half times the striking distance of the given voltage as taken from the curve on page 462, and the surface distance should not be less than three times the air distance allowed for the given voltage. It is obvious that the greater the distance the greater the factor of safety; and in large capacity stations this greater factor of safety is usually advisable on account of the greater insurance given by the use of greater distances.

The creepage distance to be maintained in the switchboard depends upon many conditions some of which are: The material of the surface; the contour of the surface; the liability to collect dust and the properties of the dust; and the amount of moisture in the atmosphere.

ALTERNATING-CURRENT SWITCHBOARD PANELS.

The instruments, switches, etc., required for the various types of panels are listed below, for assistance to the engineer when designing a switchboard. Each type of panel will be described individually.

Equipment of 3-Phase Generator Panels.

3 Ammeters (one is sufficient for practically balanced loads or may be connected by means of plugs or ammeter transfer switches, so as to read the current in either of the 3 phases).
1 Voltmeter.
1 Polyphase indicating wattmeter.
1 Field ammeter.
1 Polyphase integrating wattmeter (optional).
1 Wattless component indicator or power-factor indicator (optional). The first instrument indicates the useless watts and the rheostat should be adjusted to reduce them to a minimum. The power-factor indicator is used for the same purpose, but does not give a direct indication of the idle currents at all loads.
1 Voltmeter switch for reading voltage on either of the 3 phases (on balanced systems this is usually omitted and voltmeter permanently connected to one phase).
1 Synchronizing switch (one synchronism indicator can be used for all generators).
1 Field rheostat with chain operating mechanism (small machines may have the rheostat mounted at the back of the panel). If electrically operated rheostats are used the handwheel would be replaced by a controlling switch.

1 Field switch with discharge clips.
1 Discharge resistance for field circuit.
1 Non-automatic main switch (controlling switch required if oil switch electrically operated is used).
2 Current transformers (3 transformers are necessary if neutral of generator is grounded).
Potential transformers (3 potential transformers are desirable if neutral of generator is grounded, but one is required if used only for synchronizing). Both may be omitted on circuits of 600 volts and less, if all meters have their coils wound for operating at generator voltage.
1 Engine governor control switch if governor is electrically controlled.

If each alternator has its own exciter the exciter may also be controlled from the alternator panel, by the addition of an exciter field rheostat.

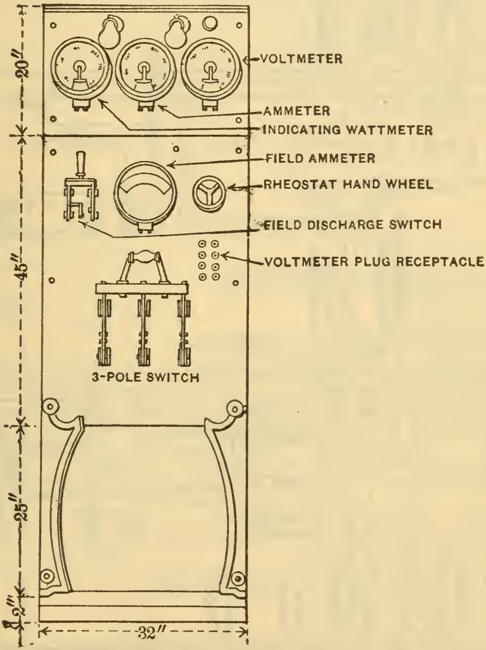


Fig. 6. 440- and 600-Volt Three-phase Generator Panel.

Two-phase generator panels have a similar equipment to the three-phase except that but two main ammeters, two current transformers and two potential transformers are required.

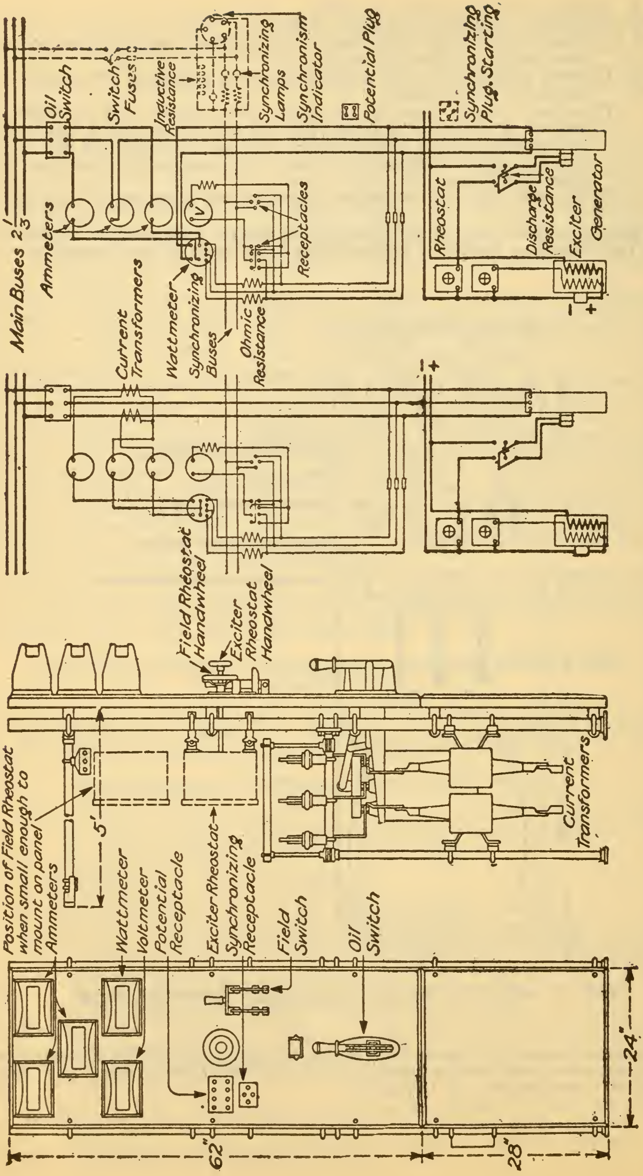


FIG. 7. 400- and 600-Volt Three-Phase Generator Panels.

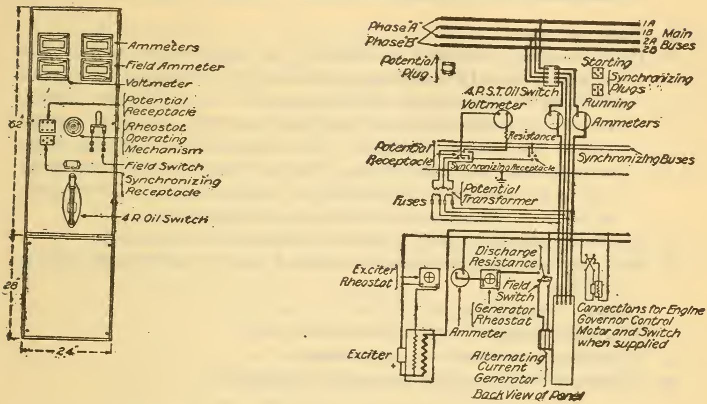


FIG. 8. Two-Phase 2300-Volt Generator Panel.

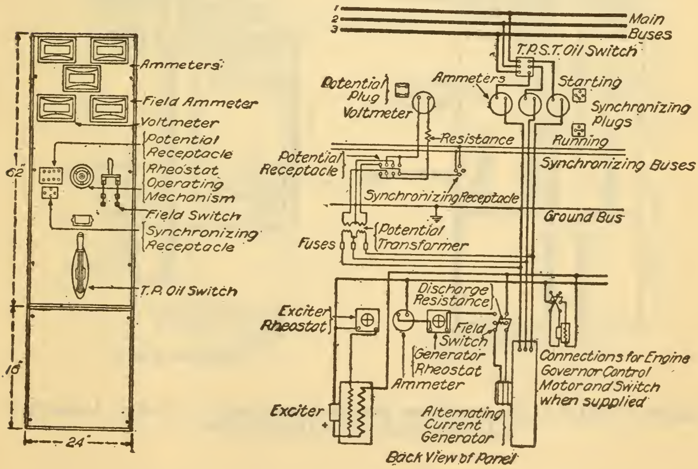


FIG. 9. Three-Phase 2300-Volt Generator Panels.

Equipment of Single-Phase Feeder Panel.

1 Main ammeter.

1 Compensating voltmeter (optional). As single-phase panels are invariably used for lighting it is necessary to maintain a constant potential at the point of distribution, and as each feeder circuit is likely to have a different load characteristic, potential regulators are frequently installed. The compensating voltmeter compensates for the ohmic drop or for both the ohmic and inductive drop in the line at all conditions of load and gives a direct indication of the voltage at the center of distribution.

1 Potential regulator and operating mechanism (optional).

1 Main switch with automatic overload trip or automatic circuit breaker.

1 Current transformer.

1 Potential transformer if voltmeter is used.

1 Time limit overload relay (optional).

1 Single-phase integrating wattmeter (optional).

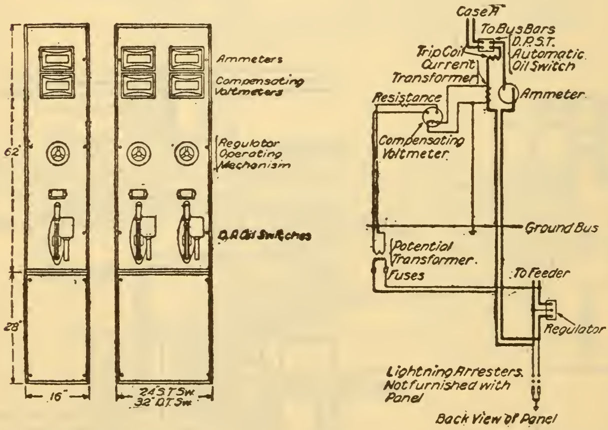


FIG. 10. 2500-Volt Single-Phase Feeder Panels with Primary Ammeters and with Series Trip Oil Switches.

Equipment of Three-Phase Feeder Panels.

3 Main ammeters for transmission lines used to detect any unbalancing due to leakage to ground. A single ammeter may be used if desired, with suitable plugs, to indicate the current in either of the three phases. (One ammeter is sufficient on feeders for induction motors and rotary converters, or on incoming lines in a sub-station.)

1 Polyphase indicating wattmeter (optional). For power circuits in mills and mines. This wattmeter gives a sufficient indication of the output without the ammeters.

1 Polyphase integrating wattmeter (optional).

1 Oil break switch with overload trip, or automatic circuit breaker.

2 Current transformers (three transformers are necessary if neutral of three-phase system is grounded).

2 Potential transformers for wattmeters.

1 Time limit overload relay (optional). The number of potential transformers can be reduced for a switchboard containing a number of feeder panels by connecting two potential transformers to the busses and feeding all the wattmeters.

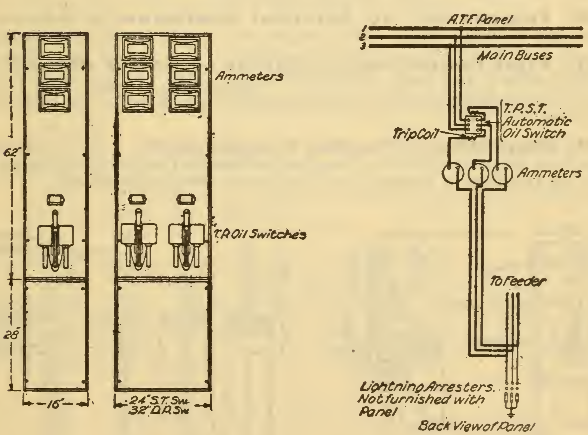


FIG. 11. 2500-Volt Three-Phase Feeder Panels with Primary Ammeters and Series Trip Oil Switches.

Equipment of Two-Phase Feeder Panels.

2 Main ammeters.
1 Polyphase indicating wattmeter (optional).
1 Polyphase integrating wattmeter (optional).
1 Oil break switch with overload trip, or automatic circuit breaker.
2 Current transformers.
2 Potential transformers for wattmeters.
1 Time limit overload relay (optional). The number of potential transformers can be reduced for a switchboard containing a number of feeder panels by connecting two potential transformers to the busses and feeding all the wattmeters.

Equipment of Induction Motor Panels.

1 Ammeter.
1 Oil break switch with overload trip, or automatic circuit breaker.
2 Current transformers.
1 Time limit overload relay (optional).

The various methods of starting induction motors are as follows:

1. **By Connecting them Directly to the Line.**—This is seldom done except on motors under 10 horse-power capacity, because it produces variation in the bus voltage unless the busses have considerable energy back of them.

2. **By Inserting an Internal Resistance** in the circuit of the motor by means of a switch on the motor shaft.

3. **By Introducing an External Resistance** in the rotor circuit through collector rings. This resistance is cut in or out by a controller.

4. **By First Connecting the Motor to Low-Voltage Taps.**—If the motor is fed from step-down transformers, it may first be connected to low-voltage taps on the transformer and then to the full-voltage connections.

5. **By Employing a Starting Compensator.** — Many compensators have an internal switch for starting; otherwise the panel should be provided with switches to connect and disconnect the compensator.

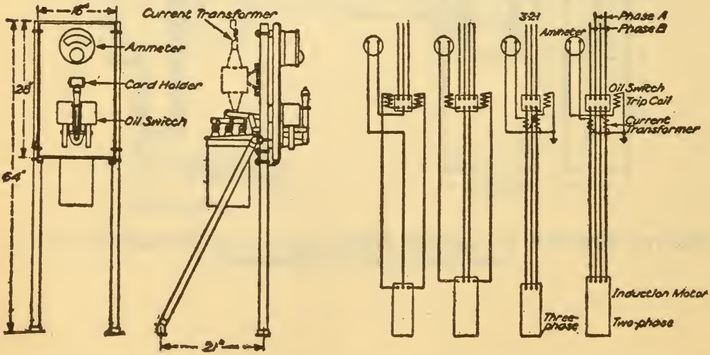


Fig. 12. 2080-Volt Induction-Motor Panel for Controlling Motors having an Internal Resistance.

Equipment of Three-Phase Synchronous Motor Panels.

1 Ammeter.
1 Three-phase indicating wattmeter.
1 Field rheostat with operating mechanism.
1 Synchronizing switch. (The synchronism indicator will answer for any number of motors or the generator synchronism indicator may be used.)
1 Main oil switch with automatic overload trip.
1 Field switch with discharge resistance.
2 Current transformers.
2 Potential transformers.
1 Time limit overload relay (optional).

A synchronous motor driving a direct-current generator can usually be started from the direct-current side, in which case the synchronizing switch is necessary. If always started as an induction motor the synchronizing switch is unnecessary.

The equipment of a two-phase motor panel is the same as for a three-phase, except that two ammeters should be used.

Equipment of a Three-Phase Rotary Converter Panel.

For rotary converters connected in the high-tension side of step-down transformers, the panel for the alternating-current side is the same for three-phase or six-phase machines.

1 Three-phase integrating wattmeter (optional).
1 Ammeter.
1 Power factor meter.
1 Main oil circuit breaker with automatic overload trip.
1 Synchronizing switch (not necessary if rotary is started from the alternating-current side).
1 Starting motor switch (only used where rotary is started by a starting motor).
1 Switch for synchronizing resistance (only used where rotary is started by a starting motor).
2 Current transformers.
1 Potential transformer (if rotary is started from the direct-current side or by a starting motor).
1 Time limit overload relay (optional).

One method of starting a rotary converter is by connecting the alternating-current side first to fractional voltage taps on the transformers, and then to full-voltage connections. This is accomplished by means of a double-pole, double-throw switch on a separate panel for a three-phase converter, and two triple-pole, double-throw switches on a separate panel for a six-phase converter, Fig. 13. Another method is by the use of a motor on the rotary shaft, as shown on diagram, Fig. 14.

The rotary may also be started from the direct-current side. In either of the latter cases it is necessary to synchronize.

In case several rotary converters must operate from the same bank of transformers, it is best to have a separate set of secondaries for each rotary. But in case of rotaries which must be parallel on the alternating-current side under such a condition, it is essential that reactances be provided in the circuits to prevent interchange of current between machines, and that switches be provided in the alternating-current leads. These are used as main switches in synchronizing and are usually mounted on the alternating-current panel. For the condition just described, the panel would contain the same list of apparatus mentioned above, except that these switches

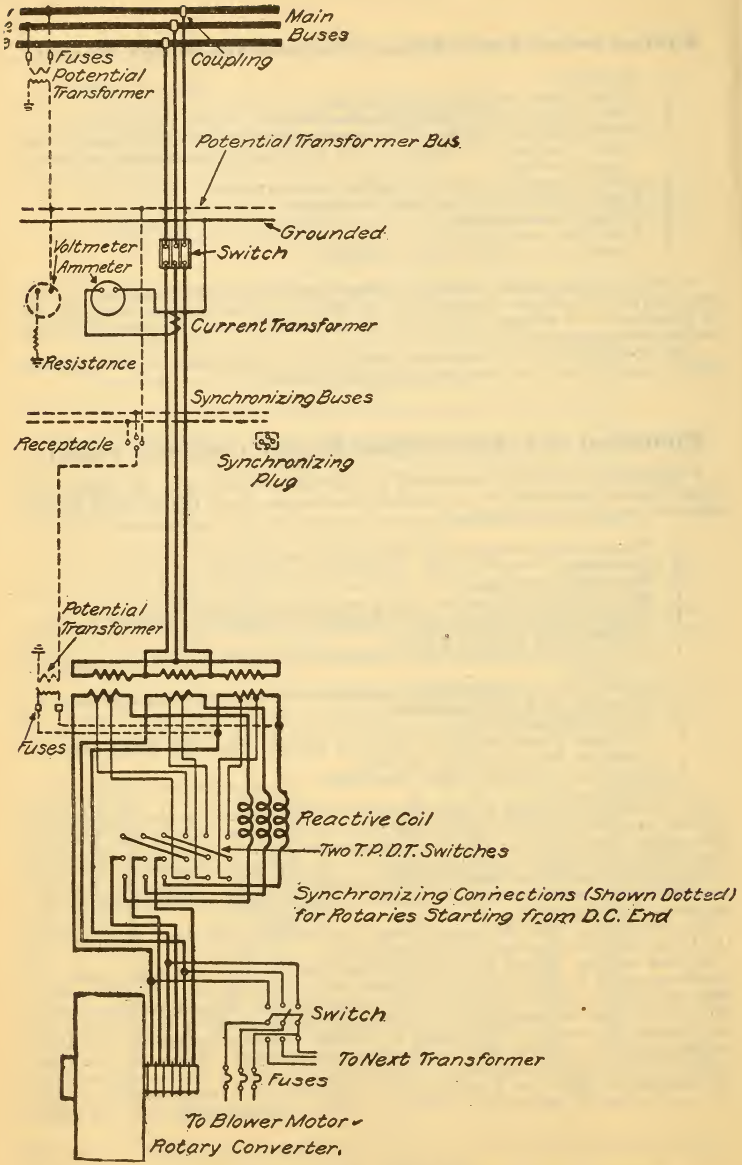


FIG. 13. Diagram of Connections. Three-Phase Rotary Converter started directly from Alternating-Current Side.

would be substituted for the automatic overload main switch and relay, and either automatic protection provided in connection with the switches or else a fuse in each lead.

When a rotary converter must run inverted (i.e., to convert direct current

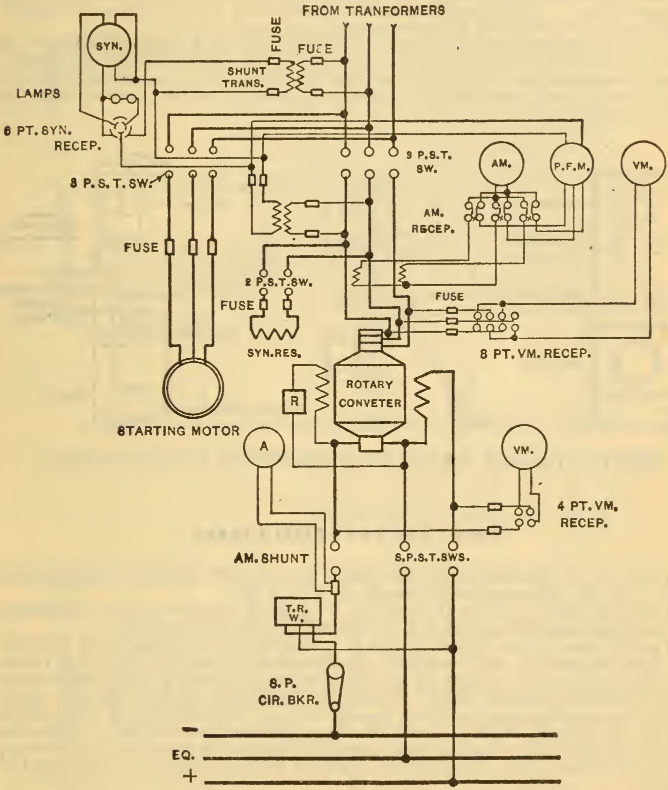


Fig. 14. Diagram of Connections. Three-Phase Rotary Converter with Starting Motor.

into alternating current), provision must always be made for starting the rotary from the direct-current side.

Two-Phase Rotary Converter Panels are essentially the same, but require two ammeters instead of one, and four-pole alternating-current switches.

Equipment of Constant-Current Transformer Panels, for Series Arc or Incandescent Lighting.

The primaries of these transformers may be controlled by an oil switch, with automatic overload trip, or by plug switches and fuses.

The secondaries, being of small capacity, are usually controlled by plug switches. An ammeter should be connected in the secondary side to indicate the current and to detect grounds or open circuits.

An integrating wattmeter on the primary side is a valuable adjunct to record the total power consumed. The diagram shown is that of a single-circuit transformer. Various modifications result from using multi-circuit transformers and introducing transfer systems in either the primary or secondary side.

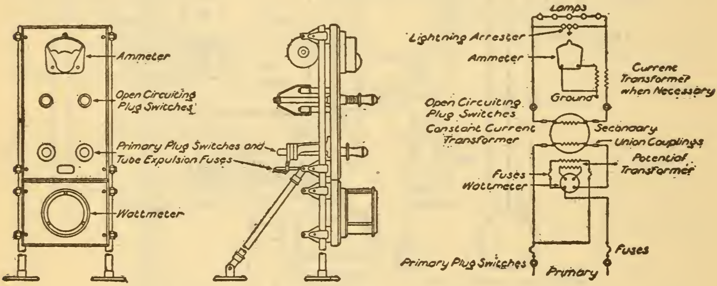


FIG. 15. Constant-Current Transformer Panel for Single Circuit.

ARC SWITCHBOARDS.

This line of switchboards represents an entirely different construction from that of ordinary switchboards.

Extra flexibility makes it desirable, and small currents make it possible, to use plug connections instead of the ordinary type of switches.

The function of arc switchboards is to enable the transfer of one or more arc light circuits to and from any of a number of generators. This transferring is sometimes accomplished by means of a pair of plugs connected with insulated flexible cable; sometimes by plugs without cables, which bridge two contacts back of the board, or by a combination of cable plugs and plugs without cables. The type using plugs without cables is preferable because danger is eliminated, which would otherwise be possible to attendant, due to contact with exposed or abraded cables carrying high-potential current.

The accompanying illustration shows an arc switchboard of the General Electric panel type, arranged for three machines and three circuits. The vertical rows of sockets are lettered and the horizontal numbered. The ends of the vertical bars are connected to the machines and circuits. Each of the bars is broken in three places, and the machine may be connected to its circuit by plugging across these breaks, thus making the bar continuous; by removing any pair of plugs the machine may be disconnected.

C11, E11 and G11 are ammeter jacks, and are used in connection with two plugs connected with a twin cable, for placing an ammeter in the circuit. The six horizontal bars are for the purpose of transferring a machine or a feeder to some circuit other than its own. Each horizontal bar is provided, at one side of the panel, with a socket (A3, A4, A5, A7, A8, and A9) by means of which it can be connected with the horizontal bar on the adjoining panel. All ordinary combinations can be made by means of the bars and plugs; but cable plugs are provided with each panel, so that when necessary, machines and feeders can be transferred without the use of the bar. These plugs and cables are intended for use only in case of an emergency.

To run machine No. 1 on feeder No. 1, insert plugs in B10, C10, B6, C6,

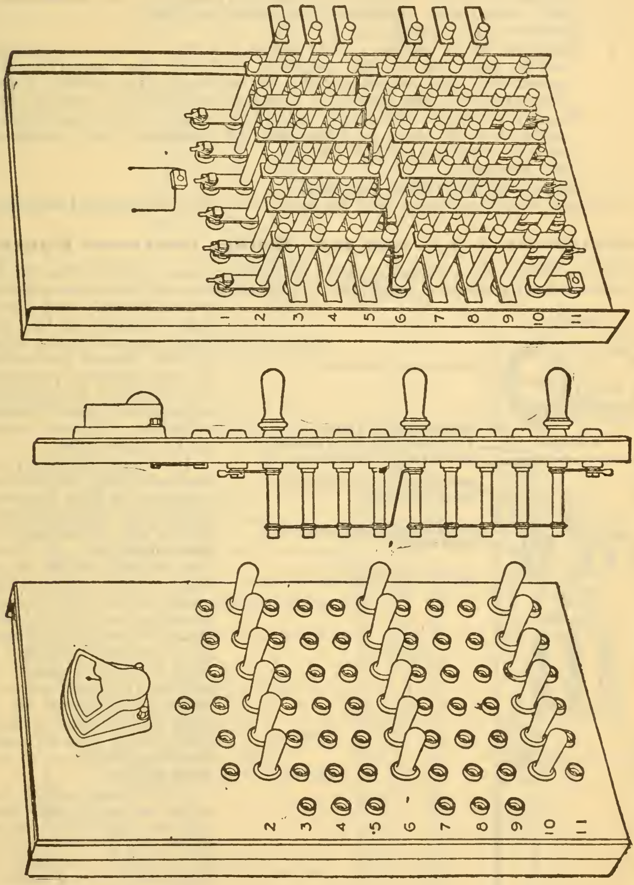


Fig. 16.

B2, and C2. To shut down machine No. 2, and run feeders Nos. 1 and 2 in series on machine No. 1, insert a plug at C5, D5, C7, and D7, and remove plugs at C6 and D6; this leaves two circuits and two machines in series. Short circuit machine No. 2 by inserting the plug at E7. Cut out machine No. 2 by removing the plug at D10 and E10. Take out plug at D7.

DIRECT-CURRENT SWITCHBOARD PANELS.

Equipment of D.C. Generator Panels.

1 Overload circuit breaker.
1 Ammeter.
1 Voltmeter switch. (One voltmeter will answer for all generators.)
1 Field switch with discharge resistance (optional).
1 Positive main switch.
1 Negative main switch. (For railway service where the generator series coils are on the negative side, and the negative side is grounded, this switch should be replaced by a circuit breaker mounted near the generator, and connected in the armature lead.)
1 Equalizer switch. (Mounted near the generator. For small capacity generators all three switches may be combined into a triple-pole switch mounted on the panel.)
1 Field rheostat.
1 Recording wattmeter (optional).

For small machines, fuses may be substituted for the circuit breakers.

Equipment of A.C. and D.C. Rotary Converter Panels.

The equipment of a direct-current converter panel may be the same as a direct-current generator panel, but a field switch with discharge resistance is unnecessary and the circuit breaker in the negative on grounded return system should be omitted as the necessary protection is secured on the alternating-current side. The main switches, however, should all be single pole.

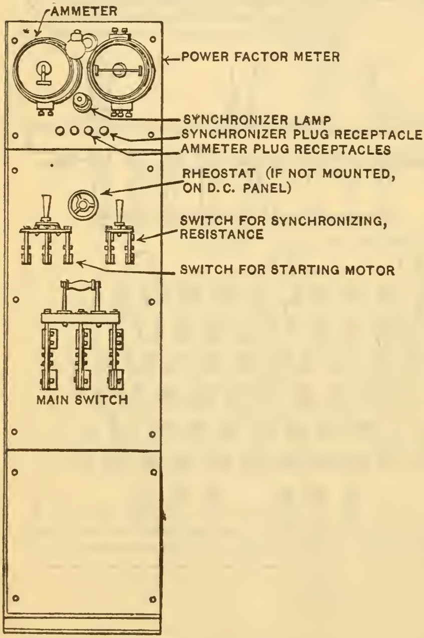


FIG. 17. Three Phase Alternating Current Rotary Converter Panel for use with Rotary and Starting Motor.

Rotary converters started from the alternating-current side may build up with reversed polarity, which will be indicated on the voltmeter. To change the polarity back to normal, a double throw field switch is provided (usually mounted on the converter frame) for the purpose of momentarily reversing the field to "Slip a pole." To reduce the destructive inductive discharge of the field a multi-pole switch is used, each pole of switch breaking only two or three field spools.

Rotary converters operating on grounded return systems may have the negative side connected directly to ground without the interposition of a switch.

Rotary converters starting from the direct-current side require a field-transfer switch, as well as a starting switch, which are usually provided with the direct-current panel. A double-reading ammeter is usually provided, or else other provision to prevent damage to the meter by reversal of current.

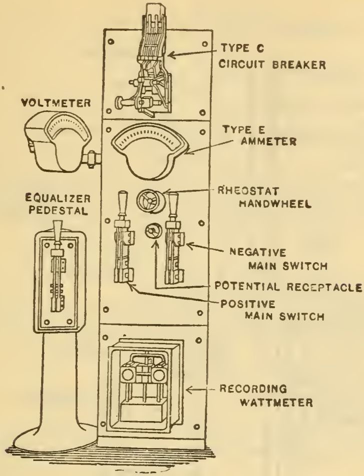


FIG. 18. Westinghouse Panel for D.C. Generator or Rotary Started by Starting Motor.

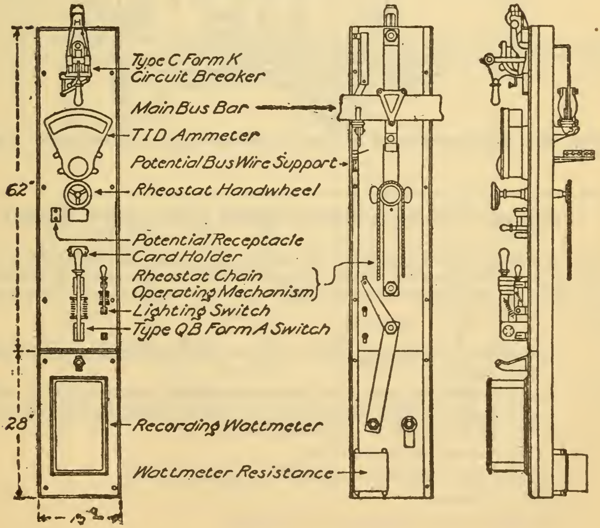


FIG. 19. Direct-Current Rotary Converter Panels. General Electric Panel Rotary Started Direct from A.C. Side.

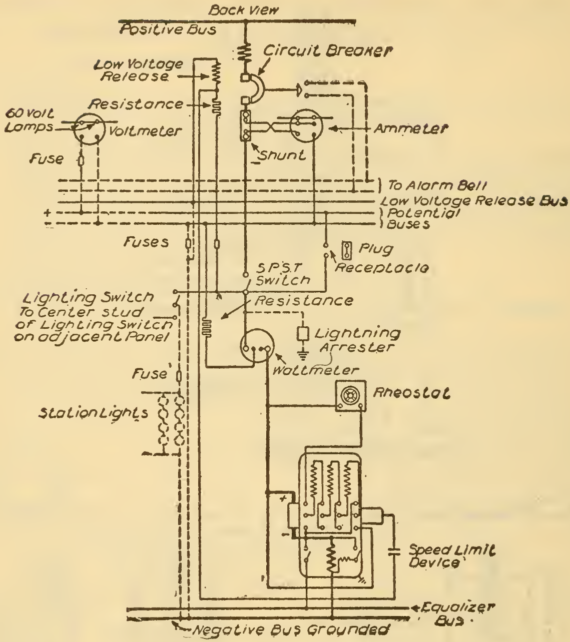


Fig. 20. Connections of a Direct-Current Rotary Converter Panel.

Equipment of a Three-Wire Generator Panel.

The Westinghouse three-wire generator combines in its system of connections all of the circuits which were required for the usual generating sets of an Edison three-wire system, and a double equipment of apparatus is required, as follows:

2 Ammeters (operating from shunts located in armature leads of generator).
2 Circuit breakers, each either two pole or supplied with equalizer contacts, to open a main and equalized lead (with operating coil in the main lead) to trip together.
2 Double-pole main switches.
1 Double-pole two-way voltmeter plug receptacle.
1 Field rheostat.
2 Double-pole balancing coil switches.

(If the unbalanced load is to be measured, a double-reading direct-current ammeter should be placed in the neutral return.)
The connections for such a system are shown in diagram, Fig. 21.

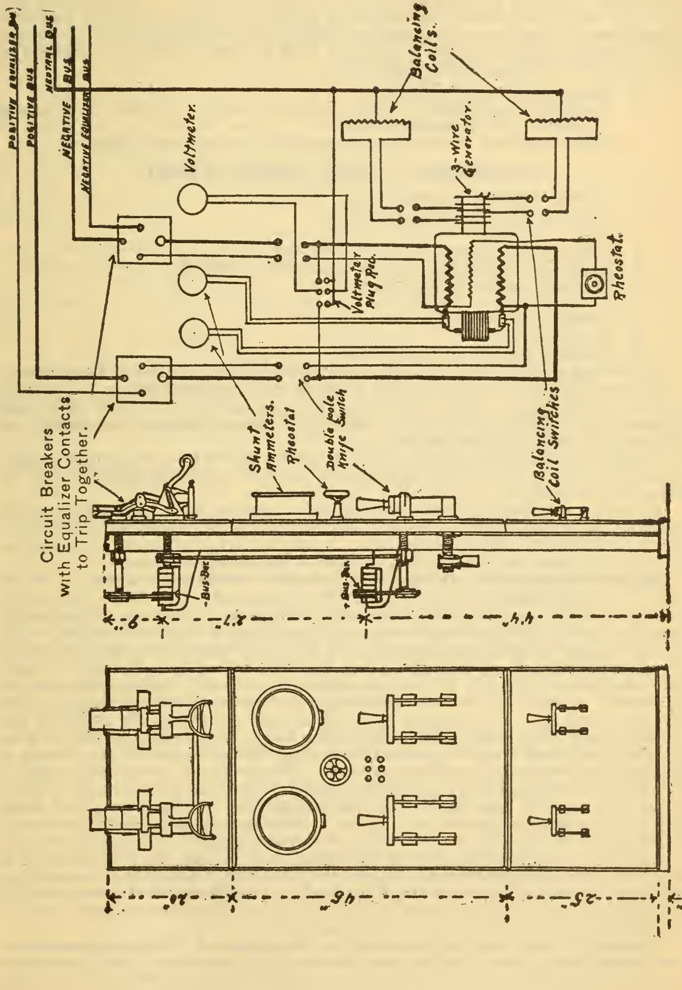


FIG. 21. Westinghouse 3 Wire Generator Panel.

Equipment of D.C. Feeder Panel.

Direct-current feeder circuits should be protected from overloads by circuit breakers or fuses. Circuit breakers should be used if overloads occur frequently, such as on railway and most power circuits. They should also be used for all large ampere capacity circuits — say above 600 amperes. Small feeder circuits may be controlled solely by a double-pole circuit breaker, but on large circuits a switch in series with a circuit breaker is necessary. The equipment should then consist of:

1 Single-pole circuit breaker.
2 Single-pole switches. (On grounded return systems the second switch will be unnecessary.)
Ammeters and integrating wattmeters are optional devices.

Equipment of D.C. Motor Panel.

1 Double-pole automatic circuit breaker.
1 Starting switch and resistance,
or
1 Single-pole automatic circuit breaker.
2 Single-pole switches or one double-pole switch.
1 Starting switch and resistance.
or
1 Double-pole switch.
2 Inclosed fuses.
1 Starting switch and resistance.

Ammeters are optional, but are recommended for motors of large sizes.

Either the circuit breaker or the starting switch should have a low-voltage release attachment. The starting switch and resistance should be so connected that the field, when the switch or circuit breaker is opened, will discharge through the armature.

Starting switches for motors starting under heavy torque should have at least eight steps. Motor-generator sets may properly be started with but three or four steps.

As the starting resistances are invariably designed for intermittent service, starting switches, except in power stations where an electrical attendant is in charge, should be provided with a spring or other means to prevent the switch arm from remaining on an intermediate starting point.

Hand-Operated Remote-Control Switchboards. — Wherever it is desirable to install a plant of moderate size and obviate the necessity of having any high potential conductors on the rear of the switchboard, a hand-operated remote-control switchboard may be installed. The panels will have the same appearance on the front as any other hand-operated alternating-current switchboard, but the rear of the panels may be made safe and accessible with a neat arrangement of small wiring, inasmuch as all heavy conductors, meter transformers and accessories are mounted apart from the panels. A common method of providing for the switches and transformers mentioned is to mount them on a separate framework in some distant place and control the switches from the switchboard by means of bell cranks, levers and connecting rods. These latter are usually made of gas pipe. The framework used to support the switches is usually utilized to support the bus bars also. As the connections between the panel board and the switching structure are made by small secondary wiring for meters and instruments, and the bell-crank attachments permit of an infinite variety of combinations, the location of the switching devices may be selected to best suit the station wiring so long as the cranks and levers can be arranged to operate suitably; the total length of any set of bell cranks and levers should not, as a rule, be greater than 12 feet, although longer runs than this will operate successfully under favorable conditions.

Central Station Electrically Operated Switchboards. — The concentration of energy in large central stations requires that the measuring and controlling devices shall be concentrated also, in order to be under the hand of a single operator and enable him to have absolute control of the whole installation. This end is best attained by the use of electrically operated switchboard apparatus.

Electrically operated switchboards may be divided into two classes, namely, alternating-current and direct-current equipment. As large central stations almost invariably generate alternating current for distribution, the electrically operated switchboard is usually of the latter class.

Circumstances which Indicate the Necessity of Installing Electrically Operated Switchboard Apparatus.

First, switches used to control the circuits may be so heavy that they cannot be easily operated by hand.

Second, the location of these switching devices can be made most convenient to the circuits to be controlled and apart from portions of the equipment which are liable to cause trouble, such as steam pipes, etc.

Third, in case of accident to any of the apparatus, the operator may be located well away from the seat of trouble and is therefore not so liable to be frightened or lose his head in an emergency.

Fourth, the entire absence of dangerous potentials at the center of control provides absolute safety for the operator.

Fifth, the number of circuits and amount of power may be such that the control cannot be concentrated within a space of reasonable size unless electrically operated.

Sixth, it may be necessary that the operator be located a long distance from the apparatus which he controls.

Reliability of Service. — When the choice of an electrically operated switchboard is made, the next consideration is as to how much apparatus to install to insure reliability of service. It is possible to carry this idea to an unnecessary refinement in some cases, where the chances of a shut down are small and the consequences of it are not very disastrous. On the other hand there are some plants where no expense must be spared to provide against the contingency of a shut down even of a very short duration. The latter case requires much duplication of apparatus and great flexibility.

Where a large number of feeders are used a circuit breaker is sometimes provided to connect between certain groups of feeders on the bus-bars, and is known as a group circuit breaker. Each feeder circuit of the group has its own individual circuit breaker to open automatically and relieve the group on the overload, but in an emergency the whole group can be switched on or off the circuit by means of the group circuit breaker.

The value of this group circuit breaker for a single-throw system is doubtful except in cases where transfers of load must be very rapid and a large number of feeders are installed. It is more valuable in such a case on a double-throw system, because it enables the transfers from one set of bus-bars to the other to be made very rapidly and with a minimum number of switches, as one pair of circuit breakers will transfer an entire group of feeders instead of having two circuit breakers for each feeder circuit. There are four systems of connections for bus-bars commonly used. The first is the single-throw system, the second is the relay system, the third is the ring system, and the fourth is the double-throw system. Each of these may be made more flexible by dividing the bus-bars into sections by means of sectionalizing switches.

Except in special cases it will be found that where any system is required to provide flexibility, the double-throw system will be most satisfactory.

It is considered the best practice to provide disconnecting switches between all bus-bars and oil circuit breakers in order to permit a disabled switch to be isolated and repaired without shutting down the system.

As the bus-bars form really the vital part of the system, it is necessary that care be taken to insulate them so that short circuits shall be impossible and that trouble on one set shall not communicate to another.

Where absolute certainty must be insured against interruption of service, all conductors should be isolated from each other and all adjacent material made as fireproof as possible. In large stations this is attained by means of masonry structures and barriers and flame proof cables, with absence of inflammable material for supporting the cables, using cells for all fuses and apparatus liable to arc and all oil-insulated transformers that are so constructed that danger from burning oil exists. This includes voltage transformers which are oil-insulated.

The greater the energy involved the greater is the necessity for isolation, especially in plants of pressures under 45,000 volts. The isolation is most needed in heavy capacity stations of 2,200 to 13,000 volts and in some cases it is advisable up to 45,000 volts, if the use of compartments makes a more consistent layout. Isolation is, however, rarely advisable in stations above

45,000 volts, as small isolated conductors well supported in air will in such cases prove quite satisfactory, while barriers or adjacent walls usually serve as so many grounds to insulate from. Whenever modern practice reaches such a point that extremely high voltage circuits carry heavy current capacities, however, barriers may be advisable, but this condition is not liable to be met with.

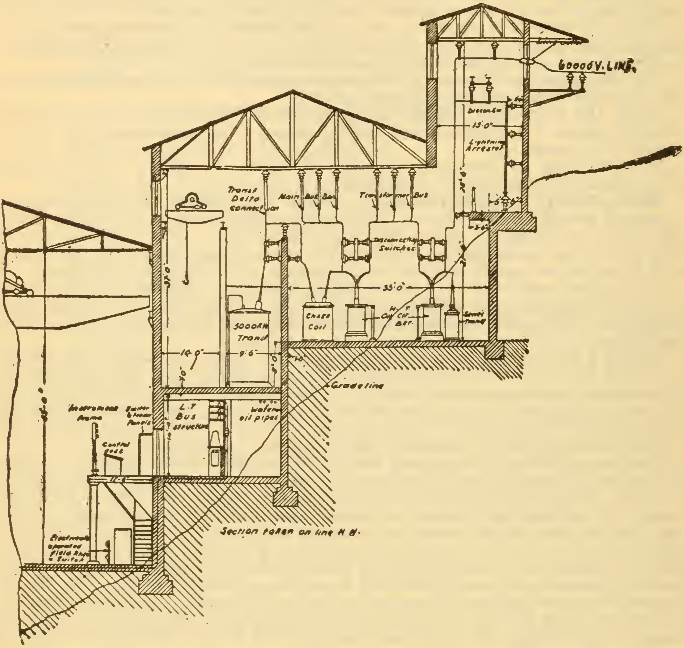


Fig. 22. 60,000-Volt Hydro-Electric Generating Station. Sectional Elevation.

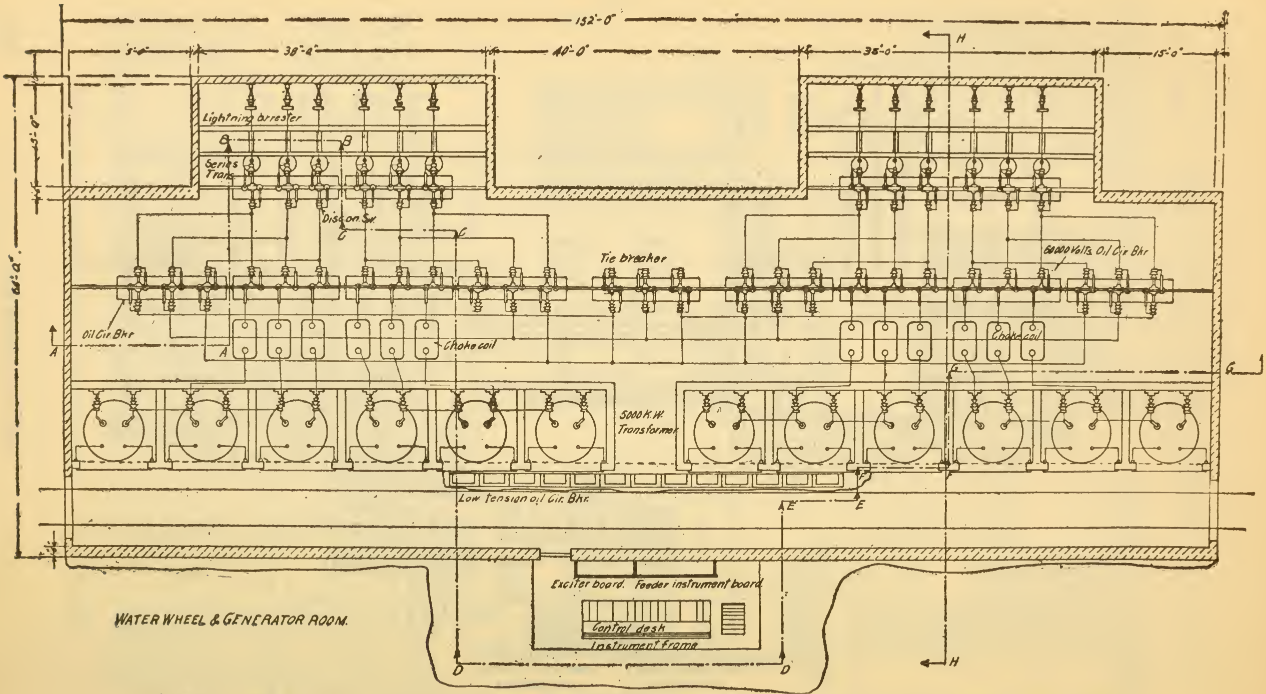


FIG. 23. 60,000-Volt Hydro-Electric Generating Station. Plan of Switchboard and Transformer Cells.

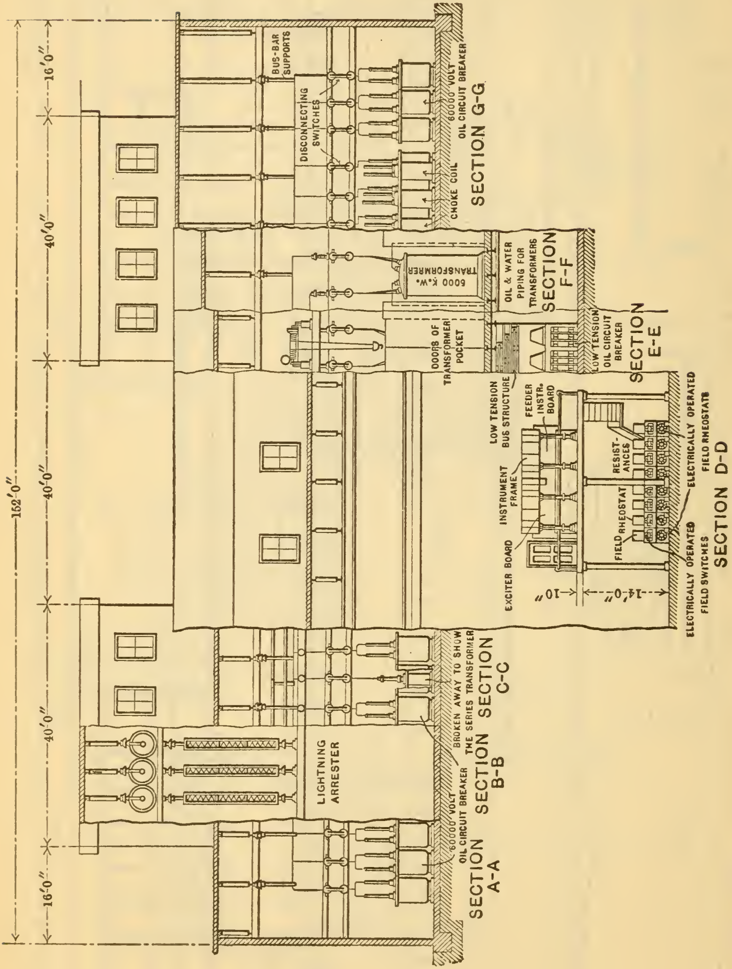

152'-0"
16'0"
40'0"
40'0"
40'0"
16'0"
BUS-BAR SUPPORTS
DISCONNECTING SWITCHES
60000 VOLT OIL CIRCUIT BREAKER
CHOKE COIL
SECTION G-G
6000 K.W. TRANSFORMER
OIL & WATER PIPING FOR TRANSFORMERS
SECTION F-F
DOORS OF TRANSFORMER POCKET
LOW TENSION OIL CIRCUIT BREAKER
SECTION E-E
LOW TENSION BUS STRUCTURE
FEEDER INSTR. BOARD
INSTRUMENT FRAME
EXCITER BOARD
RESISTANCES
FIELD RHEOSTAT
ELECTRICALLY OPERATED FIELD RHEOSTATS
ELECTRICALLY OPERATED FIELD SWITCHES
SECTION D-D
10"
14'0"
LIGHTNING ARRESTER
BROKEN AWAY TO SHOW THE SERIES TRANSFORMER
SECTION C-C
SECTION B-B
60000 VOLT OIL CIRCUIT BREAKER
SECTION A-A

FIG. 24.

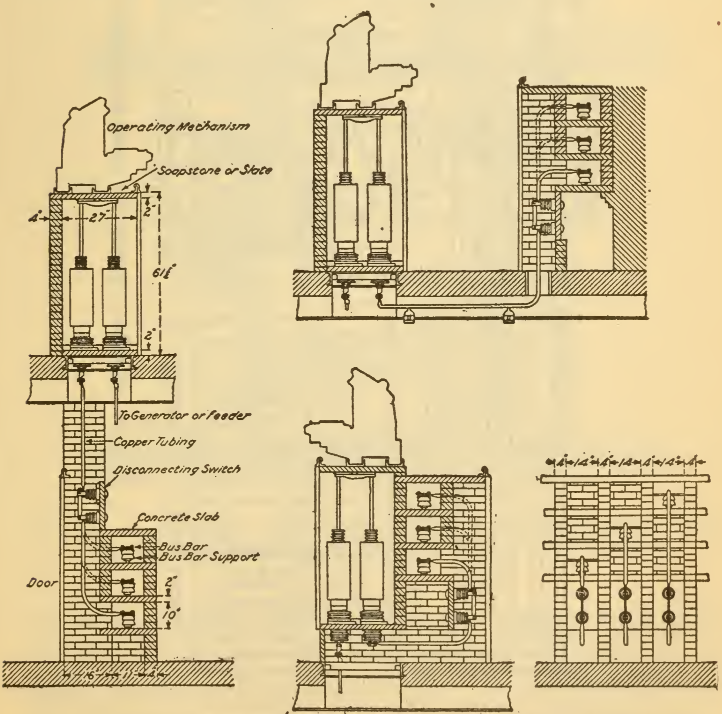
BUS-BAR AND BUS-BAR STRUCTURES.

The bus-bars of a high-tension central station make up the backbone of the installation. As the entire distribution depends upon them, the design of the station as a whole should be executed with this fact in view. The bars should be entirely isolated from all danger from arcs, short circuits or flashes. All large stations should be laid out with a suitable arrangement of bus-bars, to guard against interruption of service from unforeseen causes and to provide a means whereby circuits can be installed and connected with facility.

The modern bus-bar structure for 2,200 to 33,000 volts is of brick or concrete with each bus-bar of opposite potential in its own separate compartment, well supported on porcelain insulators.

The shelves or barriers in such a structure are usually of soapstone or concrete. Some of these structures are enclosed entirely, one side having removable doors, while others are made with the entire side open for inspection and facility in making connections and alterations. The bus-bars, being well protected and insulated, are usually composed of bare copper.

For higher voltages than above mentioned a different form of bus-bar support is generally used, and the connections to the bus-bars are made with wire or cable well supported on suitable insulators. Diagrams of a few typical arrangements of bus-bars and oil switches follow:



TYPICAL ARRANGEMENTS OF 13200 VOLT BUS-BARS, ELECTRICALLY OPERATED OIL SWITCHES, AND DISCONNECTING SWITCHES IN THREE-PHASE STATIONS

FIG. 25.

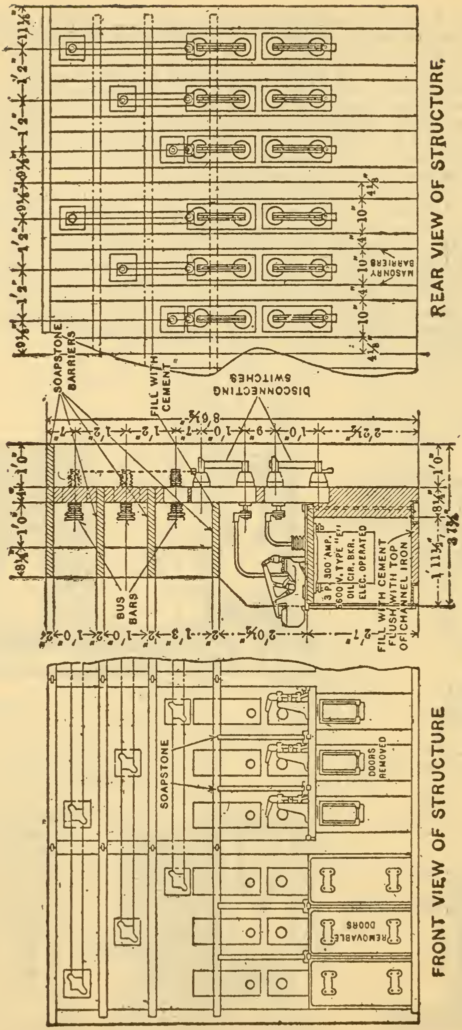


Fig. 26. Bus-Bar Structure for Three-Phase 6600-Volt Installation.

General Arrangement of Switching Devices. — In addition to the masonry required for the bus-bars, there must be provided structures for the oil circuit breakers. The elements are contained in structural work of brick or concrete. On account of this construction and the desirability of making connections between the apparatus in the most safe and direct manner, it is generally necessary to build structures in galleries

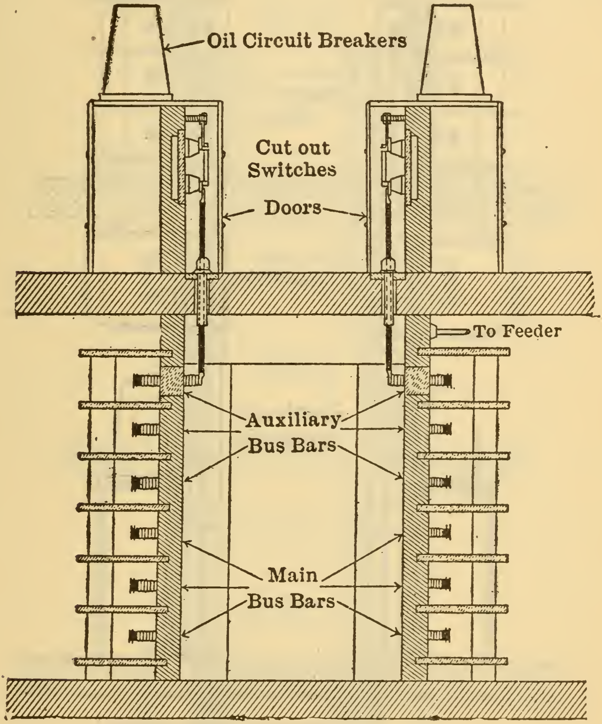


FIG. 27. Double-Deck Oil Circuit Breaker and Bus-Bar Structure. Two Sets of Main Bus-Bars and Two Sets of Auxiliary Bus-Bars.

one above the other, or if galleries are not to be considered, then a basement must be provided to take a portion of the gear. The simplest switchboards are usually double decked, while others require three or four galleries. For a given amount of apparatus, a double-decked arrangement requires the longest galleries and more material for bus-bars. It is the simplest, however, and often the most economical when the switchboard apparatus is located near the generators and transformers, and saves long and expensive lines of connecting cables. On the other hand, where the galleries must be small, a three-deck arrangement is more satisfactory.

In each particular case the conditions of space, accessibility, etc., must determine the most suitable place for the structure and the best relative arrangement of the circuit breakers and bus-bars.

The series and voltage transformers for the operation of the oil circuit breakers, meters, etc., in almost every care are placed in the structure, the best arrangement depending upon local conditions.

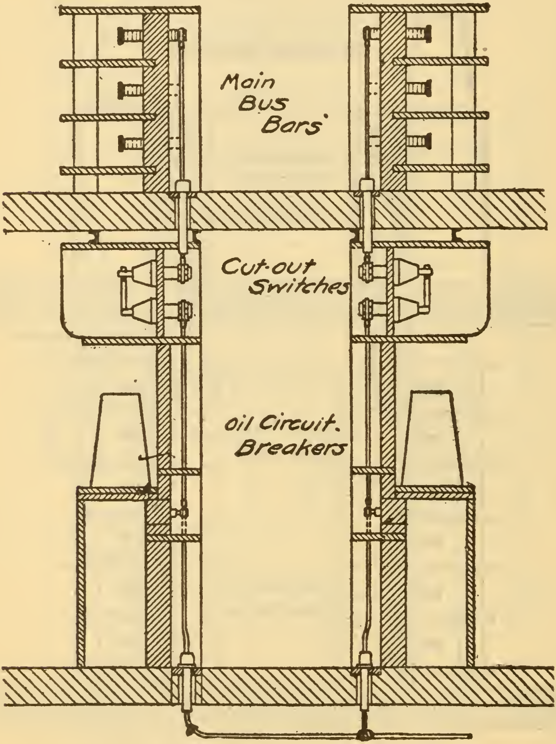


Fig. 28. Double-Deck Oil Circuit Breaker and Bus-Bar Structure. Two Sets of Three-Phase Bus-Bars.

Isolation of Conductors.—When barriers are used each conductor is confined to its own compartment and in case of accidental ground or short-circuit the flashing or combustion is confined to the conductor involved and prevented from destroying neighboring conductors.

Barriers, while fire-proof, are not necessarily made of insulating material, although, were it not for the expense, they might well be made of such material. They are frequently made of brick, masonry, concrete, or tile, while in places where insulated barriers are desired, soapstone is the most favored material. It absorbs less moisture than marble, but the insulating properties cannot be depended upon. The cost is a little less. Soapstone is readily obtained in any reasonable size or shape, and is easily drilled and cut when fitting is necessary at the place of erection.

When the barriers and compartments of the switchboard structure are made from any of the above-mentioned materials, they should be treated as

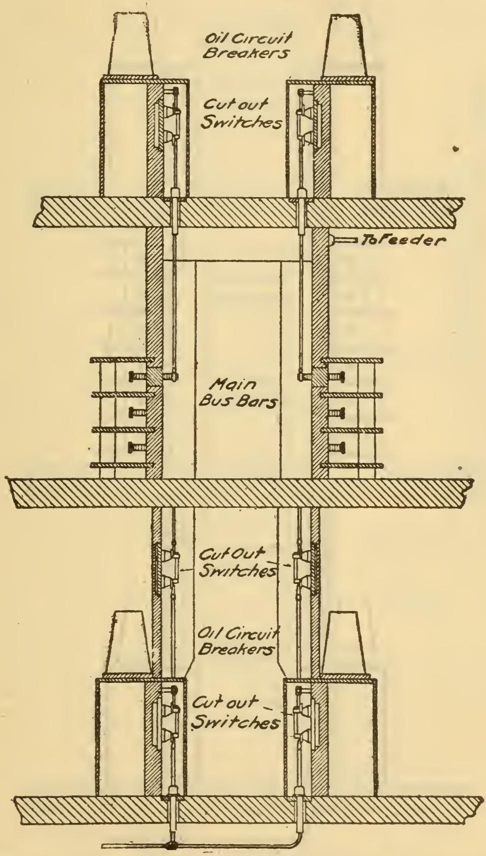


Fig. 29. Three-Deck Oil Circuit Breaker and Bus-Bar Structure. Two Sets of Bus-Bars.

grounds with reference to high-tension circuits. It is true that vitrified brick and concrete, when very dry, are more in the nature of insulators than conductors, but the tendency of all such materials, and even soapstone, is to absorb more or less moisture, preventing any absolute dependence being placed upon them as insulators, and all conductors must, therefore, be insulated from them.

Each bus-bar is in a separate fire-proof structure, and each pole of the oil circuit breaker is an independent fire-proof compartment. Masonry barriers separate the leads from the oil circuit breakers to the bus-bars and to the outgoing lines. Wherever it is desirable to use disconnecting switches between the circuit breakers and the bus-bars or circuit breakers and the

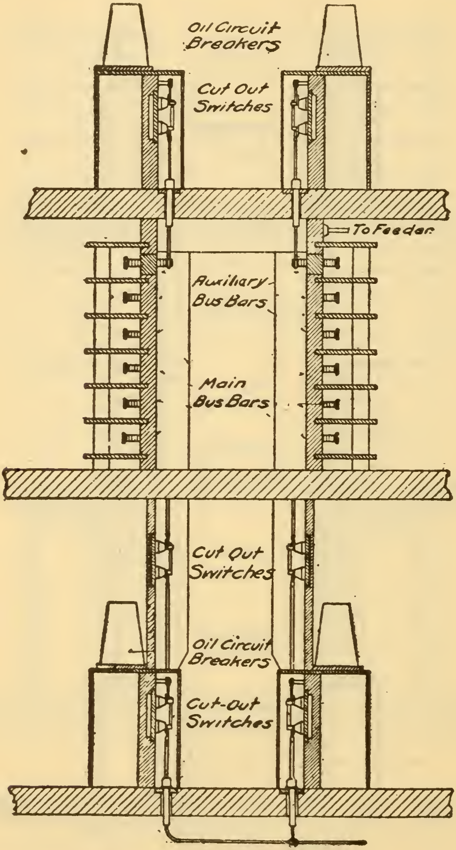


Fig. 30. Three-Deck Oil Circuit Breaker and Bus-Bar Structure. Two Sets of Main Bus-Bars and Two Sets of Auxiliary Bus-Bars.

outgoing lines on circuits not exceeding 13,000 volts, these disconnecting switches can be mounted as shown in Fig. 30, which also illustrates one of the many ways of arranging circuit breakers and bus-bars in two galleries.

Cells for Voltage Transformers and Fuses. — In installations of this nature the voltage transformers are connected to large sources of power, and it becomes necessary to avoid possible damage to the system by one of them burning out; it is therefore customary to protect them with enclosed fuses, the fuse and transformer being isolated in their own individual cell in keeping with the practice of isolation which has been described.

When the fuses are installed as described it is often desirable to close the cells with doors.

High-Tension Conductors. — Manufacturers supply rubber-insulated cables for use up to a certain voltage, which can be relied upon for a long time in regard to insulation; but it is a well-known fact that rubber deteriorates with age and the higher the voltage the faster the deterioration, when conditions are favorable; so it is the best practice in all high-tension installations not to depend upon the rubber insulation, but to support the conducting cables on porcelain insulators and keep them away from all grounds and other conductors. The insulation on the cable serves, under such conditions, only as a possible preventive of troubles due to accidental contact therewith. This does not mean that the insulation is useless, as it might at times prevent loss of life or serious troubles due to accidental contact.

Isolated cables laid against the grounded structure or covered with lead are subjected to strains, which might sooner or later break the insulation down.

Lead-covered, paper-insulated cables are seldom used in high-tension switchboard structures. Some of the best cables obtainable are insulated with rubber. As the rubber, however, is combustible and easily takes fire from flash, manufacturers supply cables, when required, covered with fire-proof braid of asbestos, or with the outer braid saturated with a fire-proof paint to prevent accidental burning of the rubber cover. For very high voltages, cables insulated with wrappings of impregnated cambric may be obtained, with or without a flame-proof covering.

The terminals of cables used in the construction of high-tension switchboards can be insulated with any good material such as oiled linen coated with shellac, but this should not be relied upon to prevent accidental contact with live terminals, and no attempt should be made to insulate for safe handling, as the only time to safely handle a high-tension cable is when it is absolutely dead.

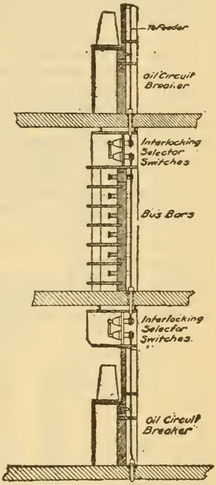


FIG. 31. Three-Deck Oil Circuit Breaker and Bus-Bar Structure. Two Sets of Bus-Bars.

Flame-Proof Coverings. — In order to prevent the flame from an arc setting fire to the insulation of a cable and being thereby communicated to other cables or setting fire to the building, flame-proof coverings are often used. These coverings are always supplied by the cable companies, being purchased under specifications which require that they shall meet the requirements of the National Board of Fire Underwriters.

When installing such cables they must in every case be supported on insulators, and not carried in ducts, as the flame-proofing is a poor insulator and when saturated with moisture will serve as a conductor. For the same reason the covering must be stripped away from all live terminals a suitable distance for insulation purposes.

Auxiliary Direct-Current Circuits. — The direct current for operating the oil switches and other apparatus may be obtained as follows:

From auxiliary storage batteries.

From motor-generator sets.

From direct-current exciter systems or other direct-current bus-bars.

It must be especially noted that where the exciter system is controlled by a Tirrill regulator, the voltage fluctuation is likely to be so great that it cannot be relied upon for standard electrically operated apparatus. In this case either a small storage battery or a motor-generator set must be relied upon to supply the energy. In cases where a storage battery must be employed, owing to such considerations, and no charging current is available, a mercury rectifier may be relied upon to charge the battery.

In cases where it is absolutely necessary to operate oil circuit breakers from direct-current exciter systems which are connected up to Tirrill regulators, the coils can generally be specially wound so as to operate at a low voltage, and the magnetic circuit be designed to saturate at high voltage so as to prevent the switch closing with too much force.

Controlling and Instrument Switchboard. — Under this head will be considered the installation of controlling switches and accessories that control electrically operated oil switches.

In this connection it is essential to make sure that direct current is available at a suitable voltage to operate the electrically operated devices. The standard controlling devices are designed to operate from 125, 250 or 500-volt circuits, but when the potential is liable to drop below 80 volts, operating coils must be specially provided for the low voltage. The controlling apparatus can be mounted on the face of the switchboard panel together with the instruments where the system is simple and an inexpensive arrangement is desired. Nearly all large stations have the generator-control apparatus mounted on control desks or pedestals. A feature of some control outfits is the use of miniature bus-bars with lamps and indicators in the circuits. By means of these bus-bars the entire main station connections are embodied in miniature on the controlling desk, and, if the indicators or lamps are placed in the miniature circuits, the switching operations can be seen to take place when the operator moves his controller exactly the same as they occur in the main circuit. When the desk type switchboard is used, it is usually placed directly in front of the instrument switchboard and the operator has his control apparatus arranged as nearly as possible opposite the respective instrument panels.

Nearly every large installation starts with a few generating units and increases as the demand for power increases. For this reason it is desirable that the structure used for carrying the control apparatus be so designed to admit of extension to meet future demands, or be made in the form of pedestals carrying the various instruments. Such controlling table or pedestal should generally contain controllers, indicators and lamps for the oil circuit breakers, synchronizing plugs and lamps, voltmeter plug, electrically operated rheostat controller, a controller for the engine governor to change the speed in synchronizing the generators, and a controlling device to open and close the electrically operated alternating-current generator field switch.

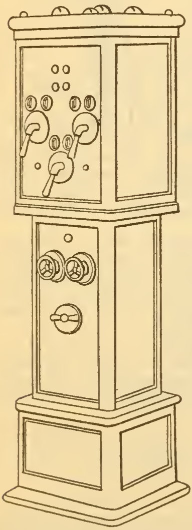


Fig. 32. Controlling Pedestal.

The usual method of controlling feeder circuits is to place the controllers on the switchboard directly beneath their respective feeder instruments.

Generator-Control Pedestals. — For auxiliary controlled switchboard apparatus, mountings must always be provided for the control apparatus of each generator. The pedestal shown in the illustration is designed for this purpose, and is used in combination with an instrument post or panel located immediately in front of it.

The pedestal as shown in Fig. 32 is designed to take the following apparatus:

Signal lamps.
Six oil circuit-breaker indicating lamps.
Three oil circuit-breaker controllers.
One voltmeter plug and receptacle.
Two synchronizing plugs and receptacles.
One controller for engine governor motor.
One controller for electrically operated field rheostat.
One control switch for electrically operated field discharge switch.
One control switch for engine signal.

The controlling devices are not included but must be specified separately, and may be selected to suit the requirements of the installation.

Controlling Desks. — Wherever great concentration of controlling apparatus is necessary, a desk or bench-board is often used. This is usually built of marble or steel, and special conditions sometimes require special designs.

This type of controlling desk as shown in Fig. 33, has an iron frame enclosed by paneled steel sides and a marble top.

The construction is such that each top panel with its corresponding paneled sides forms a section, and the desk may be extended in either direction by installing additional sections, the end panels and end moulding being removable in one piece to provide for inserting the necessary additions.

Instrument Posts. — The instrument posts used with desks or control pedestals are divided into two general classes, viz.: swivel type and stationary type.

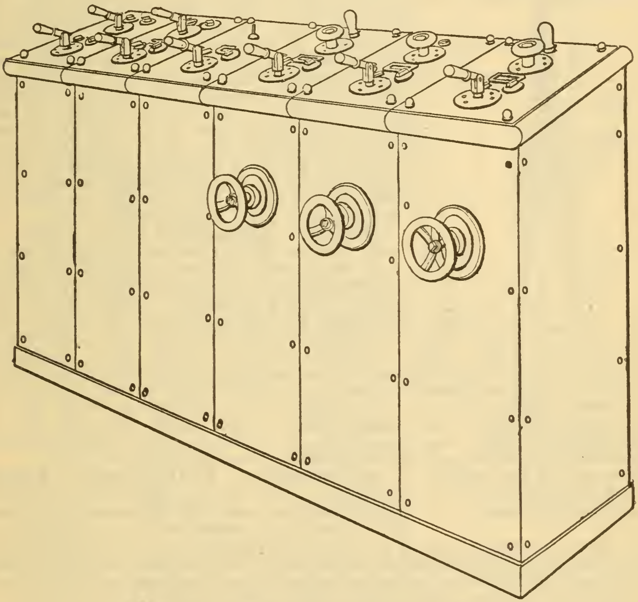


FIG. 33. Sectional Controlling Desk.

These again may be designed with suitable bases to mount jacks, or receptacles, to enable one to calibrate or check up the meters, by comparison with standards whose terminals have plugs to fit the receptacles.

A post supplied with receptacles for calibrating meters as described above is shown in Fig. 34.

Calibrating Jacks. — In many installations it is desirable to have jacks or receptacles provided in the series and shunt transformer circuits to enable standard meters with suitable plugs attached to be connected in these circuits for comparing the readings of the switchboard meters.

There are two kinds of these receptacles used, one for establishing a loop in a series transformer circuit and used for an ammeter jack or an ammeter plug receptacle, the other being a double-pole receptacle or voltmeter jack for use on shunt transformer circuits.

Field Rheostats and Field Switchboards. — If the generator control apparatus is located on a panel, the field rheostat can be conveniently operated by means of a handwheel geared directly to a face plate on the rheostat by gearing or chain and sprocket. If the rheostats are electrically controlled from a distance through face plates, they should have a small motor geared to the contact arm, the motor being controlled from the operating platform and the field switches electrically operated.

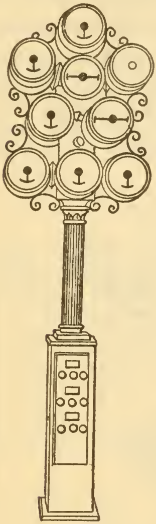


FIG. 34. Post with nine instruments. The three ammeters at the bottom are for a bank of transformers. The six instruments above are for one generator. The plug switches in the base permit testing the calibration of the instruments without removal.

Direct-Current Exciter Switchboard. — The switchboard for control of the exciters is sometimes placed in the operating gallery when this is not too remote from the machines. In other cases it is placed on the station floor, as near as convenient to the exciters. It is usually a typical direct-current board, and, while the most serviceable ones have entire panels finished in black marine, a large number of stations are using blue Vermont marble. The circuit breakers used are non-automatic, being used only to trip by hand when the circuit is to be interrupted, to prevent the arc from burning the switch. Some station managers prefer reverse-current circuit breakers in the exciter circuits, but the usual practice is to omit protective devices.

Station Apparatus. — In addition to providing for station voltmeters, synchroscopes and wattmeters, either on panels or on an instrument post, it is often necessary to install static ground detectors. These are always operated through condensers so located that the wiring is short and the conductors properly separated and far enough from neighboring metal so as not to interfere with the operation of the instruments. This is best accomplished by installing the ground detectors on the station wall or on suitable supports near the condensers if it is difficult to properly run the leads to the operating gallery.

Sub-Station Switchboard Equipments. — Sub-stations are more commonly used for railway service. The usual equipment of switchboard apparatus for a sub-station is laid out on the same lines as for a generating station, but the arrangement and selection of the equipment is changed to agree with the requirements of the case. As lighting and power sub-stations are more or less special it is impossible to give a description which will be generally applicable.

Railway sub-stations, however, fulfill practically the same purpose and in general differ only in number and capacity of the units. The conductors in such a station are usually very heavy and care should be taken to make the runs as short and direct as possible.

A number of modifications may be made in the apparatus supplied. For instance, electrically operated direct-current apparatus may be used to save cable and permit of greater concentration, or for small stations the alternating-current switchboard may have hand-operated circuit breakers mounted directly on the panels.

For single-phase alternating-current railway systems, the sub-stations are essentially transformer houses and are very simple. Figs. 35 and 36 show a typical sub-station of this character. This apparatus for such a sub-station will vary with the requirements of service.

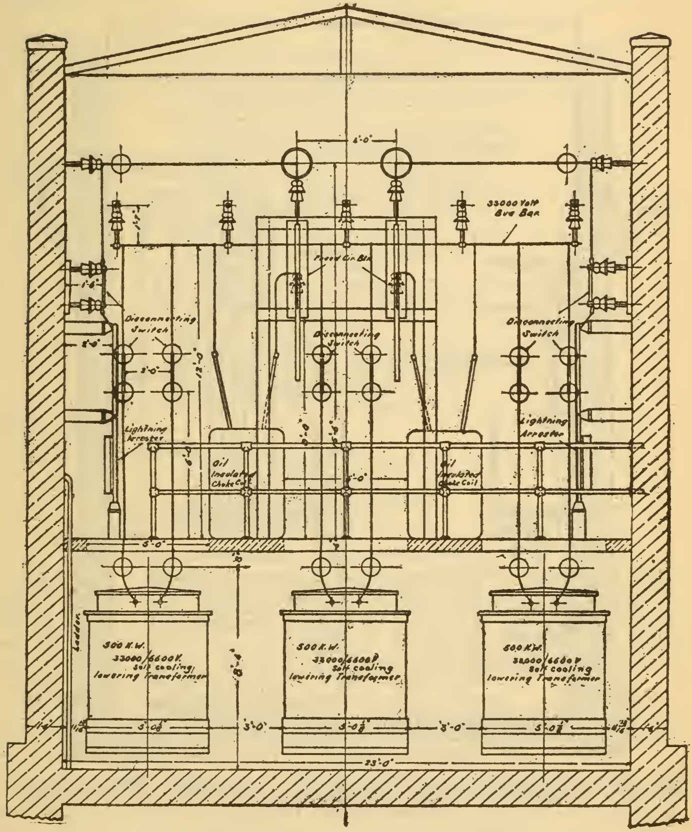


FIG. 35. Single-Phase Alternating-Current Sub-Station or Transformer House — End View.

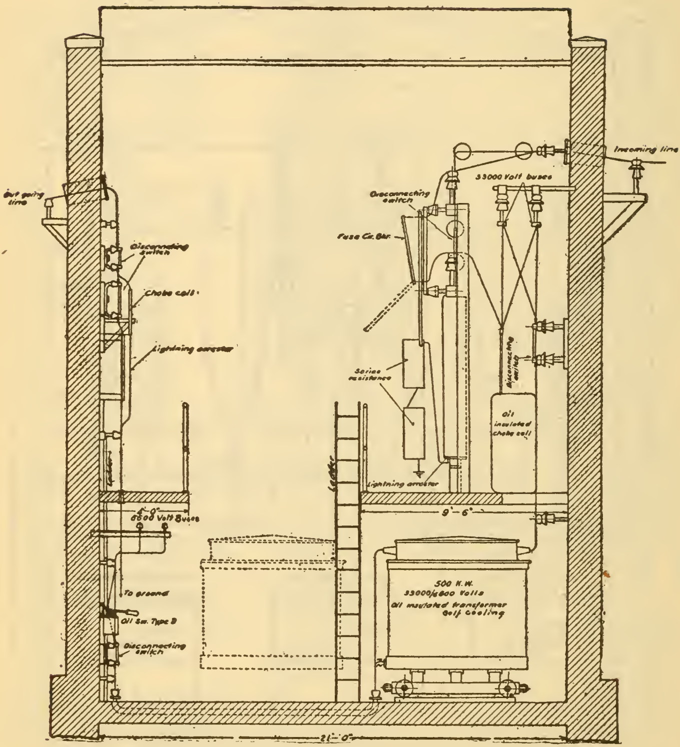


FIG. 36. Single-Phase Alternating-Current Sub-Station or Transformer House — Side View.

SWITCHBOARD INSTRUMENT AND METERS.

The following is a list of the various instruments and meters used for switchboard work:

Alternating Current

- Indicating ammeter,
- Graphic ammeter,
- Indicating voltmeter,
- Graphic voltmeter,
- Single-phase indicating wattmeter,
- Single-phase integrating wattmeter,
- Single-phase graphic wattmeter,
- Polyphase indicating wattmeter,
- Polyphase integrating wattmeter,
- Polyphase graphic wattmeter,
- Graphic frequency meter,
- Graphic power factor meter,
- Differential voltmeter,
- Power factor indicator,
- Wattless component indicator,
- Frequency indicator,
- Synchroscope,
- Indicating compensating voltmeter,
- Electrostatic ground detector,
- Electrostatic voltmeter,
- Automatic synchronizer.

Direct Current

- Indicating ammeter,
- Graphic ammeter,
- Indicating voltmeter,
- Graphic drawing voltmeter,
- Integrating wattmeter,
- Graphic wattmeter.

The names of the instruments in most cases describe their use. Integrating meters record by means of a dial the watthour output. Graphic meters record on a chart by a line the fluctuation of the voltage, current or watts of the circuit. Indicating wattmeters indicate the actual watts of the circuit which is equivalent to the volts as shown by the voltmeter multiplied by the current as shown by the ammeter multiplied by the power factor of the circuit, for single-phase circuits.

Electrostatic Voltmeters are used only for high-potential circuits, such as 20,000 to 100,000 volts. They are connected directly to the circuit without the interception of potential transformers and do not carry any current. Condensers are sometimes interposed.

Alternating-Current Instruments for high-tension circuits are not connected directly to the circuit, but are used in connection with current and potential transformers. Current transformers are connected in series with the main circuit, but are wound for different ratios of transformation so that approximately five amperes is obtained in the secondary, and therefore the instruments may all have five-ampere windings. The use of the current transformer makes it unnecessary to insulate the instrument for high voltages and furthermore does not necessitate running the high-tension leads to the switchboard. Ammeters are sometimes connected in series with circuits as high as 2500 volts.

Potential transformers are usually wound to obtain from 100–125 volts on the secondary and are used on circuits of above 600 volts for voltmeters and other instruments having potential windings.

Method of Figuring Instrument Scales.

SINGLE-PHASE GENERATORS:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000 \times (1 + \text{per cent overload guarantee})}{\text{voltage}}.$$

Wattmeter scale = ammeter scale obtained from above × voltage.

THREE-PHASE GENERATORS:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000 \times (1 + \text{per cent overload guarantee})}{\text{voltage} \times 1.73}.$$

Polyphase wattmeter scale = ammeter scale obtained from the above × voltage × 1.73.

TWO-PHASE GENERATORS:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000 \times (1 + \text{per cent overload guarantee})}{\text{voltage} \times 2}.$$

Polyphase wattmeter scale = ammeter scale obtained from the above × voltage × 2.

DIRECT-CURRENT GENERATORS:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000 \times (1 + \text{per cent overload guarantee})}{\text{voltage}}.$$

THREE-PHASE MOTORS:

Minimum ammeter scale

$$= \frac{\text{Horse-power} \times 746}{\text{voltage} \times \text{per cent Eff.} \times \text{per cent P.F.} \times 1.73} \times (1 + \text{per cent O.G.}).$$

TWO-PHASE MOTORS:

Minimum ammeter scale

$$= \frac{\text{Horse-power} \times 746}{\text{voltage} \times \text{per cent Eff.} \times \text{per cent P.F.} \times 2} \times (1 + \text{per cent O.G.}).$$

DIRECT-CURRENT MOTORS:

$$\text{Minimum ammeter scale} = \frac{\text{Horse-power} \times 746}{\text{voltage} \times \text{per cent Eff.}} \times (1 + \text{per cent O.G.})$$

THREE-PHASE ROTARY CONVERTER:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000}{\text{voltage} \times \text{per cent Eff.} \times 1.73 \times \text{per cent P.F.}} \times (1 + \text{per cent O.G.}).$$

Wattmeter scale = ammeter scale obtained from the above × voltage × 1.73.

TWO-PHASE ROTARY CONVERTER:

Minimum ammeter scale

$$= \frac{\text{K.W.} \times 1000}{\text{voltage} \times \text{per cent Eff.} \times \text{per cent P.F.} \times 2} \times (1 + \text{per cent O.G.}).$$

By per cent overload guarantee is meant the ½, 1 or 2-hour overload guarantee on the generator and not the momentary guarantee, although some prefer to have scales calibrated to read momentary fluctuations.

The per cent efficiency and per cent power factor should be taken at full load or overload.

The wattmeter scales should theoretically be multiplied by the power factor, but practically the scales work out better as given. Integrating wattmeters have no scales and therefore need only have sufficient current carrying capacity.

When the minimum scale is determined from the formula the next larger standard scale, depending on the manufacture, should be selected.

P.F. = Power Factor.
O.G. = Overload Guarantee.

A BRIEF GUIDE FOR WRITING SWITCHBOARD SPECIFICATIONS.

The initial and ultimate number of each type of generator, motor and feeder circuit with their voltage, kilowatt and frequency rating should be given. The overload guarantees of the machines and duration of same should also be specified. Other characteristics of the machine, such as "Y" connected three-phase generators with grounded or ungrounded neutral, two-phase generators with inter-connected phases, direct-current generators with grounded or ungrounded negative, should be clearly stated.

Plans of the building, or of that section of the building occupied by the switchboard should, if available, accompany the specifications. It is essential to know the construction of the floor supporting the switchboard, and if there is a basement below the floor, when oil switches, rheostats and other similar devices are not to be mounted on the panels.

Specifications should be specific as to just what the switchboard contract is to cover. Switchboards as furnished by the manufacturers usually do not include the following, which should, therefore, be furnished by the purchaser unless otherwise specified.

- Complete flooring, sills for supporting switchboard and other pieces set in the floor or wall for supporting cable racks, oil switch operating mechanism, etc. All false flooring, if any is required.
- All masonry work for oil switch cells and bus-bar compartments.
- All openings in walls or floors, with suitable bushings.
- All clay ducts, iron conduit and other similar material to be laid in the concrete floors.
- Doors for bus-bar compartments, lightning arrester or static discharge compartments.
- All cable between switchboard and machines and between switchboard and feeder circuits.
- All bus-bars not connected directly with the switchboard, such as equalizer or negative bus-bars near the machines.

If the purchaser desires to include any of the above material in the switchboard contract, such material should be clearly specified.

A connection diagram showing the proposed main connections, providing they are unusual or complicated, should accompany the specifications.

The height and width of the panels should preferably be left to the discretion of the manufacturer. The thickness of the panels depends on the size of the panel, the material of the panel and the devices mounted thereon.

The design of the supporting framework need not be specified. In general, statements in specifications can be made as follows:

1. "The material of the panels shall be such as to afford the proper insulation between live metal parts mounted directly on the panel, for the voltage on which they are used. It shall have a (natural oil), (black enameled) or (polished) finish, and the panels shall harmonize in color and markings and fit together in a neat and workmanlike manner. The panels shall be properly supported on iron framework. Connection bars, bus-bars and wires shall be properly supported and insulated."

2. "All instruments shall be dead beat and protected from stray fields produced by adjacent connections or bus-bars."

3. "Circuit breakers shall be of sufficient capacity to carry the overload ampere capacity of the generator or motor, without overheating. They shall be capable of opening under short circuited conditions without dangerously burning the contacts and shall be of such a design as to be positive in action."

4. "Oil switches shall have a kilowatt rupturing capacity based on the ultimate installation of generators as heretofore stated in these specifications. The switches shall withstand for one minute a potential test between contacts and frame, of at least twice the rated voltage of the circuit."

5. "All switches shall be of such capacities as to carry the one or two hours overload rating of the circuits to which they are connected without undue temperature rise, and shall be properly designed for the service for which they are intended and without defects of workmanship."

6. "Connection bars and wires shall be of sufficient cross section so that with maximum load the temperature rise at no point will exceed 40° C. rise above the surrounding air, which may be based on 20° C. Bus-bars shall be of sufficient cross section to carry continuously the total normal load of all the generators feeding in parallel through the busses at various points.

The design of the busses shall, as far as possible, permit additions and extensions without materially interfering with the operation at a later date, or changing the existing supports.

"Insulated main connection wires or cables should have flame-proof covering, and the insulation should not be wholly relied upon but should be supported by suitable insulators."

It is not advisable to specify the contact area, cross section or rating of switches, circuit breakers or connection bars, as this often necessitates special devices, whereas standard devices could have been used if only the temperature guarantees were given.

If purchaser has determined as to what instruments and switches are necessary, a complete list, giving the equipment of each panel, should be ncluded. Otherwise this equipment should be specified in detail in the manufacturers' proposal and inserted in the specifications forming part of contract.

SWITCHING DEVICES.

Switching devices in connection with switchboards can be divided generally into the following-named classes, viz.:

Switches for low voltage and small current are of the same general form, though differing in details. In the main they consist of a blade of copper, hinged at one end between two parallel clips, the other end of blade sliding into and out of two parallel clips. The clips are joined to copper or brass blocks to which the circuit is connected.

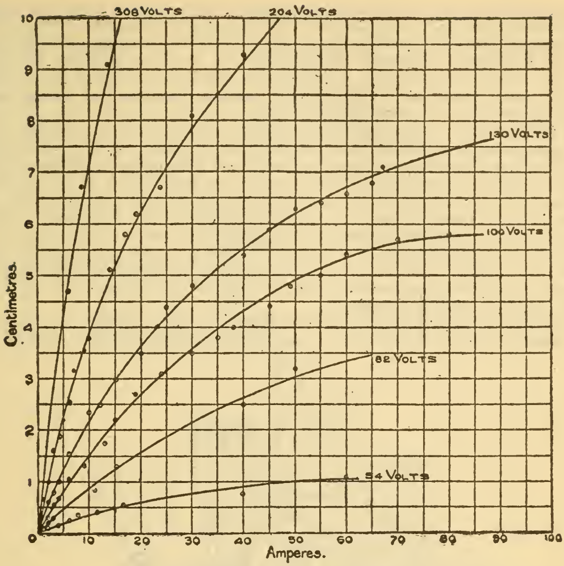
There seems to be little uniformity among manufacturers regarding the cross section of metal and surface of contact to be used. Perhaps a cross section of metal of one square inch per 1000 amperes of current capacity is as near to the common practice as any, and a contact surface for bolted contacts of at least one inch per 100 amperes or ten times the cross section of metal is also common practice, but will depend somewhat on the pressure between surfaces. For sliding contacts the density per square inch should not exceed 75 amperes.

Auxiliary breaks are demanded by the National Code for currents exceeding 100 amperes at 300 volts, and "quick-break" switches are now quite common for pressure as low as 110 volts.

The rules on switch design issued by the National Code cover the requirements well, and they must be followed in order to obtain or retain low insurance rates; all switches must meet the requirements.

Blades, jaws, and contacts should be so constructed as to give an even and uniform pressure all over the surface, and no part of the surfaces in contact should cut, grind, or bind when the blade is moved. The workmanship should be such that the blade can be moved with a perfectly uniform motion and pressure, and the clips and jaws should be retained so perfectly in line that the blades will enter without the slightest stoppage.

Sparking at Switches. — In a paper read before the British Institution of Electrical Engineers, A. Russell and C. Paterson discuss the subject of sparking at switches. In the diagram are given lengths of sparks at various constant voltages. Following are the conclusions arrived at: (1) The spark at break ought to be taken as a guide to the rating of a switch for use on direct-current circuits. (2) The shape of the terminals does not make much difference in the length of the spark. (3) The effect of increasing the speed of break above that ordinarily employed is small. (4) The effect of a double break is to make the lengths of the spark the same as the length of a spark with the same current at half the voltage. (5) The difference in the length of the spark when copper, steel, or zinc is used is not great. (6) For small double-break switches for use on circuits of 200 volts and upwards, when the trailing spark just fails to bridge the air-gap, the air-gap should be double the distance at which a permanent arc can be obtained. (7) For double-break switches for large currents under the same circumstances the air-gap should be more than double the arcing distance.



SPARKING AT SWITCHES.

FIG. 37.

Switching devices used in connection with switchboards can be divided into several classes as follows, viz.:

Circuit breakers, automatic.
Relays.
Lever switches (knife switches).
Quick-break switches.
Plug switches.
Disconnecting switches.
Controlling switches.
Oil-break switches (oil circuit breakers).
Fuses.

Circuit Breakers.

A circuit breaker is a device which automatically opens the circuit in event of abnormal electrical conditions in the circuit. Automatic circuit breakers are designed for alternating and direct-current circuits. Alternating-current circuit breakers are usually made to operate on overload or low voltage. The usual conditions under which circuit breakers operate are:

Overload.
Underload.
Reverse current.
Overvoltage.
Undervoltage.
Electrically tripped from a distance (shunt trip).

If no conditions are specified it is always understood that the overload circuit breaker is desired, as reverse current, low-voltage features, etc., are usually in the form of attachments to the standard overload circuit breaker.

The **Overload Circuit Breaker** is used to protect the system against excessive overloads. The overload feature consists of a coil connected in series with the main circuit, which operates the circuit breaker tripping trigger by means of its armature.

Since this power is obtained from a solenoid connected in series with the circuit breaker it is obvious that the number of turns of wire or bar on the magnet depends on the ampere capacity of the circuit breaker. Circuit breakers of 800 amperes and above may be designed so as to require but one turn which is obtained by encircling one of the studs of the circuit breaker with an iron horseshoe to which is pivoted the armature. In order to provide for a wide variation in capacities without introducing too many sizes, each circuit breaker is designed to cover a large range of current, between the limits of which it may be set to trip at practically any point. The limits of calibration usually range from 50 to 150 per cent of the continuous current carrying capacity.

The **Underload Circuit Breaker** is similar to that for overloads, except that it acts in event of an underload instead of an overload. This

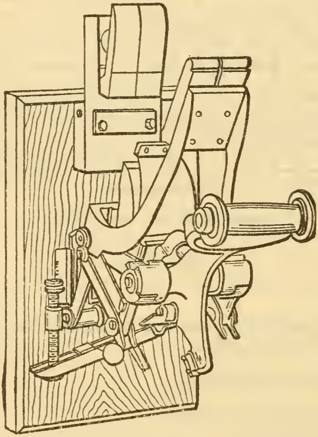


Fig. 38. Type "C," Form "K2," 2000-Ampere, 650-Volt, Automatic Circuit Breaker, as manufactured by the General Electric Company.

type of breaker is applied to storage battery circuits to cut off the battery when the current falls to an amount which would indicate that the battery was fully charged. It may also act as a reverse current circuit breaker, because during the reversal the current must fall to zero value. The underload breaker also acts as a low-voltage breaker, inasmuch as if the source of power is cut off the flow of current will cease. However, it is not always desirable to use an underload breaker for such purposes as it would operate in many cases on small loads when not intended to.

The **Direct Current Reverse Current Circuit Breaker is** essentially an overload breaker, having a potential winding operating magnetically in conjunction with the overload feature so that the circuit breaker will open in event of a reversal of the direction of the flow of current. Under some conditions the circuit breaker would be required to operate on an overload and a reversal of current. In other cases it may be required to operate only on a reversal of current. Both kinds of circuit breakers are manufactured, but the most reliable method is to apply a reverse current relay as described on page 961 to a standard overload breaker, having a shunt trip or low-voltage attachment. In this case the overload feature may be adjusted independently of the reverse-current attachment, or may be blocked to make it inoperative.

The principal uses of the reverse-current circuit breaker are briefly described under the subject relays on page 961.

The low-voltage feature is usually an attachment to a standard overload breaker, and is used chiefly on motor circuits to cut off a motor from the source of power in event of an interruption of current, in order that the motor may be properly started by the attendant, with the aid of a starting

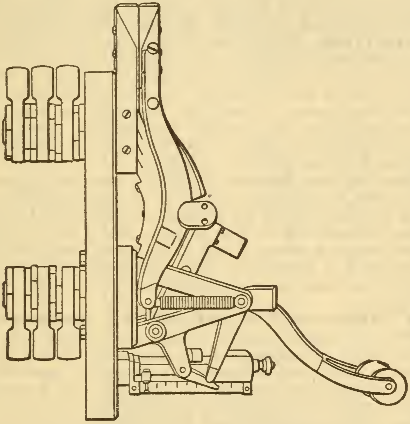


FIG. 39. Westinghouse Type C Circuit Breaker Showing Adjusting Mechanism and Terminals for Rear Connections.

rheostat or compensator, when the source of power is restored. The low-voltage coil may also be advantageously used to trip the circuit breaker from a remote place by shunting the coil. Low voltage breakers are operated by opening the circuit of the coil. Shunting the coil short circuits the line.

The Application of Reverse Current Circuit Breakers to the Protection of Transmission Line in Multiple. — Where power is delivered to a single receiving point by more than one system of feeders, it will be seen that in the absence of suitable protective devices properly disposed, a short-circuit upon one set of feeders will be fed not only through the portion of the feeder located between the short-circuit and the source of supply, but also by means of the portion of the damaged feeder beyond the short-circuit, with current flowing in the reverse sense from the receiving station. "Overload" circuit breakers at both generating and receiving ends of the cables form a means of isolating the damaged lines. Their use alone, however, is liable to cause momentary interruption of service in the uninjured cables, which will be repeated until the damaged line is finally located and put out of service. Circuit breakers having reverse current operation located at the receiving end of the transmission lines will automatically sever the damaged cables at this end and prevent the receiving station from feeding back into the short-circuit; this being attained without interruption of the service. In case of a receiving station having a number of feeders of approximately the same capacity, ordinary overload circuit breakers will generally afford ample protection because a short-circuit on one feeder will be fed through its own circuit breaker from all the other receiving station circuit breakers in parallel. This will tend to open the breaker on the short-circuited feeder line first, and relieve the system. If the station has only two incoming feeders, however, this condition obviously does not obtain and reverse circuit breakers are very essential.

The Application of Circuit Breakers to the Protection of Storage Battery Boosters. — Boosters of the compound or series type, if left connected with the system when the circuit of the driving motor is interrupted, will act as series motors rotating in the reverse direction, and, if not promptly disconnected, will attain a destructivé speed. Similar conditions occur should the booster circuit be closed before the motor has been started, or should the motor for any reason lose its field. Proper protection under these conditions is secured only by having an overload and no voltage circuit breaker in the motor circuit inter-connected with the circuit breaker in the battery circuit in such a manner that the motor circuit breaker must be closed, before the booster circuit breaker can be made to latch, while the opening of the first-named instrument instantly causes the opening of the second.

The Application of Circuit Breakers to the Protection of Boosters Supplying Feeders. — Boosters employed to compensate voltage losses in feeders, incident upon transmission over considerable distances, are either series or compound wound; if, therefore, when for any reason the driving motor is not receiving current, the booster should be left in connection with the system, it will run reversely as a motor, and in view of its series field-winding will attain destructive speed. This condition may be adequately dealt with by the employment of circuit breakers similar to those prescribed for the previous section.

The low-voltage trip coil consists of a shunt winding connected across the circuit in series with a resistance, or may be connected in series with the shunt field of a motor if used on direct current. So long as the voltage remains constant the coil holds up a plunger, but if the voltage drops below a certain limit the plunger is released and the force of the blow trips the breaker.

The shunt trip coil is normally open-circuited, and when energized, by means of a controlling switch or auxiliary switch or such device, it actuates the circuit breaker.

CIRCUIT BREAKER DESIGN.—Direct-Current Circuit Breakers are made single, double and triple pole and four pole. The double-pole circuit breakers usually have the overload feature on one pole only, which is sufficient protection, except in case of the three-wire systems where a triple-pole breaker having two or three coils should be provided. Some types of double-pole breakers have a coil to a pole.

Alternating-Current Circuit Breakers are made single, double, triple and four pole. The single-pole circuit breaker has one coil; the double-pole circuit breaker has one coil; the triple-pole circuit breaker may have but one coil if used on a motor circuit, as there is practically no chance of a short circuit between but two of the leads, otherwise it should have two coils, and in cases where the three-phase system has a grounded neutral it should have three coils; the four-pole circuit breaker should have two coils, unless the phases of a two-phase system are interconnected, in which case it should have three coils.

The carbon-break circuit breaker has been generally adopted for station work on account of the fact that it requires minimum attention, and will operate many times on short circuits without requiring cleaning or repair of the contacts.

The sequence of operation of the various contacts of the carbon-break circuit breaker, is as follows: First, the main contact opens, which shunts the current through the intermediate and carbon contacts, then the intermediate contacts separate; this leaves the circuit through the carbon contacts, where the circuit is finally broken. The object of the intermediate contact is to prevent an arc forming on the main contact.

Where it is desired to definitely direct the arc from the circuit breaker, or the amount of space for the arc is limited, such as would be the case in car work, magnetic blowout breakers are preferable.

Circuit breakers of the carbon break type which are in most common use, are preferably mounted at the top of the switchboard panels, as the arc formed in opening is invariably blown violently upward, and is liable to damage any apparatus mounted directly above it, or blacken and burn the panel. This tendency is not pronounced on small capacity circuit breakers on circuits of 250 volts or less, and this precaution is unnecessary.

CIRCUIT BREAKERS.— For Alternating-Current Service. — The class of circuit breakers required for polyphase circuits largely depends upon individual conditions; the few cases considered here will suffice to indicate the principles which should influence the selection.

In the consideration of polyphase systems, it must not be forgotten that a large proportion of the generators and motors are made with interlinked windings, and for this reason circuit breakers for the protection of two-phase, four-wire generators and circuits should, regardless of voltage, provide for the severance of all four leads, as a single break in each phase still leaves the two remaining leads subject to a potential difference of not less than seven tenths of the voltage in either phase.

This point is made clear by reference to the accompanying cut A, which shows two pieces of two-phase apparatus, as, for instance, generator and motor connected to the same circuit. On account of the windings being interlinked, it will be seen that the passage of current from one to the other is still possible, unless at least three of the four wires are severed.

Where, as is frequently the case, the entire output of the two-phase generator is supplied to single-phase transformers having independent primary windings, then it is true that in the absence of grounds or crosses

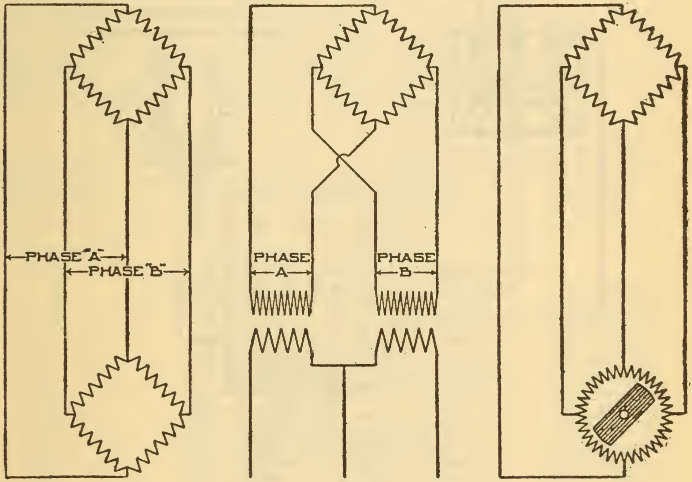


FIG. 39a. Circuits Connecting Polyphase Apparatus.

the generator will be fully relieved of its load by the opening of both phases, each at one point only. Reference to cut B shows, however, that the possibility of grounds or crosses is a contingency which in this case needs to be carefully reckoned with, as in the event of either of these conditions involving both of the unsevered mains, the opening of the circuit at one point in each phase does not relieve the generator.

Circuits Connecting Polyphase Apparatus.—In the event of a short circuit on the mains supplying a synchronous motor this piece of apparatus, kept in motion by its own momentum, acts for the time being as a generator, thus, much increasing the severity of the short circuit. Again upon the opening of the circuit breaker the coincident slowing down of the motor results in its E.M.F. dropping out of phase with that of the generator, thereby very greatly increasing the total electromotive force of the circuit and producing abnormal strains upon opening devices and insulation.

Therefore, the circuit breaker chosen should be such that when it is open, not more than one main of the circuit shall remain in connection with the source of the supply. Motors operating on three-wire circuits of moderate voltage may be adequately protected by double-pole circuit breakers. Those on four-wire systems fed from transformers whose secondaries are not in electrical connection may also be protected in the same manner. Four-wire transmission circuits require circuit breakers of not less than three poles, etc., but preferably the circuit breakers chosen for the protection of polyphase generators and feeders should be capable of severing every main of the circuit, thus securing complete interruption of the current regardless of possible grounds and crosses. The higher the voltage of the circuit the more important this consideration becomes.

The protection of polyphase motors is a subject deserving of special consideration. The staunch build of this class of apparatus and its known ability to withstand heavy overloads often lead to its being carelessly started

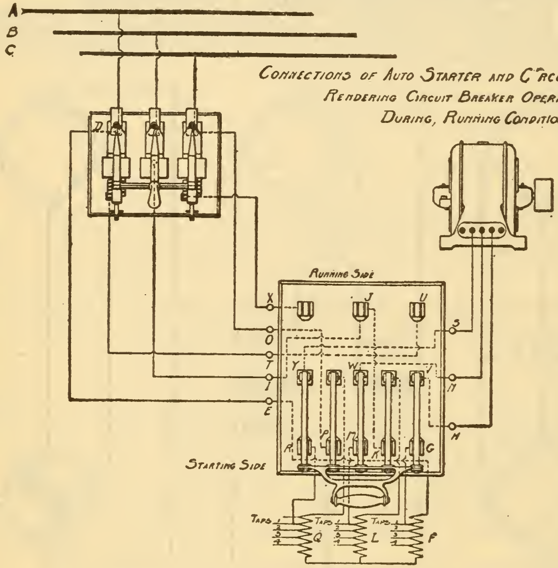


Fig. 40.

and otherwise unduly abused. While this may not result in immediate injury to the motor, it causes excessive disturbances in the voltage of the circuit, and undue waste of energy.

The heavy starting current required by many types of polyphase motors has in the past constituted a serious objection to the use of overload circuit breakers for their protection. This difficulty is overcome by making the connections between the auto-starter and circuit breaker such that the latter will be included in the circuit of the motor only when the switch of the auto-starter is in the running position. Reference to Fig. 40 shows how this may be effected. When the circuit breaker is connected in the manner there shown it will not be acted upon by the currents passing in the starting position of the switch, but should the switch be thrown into the running position at once or before the motor has come up to speed, the circuit breaker will open upon the resulting overload, as will also be the case should the motor be unduly loaded.

Perhaps the most potent source of damage to polyphase motors is the accidental severance of but one phase of the circuit, due in most cases to the blowing of a fuse, either at the motor or somewhere in the circuit supplying it. Where this occurs when the motor is running the latter will, unless very lightly loaded, come to a standstill, and if not promptly disconnected will be seriously injured.

Capacity of Circuit Breaker Required for D.C. Generators.

The size of a circuit breaker is ordinarily determined by its normal current carrying capacity, and for any generator the capacity of the circuit breaker should be the same as the normal rated capacity of the generator, and the breaker should be calibrated for such a range of overload as is required by the service conditions.

Capacity of Circuit Breaker Best Adapted for Motor of Given Size.

The Cutter Company.

The following table indicates the sizes of circuit breakers best adapted for the protection of various sizes of motors of from ½ horse-power to 100 horse-power at voltages of 125, 250, or 500.

The figures given in the left hand column indicate the horse-power of the motor at full load; the remaining columns show the normal capacity of the circuit breakers required for each of the voltages given.

Horse-Power of Motor at Rated Load.	For 125 Volts Normal Capacity of Circuit Breaker.	For 250 Volts Normal Capacity of Circuit Breaker.	For 500 Volts Normal Capacity of Circuit Breaker.
½	4 amperes	...	...
1	8 amperes	4 amperes	...
2	16 or 20 amperes	4 amperes	4 amperes
3	24 or 30 amperes	12 amperes	8 amperes
5	45 amperes	20 amperes	10 amperes
7½	60 amperes	30 amperes	20 amperes
10	80 amperes	40 amperes	20 amperes
15	150 amperes	60 amperes	30 amperes
20	200 amperes	80 amperes	45 amperes
25	200 amperes	100 amperes	60 amperes
30	300 amperes	150 amperes	60 amperes
40	300 amperes	150 amperes	80 amperes
50	400 amperes	200 amperes	100 amperes
75	600 amperes	300 amperes	150 amperes
100	800 amperes	400 amperes	200 amperes

RELAYS.

Definition. — A relay is a device which opens or closes a local circuit under pre-determined electrical conditions in the main circuit.

Classification. — There are three general classes of relays as follows:

1. Signalling.
2. Regulating.
3. Protective.

Signalling Relays.

Function. — The signalling relay acts to transmit signals from a main to a secondary circuit.

Application. — They are mainly used in telegraph and telephone work, being known by the terms telegraph or telephone relays, and do not need further description here.

Regulating Relays.

Function. — The regulating relay acts to control the condition of a main circuit through control devices actuated by a secondary circuit. This control may involve the maintenance of either the voltage, current, frequency or power factor of a circuit at a constant value.

Application. — The regulating relay finds application in generator and feeder circuit regulators, such as the Tirrill Regulator, etc., in which it forms the main device, all other apparatus being subsidiary and actuated thereby.

It differs from the usual protective relay in having its contacts differentially arranged, that is, so that contact is made on a movement of the relay to either side of a central or normal position.

The regulating relay is usually considered a component part of its particular regulator and for this reason it will not be further considered here.

Protective Relays.

Function. — Distributing systems requiring more selective and flexible protection than that afforded by the inherent control features of automatic circuit breakers are equipped with protective relays.

Protective Relays. — Protective relays are used entirely for the protection of circuits from abnormal and dangerous conditions such as overloads, short circuits, reversal of current, etc. They act in conjunction with automatic circuit breakers, operating when their predetermined setting has been reached, energizing the trip coils of the breakers and opening the circuit.

Auxiliary Relays. — Sometimes a main relay, due to inherent limitations, is not able to fulfill all of the necessary requirements. An "auxiliary" relay is then used in conjunction with the "main" relay and supplies the missing functions. Such missing functions may be for example:

1. Lack of time element feature in the main relay.
2. Insufficient carrying capacity of the main relay contacts.

Classification. — Protective relays are sub-divided according to their particular function into the following classes:

Over-voltage, overload, overload and reverse current, reverse current, underload, low-voltage and reverse phase. These designations indicate the circuit conditions under which the various classes operate. For example, the over-voltage relay operates when the voltage rises above a predetermined amount; the reverse current relay operates upon reversal of current, etc.

Time Element Feature. — Continuity of service is an essential consideration in all installations, and interruption of the service cannot be tolerated unless the protection of the apparatus demands it. There are, however, certain abnormal conditions of current flow which may exist for a short time on a circuit without causing serious damage, such as swinging grounds, intermittent short circuits, synchronizing cross currents, etc. The simple instantaneous relay would in such cases act instantly and interrupt the service unnecessarily. There has, therefore, arisen the necessity for relays having a retarded or time element action.

Definite Time Limit Relay. — For certain service it is sufficient that this retarded action have a definite predetermined value independent of the load condition. Such a relay is termed a "*definite time*" *limit relay.*

Inverse Time Limit Relay. — For other service it is necessary that this time element vary inversely with the load, that is, with greater load the time element should be less, and vice versa. Such a relay is termed an "*inverse time*" *limit relay.*

Application of the Instantaneous Relay. — Instantaneous relays are used where it is desired to give protection only at the limiting carrying capacity of the apparatus.

Application of Definite Time Limit Relay. — Definite time limit relays are used where it is necessary to maintain service on a given circuit at all hazards for a predetermined time. This allows temporary grounds and short circuits to clear by burning themselves out, and prevents synchronizing cross currents from opening the breakers. Most desirable of all, however, it enables instantaneous and inverse time-element relays on contiguous circuits of less importance to operate and cut off under disturbances without opening the important circuit, even though the latter is temporarily heavily overloaded during the disturbance.

Characteristics of the Inverse Time Element Relay. — — Inverse time element relays possess two valuable characteristics as follows:

1. Their operation is inversely proportional to the strain on the system; the greater the strain, the quicker the relay will operate.

2. By virtue of 1, they act "selectively," those nearer a point of disturbance in a system, and which, therefore, receive the greatest load, operating first, cutting out the affected portion and clearing the system while confining the disturbance to a minimum area. As an example, consider a system of three feeders (1, 2, and 3, Fig. 41) connecting a set of power station bus-bars, *A*, with a set of sub-station bus-bars *B*, and protected with automatic circuit breakers controlled by overload inverse time element relays at *D*, *E*, *F*, and reverse current inverse time element relays at *P*, *Q*, *R*. The overload relays will each be adjusted for operation at the same current; likewise the reverse current relays will each be adjusted for operation at the same current.

Assume now that a short circuit develops in 1 at point *X*. All three feeders will at once commence to supply current to the short circuit from *A*.

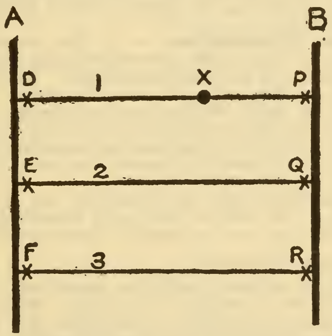


FIG. 41. Illustration of Selective Action of Inverse Time Element Relay.

If *B* is a rotary converter sub-station, the rotaries, by virtue of their enormous fly wheel effect, may tend to supply current also, but as this has no particular bearing on the point to be brought out it will not be further considered. *D* being nearest the fault *X*, and therefore in the circuit of least line drop, will receive more current than *E* and *F*. By virtue of the inverse time law it therefore operates first or "selectively," cutting off the feeder 1, from *A* before *E* and *F* have time to act. Simultaneously *P* has been receiving current in the reverse direction through bus-bars *B*, from feeders 2 and 3, and has cut off feeder 1 from *B*. *Q* and *R* will not operate as they receive current only in the normal direction, and *E* and *F* will not operate as the fault has been isolated and they have been relieved of their overload before they have had time to act. In actual practice on alternating-current circuit relays *P*, *Q*, *R* will operate on both overload and reversal of current, and are so designed that the operation on reversal of current is at a much lower value than on overload (about $\frac{1}{3}$ to $\frac{1}{5}$ in representative types). If overload and reverse current relays were used at *P*, *Q*, *R*, the relay at *P* would operate before *Q* and *R*, for the reverse fault current flowing through *P* is the sum of the normal fault currents through *Q* and *R*.

Where only two feeders exist as, say 1 and 2, *P* and *Q* would each receive the same amount of fault current, and the selective action is not so great, but is still amply sufficient to allow *P* to operate before *Q*, on account of the difference between their reverse and overload tripping values.

Similarly to the definite time element relay, the inverse time element relay will allow temporary grounds or short circuits to clear themselves and will prevent synchronizing cross currents from opening breakers. This action is somewhat more limited in the latter on account of the inverse feature, but is quite sufficient for all ordinary conditions.

Mechanism of the Protective Relay. — Protective relays in their simplest form consist of three elements:

1. The actuating mechanism energized by the line source to be protected.
2. A set of contacts operated thereby.
3. The time element feature (where present).

Actuating Mechanism. — The actuating mechanism assumes the form which will give operation under the desired conditions. It usually involves a motive device consisting of a solenoid and core, a rotating motor or some form of instrument movement.

Tripping Mechanism. — This usually consists of a set of moving platinum, silver or carbon-tipped contacts engaging a corresponding set of stationary contacts. Some relays have single contacts for closing a single tripping circuit; others are provided with multiple contacts for closing two or more tripping circuits, as in the operation of double throw systems where a relay in the main circuit has to operate circuit breakers in each of the duplicate feeder bus-bars.

Time Element Mechanism. — In this instantaneous relay all retarding mechanism is eliminated, the relay acting practically instantaneously with the application of an excessive current. In the definite time limit relay it is the usual practice to employ an air dashpot, such as used in arc lamps, to the piston of which the contact mechanism is attached. Upon the operation of the actuating mechanism the contact mechanism is released and allowed to descend by gravity against the action of the dashpot, thereby making contact a definite interval of time after the disturbance and independent of the magnitude of the disturbance.

In the inverse time limit relay the actuating and contact mechanism is attached directly to an air bellows and upon operating tends to compress the bellows against the action of a specially constructed escape valve in the latter.

The amount of the retardation varies inversely with the pressure on the bellows and, therefore, inversely with the magnitude of the disturbance. An alternative arrangement replaces the bellows with a conducting disk cutting a magnetic field, in which the retardation due to the eddy current reaction, induced on moving the disk through the field, varies inversely with the magnitude of the force with which the disk is urged through the field and hence inversely with the disturbance.

Shunt Trip Contacts. — The usual arrangement of relay contacts provides for their closure upon the operation of the relay, in which case the relay is spoken of as being provided with "shunt trip contacts." The contacts are connected in series with the tripping circuit of the breaker and an independent source of current, and upon closing energize the tripping circuit and open the breaker.

The tripping coils are wound for shunt operation from the independent source which is usually a direct-current exciter circuit or a storage battery, and the circuit breaker is spoken of as being equipped with shunt trip coils.

The operation of shunt tripping coils from the circuit being protected is inadvisable, owing to the liability of the trip coil failing to operate on the low voltage existing under short circuit and overload conditions.

Series Trip Contacts. — Where an independent source of current is not available the circuit breakers are provided with series tripping coils, wound for operation from series transformers in the main circuit. Overload relays are also provided with series trip contacts which differ from the shunt trip contacts in being normally closed instead of open, and opening upon operation of the relay. They are connected in shunt with the series trip coils short circuiting the same. Upon operation of the relay they open, allowing the transformer secondary current to flow through the trip coils and trip the breaker. As there is always sufficient current flowing under overload and short circuit conditions to operate the trip coils, this arrangement is as satisfactory as shunt tripping.

Protection of Alternating-Current Systems. — The application of relays to any given system depends almost entirely upon the local conditions of operation, varying somewhat with each installation.

Generator Circuit Protection. — Representative practice recommends the placing on generator circuits of either a reverse current relay, with a time element feature, or else the entire elimination of automatic protection.

Feeder Circuit Protection. — For feeders at the power station end, overload inverse time element relays are desirable. For feeders at the sub-station end, overload and reverse current inverse time element relays are desirable.

Rotary Converter Circuit Protection. — With rotary converters, an overload inverse time limit relay in the high tension side of the power transformers will give protection for the alternating-current side. For the direct current side a reverse current inverse time limit relay operating the direct current breakers will be required.

Protecting Four-Wire Three-Phase System. — An example of the relaying required in a typical four-wire three-phase system is illustrated in Fig. 42. Three generators operating with their neutral points grounded through a resistance, feed a common bus system, four sets of feeders, power transformers, rotaries, etc., for alternating-current and direct-current distribution of power. Automatic circuit breakers are inserted operated by relays as follows:

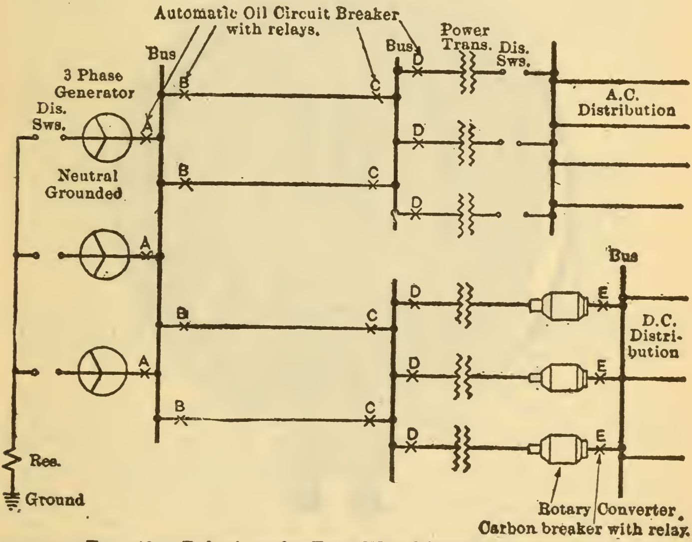


FIG. 42. Relaying of a Four-Wire Three-Phase System.

At *A*, A.C. = Overload and reverse current inverse time element relays.
At *B*, A.C. = Overload inverse time element relays.
At *C*, A.C. = Overload and reverse current inverse time element relays
At *D*, A.C. = Overload inverse time element relays.
At *E*, D.C. = Reverse current inverse time element relays.

The relays at *A* are intended for reverse protection only and so have their overload adjustment set at the maximum value.

Relays Commonly Employed.— The types of protective relays most commonly employed are:

D.C. Over-voltage relays.
D.C. Reverse current relays.
D.C. Low-voltage relays.
D.C. Underload relays.
A.C. Overload relays.
A.C. Overload and reverse current relays.
A.C. Low-voltage relays.
A.C. Reverse phase relays.

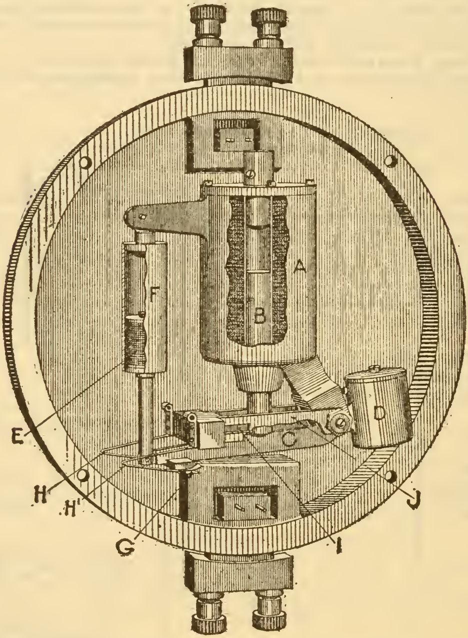


FIG. 43. Westinghouse Direct-Current Time Limit Relay Definite Time Limit Action Shunt Trip Contacts.

Application.

Direct-Current Over-Voltage Relay.—The direct-current over-voltage relay is used chiefly on battery charging panels, but is also used to protect any direct-current apparatus which would be liable to damage from excess voltage. In storage battery work the relay may be used to disconnect the battery from the circuit when it is fully charged, as under certain well-defined conditions the voltage of the battery is a measure of its charge. The voltage of a battery is dependent, however, not only on its inherent characteristics, but also upon its charge and discharge history. Abnormal charging and discharging conditions operate to temporarily or permanently change the law of a battery's voltage curve, and an over-voltage relay set for a given full charge condition may actually operate when the battery is not at full charge. The proper setting of a relay on such a circuit is, therefore, a matter entirely to be determined by the operating conditions and with full consideration being given to the effect upon the full charge voltage of the charge and discharge factors.

Direct-Current Reverse Current Relay. — The direct-current reverse current relay is chiefly used for the protection of storage battery installations and rotary converters. When applied to rotary converters operating in parallel the relay serves to protect against short circuits occurring on the alternating-current side of the rotary, on the direct-current side between the rotary and relay, or in the rotary itself.

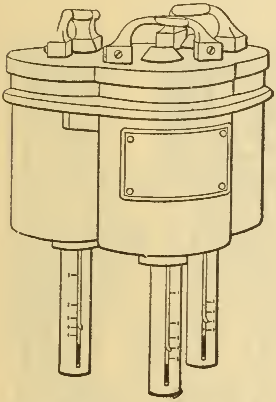


FIG. 44. General Electric Alternating-Current Overload Relay Instantaneous Action Shunt Trip Contacts.

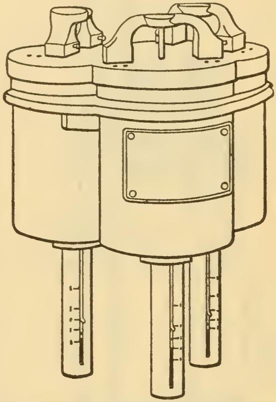


FIG. 45. General Electric Alternating-Current Overload Relay Instantaneous Action Series Trip Contacts.

Short circuits occurring on the direct-current side beyond the relay are taken care of by the circuit breaker overload coils. When applied to storage battery installations the relay prevents the battery from discharging back into its charging source.

Time Element Feature. — When synchronizing machines to a system operating a rotary converter, momentary and harmless corrective currents are liable to flow toward the rotary on the direct-current side. In order to prevent interruption of the circuit by such flow, where reverse current relays are present, it is necessary that the latter have a time element. This time element must be of the inverse order to give quick interruption on overloads and short circuits and to give a selective action so as to cut off affected circuits.

Overspeeding of Rotaries. — Reverse current relays are not a complete protection against the overspeeding and running away of rotary converters such as would result from the opening of the rotary's field. They should be supplemented by mechanical overspeed devices attached directly to the shaft of the rotary and arranged to close the trip circuit upon operation. Such additional precaution is necessary as very low reverse currents exist under such conditions, only sufficient to supply the losses in the rotary and less than the minimum setting of the ordinary reverse current relay, which will therefore fail to operate and protect the machine.

Direct-Current Low-Voltage Relay. — This relay is generally used in connection with direct-current motors and operates when the voltage of the circuit falls below a predetermined value.

Direct-Current Underload Relay. — This relay is mainly used in the charging of storage batteries to disconnect the batteries when charged.

Alternating-Current Overload Relay. — This relay is used very extensively, mainly for the protection of feeders, rotary converters, motors and transformers. All three forms exist, viz.: the instantaneous, definite time limit and inverse time limit, each finding its special application as outlined in the preceding pages. Either series or shunt trip contacts are provided depending on the tripping source.

Alternating-Current Overload and Reverse-Current Relay.— This relay is an important one, very extensively used for generator and feeder protection. It exists only in the inverse time limit form. When used for generator protection the overload adjustment is set at the maximum value to give overload protection only at the maximum carrying

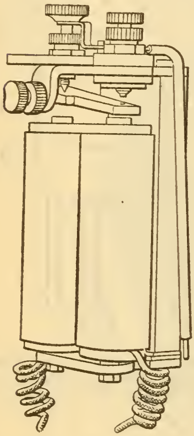


Fig. 46. Westinghouse Direct-Current Over-Voltage Relay Instantaneous Action Shunt Trip Contacts.

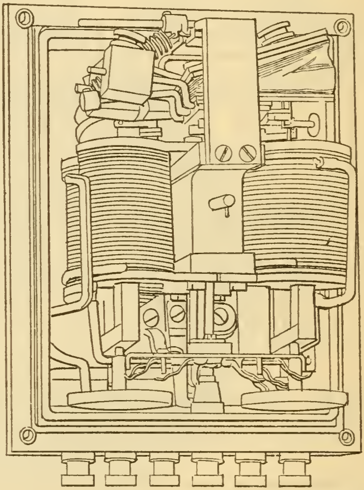


Fig. 47. Westinghouse Alternating-Current Overload Relay (Cover Removed) Inverse Time Limit Action Shunt Trip Contacts.

capacity of the generator and a sensitive reverse protection to prevent a return of energy from the line.

The selective action of this relay has been covered in the preceding pages.

Alternating-Current Low-Voltage Relay. — This type of relay is used for the protection of induction motors against a fall in the line voltage.

Alternating-Current Reverse-Phase Relay. — This relay is used to protect synchronous apparatus against a reversal of direction of rotation or phase progression of the alternating-current source.

Remote-Control Switches for Equalizer Circuits. — In large power houses of the modern type, considerations of economy as well as of convenience, dictate the placing of equalizer switches close to the generators, for the reason that the cost of cable to connect the generator to the equalizer, if carried from the machine to the switchboard and back again, would be excessive.

Figure 48 herewith is an illustration of a pair of switches, made by the Cutter Company for a large New York power house, that meet these conditions: The right-hand switch has a capacity of 2,000 amperes, and the left, 3,000. The upper terminal of each of these switches connects with the equalizer main, which takes the place of the equalizer bus otherwise required at the switchboard. The lower terminal of each is connected with the appropriate terminal of the series winding of the corresponding generator. The closing of each switch, therefore, completes the equalizer circuit of

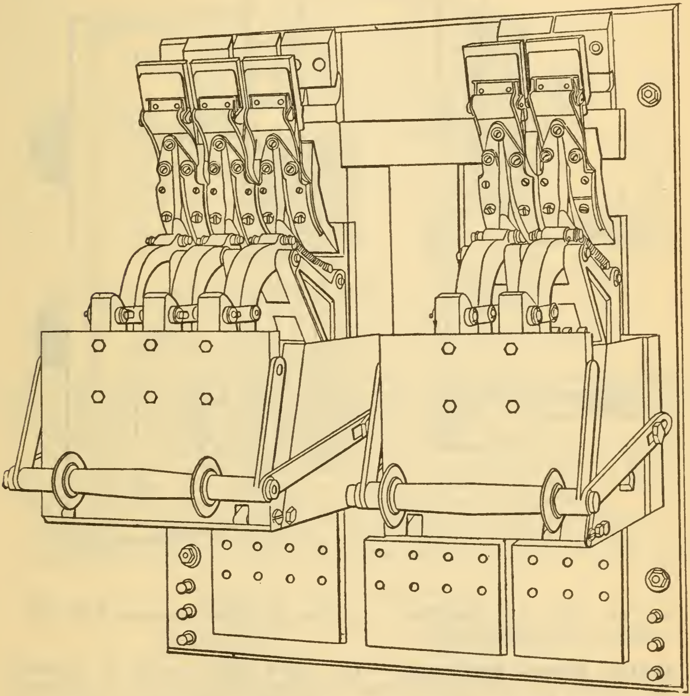


FIG. 48. Remote-Control Switch for Equalizer Circuits.

the generator with which it is connected. These switches are designed for control from a switchboard located at a distance, such control being effected by the movement of a small double-throw switch, bringing into circuit upon one movement the opening coil, and upon the opposite movement, the closing coil. Each switch is also provided with a hand-closing mechanism, so that it can be operated at the machine.

Lever Switches. — Lever switches are plain knife blade switches and are for use on direct-current circuits up to 250 volts and on alternating-current circuits up to 500 volts. The design of these switches is thoroughly covered by the "Fire Underwriters Code." The accompanying diagram represents typical lever switches. It should be noted that for switches of this class, a capacity of 4500 amperes in a single switch is about as high as is practical, as heavier capacity switches are liable to be too hard for the ordinary attendant to operate manually.

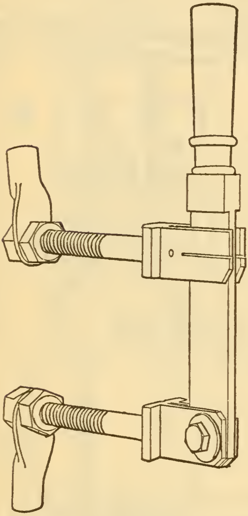


FIG. 49. S.P., S.T., 250-Volt 200-Ampere Lever Switch.

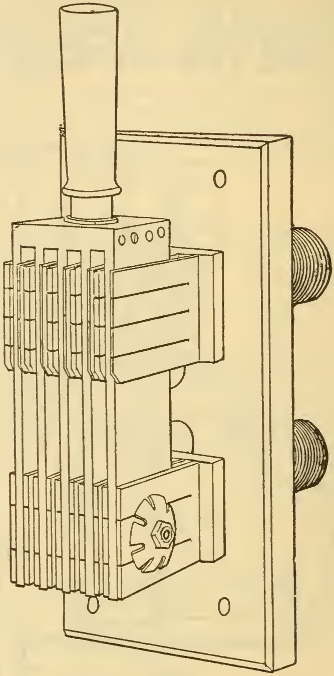


FIG. 50. 6000 Ampere, S.P., S.T.

Quick Break Switches. — The quick break switch is essentially a lever switch provided with spring-driven follower blade which remains in the clips after the main blade leaves and is opened quickly by means of a

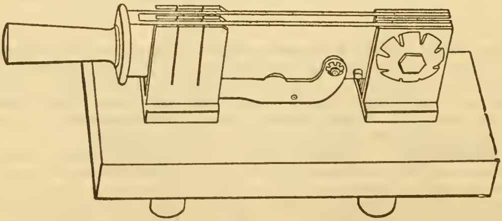


FIG. 51. 1000-Ampere 600-Volt Quick Break Switch

spring; the object being to break the circuit quickly and thereby lessen the burning of the contacts, also to have the follower take the burning instead of the main blade. A lever switch may also be opened quickly but a quick break switch cannot be opened slowly.

The design of a quick break switch is covered by the "Fire Underwriters Code." A typical switch is illustrated in the accompanying diagram.

Plug Tube Switches. — The plug switch has many forms depending on the use and the company manufacturing it. The principle of a

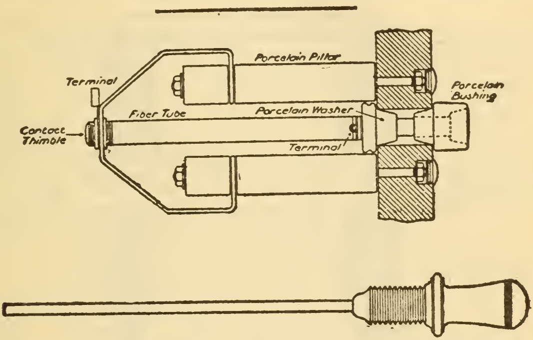


FIG. 52. 10,000-Volt 10-Ampere Plug Tube Switch.

plug tube switch is to rupture the circuit in a tube which is enclosed at one end, thereby confining the arc and limiting the supply of air. Plug switches are also used for transferring live circuits and for voltmeter and synchronizing circuits where there is no energy.

Plug tube switches may be used on high voltage circuits providing the current capacity is low. They are being used extensively on 10,000 to 20,000 volt series arc circuits, the current ranging from 4 to 7.5 amperes. One of these switches is shown in the accompanying diagram.

Plug tube switches are also used on 100 ampere 2500 volt circuits.

Disconnecting Switches. — This type of switch is connected in series with oil break switches and other devices so as to be able to dis-

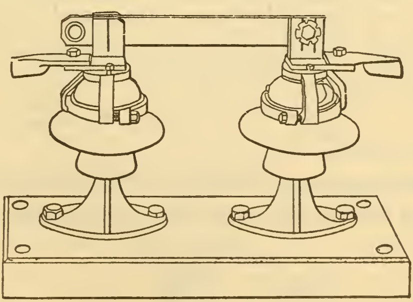


FIG. 53. 15,000-Volt 300-Ampere Front Connected Disconnecting Switch.

connect the oil switches, transformers or cable, as the case may be, from the live circuit or bus-bars in order to make alterations, repairs or adjustments.

The form of switch is similar to the low-voltage lever switch except that it is mounted on insulators. It is not intended to open any load, with a possible exception of the magnetizing current of a transformer, and should not be used for such purpose. However, it should be thoroughly insulated for the voltage of the circuit to which it is connected and should be capable of carrying the maximum current of the circuit. Disconnecting switches for high voltage circuits, such as 60,000 volts, are designed with a view to rigidity rather than current-carrying capacity as the switch becomes very large and the current correspondingly small.

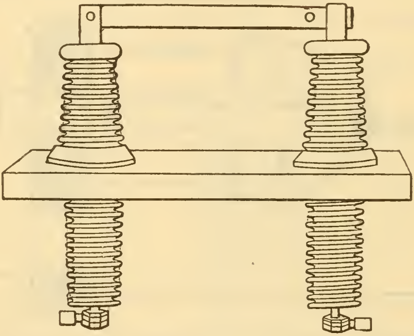


FIG. 54. Rear Connected 300-Ampere 33,000-Volt Disconnecting Switch.

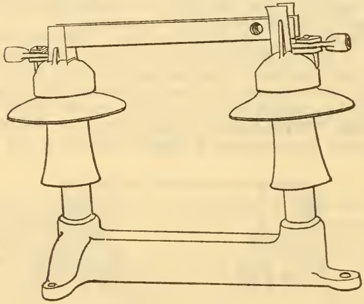


FIG. 55. Front Connected 300-Ampere 33,000-Volt Disconnecting Switch.

Disconnecting switches have the following voltage rating:

Voltage { 6,600–15,000
22,000
33,000
45,000
66,000

These switches are made single pole only and are operated by means of a long wooden handle provided with a hook. This handle acts as insulation between the attendant and the switch.

Switches for High Potentials.

Types. On American high-tension transmission lines there are four general types of switches now in use:

(1) Switches designed to break the circuit in the open air.
(2) Switches designed to break the circuit in an enclosed air space.
(3) Switches designed to break the circuit with the aid of an enclosed metal fuse.
(4) Switches designed to break the circuit under oil.

Type No. 1. The large amount of space required by this switch, in order to be certain that the arc will be broken, makes its use limited and it can be used only with safety when the line potential is comparatively low for the reason that a circuit containing inductance and capacity may have very high-voltage oscillations set up in it by an open air arc unless the current is broken at zero value, resulting in highly increased voltage.

Type No. 2. This switch occupies less space than type No. 1, but its effect on circuits containing inductance and capacity is very little different, so that there will be the same oscillatory rises of potential on opening the circuit. In addition, the explosion on opening heavy currents with this switch is at times so heavy as to endanger not only the switch itself but all delicate instruments in the immediate neighborhood.

Type No. 3. Two forms of this switch have been more or less used. In the first form the fuse is connected in parallel, and in the second in series with the current-carrying parts of the switch. The first form is limited to low-voltage circuits, because of the unreliability of the enclosed fuse on comparatively high potentials when the circuit is fed from large central stations. The second form operates through the severing of a metal fuse within an enclosing tube filled with powdered carbonate of lime or some other non-conducting powder. The end of the fuse is drawn through the tube by the moving arm of the switch and the circuit is opened without serious commotion, if the switch has been well designed and care has been taken to properly fill the tube. This switch will open safely almost any circuit at almost any potential, but like the open air switch is limited by the amount of space required, and the powder set flying by the explosion of the arc is a decided objection if there is any moving machinery in the same room.

Type No. 4. This type of switch is almost universally recognized as the only switch suitable for use upon high-tension circuits.

It has been shown by numbers of experiments that the opening of a circuit by an oil switch is not a *quick break;* the oscillograph shows that the effect of the oil is to allow the arc to continue for several periods and then to break the current, as a rule, at the zero point of the wave. The result of the breaking at this point is that the opening of any circuit with oil switches is rarely accompanied by destructive rises of potential. An oil switch creates less fuss in the oil if it is opened slowly, but it is also true that an oil switch for 40,000 or 50,000 volts must have a depth of oil over the terminals of at least four or five inches. If less depth of oil is used, the oil is likely to be thrown out of the oil pots, on the opening of the circuit, although the arc will be broken.

On the assumption that the oil switch is to be used for high-tension work, the following points of construction will bear consideration after the particular form of oil switch has been selected:

(1) Rating. The performance of the switch under abnormal conditions of a low resistance short circuit should be considered as well as the capacity of the switch under normal operating conditions.

(2) Oil. Any good paraffine oil will answer, but it should have about the following characteristics: flashing point not less than 180° C.; fire-test not less than 200° C.; specific gravity, .865; acid, none; alkali, none; evaporation, negligible.

(3) Insulation. The insulator and insulating bushings should be either glass or porcelain. The switch should stand a break-down test between the live parts and the metal case and frame work of at least twice the working voltage applied for one minute. The external terminals should be far enough apart, or sufficiently well insulated, so that there can be no possibility of the current striking across through the air from terminal to terminal.

(4) Location. Oil switches for use on circuits of above 6000 volts should be placed at a distance from the switchboard and away from the generating and transforming apparatus. Each pole should be placed in a separate fire-proof cell, so that by no possibility could an arc or explosion in one cell be communicated to another cell, or to the neighboring machinery.

(5) Method of operation. All switches should be either magnetically or electrically controlled from a central switchboard, and all the poles of a switch should be operated simultaneously. When equipped with relay for opening automatically this switch becomes one of the best forms of *circuit breakers*, and is so designated by the Westinghouse Company. It is also desirable to equip each switch, especially if it is automatic, with a time element attachment, so that the circuit cannot be opened for at least a second after the operating mechanism is set in motion.

Following are cuts of oil switches for different purposes and potentials as at present developed.

In selecting the type of oil switch for any particular installation it is necessary to first determine the ultimate capacity of the installation and the total power which may be supplied to the switch from all sources. Care should then be taken to select the type of switch whose ultimate breaking capacity is not less than the ultimate capacity which may be supplied to it.

It sometimes happens, however, when several stations are tied together by long transmission lines that it is impossible to concentrate all of the

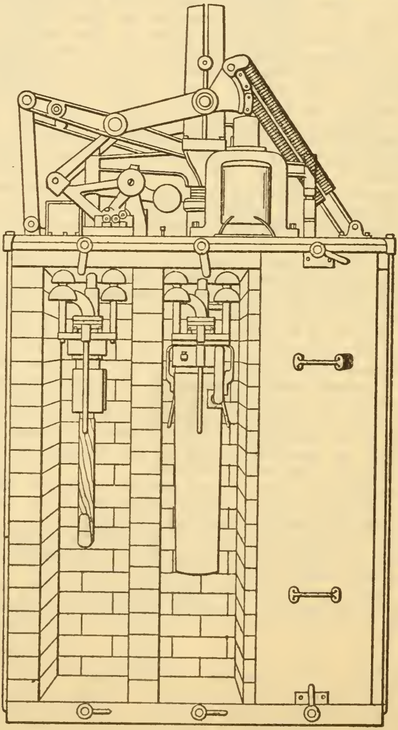


Fig. 56. Type C Oil Circuit Breaker, Showing Oil Tank and Contacts.

power at certain stations on account of the drop in the line. Also, some sub-stations are well protected by having adequate switches installed on the outgoing feeders supplying this station from the main generating station. In such cases it is sometimes possible to supply switches which have an ultimate breaking capacity that is less than the ultimate capacity of the sources of power connected to them, and such cases are exceptions to the rule.

Westinghouse Type C Oil Circuit Breakers. (Figs. 56, 57.)

This circuit breaker will open circuits carrying the heaviest currents encountered in modern practice.

It is designed for operation on circuits up to and including 35,000 volts,

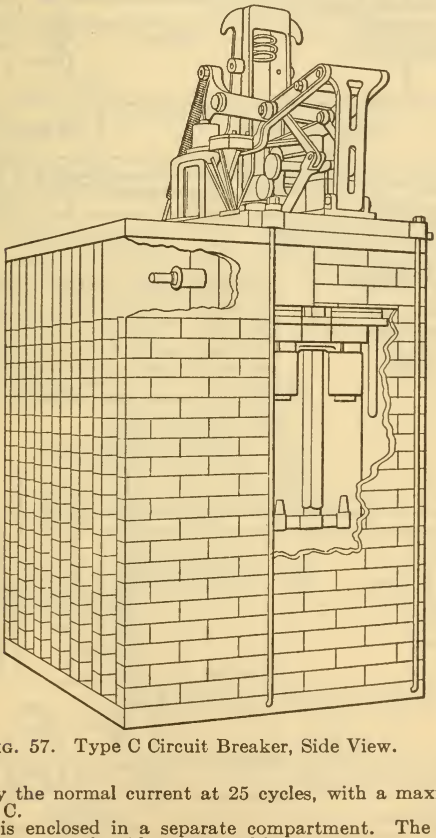


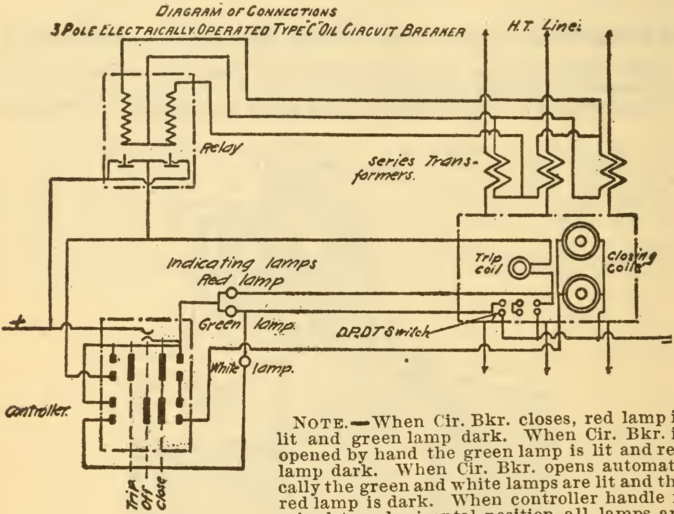
FIG. 57. Type C Circuit Breaker, Side View.

and will carry the normal current at 25 cycles, with a maximum rise not exceeding 25° C.

Each pole is enclosed in a separate compartment. The mechanism is closed by means of a solenoid and opened by gravity.

Terminals are brought out at the rear of the breaker, and the leads may be carried upward or downward in suitable runways, leaving no high-tension wiring exposed.

Mounted on each circuit breaker is a small, double-pole double-throw knife switch. Provision is made for a second switch when required. The switch is operated by the motion of the levers of the oil switch and is used for the indicating and tripping circuits, also for use in electrically interlocking the circuits when required.



NOTE.—When Cir. Bkr. closes, red lamp is lit and green lamp dark. When Cir. Bkr. is opened by hand the green lamp is lit and red lamp dark. When Cir. Bkr. opens automatically the green and white lamps are lit and the red lamp is dark. When controller handle is raised to a horizontal position all lamps are dark, indicating that switch is out of service.

FIG. 58.

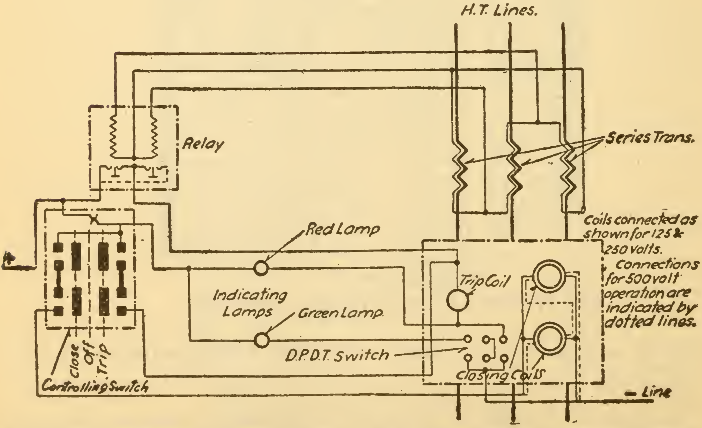


FIG. 59. Diagram of Connections. 3-Pole Electrically Operated Type C Oil Circuit Breaker.

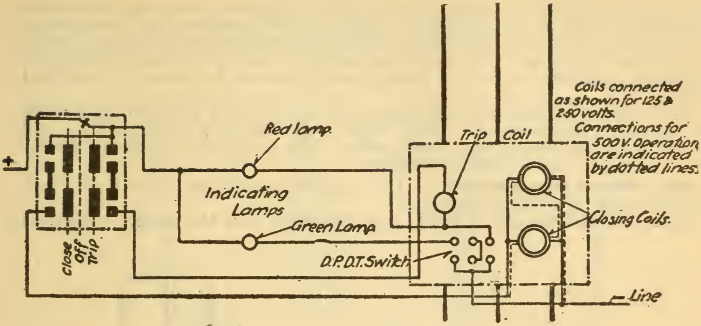


FIG. 60. Diagram of Connections. 3-Pole Electrically Operated Non-Automatic, C Oil Circuit Breaker.

Westinghouse Type B Oil Circuit Breaker for Potential 3500 to 22,000 Volts.

The type B circuit breakers are made in the electrically operated form for potentials of 3500 to 22,000 volts, and in capacities up to 600 amperes.

A simple system of toggles and levers is mounted on the top of the breaker, and a powerful electromagnet is arranged with its movable core

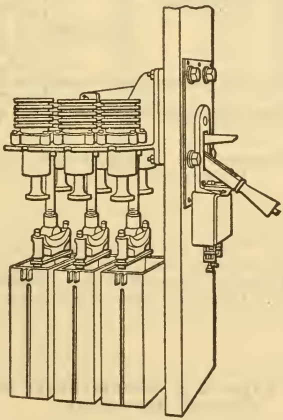


FIG. 61. Hand-Operated, Automatic, 600-Ampere, 3-Pole, Type B, Oil Circuit-Breaker Mounted on Panel. Tank Removed, Open Position, not Over 22,000 Volts.

attached to the lever system, so that when it is drawn into the coil, the circuit breaker will be closed. A tripping-coil is also mounted with the operating mechanism. A small single-pole, double-throw switch is mounted on the breaker, and is operated by the motion of the levers in opening and closing the circuit; it controls the tell-tale indicator and lamp which are mounted in view of the operator. These circuit breakers are operated by 125, 250 or 500-volt direct current, and are calibrated for 25 cycles.

The electrically operated type E oil circuit breakers are made both non-automatic and automatic, the latter being operated by means of overload relays.

The breaker is made in single-pole units, each being mounted in a brick or concrete compartment. Two, three and four-pole combinations are made by placing these units side by side. The tanks are of a design similar to those of the type C circuit breakers.

Oil Switch Structures. — The structural work for types C or E oil switches may be brick or concrete.

When the structure is of brick, it is necessary that the anchor bolts pass

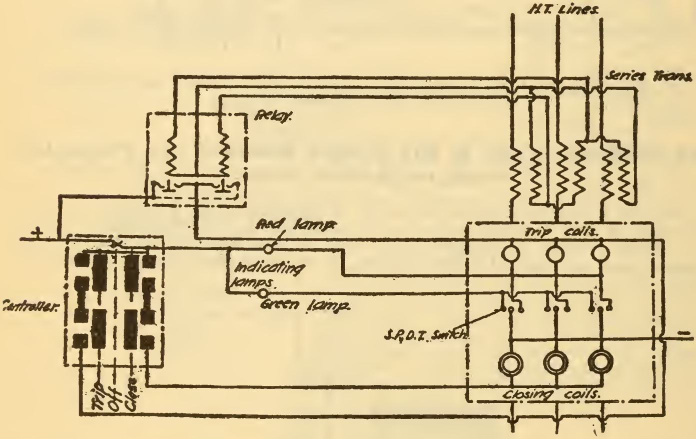


FIG. 62. Diagram of Connections. 3-Pole Electrically Operated Type E Oil Circuit Breaker.

outside of the brickwork. When the switch has a concrete base, however, the bolts are usually anchored in the concrete. The only soapstone supplied with the type C oil circuit breakers is the top slab, the blocks to hold the terminal insulators in the rear, and the soapstone barriers between these terminals.

Westinghouse Type GA Electrically Operated Oil Circuit Breaker.

Westinghouse type GA oil circuit breakers are designed for use on circuits carrying large amounts of power.

The distinctive features of the type GA circuit breakers are: Liberal insulation and breaking distances; open position maintained by gravity; all metal tanks and tank tops; accessibility of parts; long break in clean oil; low first cost.

Construction. — Type GA circuit breakers consist of one or more poles self-contained in heavy steel oil tanks with treated linings and provided with heavy cast-iron covers to which all of the mechanism for operating each pole is secured. Each pole is entirely separate and distinct from the others, the operating rod being the only connection between them.

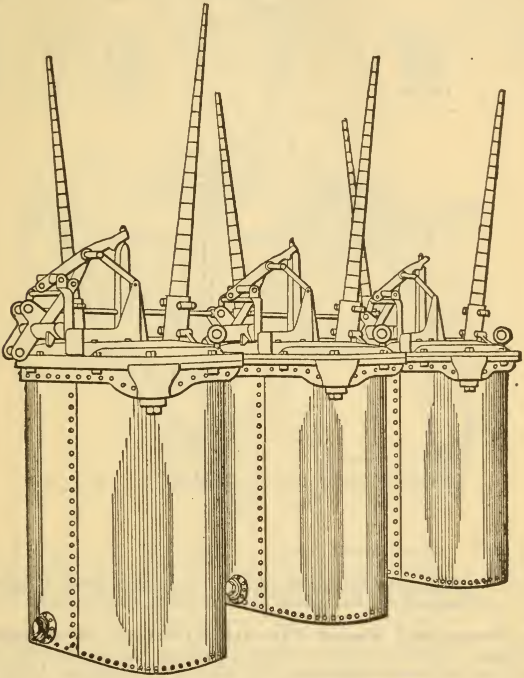


FIG. 63. Type GA Oil Circuit Breaker, without Closing Mechanism, for Potentials of 44,000 to 110,000 Volts.

Current-carrying Capacity. — Type GA circuit breakers are designed to carry 300 amperes per pole with a maximum temperature rise of 20° C. They can be built with a larger current-carrying capacity if desired.

Voltages. — These circuit breakers are built for use on circuits of 44,000, 66,000, 88,000 and 110,000 volts.

Breaking Capacity. — Type GA circuit-breakers are guaranteed to open any short circuit which may develop on transmission systems of the following capacities:

60,000 kilowatts at 44,000 volts;
80,000 kilowatts at 66,000 volts;
100,000 kilowatts at 88,000 volts;
120,000 kilowatts at 110,000 volts.

The breaking distances, or distances between contacts when the circuit breaker is open, are large and there are two breaks on each pole. The breaking distances of different capacity circuit breakers are given in the following table:

Breaking Distances.

Amperes.	Voltage.	Minimum Distance of Terminal to Case or Ground.	Breaking Distance per Break, Inches.	Breaking Distance per Pole, Inches.
300	44,000	16	11.5	23
300	66,000	22	16.5	33
300	88,000	30	20	40
300	110,000	32	23.5	47

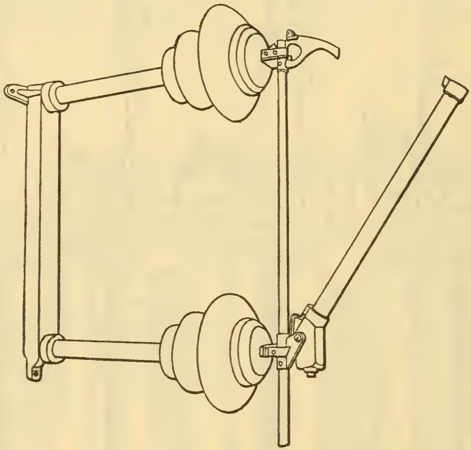


FIG. 64. Westinghouse High-Potential Fuse-Type Circuit Breaker — Open Position for Potentials not Exceeding 66,000 Volts.

High-Potential Fused Circuit Breaker, Westinghouse. — This fuse-type circuit breaker consists of a long hardwood pole on which is mounted a movable arm consisting of a reinforced fuse tube. At the bottom of the fuse tube is a brass expulsion chamber which is connected to the lower terminal of the breaker by a flexible copper shunt. Attached to the top of the pole and forming the upper circuit-breaker terminal there is a brass bracket, with a groove along its top, which supports the fuse, and a wing nut to hold the end of the fuse when the breaker is closed. The fuse passes from the wing nut over the bracket and down through the fuse tube to the expulsion chamber when it is attached to the screw-plug terminal shown in the end of the expulsion chamber. The pole of the circuit breaker is provided with spring jaws or clips so that it may be quickly and easily attached to or detached from the line terminals at the base.

Adjustment. — First: Remove the mechanism from its base, taking hold of the long pole.

Second: Remove the screw-plug terminal from the lower end of the expulsion chamber and attach the fuse to the terminal.

Third: After passing the fuse through the fuse tube replace the screw plug and attach the other end of the fuse to the wing nut on the bracket at the upper end of the long pole, passing a turn or two around the lug, at the same time drawing the moving arm into its proper position against the end of the bracket.

Fourth: Replace the mechanism on the base and the breaker is ready for use.

Operation. — When the load on the line exceeds the capacity of the fuse the latter blows and the arm of the breaker swings by its own weight away from the upper line terminals, thus giving a positive indication that the fuse has blown.

Oil Circuit-Breaker Controller. — This controlling switch is of the drum type with a hinged handle, which, when thrown to the open position, may be locked by swinging the handle outward so that it is in line with the drum shaft. It cannot be locked in the closed position. When the handle is raised as described it indicates to the operator that the switch is out of service. The act of raising the handle cuts the current off from the controller and thus extinguishes the lamps. The switch is arranged for switchboard mounting, the dial and handle being on the face of the panel. It may also be provided with an indicator to show the last operation performed.

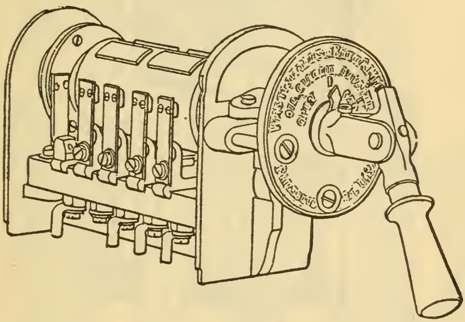


FIG. 65. Controlling Switch, Cover Removed.

Lamp Indicator for Oil Circuit Breaker. — The indicator consists essentially of a hollow tube with a lamp socket mounted on a porcelain base in one end, held in position by suitable clips. The socket can be easily removed and is intended to hold a 5 c.p. candle-shaped incandescent lamp which extends into the tube. Suitable holes are provided for ventilation.

A colored lens is secured to the front end of the tube. A special feature of the lens is a V-shaped projection which extends across its face, enabling the operator to see the light from any angle within an arc of 180°.

Control and Instrument Leads. — The control wires for the electrically operated circuit breakers are run in conduits, or in some other suitable manner, to the place where the operating switchboard is located. The small size of the controlling and conducting devices permits a large number to be grouped in a comparatively small space where they are easily accessible to the operator.

The sizes of conductors usually required where lengths do not exceed 200 feet, are as follows:

For series tranformer circuits, each lead equivalent to No. 7 B. & S. conductor.

For voltage transformer circuits, each lead equivalent to No. 10 or 12 No. B. & S. conductor.

For static ground detectors, each lead equivalent to No. 10 B. & S. conductor.

For oil circuit breaker, 1 closing coil lead equivalent to No. 7 conductor, B. & S.; 1 tripping coil lead equivalent to No. 12 conductor, B. & S.; 2 indicator leads equivalent to No. 12 conductor, B. & S.

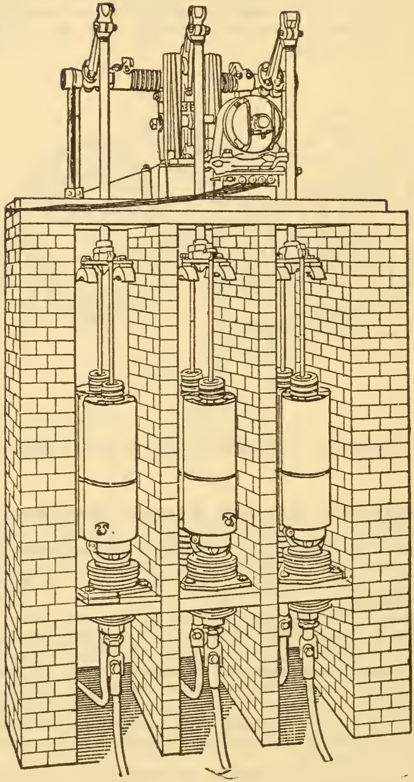


Fig. 66. 13,000-Volt, 500-Ampere T. P. Motor Operated Oil Break Switch as Manufactured by the General Electric Company.

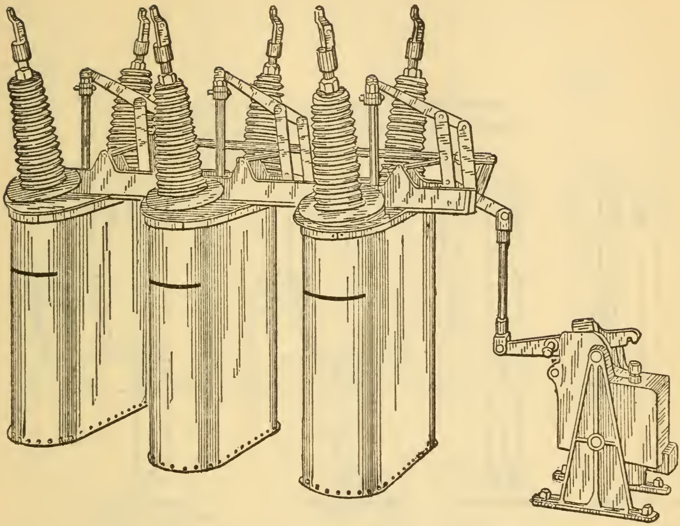
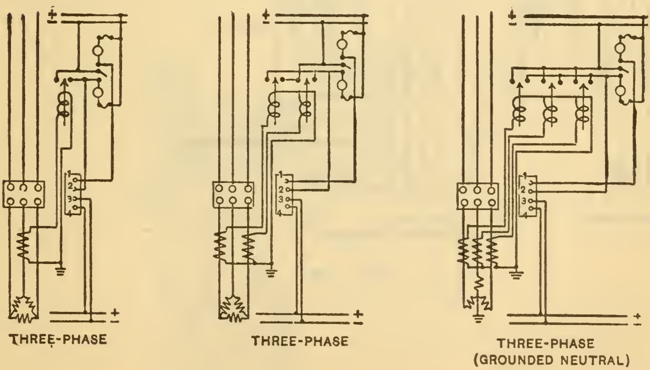


Fig. 67. 3 Single-Pole, 45,000-Volt, 300-Ampere Solenoid Operated Type "F," Form "K 21," Oil Switch as manufactured by the General Electric Company.



CONNECTIONS OF ELECTRICALLY OPERATED OIL SWITCHES OPERATED BY DIRECT CURRENT BY MEANS OF CIRCUIT CLOSING RELAYS

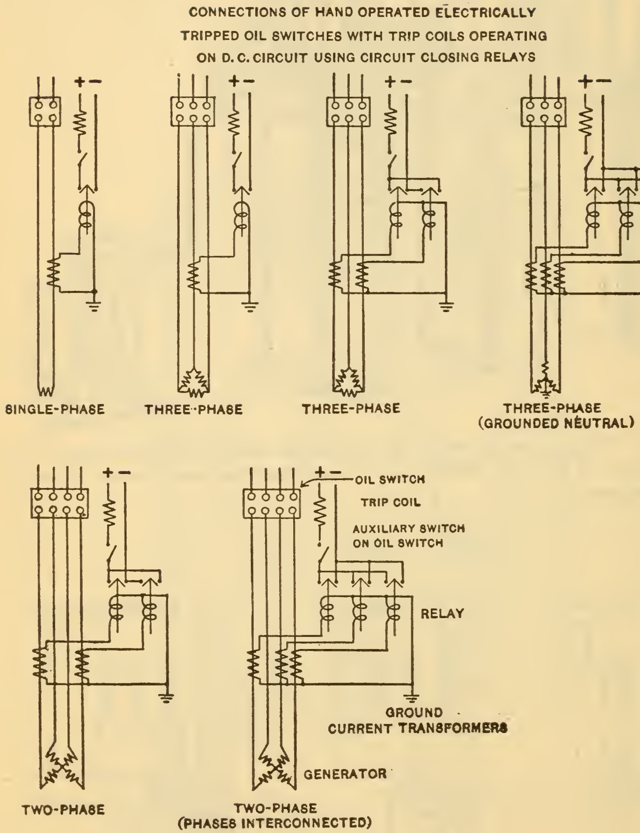

CONNECTIONS OF HAND OPERATED ELECTRICALLY
TRIPPED OIL SWITCHES WITH TRIP COILS OPERATING
ON D. C. CIRCUIT USING CIRCUIT CLOSING RELAYS
+ −
SINGLE-PHASE
THREE-PHASE
THREE-PHASE
THREE-PHASE
(GROUNDED NEUTRAL)
TWO-PHASE
OIL SWITCH
TRIP COIL
AUXILIARY SWITCH
ON OIL SWITCH
RELAY
GROUND
CURRENT TRANSFORMERS
GENERATOR
TWO-PHASE
(PHASES INTERCONNECTED)

Fig. 68.

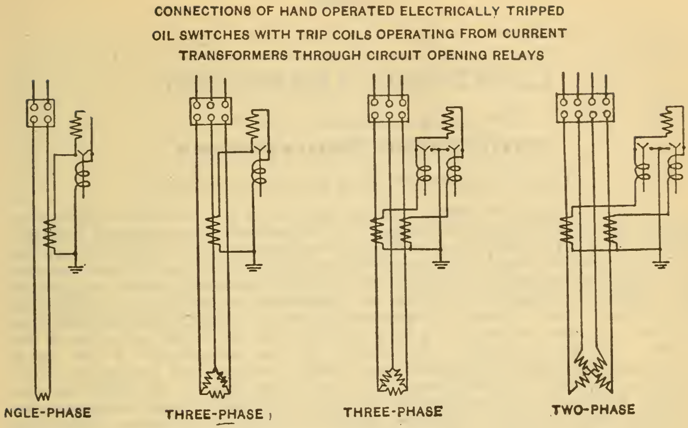


Fig. 69.

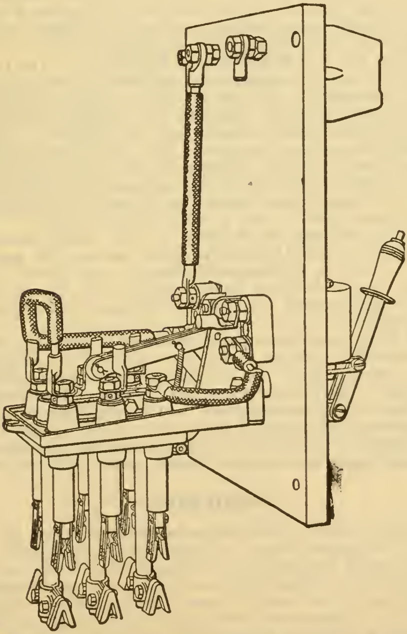


Fig. 70. General Electric Company Type F, Form K 3 — 100 Amperes, 2500 Volts T.P.S.T. Oil Switch.

LIGHTNING ARRESTERS.

REVISED BY TOWNSEND WOLCOTT.

LIGHTNING PROTECTION.

(From Bulletins of W. E. & M. Co. and G. E. Co.)

ELECTRICAL apparatus may receive injuries of two sorts from lightning, namely, grounds and short circuits. (1) A ground or connection between the circuit and the earth is caused by the potential of the insulated portions of the apparatus rising abnormally above that of the earth and thereby rupturing the insulation. But as any properly designed piece of apparatus has sufficient insulation strength to withstand a potential considerably higher than that normally impressed upon it, a lightning discharge to produce a ground must cause a very considerable rise in the potential of the circuit. (2) Short circuits are caused by the abruptness of the static disturbances produced by lightning. The abruptness of the static wave which is the form of disturbance produced in the line by the lightning discharge, may strike a coil a blow, so to speak, that under some circumstances causes a short circuit. Electric apparatus requires, therefore, lightning protection of two sorts. First, protection against grounds; second, against short circuits. Protection from grounds is secured by means of lightning arresters; protection against short circuits, by choke coils or static interrupters. In very high tension circuits all sudden changes of static potential, such as may be produced by switching, accidental grounds, or short circuits, cause the same abrupt static disturbances as lightning.

The Function of a Lightning Arrester. — The proper function of a lightning arrester is to prevent, in an insulated circuit, an abnormal rise of potential above the earth. This result is best attained by placing one or more carefully adjusted air gaps between the insulated circuit, commonly called the "line," and the earth connection, or "ground." Except during times of discharge, these gaps resist any flow or current arising from the normal voltage of the line; but, whenever the line potential rises abnormally, they break down, allowing a free discharge of electricity. By careful adjustment of the gaps, an arrester can be made to discharge when the voltage of the line has risen to any predetermined value.

On account of the extreme suddenness of the surges caused in the line by lightning discharges and other static disturbances, the gaps and ground connection must be able to discharge electricity very freely or a dangerous rise of potential of the line will not be prevented — in other words, the lightning arrester as a whole must be able to discharge electricity faster than it appears on the line.

It is found that there is a very strong tendency, especially with generators of large output and high voltage, for an arc to form in the gaps when once their resistance is broken down by a lightning discharge. This arc, which can occur only when one line is grounded, or when two legs of the same circuit discharge at once, is maintained by the generators, and if not prevented or extinguished will cause a shut-down of the plant. Consequently the lightning arrester, in addition to preventing an abnormal rise of line potential, must also suppress any arc which tends to form in the arrester gaps.

Switching.

On high potential circuits of considerable capacity, an arc produced by switching, circuit breakers, fuses, or short circuits, causes an electrical oscillation of extremely high value. Voltages of double normal potential are often produced when connecting a circuit of considerable capacity to the generating system at no load. These high potentials subject the apparatus momentarily to enormous strains, and it is well to have some low breakdown path in which the dynamic arc will be immediately ruptured, so that these high potentials will equalize themselves from line to line without damage to the apparatus.

Cables.

In laying out circuits, it is frequently necessary and desirable to dip underground when passing through cities, or under rivers, etc., and in these cases some form of metal covered cable is generally used. It has been noticed from numerous installations that high potentials invariably occur where these underground cables are used, due to resonance effects, and these high potentials are often of sufficient value to break down the cables themselves, or the insulation of apparatus installed on the lines. The strains very often produce pinhole punctures in the insulation of underground cables and thus relieve themselves temporarily; they may therefore remain unnoticed for a number of months until the insulation becomes very much impaired, ultimately resulting in a complete breakdown.

Whenever lines contain both inductance and capacity in noticeable quantities, high voltages, which endanger the insulation of the whole system and which it is impossible to detect on ordinary switchboard instruments, may exist. We therefore frequently find such abnormal voltages in circuits containing a combination of underground and overhead circuits, and in long-distance transmission lines.

Engine or Water Wheel Governor Troubles.

A great many cases have been noted where engines and water wheels have raced, caused by the governors becoming inoperative, and high potentials have resulted, which have caused serious breakdowns in insulation. This has generally occurred when a considerable load has been switched off from a circuit.

Difference in Elevation Between Different Portions of the Circuits.

Particular mention was made at the recent meeting of the A. I. E. E. at Niagara Falls, of the abnormal high potential strains which have been noted on long transmission lines running through mountainous countries where considerable differences of elevation occur between different portions of the circuits. These differences in potentials are, without a doubt, due to difference in magnitude of the atmospheric electrical potential at different altitudes, and in some cases the condenser effects of the line produce potentials considerably in excess of the line voltages.

Protection Against Abnormally High Potentials on A. C. Circuits.

In planning protection against the disturbances previously mentioned, it is necessary to provide discharge paths from line to line of the different phases, and discharge paths from lines to ground with suitable ground connections, except when the circuits are entirely underground, when the ground connections may be omitted.

In view of the fact that it is necessary to take care of considerable quantities of current from line to earth when lightning discharges take place, it is advisable to have an arrester of as large current carrying capacity as possible, and with this in view, it is often advisable to install a number of arresters in multiple where the conditions are particularly severe.

Potentials between lines, which are more of a static nature, can generally be equalized with small flow of current.

In discharging a line to ground, the simplest form of discharger would be one single gap, or a series of small gaps with a breakdown point just above the voltage of the circuit. Although it has been found that a single gap will discharge a line effectively, the single gap, of course, will not rupture the dynamic arc when it is once started by a high potential discharge.

With a sufficient number of short gaps, it has been found that under certain conditions, the dynamic current is ruptured by cooling the arc down between the numerous conductors; also due to the fact that in some of the gaps the value of the alternating wave is zero, and, therefore, after a high potential discharge has passed, the dynamic arc does not start again. This arrangement of a large number of small gaps in series is, however, out of the question as far as practical use is concerned, as enormously high break-down voltage is necessary to overcome the gaps, resulting in injurious strains on the insulation of the apparatus. Under certain conditions of inductance, capacity, etc., a discharger of this construction will not interrupt the dynamic arc.

Having selected a length of spark gap as a standard, the point above the line voltage at which it is decided that the arrester shall discharge should be decided upon. A definite number of these standard gaps will be necessary to prevent the arrester from discharging below this point, and this number of gaps will interrupt the dynamic arc, provided the current is limited to a proper value. With this in view, it is necessary to place a determinate resistance in series with the gaps, in order to limit the current to this point.

High potentials between lines or phases occur much more frequently than is the case with lightning, and it is advisable to increase the non-inductive resistance in series with the gaps to a considerable extent, as this renders the possibility of short circuits less liable and, as stated above, these high potentials between phases can be equalized through high resistances as well as through low resistances. A further reason for placing a considerable amount of resistance in series with the gaps when placed between lines is that in case of discharge from phase to phase, if the resistances are low, the circuit breakers or other automatic devices on the line open, causing a temporary shut-down, and this, of course, is inadvisable as well as annoying.

Use of Reactive Coils.

Although considerable doubt has existed as to the advisability of installing reactive coils in connection with lightning discharges, it is believed by many prominent engineers that reactive coils are of considerable value, in connection with the proper protection of apparatus.

Without a doubt, the frequency of lightning disturbances varies greatly in different cases, although, as a whole, it is probably high. Inasmuch as the action of the reactive coils is not dependent on the voltage or frequency of the line, it is inadvisable to design a large number of coils having different reactances, and it is evident that a coil can be designed with ample current carrying capacity, which may be used on a number of voltages, provided it has sufficient insulation for the highest voltage determined upon. In this connection, air insulation is to be inferred between turns and layers, as other forms, due to minute discharges, gradually deteriorate and change, becoming partial conductors.

Use of a Protective Wire.

Protective wires have been used in a great many cases by different transmission companies with varying success, although the experience gained, as a whole, has been in favor of this form of protection. A great many of the troubles encountered through the use of this wire have been due to the selection of improper materials in making the insulation. Barbed wire has been used in a great many cases, and the commercial barbed wire purchased in the open market is of very poor quality and has a tendency to hold water in the joints and interstices.

In one place, in particular, different forms of protective wire have been used, placed in various positions with regard to the circuit wires, and it has been found that plain iron wire installed directly below the transmission wires, furnishes practically as good protection as barbed wire installed over the transmission.

As a matter of fact, there are few reasons why this should not be the case, provided the iron wire is properly grounded at every third or fourth pole, as the disturbances which this form of protection is supposed to take care of are generally at considerable distances from the transmission wires.

While this form of protection may help out in the case of a direct stroke of lightning, it is not to be presumed that it will prove entirely efficient under this condition of affairs.

While the experience of the above mentioned plant has been that a wire placed below the transmission is as satisfactory as if placed in any other position, it is as well to string it above the transmission lines at an angle of approximately 45° to the outside transmission wires, as this locality will aid in taking care of direct strokes of lightning.

With the improved lightning protective devices on the market, the grounded protective wire need only be resorted to where the most severe conditions exist, and then it should be put up in the most thorough manner with regard to the size and quality of the material used and with regard to grounds.

Ground Connections.

In the installation of lightning arresters it is very undesirable to endeavor to effect a saving by cutting down the expenses connected with making proper ground connections, as fully 75% of lightning arrester troubles can be traced directly to this source.

The connections from the line to the arrester and from the arrester to the ground should be as free from angles and bends as possible, and where turns are absolutely necessary, the wire should never be bent at an angle, but in a curve of long radius. Care should be taken that no inductive loops are formed by the complete arrester and its connections.

When the use of an iron pipe at the foot of a pole is considered advisable for the protection of the ground wire, a plug should be put in the top of the iron pipe and the wire soldered to it; otherwise the reactance of the ground wire surrounded by the iron pipe will impede the discharge.

Copper sheets should be used for the ground, thick enough to prevent wasting away and having at least 4 square feet surface. The ground wire, which should not be less than $\frac{3}{8}$ inch diameter in cross section, and preferably in flexible strip form, must be carefully soldered and riveted to this plate, the joint covered with asphaltum, and the plate then buried in powdered coke in soil which is always damp.

Dry, sandy soil should be kept wet by artificial means if this is the only soil available for the ground connection, and it is advisable to dig several trenches radiating out 50 feet from the main ground wire, in which ground wires are buried, so as to get a large surface for the dissipation of the discharges. Where plates are buried in streams of running water or dead water, they should be buried in the mud along the bank in preference to merely laying them in the streams, and streams with rocky bottoms are to be avoided unless as a last resort. Where there are metal flumes, pipes or rails, it is advisable to rivet and solder the ground wires to them in addition to the connections to the copper plates, and when rails are utilized they should be thoroughly grounded.

Lightning Arresters.

Practically all plants with outdoor circuits require lightning protection. With reference to the type of lightning protection required, electric plants may be divided into two general classes — those plants in which the apparatus is widely distributed, and those in which the apparatus is concentrated at a comparatively few points.

Plants Having Apparatus Distributed. — To obtain absolute protection, arresters must be placed at all points where apparatus is located, but experience has shown that in certain cases such a large number of arresters is unnecessary.

In circuits not exceeding 2500 volts, it will usually be sufficient to place arresters at various intervals where good grounds are available. These arresters should be so placed as to leave no considerable length of circuit (electrically speaking) unprotected, and should be more numerous in neighborhoods where the circuits are exposed. These are more likely to be the outlying districts where the lines are not protected by buildings and trees. The exact number to be used in any given case depends upon circumstances. Under average conditions satisfactory protection will be secured if no point of the circuit be more than 1000 feet from an arrester.

For voltages exceeding 2500 volts, arresters should be placed as nearly as possible at or near apparatus on exposed lines. However, circuits of this type with voltages exceeding 2500 are rare.

Plants Having Apparatus Concentrated at a Few Points. — In plants of this class, which comprise practically all high tension work, one arrester should be used for each line wire, at or near each point at which apparatus is connected to the circuit.

In all cases of circuits with ungrounded neutrals, arresters rated at the voltages between line wires should be chosen; that is, for the maximum working voltage and not for the voltage between line and ground. This method insures that the arrester will be non-arcing when one leg of the circuit is accidentally grounded.

If the circuit has a *Grounded Neutral*, arresters, to secure ample margin for protection, should be chosen for a voltage 20 per cent greater than the maximum voltage between line and ground. For example, for a circuit with grounded neutral having 16,500 volts between line and ground (approximately 28,000 volts between lines) arresters for 20,000 volts should be chosen. If, however, the transformers are connected in star in both high tension and low tension windings, arresters should be chosen as though the neutral were not grounded.

The arrester should always be placed on the line side of all apparatus. The arrester (if of low equivalent alternating current type) is chosen solely with reference to the *voltage* of the line upon which it is placed, and is independent of current.

Insulation. — A lightning arrester is naturally exposed to severe potential strains, and therefore all active parts must be well insulated. To obtain sufficient insulation on circuits exceeding 6000 volts, the panels should be mounted on shellacked wooden supports, well seasoned and very dry. On arresters exceeding 12,500 volts, the panels should receive additional insulation in the form of porcelain or glass insulators. It should be assumed in installing an arrester that all parts of the resistance except the ground terminal of the series resistance may be momentarily at line potential during the discharge. Two high tension arresters attached to different line wires should not be placed side by side without either a barrier or a considerable insulation space between them. The resistance, which during the discharge may reach full line potential, must be spaced or insulated (except the ground end of the series resistance) as well as the line.

Inspection. — As the effectiveness of the arrester is of great importance it should be inspected from time to time and the resistances and earth connection tested for open circuit.

Choke coils should be so mounted as to have free access of air for cooling purposes, and should be so spaced from one another and removed from other objects that sufficient insulation space will be obtained for the most severe conditions, viz.: during lightning discharges.

LIGHTNING ARRESTERS FOR DIRECT CURRENT.

A non-arcing D. C. arrester has been devised by Mr. A. J. Wurts based upon the following facts: —

First. A discharge will pass over a non-conducting surface, such as glass or wood, more readily than through an equal air-gap.

Second. The discharge will take place still more readily if a pencil or carbon mark be drawn over the non-conducting surface.

Third. In order to maintain a dynamo arc, fumes or vapors of the electrodes must be present; consequently, if means are provided to prevent the formation of these vapors there will be no arc.

The Type "K" Arrester. — The illustration, Fig. 1, shows the type "K" arrester for station use on D. C. circuits up to 700 volts. The instrument is single pole, and consists of two metal electrodes mounted upon a lignum-vitæ block, flush with its surface. Charred or carbonized grooves provide a ready path for the discharge. A second lignum-vitæ block fits closely upon the first block, completely covering the grooves and electrodes. Disruptive discharges will pass readily between the electrodes over the charred grooves, which act simply as an electrical crack through the air, providing an easy path.

The resistance between the electrodes is more than 50,000 ohms, so that there is, of course, no current leakage, but it should not be understood that the lightning discharge passes through this high resistance — it leaps over

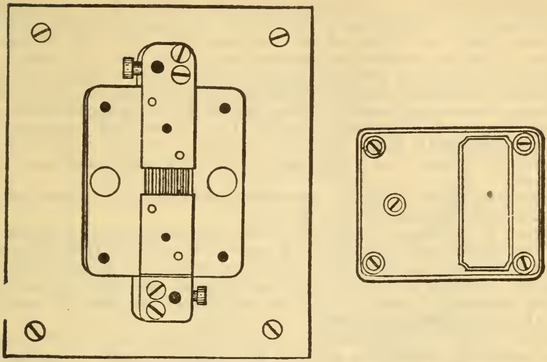


FIG. 1. Non-Arcing Railway Lightning Arrester, Type "K."
(For Station Use.)

the surface of the charred grooves from one electrode to the other exactly as it would if there were but a simple air-gap. The presence of the charred grooves simply makes the path easier.

There being no room for vapor between the two tightly fitting blocks, no arc can be formed, hence the arrester is non-arcing.

Some years ago Prof. Elihu Thomson devised a lightning arrester based on the principle that an electric arc may be repelled by a magnetic field.

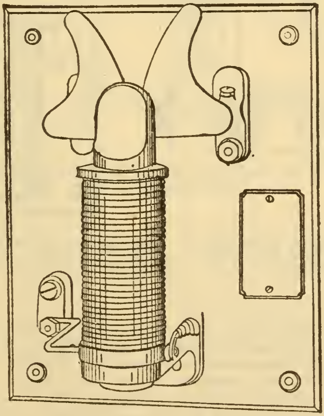


FIG. 2. Type "A" Arc Station Arrester.

In this device, the air-gap, across which the lightning discharges to reach the ground, is placed in the field of a strong electro-magnet. When the generator current attempts to follow the high potential discharge, it is instantly repelled to a position on the diverging contacts where it cannot be maintained by the generator.

The magnetic blow-out principle has been employed in the construction of a complete line of lightning arresters for all direct current installations, and in more than ten years of service magnetic blow-out arresters have always been effective in affording protection to electrical apparatus.

In designing lightning arresters for the protection of high-voltage alternating current circuits, however, different conditions have to be met, since high-voltage arcs are not readily extinguished by a magnetic blow-out. In a recently designed lightning arrester for alternating current circuits, metallic cylinders with large radiating surfaces are found so to lower the temperature of the arc that volatilization of the metal ceases and the arc is extinguished.

The variety of these lightning arresters provides for the protection of all forms of electrical apparatus and circuits.

The Type "A" Arrester is manufactured for the protection of arc lighting circuits. Its construction includes a pair of diverging terminals mounted on a slate base with an electro-magnet connected in series with the line. The magnet windings are of low resistance, and therefore consume an inappreciable amount of energy with the small current used for arc lighting, although they are always in circuit.

The single Type "A" Arrester is suitable for circuits of any number of series arc lamps not exceeding seventy-five. For circuits of higher voltage, a double arrester known as the type "AA" is made by mounting two arresters on one base and connecting them in series. One arrester should be installed on each side of the circuit, as shown in the Diagram of Connections.

For use in places exposed to weather, the Type "A" Arrester is furnished enclosed in an iron case, and designated Type "A," Form "C."

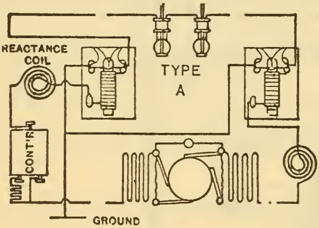


Fig. 3. Connections for Type "A" Arresters.

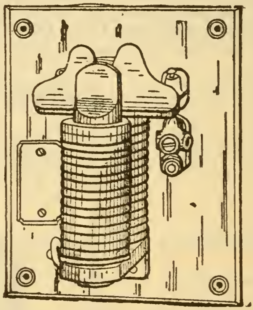


Fig. 4. Type "B" Incandescent Station Arrester 300 Volts or Less.

The construction of the Type "B" Arrester is similar to that of the Type "A," but its magnet windings are excited only when a discharge takes place across the air-gap. A supplementary gap is provided in the Type "B" Arrester, in shunt with the magnets, thus providing a relief for the coils from excessive static charge without affecting their action upon the main gap. The magnet coils, carrying current only momentarily, allow the same arrester to be used on circuits of large and small ampere capacity. The Type "B" can also be furnished with weatherproof case similar to that used with Type "A."

The Type "MD" Lightning Arrester has been designed for use on direct current circuits up to 850 volts. While similar to Type "M," Form "C," Arrester, it is considerably smaller, and is enclosed in a compact porcelain box measuring 7½ inches x 5 inches x 4½ inches. For street car and line use, the arrester is furnished in an additional box of iron or wood.

The arrester has been adopted as standard for railway and all direct current 500-volt circuits. It has a short spark gap, a magnetic blow-out and a non-inductive resistance.

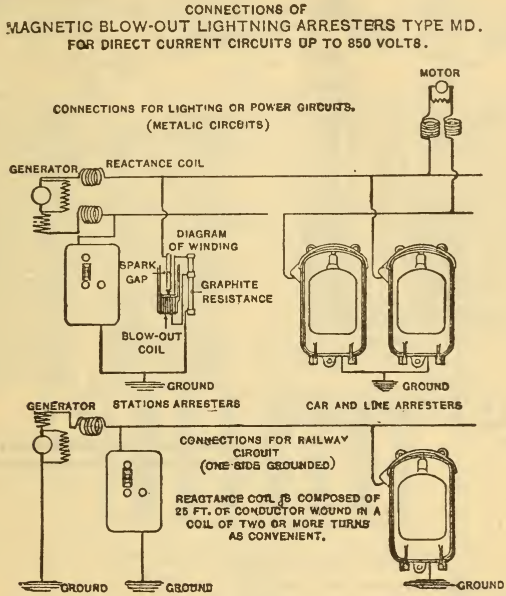


FIG. 5. Connections of Magnetic Blow-out Lightning Arresters, Type "MD," for Direct Current Circuits up to 850 Volts.

LIGHTNING ARRESTERS FOR ALTERNATING CURRENT.

The G. E. Alternating Current Arresters have been designed to operate properly with very small gap spaces. The arrester for 1000-volt circuits has two metal cylinders 2 inches in diameter and 2 inches long, separated by a spark gap of about $\frac{1}{32}$ inch. One cylinder is connected to the overhead line and the other cylinder to the ground, and a low non-inductive graphite resistance is placed in circuit. The large radiating surface of the metal cylinders combined with the effect of the non-inductive resistance prevents heating at the time the lightning discharge passes across the gap, and the formation of vapor which enables the current to maintain an arc is thus avoided.

The arrester under normal action shows a small arc about as large as a pin-head between the cylinders.

The arrester for 2000-volt circuits is designed with two gaps of approximately $\frac{1}{32}$ inch each and a low non-inductive resistance.

The G. E. Arresters are now furnished by the General Electric Company for use on all alternating current circuits at practically any potential. For circuits above 2000 volts, the standard 2000-volt double-pole arrester has been adopted as a unit, and several of these are connected in series to give the necessary number of spark gaps.

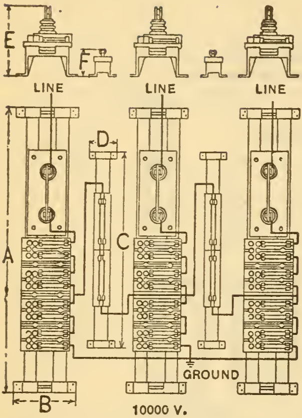
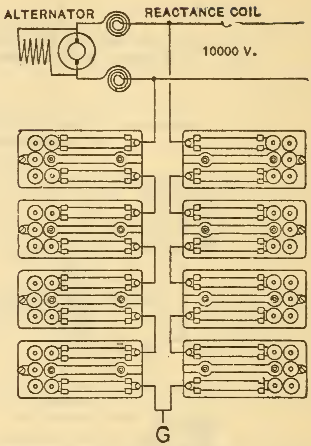
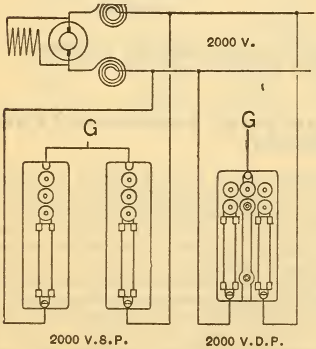
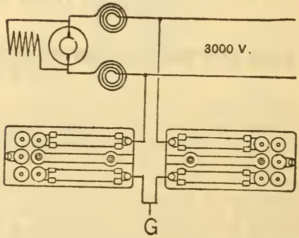


FIG. 6. G. E. Alternating Current Three-Phase Multiplex Lightning Arresters,



10000 V. ARRESTER CONSISTS OF FOUR 2000 V.D.P. ARRESTERS CONNECTED IN SERIES.





2000 V.D.P. ARRESTERS CONNECTED AS 3000 V.S.P. ARRESTERS.

FIGS. 7, 8, 9. Connections of G. E. Alternating Current Lightning Arresters 2000, 3000, 10,000 Volts.

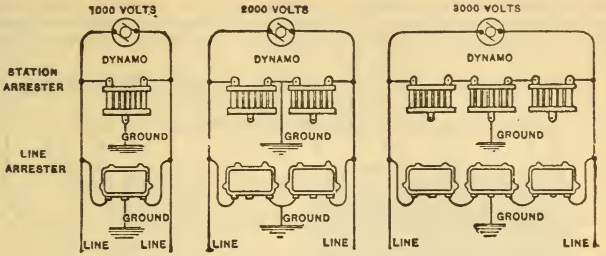


Fig. 10. Diagram Showing Electrical Connections for A. C. Lightning Arresters.

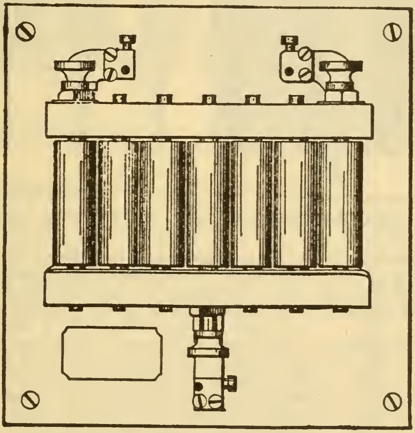


Fig. 11. Double-Pole Non-Arcing Metal Lightning Arrester, Type "A." (For Station Use.)

The Non-Arcing Metal Lightning Arrester. — The non-arcing metal lightning arrester made by the Westinghouse Co. for alternating current circuits is based upon the discovery made by Mr. A. J. Wurts that an alternating current arc cannot be maintained over a short air-gap when the electrodes consist of certain metals and alloys thereof. Types "A" and "C" arresters, described below, are of the non-arcing metal type.

The Type "A" Arrester. — The construction of this arrester can be best understood by reference to Fig. 11.

It will be noted that there are seven independent cylinders of non-arcing metal placed side by side and separated by air-gaps. The cylinders, which are mounted on a marble base, are knurled, thus presenting hundreds of confronting points for the discharge. The dynamo terminals are connected to the end cylinders, and the middle cylinder is connected to the ground. The arrester is, therefore, double pole, that is, one arrester protects both sides of the circuit. When the lines become statically charged the discharge spark passes across between the cylinders from the line terminals to the ground. The non-arcing metal will not sustain an arc or become fused by it; hence with an arrester constructed of this material all possibility of vicious arcing and short circuits is avoided.

The Type "C" Arrester.—This is similar to type "A," but instead of being mounted on marble it is enclosed in a weather-proof iron case for line use. The cylinders are placed in porcelain holders, as shown in Fig. 12.

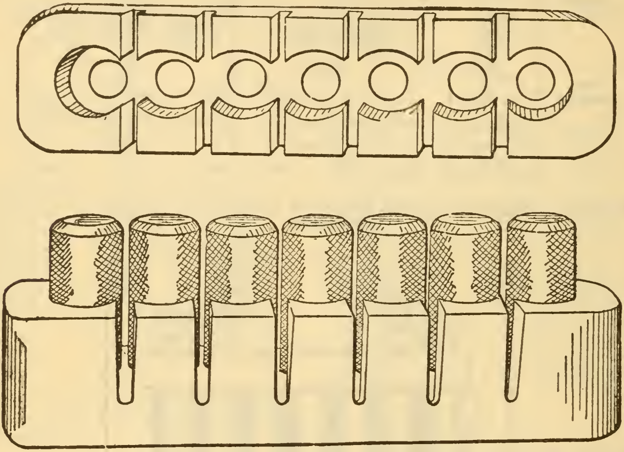


Fig. 12. Unit Lightning Arrester, Type "C," Showing Cylinders in Place.

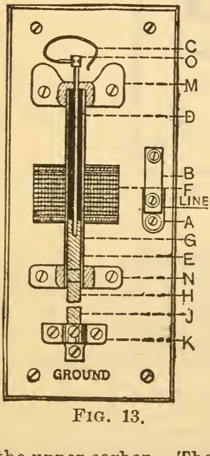


Fig. 13.

The Garton Arrester.—In Fig. 13 a cross-section view is shown of the Garton Arrester.

The discharge enters the Arrester by the binding post A, thence across non-inductive resistance B, which is in multiple with the coil F, through conductors imbedded in the base of the Arrester, to flexible cord C, to guide rod D and armature E, which is normally in contact with and resting upon carbon H, thence across the air-gap to lower carbon J, which is held in position by bracket K. This bracket also forms the ground connection through which the discharge reaches the earth.

We have noted that the discharge took its path through the non-inductive resistance in multiple with the coil. This path is, however, of high ohmic resistance, and the normal current is shunted through the coil F, which is thereby energized, drawing the iron armature E upward instantly. This forms an arc between the lower end of the armature and the upper carbon H. As this arc is formed inside the tube G, which is practically air-tight, the oxygen is consumed, the current ceases, and the coil loses its power, allowing the armature to drop of its own weight to its normal position on the upper carbon. The arrester is again ready for another discharge.

The S. K. C. Lightning Arrester Equipment, manufactured by the Stanley Electric Mfg. Company of Pittsfield, Mass., consists of three essential parts. The Lightning Arrester proper is two nests of concentric cylinders, with diverging ends held in relative position by porcelain caps, as shown in cross section, Fig. 14. To the innermost cylinder the line is connected; to the outer, the earth. The porcelain caps are provided with grooves so placed as to make all spark gaps one-sixteenth inch wide. Between these grooves are sufficient perforations to allow the free circulation of air between the cylinders. If, on the occasion of lightning, the dynamo current follows the lightning, a current of air is at once established through the perforations between the cylinders, blowing the arc between the flaring ends where it is instantly ruptured.

Between the line terminal and the ground connection there are three spark gaps, each one-sixteenth inch in width, making a total of three-six-

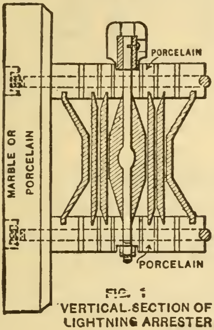


FIG. 14.

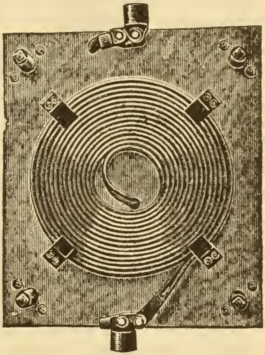


FIG. 15.

teenth inch air-gap between either line-wire and the ground. At ordinary frequencies five thousand volts or over are required to jump the gaps of the arrester; but at the frequency of a lightning discharge the sparking potential is reduced to less than one-half of this. This phenomenon shows that the relative value of spark gaps cannot be expressed by "short" and "long," and their effectiveness as lightning protection cannot be measured by inches.

The spark gaps of the arrester described are about double the widths ordinarily used, yet the sparking potential at lightning frequencies is less. The concentric cylinders provide large discharge surface, enabling the arrester to take care of all the heavy discharges, relieving the line completely.

The second essential feature of the S. K. C. Lightning Arrester Equipment is a Choke Coil, so wound (Fig. 15) as to possess great opposition to the passage of lightning, yet practically no self-induction with currents of ordinary frequency. This coil is to be placed in the circuit between the lightning arrester and the apparatus to be protected. Introducing such a coil between the lightning arrester and the machine will offer practically no disturbing effect, either as to magnitude of the output or regulation of the system, and at the same time interposes enormous opposition to the passage of lightning discharges towards the machine to be protected.

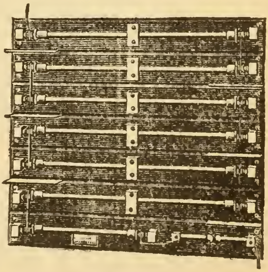


FIG. 16.

To remove even the slightest static discharge from the line, an instrument similar to the one illustrated in Fig. 16, called a "Line Discharger," when used with the apparatus above described, discharges the line completely. The S. K. C. Line Discharger is a minute air-gap in series with a tube or tubes, filled with oxidized metallic particles, thus offering practically an infinite resistance to dynamic currents, yet allowing static discharges of extremely low potential to pass readily to earth. The Line Discharger is connected to the line as shown in Fig. 17. The number of tubes required is determined by the voltage. As the Line Discharger will remove even the small static charge, it prevents the accumulation of such charges on the line which might prove dangerous.

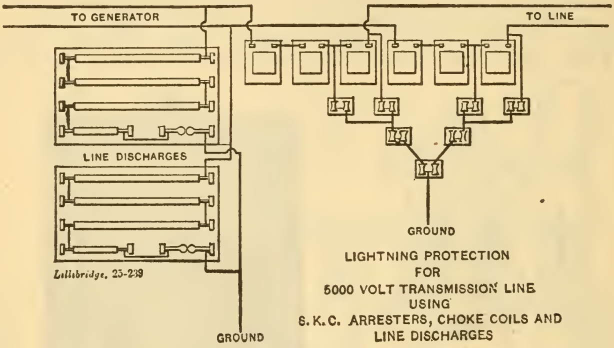


FIG. 17.

Static Dischargers.

Where circuits are entirely underground and ground connections are unnecessary, static dischargers are recommended. These consist of a number of gaps in series with very high resistances and are connected directly between phases and adjusted to break down at slight increases over the line potentials.

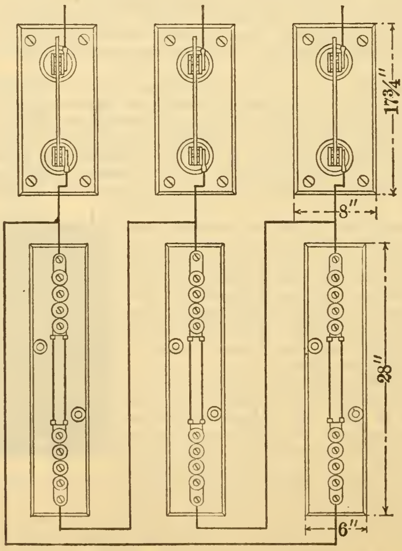


FIG. 18. Connections of Static Dischargers.

ARRESTERS FOR HIGH POTENTIAL CIRCUITS.

(Abstract of paper by Percy H. Thomas in *Franklin Inst. Journ.*)

A lightning discharge is of an oscillatory character and possesses the property of self-induction; it consequently passes with difficulty through coils of wire. Moreover, the frequency of oscillation of a lightning discharge being much greater than that of commercial alternating currents, a coil can readily be constructed which will offer a relatively high resistance to the passage of lightning and at the same time allow free passage to all ordinary electric currents.

A more complete method, a method of prevention rather than resistance, which is available for higher voltages, is the use of the static interrupter, which is substantially a magnified choke coil. Its function is so to delay the static wave in its entry into the transformer coil that a considerable portion of the latter will become charged before the terminal will have reached full potential.

If a very heavily insulated powerful choke coil be placed in the lead of the transformer, when a static wave approaches electricity will begin to pass in small quantity and will pass in gradually increasing quantity at later instants of time, so that the coil will be, comparatively speaking, gradually brought to full potential; meanwhile the volume of the static wave is being reflected and choked back and perhaps being discharged to the ground if there be a lightning arrester near. It is evident that this choke coil, to be effective, must be so proportioned as to delay the incoming wave enough so that the portion of the winding which has become charged when full potential is reached at the terminal shall be sufficient to withstand the strain of the full voltage of the wave. It is evident that such adjustment does not depend directly on the frequency or abruptness of the static wave, since both the transformer and the choke coil are similarly affected by the frequency.

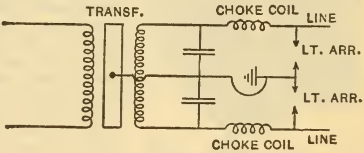


FIG. 19. Static Interrupter Protecting Transformer.

But a choke coil sufficiently powerful to accomplish this result satisfactorily is found to be impracticable on very high potential circuits on account of the size, cost and interference with the operation of the system. However, if the arrangement of the static interrupter be used, that is, if a condenser be connected between line and ground behind the choke coil nearer the apparatus to be protected, this choke coil will absorb a considerable portion of the current actually passed by the choke coil, and the time required to pass sufficient electricity to charge the terminal will be much increased. With this arrangement a comparatively small choke coil may be used. The condenser has a very small electro-static capacity, and has no appreciable effect upon normal operation, and yet has a very powerful effect on the static wave on account of its extremely high frequency. As in the case of the choke coil, the static interrupter must be roughly proportioned to the transformer winding to be protected. The condenser must also be suitable for the voltage between line and ground.

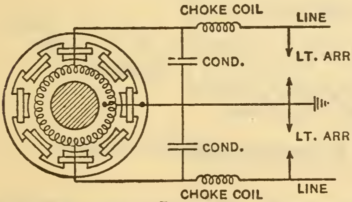


FIG. 20. Static Interrupter Protecting High-tension Generator.

If static interrupters be placed in each lead of high tension apparatus which may be injured by local concentration of potential, its windings will be amply protected against danger of short circuits from static wave either positive or negative. Such an arrangement is shown diagrammatically in connection with a transformer and a high tension generator in Figs. 3 and 4.

Static Interrupters and Low Equivalent Lightning Arresters.— A short description of the salient features of some actual lightning arresters and static interrupters will be given.

The Low Equivalent A. C. Lightning Arrester consists of a number of $\frac{1}{32}$ inch air gaps between non-arcing metal cylinders in series with non-inductive resistance. A portion of the resistance, called shunt resistance, is shunted by a second set of air gaps called shunted gaps. The object of this arrangement is to reduce the amount of the series resistance through which the discharge must pass to ground. This arrester is diagrammatically illustrated in Fig. 22.

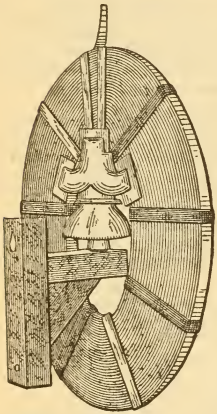


Fig. 21. Choke Coil with Support, for Use with Low Equivalent Lightning Arrester.

The series gaps withhold the line voltage and are chosen so as to break down at something between 50 per cent and 100 per cent rise of voltage above that of the earth. A portion of the series resistance is shunted by gaps so that the static discharge can pass around this portion, thus avoiding its resistance. It evidently is then necessary to suppress the arc from the generator which tends to follow through the shunted gaps. It is found that with a number of shunted gaps equal to the series gaps, the arc will be withdrawn from the shunted gaps by the shunt resistance when the shunt resistance does not exceed a proper value, which is a considerable portion of the total resistance in the arrester. A very marked gain in the reduction of the resistance offered to the discharge is therefore made by means of the use of shunted gaps and shunt resistance. It must be noted as well that no more voltage is required to cause a rise of potential to jump over all the series gaps and shunt than would be required to jump the series gaps alone, since on account of the shunt resistance the series and shunted gaps are broken down separately one after the other.

A Static Interrupter consists of a choke coil in series with the line and a condenser connected between line and ground on the apparatus side of the choke coil.

Cables. — The high tension electric cable is in principle no different from the electric air line, but has a different insulating material, paper or rubber

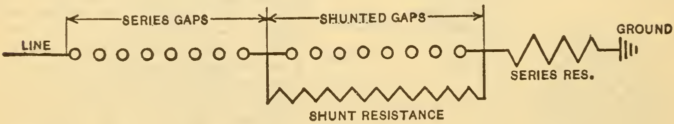


Fig. 22. Diagram of Low Equivalent Lightning Arrester.

in place of air. This has the double effect of increasing its electrostatic capacity and changing the velocity at which waves progress. The increased electrostatic capacity tends to decrease the speed, but as the inductance of the cable is small this partially compensates for the increased capacity. The differences from the air line are differences in degree only, and do not affect the passage of waves, reflection, resonance, etc. Consequently, no phenomena different from the air lines may be expected as a result of static disturbances.

Since the cable contains no coils of wire, no local concentration of potential will be found like that in transformer coils, and there is no occasion for the use of a static interrupter.

In a general way it must be expected that the surging about of the energy which is stored whenever a line is charged will cause increased potential at certain points. This should be provided for by placing suitable lightning arresters at all points where important and vulnerable apparatus is located. There will also be local concentration of potential in windings connected to the circuits as the result of all static disturbances. Such transformer or other coils should always be either sufficiently insulated or protected by choke coils or static interrupters or by some other suitable method.

Horn Type. — This arrester was invented by Oelschlaeger for the Siemens & Halske, A. G., and like the Thomson arc-circuit arrester, its operation is based on the fact that a short circuit once started at the base, the heat of the arc will cause it to travel upward until it ruptures by attenuation. On circuits of high voltage this rupture sometimes takes a second or two, but seems to act with but little disturbance of the line. It has been used little in this country until lately when it has been installed on a few of the high voltage lines on the Pacific coast, and the results are so far highly commendable.

The following figures, Nos. 23 and 24, show the application, one as applied to the line, and the other in diagram.

The knee-shaped horns are of No. 0000 copper wire, one connected directly to the line, the other through a water resistance and choke coil to the ground. The horns are mounted on the regular line insulators, and for 40,000 volts the distance between the knees varies from $2\frac{1}{4}$ to 3 or $3\frac{1}{4}$ inches. The water receptacle should have a capacity of at least 15 gallons, and users differ as to whether the water should have salt added. The water should, however, be covered by a layer of oil about one-eighth inch deep in order to prevent evaporation. The choke coil can be made of about eighteen turns of iron wire wound on a 6-inch cylinder.

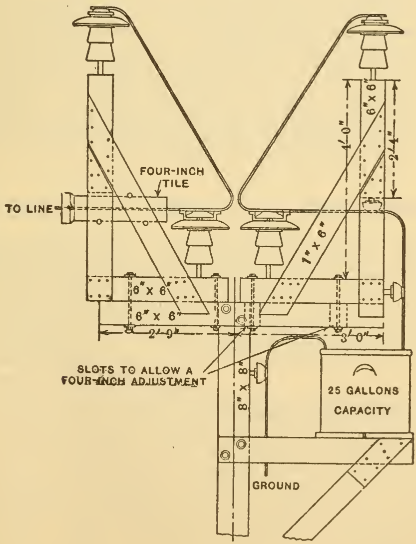


FIG. 23. Construction of the Horn Type Arrester as used by the American River Electric Company.

Care should be taken that the knee is not too sharp, or the arc is liable to reform after being once broken: again, the horns should not lie too flat, or the arc will strike down as shown in Fig. 24. The curve of the knee is not alike for all parts of the line, but depends on the line constants, and will have to be fitted to each case.

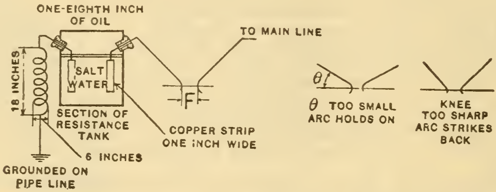


Fig. 24. Arrangement of the Parts of a Horn Type Lightning Arrester, the Two Small Diagrams to the Right Showing Faulty Construction of the Horns. — N. A. Eckert.

ELECTRICITY METERS.

REVISED BY H. W. YOUNG.

METERS for measuring the amount of electrical energy furnished to consumers are known as recording or integrating watt-hour meters and are made in several different forms to meet the varying conditions. The registration of an integrating meter must be very accurate to meet commercial requirements owing to the fact that any errors which may be present are cumulative and even a small percentage error will, after a lapse of time, become relatively important from a pecuniary standpoint. The accuracy must be especially high at the lower end of the curve owing to the fact that for the larger part of the time the actual load is but a small percentage of the meter's capacity, and a meter which shows inaccuracy at this point cannot be a profitable investment for the central station for the reason that the tendency is to under register rather than over register.

Action of Integrating Meters.—The action and operation of an integrating meter may be likened to that of a small direct-connected motor generator set in which the current and potential coils are considered as the motor element and the disk and the permanent magnets as a magneto-generator with a short-circuited disk armature. The work expended by the motor is absorbed in driving the short-circuited generator and overcoming friction in the bearings and registering mechanism. In a perfect meter (or motor generator) all the work would be expended in driving the disk or generator — friction being absent — in which case a direct ratio would exist between the speed and the energy passing through the motor system, thus giving a meter absolutely accurate throughout its entire range.

It is, however, impossible to entirely eliminate friction, but it will be seen that the more perfect the meter is, the greater will be the ratio between the work expended usefully in driving the disk or armature of the generator and that expended in overcoming friction; or, in other words, the "Ratio of Torque to Friction" in the meter will be high. Meter manufacturers, recognizing this essential feature, endeavor to make this ratio of torque to friction very high by efficient design of the measuring elements and reduction of friction in the bearings and registering mechanism.

Direct-Current Commutator Type Meters.

The best known of the direct-current meters is the commutator type consisting of a small motor driving a registering mechanism. There are usually two series coils wound with comparatively few turns of heavy wire and practically surrounding a pivoted armature containing several coils of fine wire suitably connected to a commutator on which bear small brushes. In series with the armature is a comparatively high resistance and a light load or friction compensating coil. The stationary series coils are connected in series with the load and the shunt circuit consisting of the armature and its resistance is connected across the line.

The construction employed gives a driving torque proportional to the energy flowing in the circuit, and to secure correct registration it is necessary for a retarding torque to be provided which will be proportional to the driving torque. A controlling force varying directly with the speed is obtained by causing an aluminum or copper disk to pass between the poles of permanent magnets whose fields induce "Foucault" or eddy currents in the disk. The interaction between the fields of these eddy currents and the field of the permanent magnets produces a retarding torque varying directly with the disk speed. With such an arrangement of driving and retarding torques a rotation is produced which is always proportional in speed to the driving torque and, therefore, to the energy passing through the measuring coils. As the measuring elements do not employ iron and are practically non-inductive, the meters can be used on either A. C. or D. C. circuits.

Thomson Recording Wattmeters.

(General Electric Company.)

These meters (Fig. 1) are of the commutator type previously described, and the salient features claimed are as follows: High torque, direct-reading registers, dust proof construction, small size commutator, gravity brushes, adjustable shunt field coil, interchangeable on D. C. and A. C., high accuracy, heavy overload capacity, jewel bearings.

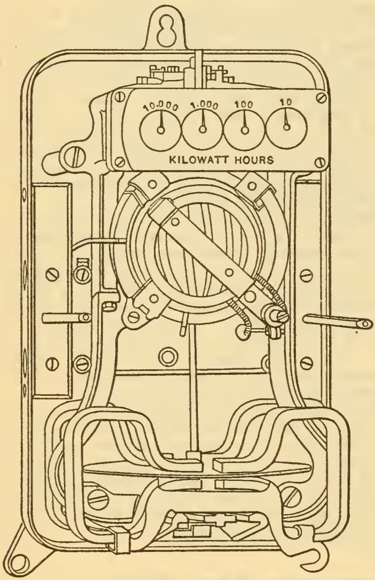


FIG. 1. Thomson Recording Wattmeter (Cover Removed).

Bearings.—The top bearing consists of a simple brass plug having a hole of sufficient size to allow free rotation of the armature shaft.

The lower bearing consists of a hardened steel pivot made of piano wire and resting on a spring supported sapphire or diamond jewel. This insures a bearing having a low friction value and long life. During shipment the jewels are protected by a special armature locking device which, when the jewel is backed away from the pivot, automatically locks the moving element.

Westinghouse D. C. Integrating Meters.

These meters (Fig. 2) are of the same general type as the Thomson, but differ in mechanical construction. The salient features claimed are practically identical with those of the Thomson meter.

The lower bearing is, however, of an entirely different type, consisting of a small, highly polished steel ball resting between two sapphire jewels, one of which is secured in a removable jewel screw. The idea of this form of bearing is to present constantly changing contacts between the ball and its jewels owing to the attendant rolling action, thus securing a long useful jewel life and increased accuracy. During shipment the disk is locked in position by a suitable locking device operated from the top bearing.

Duncan Meters.

This meter (Fig. 3) in common with the Thomson and Westinghouse forms, is of the commutator type and practically the same claims are made as for the other forms.

It differs in the method in the friction or light load compensation in that the auxiliary field coil is provided with taps brought out to a multi-point switch. This arrangement enables the auxiliary torque to be varied by cutting in or out one or more coil sections.

The lower bearing is of the "visual" type designed to permit inspection of the jewel and pivot while the meter is in operation. The pivot is of hardened steel piano wire and is securely held in position. During transportation the jewel post is lowered, thus locking the disk in position.

Induction Type Alternating Current Integrating Wattmeters.

Principle of Operation. — The single-phase induction wattmeter is in principle and operation analogous to a single-phase induction motor having a stationary shunt and series winding so related and located as to produce a rotating field acting upon a closed rotable secondary. In the induction meter the secondary consists of a light aluminum disk. The shunt winding, consisting of a large number of turns of fine wire wound on a laminated iron core, is highly inductive and its current lags approximately 90 degrees behind the impressed or line voltage. The series winding consisting of but

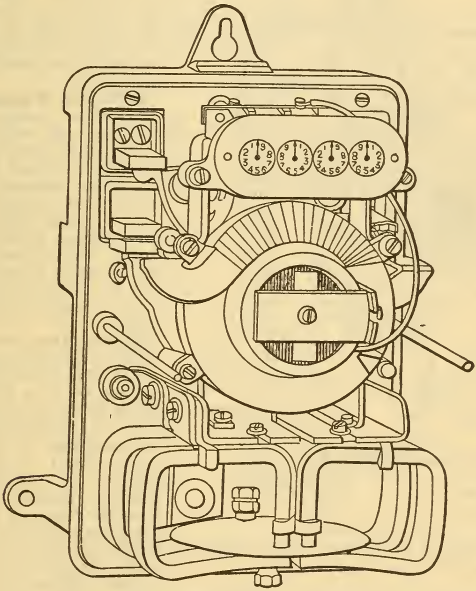


Fig. 2. Westinghouse D. C. Integrating Wattmeter (Cover Removed).

a few turns of comparatively heavy wire, has low self induction, and on non-inductive load (such as incandescent lamps alone) the current producing the series magnetic field will be in phase with the impressed or line voltage. Thus the magnetic field produced by the shunt winding will lag approximately 90 degrees behind that of the series winding on a non-inductive load.

With this relation of the two fields at the instant of time when the current in the series coil is *greatest* the current in the shunt coil is the least. (If it were not for the iron loss and small resistance or copper loss in the shunt circuit, the angle would be exactly 90 degrees.) During a portion of each alternation of the circuit the series coil helps the flux of one pole of the shunt field, opposing the other, and during another portion of the alternation it has the opposite effect; these reactions being combined in such a way as to give a general shifting of the lines of force in one direction — that is, *producing a rotating field.*

Rotating Field.—That the shunt and series fields combine to form a rotating field may be more clearly understood by tracing the action or relation of these two fields for a complete cycle by one-quarter periods of the same.

Referring to Fig. 4 and noting that the two poles of the shunt coil magnet are designated by the letters $A-A_1$ and C, and the poles of the series coil magnet by B — D, a clear statement of the relation of the fields by one-quarter periods is given in the table shown in Fig. 5.

The signs given in this table represent the instantaneous magnetic values of the poles indicated, and it will be observed that both the positive and negative signs move constantly to the left indicating a shifting of the field in this direction, the process being repeated during each cycle.

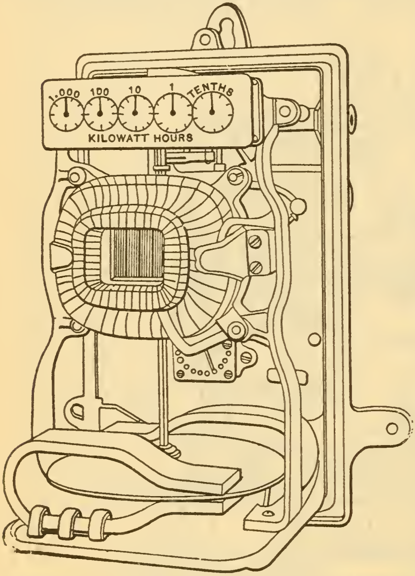


Fig. 3. Duncan D. C. Recording Wattmeter (Cover Removed).

Driving Torque.—This continuous motion of the field induces eddy currents in the aluminum disk which react to produce rotation in the same manner as in the rotor of an induction motor.

The rotary field being a combination of the series and shunt fields, the torque on the moving element or disk will be directly proportional to the energy flowing in the circuit.

Retarding Torque.—With a driving torque proportional to the energy flowing in the circuit it is necessary, in order to obtain steady rotation, for a retarding torque to be provided which will be proportional to the driving torque. A controlling force varying directly with the speed is obtained by causing the aluminum disk to pass between the poles of two permanent magnets whose fields induce "Foucault" or eddy currents in the disk. The interaction between the fields of these eddy currents and the fields of the permanent magnets produces a retarding torque varying directly with the speed of the disk. With such an arrangement of driving and retarding torque a rotation is produced which is always proportional in speed to the driving torque and therefore to the energy passing through the operating coils.

Wattmeters on Inductive Circuits.—Assuming that the current producing the shunt field lags exactly 90 degrees behind the line voltage and neglecting for the moment the iron loss and resistance loss in the circuit, it will be seen that when the load is *non-inductive* (such as offered by incandescent lamps) the current of the series coil will be in phase with the line voltage and the shunt and series fields will differ in phase by exactly 90 degrees. From the table (Fig. 5) it will be seen that this gives a maximum pull on the disk.

If, however, the load is *purely inductive* having zero power factor, the current in the series coil will lag 90 degrees behind the line voltage and will be in phase with the current in the shunt coil. Under these conditions the relation between the fields for each one-quarter period of a complete cycle is shown in the table on page 1002.

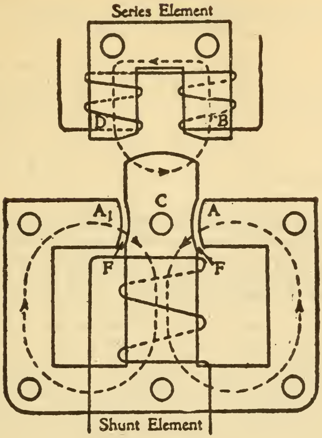


FIG. 4.

	A	B	C	D	A1
Start	+	0	−	0	+
¼ Period	0	−	0	+	0
½ Period	−	0	+	0	−
¾ Period	0	+	0	−	0
Full Period	+	0	−	0	+

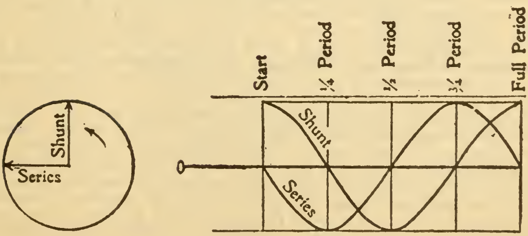


FIG. 5. Table Giving Relation of Fields by One-quarter Periods.

	When A is	B is	C is	D is	A_1 is
At start	+	+	−	−	+
At $\frac{1}{4}$ period	0	0	0	0	0
At $\frac{1}{2}$ period	−	−	+	+	−
At $\frac{3}{4}$ period	0	0	0	0	0
At full period	+	+	−	−	+

As no progression or shifting of the field occurs, there is no rotation of the disk and thus the meter will not record when the current in both the series and shunt coils is 90 degrees out of phase with the impressed voltage; hence, *the meter will record true power whether the load be inductive or non-inductive.*

Power Factor Compensation. In the preceding diagrams it was demonstrated that for correct registration on any power factor, exactly 90 per cent phase relation between the shunt and series fields must be obtained. Consequently, compensation must be made for the small decrease of this angle caused by the copper and iron losses in the shunt circuit.

This compensation is usually obtained by placing one or more short circuited turns (or secondary) of conducting material around the projecting pole C of the shunt electromagnet, producing an induced magnetic field which, acting with the shunt magnetic field, produces a resultant field lagging behind the field of the series coil. By varying the position or resistance of this short-circuited turn (or secondary) the compensation necessary to obtain the exact 90 degrees phase relation may be obtained. This method of securing the resultant field can be better understood by referring to Fig. 6 in which:

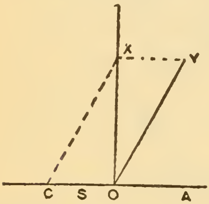


FIG. 6. Diagram of Resultant Field.

OA represents the voltage of shunt coils.

OY represents current passing through shunt coils.

YOA represents angle less than 90 degrees due to iron and copper losses in shunt coils.

OS represents induced voltage of short-circuited turn K and exactly opposite in phase relation to that of OA, but very small in value; the current passing through the short-circuited turn K being in phase equal and approximate to OC.

This current OC and main current OY have a combined magnetizing effect on the iron core, which effect is found by forming the parallelogram OC—XY when OX is the resultant effect now practically at right angles to the impressed E.M.F. of the circuit. By raising or lowering, thus changing the position of the short-circuited turn, the magnetism of the shunt field can be shifted back to the proper angle, giving the 90 degree phase relation and adjusting the meter so as to read correctly under all conditions of power factor.

NOTE.—This power factor compensation holds true only for approximately the frequency for which the meter is adjusted and if highest accuracy is expected, wattmeters should not be used on inductive loads having a frequency variation from normal of more than 10 per cent plus or minus.

Minimizing Effect of Voltage Variations.—It is desirable that induction meters be capable of operating over a wide voltage variation without impairment of accuracy, and freedom from error due to voltage variations is accomplished by the design of the shunt magnetic circuit. By referring to Fig. 4 it will be seen that the shunt magnetic circuit is so arranged that the greater portion of the magnetic lines generated by the shunt winding are shunted across the narrow air gaps FF and do not pass through the disk, thus cutting or damping its action and thereby impairing the accuracy. While the exact leakage across the gaps cannot be accurately determined, it is a large proportion of the total flux generated so that a comparatively wide variation from the normal voltage has practically no effect on the meter's registration owing to the small percentage of damping flux which is produced.

Figure 7 illustrates a typical voltage curve of an induction wattmeter. It will be noted that a voltage range from 50 per cent to 125 per cent of normal voltage does not materially impair the accuracy.

Westinghouse Single-Phase Induction Wattmeters.

These meters (Fig. 8) are of the rotating field type previously described and the salient features claimed are as follows: High ratio of torque to

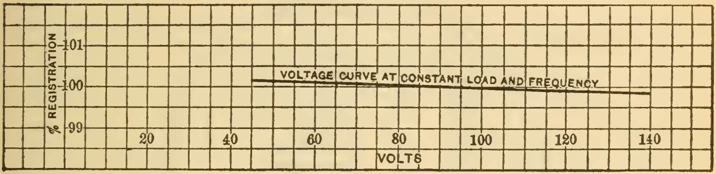


FIG. 7.

friction; high ratio of torque to weight; improved lower rolling ball bearing; improved self oiling top bearing; light load adjustment located in leakage gap of shunt coil and unaffected by flux of series coil; mechanical power factor and frequency adjustment; accurate on non-inductive or inductive loads; freedom from effect of stray fields; permanent magnets magnetically shielded; light rotating element (15 grammes); unaffected by voltage variation from 50 per cent to 125 per cent of normal; unaffected by wide variations in wave form and frequency; freedom from rattling or

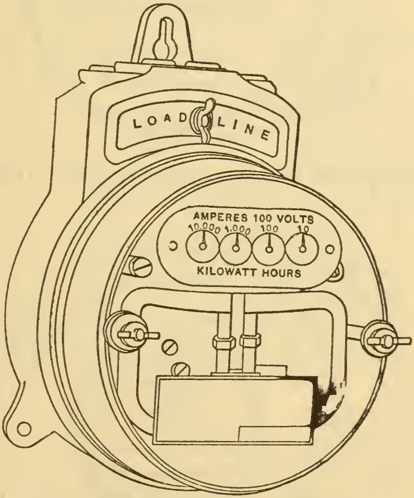


FIG. 8. Type "C," Westinghouse Single-Phase Induction Meter.

humming; dust proof; light running, gold plated, non-corrosive registering mechanism; meters shipped ready for installation without preliminary adjustment.

Westinghouse Polyphase Induction Wattmeters.

These meters consist of two single-phase elements which are mounted in a single case and actuate a common registering mechanism.

Figure 9 illustrates a House Service Polyphase Meter and Figure 10 the Polyphase Switchboard Service Meter.

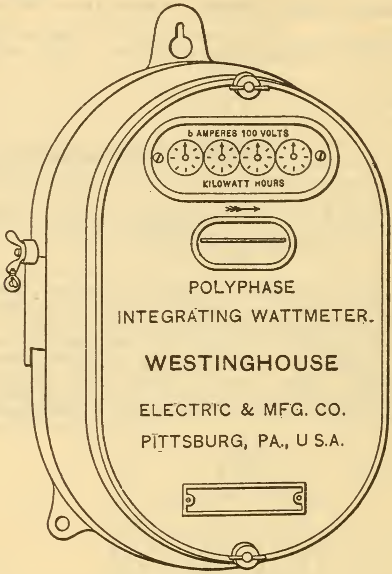


FIG. 9. Westinghouse Polyphase Induction Meter (House Service).

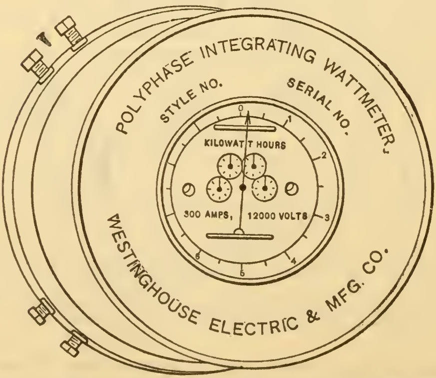


FIG. 10. Westinghouse Polyphase Induction Meter (Switchboard Service).

Thomson High Torque, Single-Phase Induction Wattmeters.

(General Electric Co.)

These meters (Fig. 11) are of the same general type as the Westinghouse, but differ in mechanical construction. The salient features claimed are practically identical with those of the Westinghouse meters.

The bearings, however, are of a different type, being of the same construction as employed in the Thomson D. C. meter. The torque is of high value, thus giving a high ratio of torque to weight. During shipment the armature is locked in position in a manner similar to that of the Thomson D. C. meter.

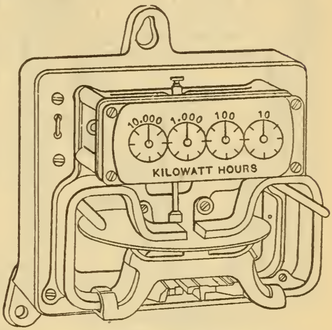


Fig. 11. Thomson High Torque Single-Phase Induction Meter (Cover Removed).

Thomson Polyphase Induction Wattmeters.

These meters (Fig. 12) in common with the Westinghouse form, consist of two single-phase elements in a single case.

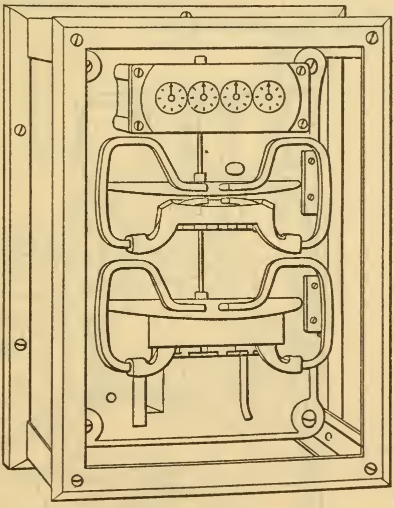


Fig. 12. Thomson Polyphase Meter, Glass Cover.

Type "K" Single-Phase Induction Wattmeters.

(Fort Wayne Electric Co.)

These meters (Fig. 13) are also of the rotating field type, but employ a drum-shaped rotor instead of a disk. The light load adjustment is affected

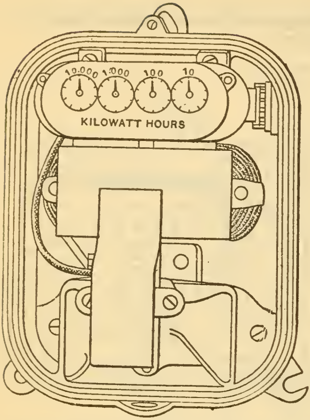


Fig. 13. Type "K" Meter (Cover Removed). Fort Wayne Elec. Co.

by an adjustable starting coil which can be shifted to give the necessary compensation for friction effect at light loads. The salient features claimed are practically identical with those of the Westinghouse and Thomson meters.

The upper and lower bearings are similar to those employed in the Thomson meter.

Type "K" Polyphase Induction Wattmeters.

These meters (Fig. 14) consist of two single-phase measuring elements mounted in a single case and acting upon a single drum-shaped rotor.

Sangamo D. C. Integrating Meter.

This meter (Fig. 15) is a mercury contact motor meter of a type that has been used to a greater extent abroad than in this country.

In common with all motor type integrating meters the Sangamo contains the three necessary elements, namely, a motor producing a driving torque; a generator providing a load or drag varying with the speed, and a registering mechanism arranged to integrate the instantaneous values of the electrical energy passing through the measuring coils.

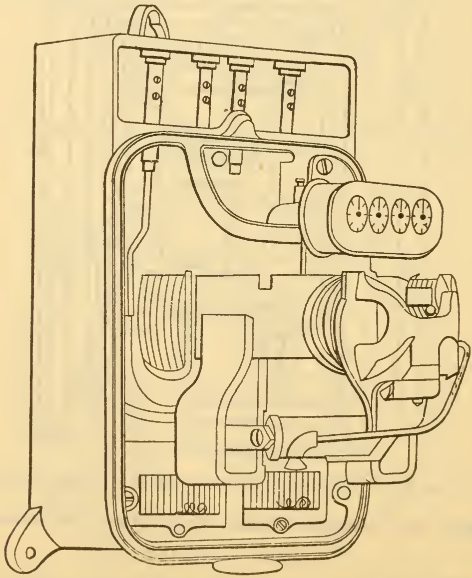


Fig. 14. Type "K" Form MAB Wattmeter — Half Front View, Case off. Fort Wayne Elec. Co.

Principle of Operation.—The principle of operation may be understood by referring to Fig. 16, and the following description: A — A are the poles of an electromagnet energized by the potential coil which, through a resistance, is connected directly across the line, thus forming the voltage element of the meter. E is a soft iron bar located just above A – A and forming the air gaps in which the copper disk D is located. This copper disk is connected in series with the line and forms the current element of the meter. In capacities exceeding 10 amperes the disk only carries a certain portion of the main current which is obtained by inserting a shunt in series with the line and allowing but a small portion to pass through the mercury and disk. These voltage and current elements form the driving motor element of the meter.

B is an aluminum disk so arranged that its edges pass between the poles of two permanent magnets, F — F thus forming the generator or load element of the meter. D and B are mounted on a common shaft which is suitably pivoted or suspended.

The third element of the meter, namely, the registering mechanism, is not shown, but, in common with other forms of motor meters, is driven by a suitable gearing actuated by the rotable shaft.

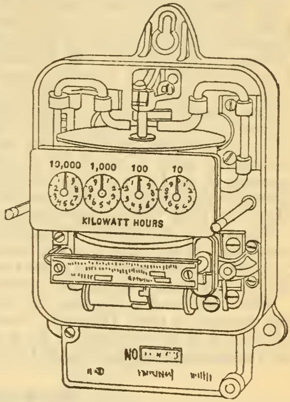


FIG. 15. Sangamo Direct-Current Meter, Case off.

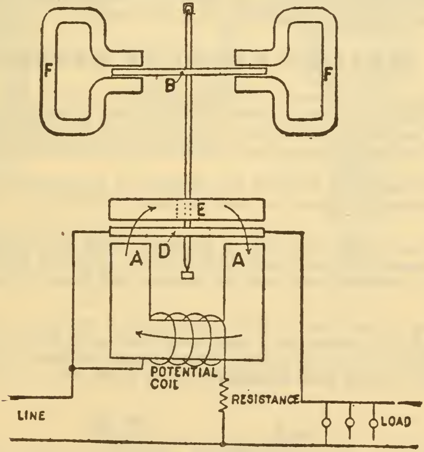


FIG. 16.

Elementary Diagram of Sangamo D. C. Meter.

From the arrows on A – A it will be seen that the field generated by the potential coil threads the two air gaps and in doing so cuts or passes through the copper disk D. The disk D being in series with the load is, therefore, carrying a current which, due to the position of the leading in contacts, passes across the magnetic fields produced by the magnet poles A — A and is at right angles to this field. As is well known, a conductor free to move and carrying a current whose direction of flow is at right angles to a fixed field will tend to move out of the fixed field.

As the disk moves from its initial position the current enters at a new point on the periphery of the disk which is again impelled forward, and this constant change in point of current entrance to the disk produces a continuous rotation. It will thus be seen that the meter, in common with the Westinghouse D. C. meters, operates as a simple motor driving a magneto-generator having a short circuited armature.

The Sangamo meter differs, however, in its construction from that employed in the commutator D. C. meters in that the voltage element is stationary rather than rotable; the current element being rotable rather than stationary and instead of employing a commutator and brushes to lead current in and out of the rotable element, or armature, it is submerged in mercury contained in an insulating chamber having contact pieces at each edge to which the circuit connections are made.

Figure 15 illustrates a meter as actually constructed. The mercury is contained in a dome-shaped chamber and not only serves to conduct the current to and from the armature, but also tends to buoy up the disk and relieve the pressure on the lower bearing.

The full load adjustments are accomplished by varying the strength of the magnetic field through which the disk passes, and the adjustment at light load is accomplished by a compounding coil so located as to assist the field generated by the potential coil.

Sangamo A. C. Meter.

This meter has the same general appearance and operates upon the same principle as the D. C. meter, but differs somewhat in the arrangement of the measuring elements. In the A. C. meter the main current energizes the stationary electromagnet and the shunted or potential current passes through the copper disk. Compensation is provided for light load and inductive load.

WRIGHT DISCOUNT METER.

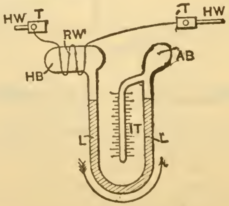
This instrument is for use in connection with a watt hour meter for determing the maximum use of current during any given period; or may be used without the watt-hour meter in connection with any electrical device for which it is desired to know the maximum use of current, either direct or alternating.

It is slow acting so as to take no account of momentary spurts, such as starting an elevator or street car, and is rated to record as follows:

If the maximum load lasts 5 minutes, 80 % will register;
If the maximum load lasts 10 minutes, 95 % will register;
If the maximum load lasts 30 minutes, 100 % will register.

The following figure shows the working parts in theory, which, being of glass and liquid, are placed in a cast-iron case, with a glass front to permit reading. As shown, one leg of the circuit passes around a glass bulb which is hermetically sealed, and connected to a glass tube holding a suitable liquid.

T, Terminals.
H W, House wires.
R W, Resistance wire.
H B, Heated bulb.



A B, Air Bulb.
I T, Indicating tube.
L, Liquid.
——> Direction.

Wright Discount Meter.

The heat due to the current passing in the circuit expands the air in the bulb, which forces the liquid down in the left column and up in the right. Should the quantity of heat be such as to force some of the liquid high enough, it will fall over into the central tube, where it must stay until the instrument is readjusted. The scale back of the central tube is calibrated in amperes on the left and in watts on the right. After reading and recording the indication for any period of time, the liquid is returned to the outer tubes by simply tipping up the tubes, etc., which are hinged at the top connections for the purpose.

The readings of the *demand meter* or *discount meter*, either of which names are used, together with those of the watt-hour recording meter, furnish a basis for a more rational system of charging for electricity than has been customary. This subject is being taken up by many of the larger electricity supply companies.

The instrument is handy to use in circuit with a transformer to show how the *maximum demand* compares with the transformer capacity; also on feeders and mains to show how heavily they may be loaded.

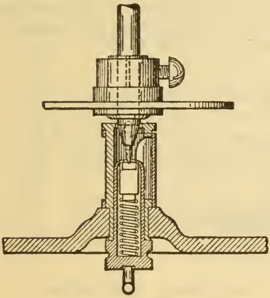


FIG. 17. Visual Pivot Type Bearing.

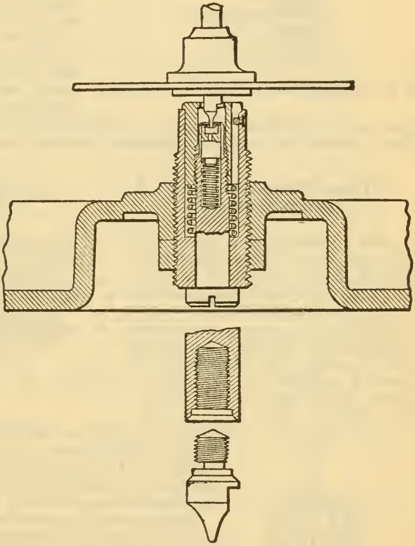


FIG. 18. Pivot Type Bearing.

METER BEARINGS, REGISTERS AND COMMUTATORS.

Two forms of lower bearings are in general use in both direct and alternating-current meters. Figs. 17 and 18 represent the pivot forms consisting of a hardened and highly polished steel pivot resting on a cupped sapphire, or on a ringstone end-stone or cupped diamond jewel.

Figure 19 is a rolling type ball bearing formed by a small hardened and polished steel ball resting between two jewels, one of which is attached to

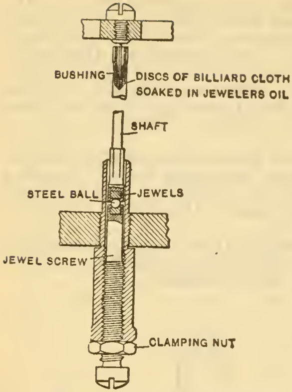


FIG. 19. Rolling Type Ball Bearing.

the armature shaft and the other to a fixed support. By this construction a rolling action is secured as contrasted to the rubbing action of the pivot bearing.

Both types of bearings are extensively employed by meter manufacturers and each has strong advocates. The pivot form of bearing is invariably supported by a spring suspension, while with the ball bearing the spring is only resorted to in the direct-current meters having comparatively heavy moving elements.

The registering mechanisms of the various types of meters are quite similar in appearance, differing principally in the method of construction. Fig. 20 illustrates a typical form of registering mechanism employed in both D. C. and A. C. meters.

To reduce the variable nature of the contact surfaces of the commutator and brushes it is customary to employ non-oxidizing metal in the construction of these elements, thus reducing to a minimum changes at this point. Fig. 21 illustrates the damping disk, armature and commutator mounted on the rotable shaft.

The Prepayment Wattmeter.

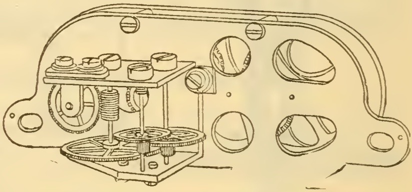


FIG. 20. Registering Mechanism.

The prepayment idea for the purchase of practically all forms of commodities is rapidly growing, for the vending of practically all forms of commodities, and is now receiving recognition in the electrical field. Like the installment plan of payments, the prepayment meter appeals to a class of people who are accustomed to receive and spend their money in small quantities. The success of gas companies has been greatly aided and furthered by the prepayment meter, and its use in the electrical field should prove as great a success as it has proven in this field.

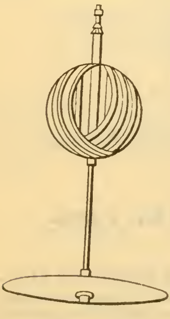


FIG. 21. Rotating Element of D. C. Commutating Type Meter.

Prepayment meters are especially applicable in supplying energy to customers whose total consumption is relatively small and the collection of whose bills is a very considerable proportion of the total revenue derived. Their use reduces the amount of bookkeeping and unavoidable monetary loss due to poor accounts, for the service is such that before securing light it is necessary that payment be made. This system, therefore, automatically collects its own bills, registers the actual consumption, and when the energy prepaid for is consumed, automatically disconnects the service. In installations such as flats, dormitories, barber shops, cafés, saloons, boot-blacking establishments, cigar stands, rented houses, or in any other installations where the volume of energy consumed is necessarily small, the prepayment meter will be found extremely useful. Central stations supplying towns having a large "floating" population, such as seashore resorts or college towns, where the rapid shifting of population renders difficult the following of accounts, will find the prepayment meters extremely useful.

Another use for the prepayment meter is in the collection of old accounts. Central stations frequently have a considerable number of customers who are usually backward in payments, although they ultimately pay their bills. One method of forcing such customers to pay back bills is to threaten discontinuance of service, but this method is only resorted to as an extreme measure, owing to the resulting unpleasantness and very possible loss of a customer. On the other hand, a central station cannot afford to have its legitimate revenue tied up even with customers who will ultimately pay.

An effective way to collect these old bills, and at the same time continue the service, might be to install a prepayment meter adjusted for a higher rate per kw.-hour than the regular rate. For instance, assuming the normal rate to be 10 cents per kw.-hour, the meter may be set at 15 cents per kw.-hour, so that the customer not only pays for the energy being consumed, but also gradually pays up the old bill on the installment plan. The majority of customers would undoubtedly prefer this method of paying up

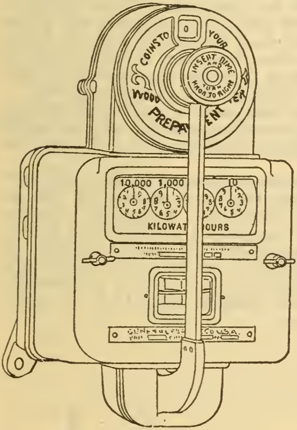


FIG. 22. General Electric Prepayment Wattmeter.

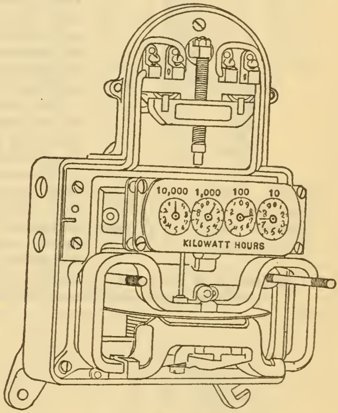


FIG. 23. General Electric Prepayment Wattmeter (Internal View).

old bills to being forced by threats of discontinuance of service. After the account has been settled, the meter can be reset for the normal rate per kw.-hour.

At the present time many central stations are unable to connect a considerable number of relatively small consumers, owing to the fact that the amount of energy used by each customer would be so small as to hardly justify the collection and accounting expense, which would be a very considerable percentage of the total receipts. For example, many station managers would hesitate to connect up consumers whose bills would probably not average over $1 per month, and, furthermore, these consumers do not understand and will not agree to a fixed minimum charge. However, assuming that the total revenue from such a consumer would average $12 per year, and assuming the cost of generation and distribution is one-half the gross receipts, it would leave a remainder or profit of $6, less the interest, collection and maintenance cost. While the gross profit would not be very large, yet the percentage is very satisfactory, and there is the additional advantage that a large majority of these new customers would gradually use larger amounts of energy and in time come within the class of desirable customers.

The use of electricity increases with the knowledge of its advantages, and there is no better way of introducing its use especially with the smaller customers, than with the prepayment meter.

With the prepayment meter, differential rates can easily be made, owing to the fact that the rate per kw.-hour is not shown on the meter bills and the central station may, therefore, place meters adjusted for different rates to meet the various conditions which arise; for instance, a long-hour consumer could be supplied through a meter adjusted at a lower rate than the short-hour consumer. This method of differential rates, though not in general use, is feasible for the reason that with a prepayment meter consumers feel they are purchasing light and not kw.-hours.

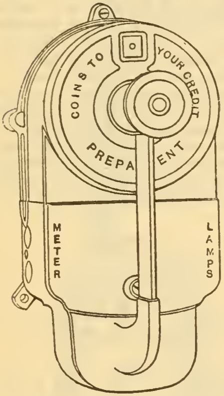


Fig. 24. Prepayment Attachment for General Electric and Fort Wayne Wattmeters.

Another use for the prepayment meter is in connection with electric cooking and heating appliances, which frequently are supplied with energy from a separate circuit at a different rate than is charged for lighting. These appliances may be supplied through a prepayment meter, and this system has the additional advantage of permitting the consumer to determine accurately just what the electric cooking or heating outfit is costing for the results obtained.

By prepaying the meter for a definite amount it can be used as a time switch to automatically turn off arc lamps, electric signs and store window lighting.

The construction of several forms of commercial prepayment meters is shown in the accompanying illustrations. Essentially the prepayment meter consists of a measuring element used in conjunction with a special register, automatic switching device and coin chute. Fig. 24 illustrates a separate attachment which can be used in conjunction with a specially arranged standard meter and located apart from the meter itself.

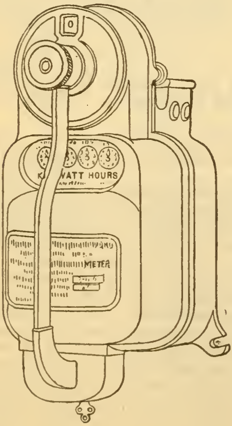


Fig. 25. Fort Wayne Prepayment Wattmeter.

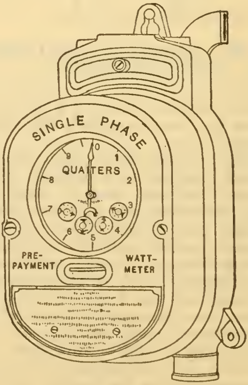


Fig. 26. Westinghouse Prepayment Wattmeter.

INTEGRATING WATTMETER TESTING.

It is quite generally recognized that integrating wattmeters can only be maintained in an accurate and efficient condition by comparing them at certain intervals with known standards, and it is obvious that the standards for this purpose should be highly accurate. To avoid a multiplicity of instruments they should have a wide operating range which may be obtained primarily by a long scale, and where possible the range should be further increased by combining several current and potential capacities in one meter. To combine laboratory accuracy with the speed necessary in commercial work, two sets of standards should be provided which may be designated as "primary" standards for extreme accuracy and "secondary" or working standards for use directly with the service meters.

Checking of Secondary Standards. — All secondary standards should be frequently checked with the primary standards, the frequency of such checking varying largely with local conditions. As a rule, however, it is advisable to check the secondary standards at least once a month, especially when such standards consist of indicating meters, owing to the fact that all portable indicating meters are more or less delicate and the rough usage attendant on commercial testing is liable to materially change the calibration.

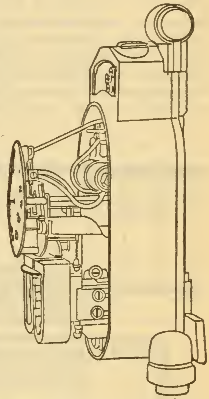


Fig. 27. Westinghouse Prepayment Wattmeter (Internal View).

To compare the calibration of a secondary standard indicating wattmeter with the primary standard, it should be connected into the circuit as shown in Fig. 28, having the current coils of the meters in series and the shunt coils in multiple with each other. Care should be taken to have the shunt coil of each meter connected to the same point or source of potential to avoid the possibility of one meter measuring the shunt loss of the other.

Testing Load. — The load for the test can readily be obtained by a bank of incandescent lamps so arranged that any value from zero to full-load current may be easily and quickly obtained. The load should be taken from a source of supply having as little voltage variation as possible on account of the effect of rapid fluctuations on the reading of indicating

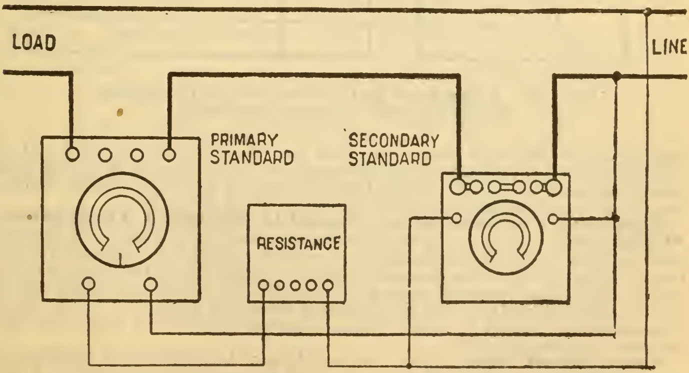


Fig. 28. Connections for Comparing Secondary with Primary Standard.

meters, it being somewhat difficult to secure accurate readings on a circuit having a badly fluctuating voltage. A convenient arrangement of load is shown in Fig. 29, and consists of a bank of lamps of different candle-power ranging from 4 to 50 C.P., these lamps being arranged in connection with single-pole, single-throw switches so that the smaller sizes may be thrown in circuit individually and the larger sizes in groups. The arrangement shown may, of course, be varied to suit local conditions.

In circuit with a portion of the lamp bank is placed an adjustable resistance or rheostat for use in obtaining exact current values and also to assist in maintaining a constant load. The water rheostat is very convenient for this class of work as the load can be varied quickly and with perfect uniformity. The resistance of the water rheostat can be readily changed to almost any value by changing the strength of the solution. Having made connections as above, it is now only necessary to take the readings on the portable meter at convenient points and to compare these

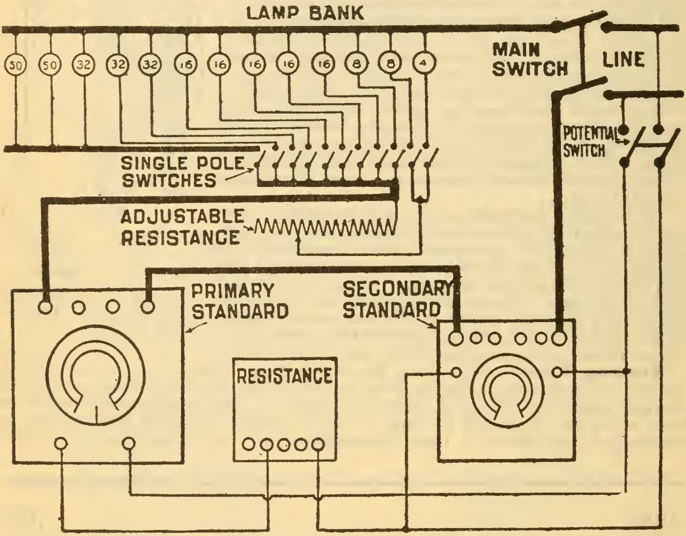


FIG. 29. Lamp Bank and Connections for Comparing Secondary with Primary Standards.

readings with the true values as given on the primary standard. It is considered good practice to check the portable meter at each of the marked points on the scale, simply estimating the error of the intermediate points, thus showing the error very closely at all points of the scale.

Checking Calibration of Portable Standard Integrating Wattmeter.—If the portable rotating standard meter is used as a secondary standard, it should be checked with a primary standard wattmeter from time to time and for this purpose should be connected in the same manner as the indicating standard shown in Fig. 28. To make a comparison of the rotating standard with the primary standard it should be properly connected and placed in series with a primary standard of approximately the same ampere capacity.

Light Load Test.—The load should now be maintained constant at approximately 4 per cent of full load and the pointer revolutions of the rotating standard timed by a stop watch. Having obtained the time consumed in making a certain number of pointer revolutions, the watts should be computed by the formula applying to the particular meter under test.

Full-Load Test.—The meter may be tested on other loads ranging from the light load to full load, but as the calibration curve of the rotating standard from light load to full load is practically a straight line, it is unnecessary to take readings at other points than light and full load unless extreme accuracy is required. If this is desired, readings may be taken at several intermediate points, from which readings a curve may be plotted giving the exact calibration of the meter at all points.

Selection of Primary Standard Meter Capacity.—In comparing secondary with primary standards, care should be taken to select the windings of the primary meter having a capacity nearest that of the meter under test, in order that it may be used at the highest possible part of the scale. This rule also applies to the comparison of service meters with secondary standards.

Testing Service Meters.—For the testing of service meters, either the "portable indicating" meters may be employed in conjunction with a stop watch and the reading computed by the use of a calibrating formula, or the meter may be compared with a portable standard integrating wattmeter. To use either of these methods the standard should be connected in circuit with the service meter as shown in the diagrams usually accompanying each meter.

Where meters operating from series and voltage transformers are to be tested, it will usually be found advisable to test them as 5-ampere, 100-volt meters without using the transformers. If such meters are to be tested under the running load, the standard may be connected in the secondary transformer circuit of the meter under test, using the 5-ampere, 100-volt coils of the standard.

Testing Service Meters with Standard Indicating Meters.—To conduct a test with the indicating meter it will be necessary to hold the load as constant as possible and while noting the reading of the standard, count the revolutions of the disk of the meter under test, taking the time by means of a stop watch. To eliminate personal errors several readings of at least one minute each should be taken and averaged. To compare the reading of the meter with the standard, it is necessary to use a formula pertaining to the particular meter under test.

Use of Stop Watch.—When employing the indicating wattmeter method it should be remembered that the stop watch is not infallible and should be frequently checked by comparing it with the second hand of a good clock. For this purpose a clock in which the pendulum beats seconds or half seconds should be used, starting the watch with a certain beat of the pendulum and having allowed the watch to run several minutes to eliminate personal errors, it should be stopped on the same beat of the pendulum on which it was started. A little practice will enable the operator to check the watch within .1 of a second without difficulty.

Testing Service Meters with Portable Standard Integrating Wattmeters.—If the integrating standard is used for testing single-phase service meters, the operation is much simplified, as the use of the formula and stop watch can be eliminated. To conduct a test by this method, the standard should be connected as shown in Fig. 30, and the connections so arranged, if possible, that the capacity of the standard will be the same as that of the meter under test. The proper connections having been made, the load should be adjusted to the desired value and a direct comparison made of the number of revolutions of the meter under test with the number of revolutions shown on the counter of the standard. In common with the indicating standard method, readings should be taken for at least one minute to eliminate personal errors. The percentage of error in the meter under test may be found directly by dividing the number of revolutions of the service meter by the number of revolutions made by the standard meter; that is, if the meter under test makes 10 revolutions while the standard meter shows 10.4 revolutions, the ratio would show the meter under test to be approximately 4 per cent slow. The above applies only when the meter under test has the same full-load speed as the standard.

In order that the standard meter may be conveniently employed in testing meters in which the full-load speed is other than twenty-five revolutions per minute, the following table has been prepared as applying to Westinghouse, General Electric and Fort Wayne meters. By the use of

Calibration Data for Westinghouse Standard Portable Integrating Wattmeters.

Make.	100–125 Volt Service Meter.			Standard Meter Ampere Capacity.	Revolutions of Westinghouse Portable Integrating Wattmeter for 94 Per Cent to 106 Per Cent Registration of Service Meter.												
	Amp. Capacity.	Revolutions. Heavy Load.	Revolutions. Light Load.		94 Per cent.	95 Per cent.	96 Per cent.	97 Per cent.	98 Per cent.	99 Per cent.	100 Per cent.	101 Per cent.	102 Per cent.	103 Per cent.	104 Per cent.	105 Per cent.	106 Per cent.
* Westinghouse Types "B" and "C."	5 10 20 40	25 25 25 25	... ...	5 10 20 40	26.6	26.32	26.04	25.77	25.51	25.25	25.	24.75	24.51	24.27	24.04	23.81	23.58
	5 10 20 40	... ...	1.0 1.0 1.0 1.0	5 10 20 40	1.06	1.05	1.04	1.03	1.02	1.01	1.	.99	.98	.97	.96	.95	.94
	80 80	15 ...	... 1.0	40 40	31.91 2.12	31.58 2.1	31.25 2.08	30.92 2.06	30.61 2.04	30.3 2.02	30. 2.	29.7 1.98	29.41 1.96	29.12 1.94	28.85 1.92	28.57 1.90	28.3 1.88
General Electric Type "I."	3 3	30 ...	... 2.0	5 5	19.15 1.27	18.95 1.26	18.73 1.25	18.55 1.23	18.36 1.22	18.18 1.21	18. 1.2	17.82 1.19	17.64 1.18	17.47 1.16	17.30 1.15	17.14 1.14	16.98 1.13
	5 10	30 30	... ...	5 10	28.72	28.42	28.12	27.83	27.55	27.27	27.	26.73	26.47	26.21	25.96	25.71	25.47
	5 10	... ...	2.0 2.0	5 10	1.91	1.89	1.87	1.85	1.84	1.81	1.8	1.78	1.76	1.75	1.73	1.71	1.69
	15 15	30 ...	... 2.0	20 20	23.93 1.6	23.68 1.58	23.43 1.56	23.19 1.54	22.96 1.53	22.72 1.51	22.5 1.5	22.28 1.48	22.06 1.47	21.84 1.45	21.61 1.44	21.42 1.42	21.13 1.42
	25 50	30 30	... ...	20 40	35.85	35.47	35.10	34.74	34.39	34.04	33.7	33.36	33.04	32.72	32.41	32.09	31.79
	25 50	... ...	2.0 2.0	20 40	2.39	2.36	2.34	2.32	2.29	2.27	2.25	2.23	2.2	2.18	2.16	2.14	2.11

* Westinghouse Round Pattern and type "A" meters make fifty revolutions per minute at full load.

Calibration Data for Westinghouse Standard Portable Integrating Wattmeters.

Make.	100–125 Volt Service Meter.			Standard Meter Ampere Capacity.	Revolutions of Westinghouse Portable Integrating Wattmeter for 94 Per Cent to 106 Per Cent Registration of Service Meter.												
	Amp. Capacity.	Revolutions. Heavy Load.	Revolutions. Light Load.		94 Per cent.	95 Per cent.	96 Per cent.	97 Per cent.	98 Per cent.	99 Per cent.	100 Per cent.	101 Per cent.	102 Per cent.	103 Per cent.	104 Per cent.	105 Per cent.	106 Per cent.
Fort Wayne Type "K."	5 10 40	30 30 30	... ...	5 10 40	23.93	23.68	23.43	23.19	22.96	22.72	22.5	22.28	22.06	21.84	21.61	21.42	21.13
	5 10 40	... ...	2.0 2.0 2.0	5 10 40	1.6	1.58	1.56	1.54	1.53	1.51	1.5	1.48	1.47	1.45	1.44	1.43	1.42
	25 50	30 30	... ...	20 40	23.93	23.68	23.43	23.19	22.96	22.72	22.5	22.28	22.06	21.84	21.61	21.42	21.13
	25 50	... ...	2.0 2.0	20 40	1.6	1.58	1.56	1.54	1.53	1.51	1.5	1.48	1.47	1.45	1.44	1.43	1.42

It is recommended that test be made at approximately 100 per cent and 4 per cent of full load if these loads are within the range of standard meter.

Load service meter so as to give revolutions stated in table in approximately one minute's time.

Where possible, the capacity of coils used should be the same for both service and standard meters.

The data given on pages 1016–1017 primarily applies to testing 100–125 volt meters, but applies equally well to testing 200–250 volt meters if the standard is connected for the higher voltage.

this table any one of the three makes can easily be tested with the one standard.

In explanation of the use of this table the following examples are given:

(1) If it is desired to test a Westinghouse service meter by using the rotating standard, the two meters should be connected in series and loaded so as to give one revolution of the disk in approximately one minute's time for a light-load test, and for full load, twenty-five revolutions of the disk in the same time. The number of revolutions made for these two loads by the standard — if the service meter is correct — would be one and twenty-five respectively. If the number of revolutions made by the standard is 25.77 the service meter is three per cent slow at full load. If the number of revolutions of the standard is 24.27, the service meter is three per cent fast at full load. From this example it will be seen that the accuracy can be determined for any speed within six per cent fast or slow, reading same directly from the table without any calculation whatever.

(2) If it is desired to test a five-ampere General Electric meter the load can be adjusted to give say — two revolutions at light load and thirty revolutions of the disk at heavy load in approximately one minute's time. If the meter is correct the standard will show 1.8 and 27 revolutions respectively. If the standard shows 1.85, the service meter is three per cent slow

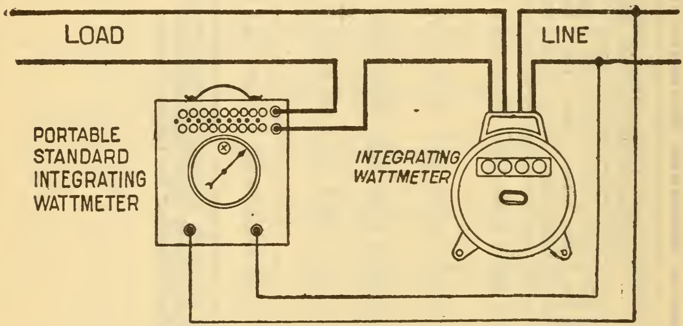


Fig. 30. Connections for Checking Service Meter with Portable Standard Integrating Wattmeter.

at light load. If the standard shows 1.75 the service meter is three per cent fast at light load.

(3) It it is desired to test a five-ampere Fort Wayne meter the load can be adjusted to the same value as with the General Electric meter. If the meter is correct the standard will show 1.5 and 22.5 revolutions respectively. If the standard shows 1.54 the service meter is three per cent slow at light load. If the standard shows 1.45, the service meter is three per cent fast at light load.

If it is desired to test three-wire meters, the standard should be connected into the circuit with one side of the meter under test, the other side of the circuit being left open. When the test is conducted in this manner the pointer of the standard will revolve at a rate twice as fast as the disk of the meter under test, which has but one-half of its current winding in use during the test. To effect a direct comparison, the number of revolutions made by the meter bing testeed should be multiplied by two.

Testing Meters for Accuracy on Inductive Loads.—When it is desired to test meters for inductive load accuracy the necessary load may be obtained in one of several ways as outlined below:

For obtaining the inductive load from a single-phase circuit a set of two or more five-ampere reactance coils, such as are used in the multiple A. C. arc lamp, will be found convenient. The coils can be arranged to give almost any current value, when used on a 110-volt circuit, up to 25 amperes by means of series parallel connections. The taps which are brought cut at numerous points are useful in obtaining close adjustments of current value. Fig. 31 illustrates a method of connection for use in testing meters on inductive loads, the power factor of which can be directly determined by a power-factor meter or by the use of an ammeter, voltmeter and wattmeter connected in circuit as indicated.

Method of Testing Service Meter for Inductive Load Accuracy.—To conduct this test, the service meter should be loaded to its full current capacity as indicated by the ammeter. The lamp load and inductive load should be so adjusted as to give a reading on the wattmeter equal to one-half of the volt-ampere reading as shown by the reading of the ammeter multiplied by the voltage of the circuit. If a standard indicating wattmeter is used, the watt value is at once apparent. If the rotating standard integrating meter is used, however, the approximate watt value may be obtained by noting the speed of the pointer which should rotate one-half as fast as it would if the same volt-amperes were applied at unity power factor. The full-load speed of the rotating standard operating at the cur-

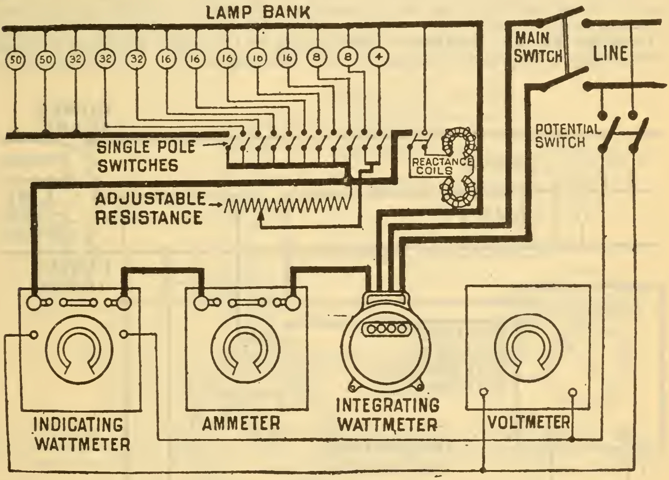


Fig. 31. Obtaining Inductive Load from Single-Phase Circuit.

rent and voltage marked upon the dial is 12½ R.P.M., at a power factor of 50 per cent. With this method of testing on inductive load at a power factor of 50 per cent, it is necessary to take comparative readings the same as in the ordinary test of meters.

Obtaining Inductive Load from Two-Phase Circuits.—An integrating meter can readily be checked for inductive load accuracy if a two-phase circuit is available by connecting the current coils of the meter in one phase and taking the potential from the other phase as shown in Fig. 32. The meter should be given normal full-load current and potential and as the current and potential in this case are 90 degrees apart or in quadrature, it is obvious that the meter disk should not move. A standard indicating or integrating meter should be in circuit during this test as a check upon the two-phase current being exactly in quadrature.

If the standard shows any load the current should be further lagged by inserting a sufficient number of lamps in the phase B circuit, or, if desired, an inductance can be inserted in the series circuit of the wattmeter. In order to secure the proper phase relation it may in some instances be necessary to reverse the primary or secondary connection of the transformer in phase

B. When the phase displacement is exactly 90 degrees the standard should not show any load.

Obtaining Inductive Load from Three-Phase Circuits.—The above condition of zero power factor or quadrature may also be obtained from a balanced three-phase circuit by connecting the meter as shown in Fig. 33 with the current coils in phase A, taking the potential across phases B and C, the load being placed between phases AB and AC. This load must be the same (balanced) on each phase to obtain the desired result.

Another method of obtaining this condition from a three-phase circuit is to transform from three-phase to two-phase and connect the meter into the two-phase circuit as shown in Fig. 34. This method necessitates the use of special transformers having the "Scott" three-phase to two-phase connections, but in some cases this method may be more convenient than the method shown in Fig. 33, as it eliminates the necessity of maintaining the balanced load on the three-phase circuit, it being only necessary to have one lamp bank on one phase of the two-phase circuit for a load. Having obtained a current in quadrature with the potential, the test should be conducted as outlined in the preceding paragraph describing the two-phase method.

Testing D. C. Meters.—For testing D. C. meters a testing arrangement similar to that shown in Fig. 31 may be employed and the meters tested

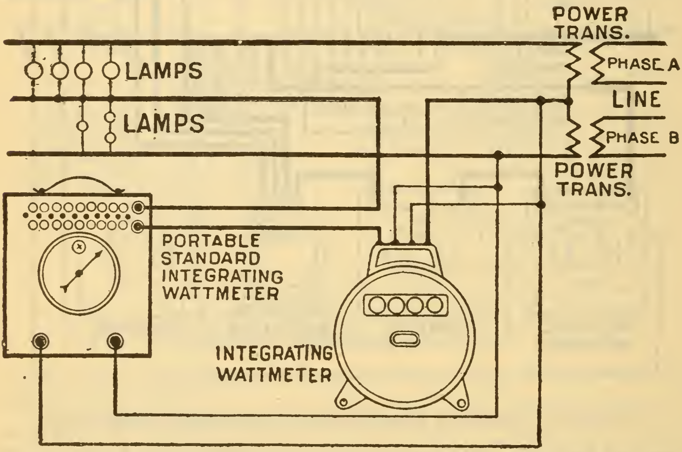


FIG. 32. Obtaining Inductive Load from Two-Phase Circuit and Using Integrating Wattmeter as Standard.

by the voltmeter-ammeter method or by the indicating wattmeter method. The reactance coils would not be employed, but in general the method of test is the same as for A. C. meters previously described. Owing to the rate of heating being different for the shunt circuit and the disk, it is necessary that the meter be run long enough before test to allow it to reach its normal operating condition, which is approximately 15 minutes.

Testing Polyphase Service Meters.—As the polyphase meter is really two single-phase meters having a common shaft and registering mechanism, the general instructions for the single-phase meters will apply to the polyphase meters. The calibration and checking of these meters, however, is necessarily more complicated and the following general instructions will be of assistance in the testing of this type of meter.

Standards for Testing Polyphase Meters.—As yet a rotating standard of the polyphase type is not (December, 1907) on the market, and it is customary to use the indicating meter and stop watch method for testing this class of meter, although a single-phase portable integrating standard wattmeter may be used if the method is properly applied.

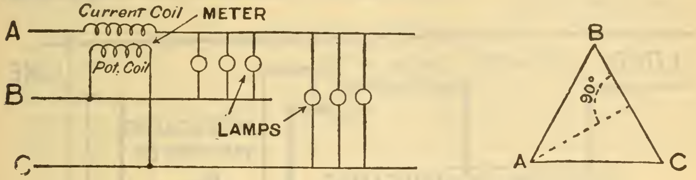


FIG. 33. Obtaining Inductive Load from Three-Phase Circuit.

To test a polyphase meter it is customary to employ an artificial load and test each side as a single-phase element. To test a self-contained meter using neither series or voltage transformers the connections should be made as shown in Fig. 35, and for testing a meter using transformers

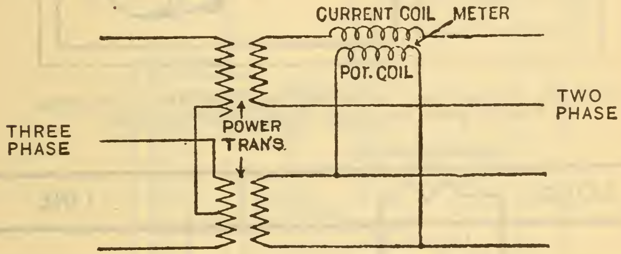


FIG. 34. Obtaining Inductive Load from Three-Phase Circuit by Use of "Scott" Three-Phase-Two-Phase Connection.

connect as shown in Fig. 36. A three-point switch is provided to cut either series element of the service meter in circuit with the standard. As but one series side of the meter is in service at a time it is either necessary to

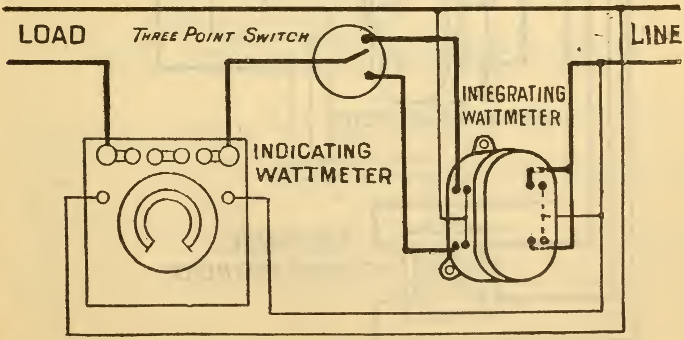


FIG. 35. Connections for Testing Self-Contained Polyphase Meter Using Single-Phase Standard.

multiply the disk revolutions by two or divide the calibrating constant by two. The test should be conducted in the same manner as when testing single-phase meters previously described. It will be noted that both potential elements of the service meter are energized, this being essential in polyphase testing.

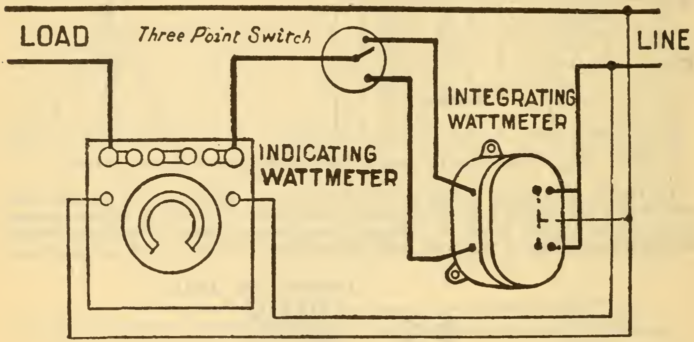


FIG. 36. Connections for Testing Polyphase Meter Employing Transformers and Using Single-Phase Standard.

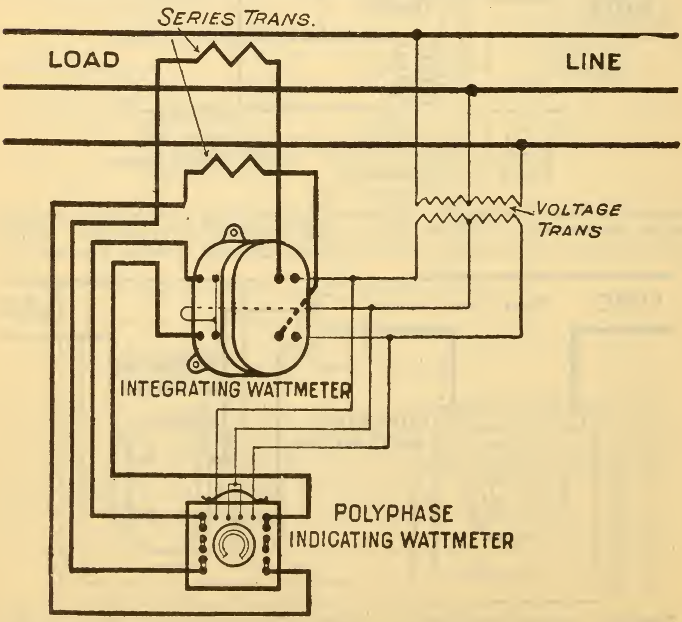


FIG. 37. Connections for Testing Polyphase Meter Employing Transformers. Testing on Running Load and Using Polyphase Standard.

To test a polyphase meter on the running load, connections should be made as shown in Figs. 37–38 and the test conducted in the same manner as for single-phase testing. Care should be exercised to connect the potential element to the same point to avoid danger of one meter measuring the watt loss of the other.

When desired, the single-phase portable standard integrating wattmeter may be used for checking polyphase meters instead of the indicating wattmeter. For this purpose the polyphase meter should be connected as shown in Figs. 35–36 and the standard integrating meter substituted for the indicating meter. When so connected the disk revolutions of the polyphase meter should be multiplied by two and directly compared with the rotating standard, in which case instructions for single-phase testing will apply. If desired the current elements of the polyphase meter may

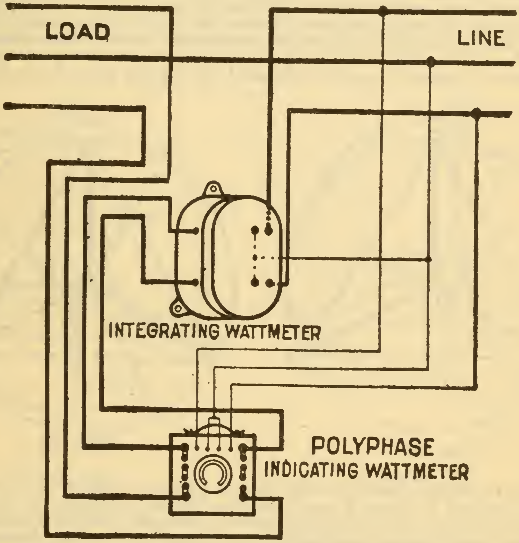


Fig. 38. Connections for Testing Self-Contained Polyphase Meter on Running Load and Using Polyphase Standard.

be connected in series, in which case the service and test meter disks will revolve at the same speed.

Note: — In all tests of polyphase meters both potential coils must be connected in circuit and energized. Polyphase meters should be given the same tests at light and full loads as the single-phase meters and the same adjustments apply.

Service Connections of Polyphase Meters. — Great care should be exercised in the installation of polyphase meters to insure the connections being made exactly in accordance with the proper diagrams. This is extremely important, as it is possible to make incorrect connections producing excessive errors on inductive loads and still have the meter rotate in the proper direction. It is not a safe plan to try out polyphase meter connections by alternately opening the sides of the measuring elements and noting that the disk rotates in the forward direction in each case, unless the power facter is definitely known. If the meter should be connected to a three-phase circuit operating at a power factor of less than 50 per cent, one element should cause the disk to rotate backwards, and if the above test alone is depended upon when installing the meter, it is very probable that the average man installing the meter under these conditions would reverse the side rotating backwards, thus introducing an enormous error as the power factor of the circuit changed. It is also possible to so connect a polyphase meter that it will run in either the forward or reverse direction on both elements regardless of the power factor, the meter either running faster or slower than it would on unity power factor, depending upon the phase relation of the particular connection used.

The action of two single-phase meters, or the two single-phase elements of a polyphase meter operating upon a three-phase circuit, may be explained by the following vector diagrams.

Figure 39 shows the phase relations between the current and potential of each single-phase element when operating on a three-phase circuit at unity power factor, one meter element having its series coil in A and its potential coil across AC and the other element having its series coil in B and its potential coil across BC. From this diagram it will be seen that the current in phase A is displaced 30 degrees from its respective potential AC and the current in phase B is also displaced 30 degrees from its potential BC,

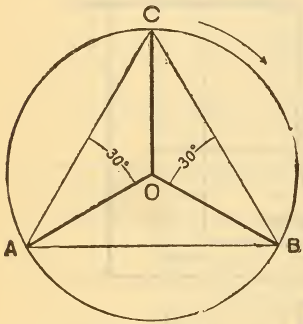


FIG. 39.

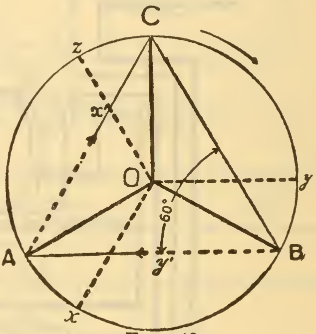


FIG. 40.

but in the opposite direction from that in phase A, thus giving the effect of a lagging current in phase B and a leading current in phase A, the resultant being zero displacement, or unity power factor, on the three-phase circuit. From this it will be seen that at unity power factor on the three-phase circuit each single-phase element of the polyphase meter will operate at the same speed, each element operating at a single-phase power factor of about 86 per cent, or the cosine of 30 degrees.

Figure 40 shows the condition existing when the current in the three-phase circuit lags 30 degrees or is operating at a power factor of 86 per cent. From this diagram it will be seen that the current in phase B lags behind its respective potential BC 30 + 30 degrees or 60 degrees, while the current in A has been brought exactly in phase with its respective potential AC. This gives a condition where one single-phase element is operating at a power factor of 50 per cent (or cosine of 60 degrees), while the other element is operating at unity power factor, its current and potential being exactly in phase. Under this condition one element will run twice as fast as the other. Ox, Oy and Oz show positions of three-phase current with 30 degrees lag. To show phase relation of each current with its respective voltage, Ox is rotated about center A instead of O and falls in phase with its voltage AC. Current Oy is rotated about center B and falls 60 degrees behind its voltage BC.

Figure 41 shows the condition met with when the current in the three-phase circuit lags 60 degrees or is operating at a power factor of 50 per cent. From this diagram it will be seen that the current in phase B lags its respective potential BC 60 + 30 degrees or 90 degrees, while the current in phase A lags its potential AC 60 − 30 degrees or 30 degrees. This gives a condition where one single-phase element is operating at zero power factor or cosine of 90 degrees, while the other element is operating at 86 per cent or cosine of 30 degrees. Under this condition one element has stopped, the other element doing all the work. For clearness in showing phase relations the centers of rotation of the currents are changed as in Fig. 40.

Figure 42 shows the condition met with when the current in the three-phase circuit lags 90 degrees or is operating at a power factor of zero. From this diagram it will be seen that the current in phase B lags its respective potential BC 90 + 30 degrees or 120 degrees, while the current in phase A lags its respective potential AC 90 − 30 degrees or 60 degrees. As the angle of lag in phase B now exceeds 90 degrees, the cosine of the angle is the same as the sine of the difference between the angle and 90 degrees, in this case minus 30 degrees, giving a power factor of minus 50 per cent in phase B and a power factor of plus 50 per cent in phase A. From this it will be seen that at zero power factor of the three-phase circuit, one single-phase element of the meter will try to operate at half speed in one direction

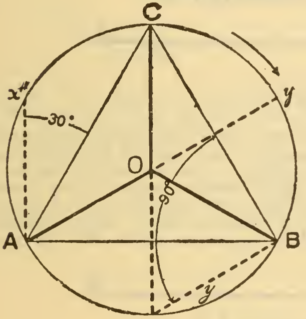


FIG. 41.

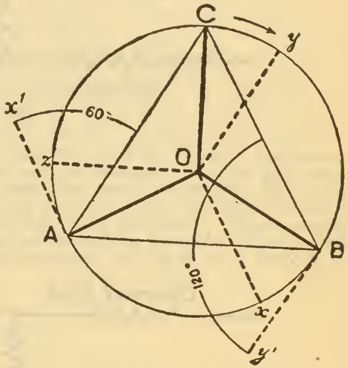


FIG. 42.

while the other element is trying to operate at half speed in the opposite direction, the resultant of these two equal forces acting in opposite directions being zero; hence, the meter as a whole will not move.

From the preceding explanation of the phase relations of single-phase meters used on a three-phase circuit, it will be apparent that the energy of a three-phase circuit cannot be measured by the use of one standard single-phase meter. It also shows why it is extremely important to have the polyphase meter connected into the circuit in accordance with the proper diagrams as, owing to the fact that one element of the polyphase meter should tend to reverse its direction of rotation on a power factor of less than 50 per cent, it is not safe to depend upon the direction of rotation of each element separately to determine whether or not a meter is connected into the circuit properly unless the power factor is known.

The general scheme of connections for correctly connecting a polyphase meter to measure the energy of a three-phase circuit is shown in Fig. 43, the current coil of one element being connected in line A and its potential across A and B, the current coils of the other element being connected in line C and its potential coils across B and C.

If a meter should be connected, as shown in Fig. 44, with the current coil of one element in line A and its potential across A and C and the current of the other element in line C with its potential coil across B and C, both elements of the meter will run in either the forward or reverse direction at all values of power factor at equal speeds, and will be either fast or slow on all power factors other than unity, depending on the phase relations of the particular connection used. This erroneous connection should be carefully guarded against, and it will be readily seen that this condition cannot be detected by the common method used of opening one side of the meter at a time to determine that the meter runs in the forward direction on each element alone.

The effect of the connections shown in Fig. 44 can be seen by referring to Fig. 45. If one series element of the polyphase meter is connected in at A and its potential element connected across AC, and the other series element

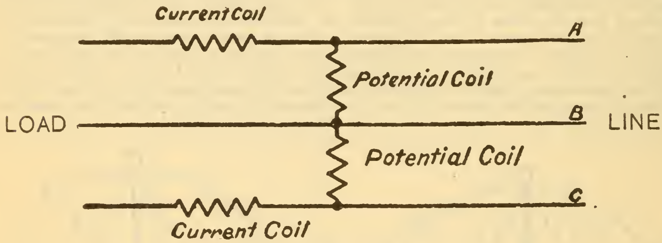


FIG. 43.

connected in at B with its potential element connected across BA, when operating under 30 degrees lag the currents Ox and Oy will be shifted so that both will be in phase with their voltage and the meter will run in a forward direction faster than it will at unity power factor of the three-phase circuit. With one series element of the meter connected in at A and its potential element connected across AB and the other series element connected in at B and its potential element connected across BC, the cur-

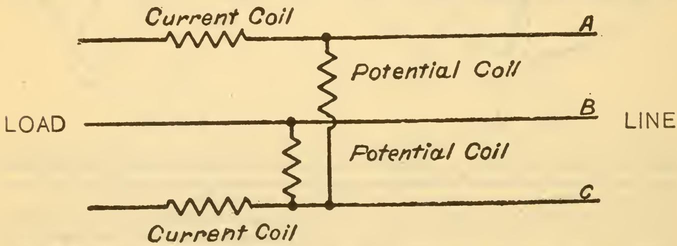


FIG. 44.

rents will be shifted so that both Ox and Oy lag behind their respective voltages and the meter will consequently run slower than it will at unity power factor of the three-phase circuit.

Practical Methods of Checking Connections of Polyphase Meters.—In cases where it is not positively known that the power factor is above 50 per cent, the following method may be used, which is based on the fact that the sum of the two readings should be positive, so long as the power is in the positive direction. When the currents in the voltage and series coils, as indicated by the clock diagram, are in the same direction, or within 90 degrees of being in the same direction, the meter will read forward. When the current in the series coil is more than 90 degrees out of phase with the voltage, the meter will reverse.

First. By proper testing with an incandescent lamp or a voltmeter, obtain three voltage leads, A, B, C, having equal voltages between them.

Second. Connect these leads to the voltage circuits of the wattmeters as per Fig. 43.

Third. Connect the series transformer at A to meter whose potential is connected to AC, and series transformer at B to meter whose potential is connected to BC. See clock diagram (Fig. 46) giving the phase relations. In this diagram, AC represents the voltage on meter connected at A, BC the voltage on meter connected at B, OA the current in meter connected at A, and OB the current in meter connected at B.

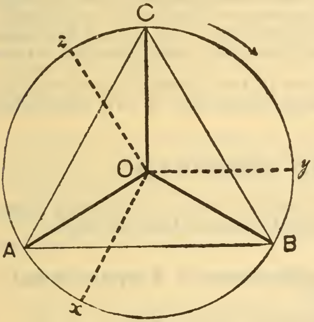


Fig. 45.

Fourth. Change voltage connection from AC to AB on meter connected at A. If power factor is 100, the readings will be alike with both connections. If the power factor is less than 100 and greater than 50, the readings will differ, but be in the same direction (either both positive or both negative). If equal to 50, one of the readings will be zero. If less than 50, the readings with connections AC and AB will be reversed in direction, with respect to each other.

Fifth. The same test may be performed on meter connected at B, by changing the voltage connections from BC to BA. If the power factor

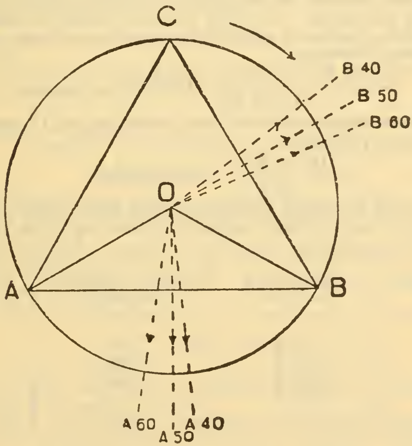


Fig. 46.

OA current in meter at A 100 per cent P.F.
OA 60 current in meter at A 60 per cent P.F.
OA 50 current in meter at A 50 per cent P.F.
OA 40 current in meter at A 40 per cent P.F.
OB current in meter at A 100 per cent P.F.
OB 60 current in meter at A 60 per cent P.F.
OB 50 current in meter at A 50 per cent P.F.
OB 40 current in meter at A 40 per cent P.F.

is 100, the readings will be alike. If less than 100 and more than 50, the readings will differ, but be in the same direction. If equal to 50, one of the readings will be zero. If less than 50, the readings with connections BC and BA will be reversed in direction with respect to each other.

Sixth. If it is found from the above tests that the power factor is greater than 50, connect the series coil of the meters so that both read forward. If the power factor is less than 50, connect the series coil of the slower meter so that meter reads backward, and the series coil of the faster meter so that it reads forward.

The above description indicates the use of two single-phase meters, but holds equally true for a polyphase meter consisting of two single-phase meter elements driving the same shaft.

METER TESTING FORMULÆ.

Below will be found the formulæ and testing constants to be used in conjunction with the testing methods described on pages 1013 to 1023.

Formula for Testing the Shallenberger Ampere-hour Meter.

To Tell the Exact Current Flowing at any Time.

Note the number of revolutions made by the small "tell-tale" index of the register dial, in a number of seconds equal to the constant of the meter. The number of revolutions noted will correspond to the number of amperes passing through the meter. For example: the 20-ampere meter constant is 63.3; if the index makes 10 revolutions in 63.3 seconds, 10 amperes are passing through the meter. In order to avoid errors in readings, it is customary to take the number of revolutions in a longer time, say 120 seconds, using the following formula:

$$\frac{\text{No. of Rev.} \times \text{Meter Constant}}{\text{No. of Sec.}} = \text{Current.}$$

If, therefore, the index of a 20-ampere meter makes 19 revolutions in 120 seconds the current passing is

$$\frac{19 \times 63.3}{120} = 10 \text{ amperes.}$$

The cover should be left on the meter while these readings are taken.

The constants of the different capacity meters are given below:

Meter Capacity. Amperes.	Calibrating Constant.	Meter Capacity. Amperes.	Calibrating Constant.
5	22.5	80	253.1
10	33.8	120	386
20	63.3	160	506
40	126.6		

Testing Formula for Shallenberger and Westinghouse Integrating Wattmeters.

The standard formula for testing all types and capacities, when using indicating standards and stop watches, is Watts $= \frac{R}{T} K$ in which:

R = Number of complete revolutions in time T.
T = Time in seconds required for revolutions R.
K = Constant.

The constant "K" varies with different types and capacities as outlined on the following page.

Ratings.—In all cases the volt and ampere values used with the formula are those marked on the meter. The full-load speed of Types "B" and "C" meters is 25 R.P.M.

Full-Load Speeds.—The full-load speed of Shallenberger, Westinghouse, Round Pattern and Type "A" Single and Polyphase Wattmeters is 50 R.P.M. The full-load speed of Type "B" single phase and Type "C" single or polyphase wattmeters is 25 R.P.M.

For Shallenberger, Westinghouse Round Pattern Back Connected and Type "A" Meters the constant "K" has the following values:

2-Wire Meters (Single Phase).

For self-contained meters K = volts × amps. × 1.2.

For meter used with series transformer only (but checked without) K = volts (as marked on dial) × 6.

For meter used with series and voltage transformers (but checked without) K = 600.

For meter used with transformers of either or both forms (and checked with) K = volts × amps. × 1.2.

3-Wire Meters (Single Phase).

For self-contained meters K = volts × amps. × 2.4.

For meters used with series transformers only (but checked without) K = volts × 6.

Type "A" Polyphase Wattmeters.

For self-contained meters K = volts × amps. × 2.4.

For meters used with series transformers only (but checked without) K = 5 × volts × 2.4.

For meters used with series and voltage transformers (but checked without) K = 1200.

For meters used with transformers of either or both forms (and checked with) K = volts × amps. × 2.4.

The Testing Constant "K" of Westinghouse Types "B" and "C" Meters is as follows:

2-Wire Meters (Single Phase).

For self-contained meters K = volts × amps. × 2.4.

For meters used with series transformers only (but checked without) K = volts × 5 × 2.4.

For meters used with series and voltage transformers (but checked without) K = 5 × 100 × 2.4.

For meters used with transformers of either or both forms (and checked with) K = volts × amps. × 2.4.

3-Wire Meters (Single Phase).

For self-contained meters K = volts × amps. × 4.8.

For meters used with series transformers (but checked without) K = volts (as marked on meter) × 12.

NOTE.—When the voltage marking of Westinghouse three-wire meters covers *both* the voltage between neutral and outer and the voltage between outers such as 100–200 volts, K = volts (between outside wires) × amperes as marked on meter × 2.4.

Type "C" Polyphase Wattmeters.

For self-contained meters K = volts × amps. × 4.8.

For meters used with series transformers only (but checked without) K = 5 × volts × 4.8.

For meters used with series and voltage transformers (but checked without) K = 2400.

For meters used with transformers of either or both forms (and checked with) K = volts × amps. × 4.8.

WESTINGHOUSE DIRECT-CURRENT METERS.

For all capacity meters K = volts × amps. × 2.4.

Formula for Testing General Electric Recording Wattmeters.

The standard formula for testing all types and capacities when using indicating standards and stop watches is $\text{Watts} = \frac{3600 \times K \times R}{S}$ in which:

R = number of revolutions.
S = number of seconds in which revolutions is made.
K = calibrating constant marked on dial face of "non-direct" reading meters and on disk of "direct" reading meters.

Table of General Electric D. C. Type "C 6" Testing Constants "K" and Watts per Revolution per Minute.

Capacity of Meters in Amperes.	100–120 Volts.		200–240 Volts.		500–600 Volts.	
	Testing Constant.	Watts Per Revolution per Minute.	Testing Constant.	Watts Per Revolution Per Minute.	Testing Constant.	Watts Per Revolution Per Minute.
3	.125	7.5	.25	15	.6	36
5	.2	12.	.4	24	1.	60
10	.4	24.	.75	45	2.	120
15	.6	36.	1.25	75	3.	180
25	1.	60.	2.	120	5.	300
50	2.	120.	4.	240	10.	600
75	3.	180.	6.	360	15.	900
100	4.	240.	7.5	450	20.	1200
150	6.	360.	12.5	750	30.	1800
300	12.5	750.	25.	1500	60.	3600
600	25.	1500.	50.	3000	125.	7500

Table of General Electric A. C. Type "I" Testing Constants "K" and Watts per Revolution per Minute.

Capacity of Meters in Amperes.	100–130 Volts.		200–260 Volts.		500–600 Volts.	
	Testing Constant.	Watts Per Revolution Per Minute.	Testing Constant.	Watts Per Revolution Per Minute.	Testing Constant.	Watts Per Revolution Per Minute.
3	.2	12	.4	24	1.	60
5	.3	18	.6	36	1.5	75
10	.6	36	1.25	75	3.	180
15	1.	60	2.	120	5.	300
25	1.5	90	3.	180	7.5	450
50	3.	180	6.	360	15.	900
75	5.	300	10.	600	25.	1500
100	6.	360	12.5	750	30.	1800
150	10.	600	20.	1200	50.	3000
200	12.5	750	25.	1500	60.	3600
300	20.	1200	40.	2400	100	6000

"D 3" Polyphase Meters.

	100–120 Volts.		200–260 Volts.		500–650 Volts.	
Amps.	25 Cycles Testing Constant.	60 Cycles Testing Constant.	25 Cycles Testing Constant.	60 Cycles Testing Constant.	25 Cycles Testing Constant.	60 Cycles Testing Constant.
3	1.	.4	2	.75	5.	2
5	1.5	.6	3	1.25	7.5	3
10	3.	1.25	6	2.5	15.	6
15	5.	2.	10	4.	25.	10
25	7.5	3.	15	6.	40.	15
50	15.	6.	30	12.5	75.	30
75	20.	7.5	40	15.	100.	40
100	30.	12.5	60	25.	150.	60
150	40.	15.	75	30.	200.	75

NOTE: — Testing constant is actual watt-hours per revolution of disk.

Formula for Testing Duncan Recording Wattmeters.

The standard formula for testing all types and capacities when using indicating standards and stop watches is Watts $= \frac{\text{Rev.} \times 3600 \times K}{\text{Sec.}}$, in which:

R = Number of complete revolutions.
Sec. = Time in seconds required for revolutions R.
K = Testing constant marked on meter disk.

Table of Duncan Testing Constants "K" and Watts per Revolution per Minute.

Capacity of Meters in Amperes.	100–125 Volts.		200–250 Volts.		450–550 Volts.	
	Testing Constant.	Watts per Revolution per Minute.	Testing Constant.	Watts per Revolution per Minute.	Testing Constant.	Watts per Revolution per Minute.
$2\frac{1}{2}$	$\frac{1}{4}$	15	$\frac{1}{2}$	30	1	60
5	$\frac{1}{4}$	15	$\frac{1}{2}$	30	1	60
$7\frac{1}{2}$	$\frac{1}{2}$	30	1	60	2	120
10	$\frac{1}{2}$	30	1	60	2	120
15	1	60	2	120	5	300
25	1	60	2	120	5	300
50	2	120	4	240	10	600
75	3	180	6	360	16	960
100	4	240	8	480	20	1,200
150	6	360	12	720	30	1,800
200	8	480	16	960	40	2,400
300	12	720	25	1,500	60	3,600
450	20	1,200	30	1,800	80	4,800
600	25	1,500	50	3,000	100	6,000
800	30	1,800	60	3,600	160	9,600
1,000	40	2,400	80	4,800	200	12,000
1,200	50	3,000	100	6,000	250	15,000
1,500	60	3,600	120	7,200	300	18,000
2,000	80	4,800	160	9,600	400	24,000
2,500	100	6,000	200	12,000	500	30,000
3,000	120	7,200	250	15,000	600	36,000
4,000	160	9,600	300	18,000	800	48,000
5,000	200	12.000	400	24,000	1,000	60.000
6,000	250	15,000	500	30,000	1,200	72,000
8,000	300	18,000	600	36,000	1,600	96,000
10,000	400	24,000	800	48,000	2,000	120,000

The table given below will be found convenient in showing the per cent fast or slow which a meter is running when employed in conjunction with the following formula : $\frac{\text{Watts Constituting Load}}{\text{Testing Constant} \times 60} = \text{Rev. Per Min.}$

Per Cent Error Table for Fifths of a Second.

Time in Seconds	Per Cent Fast	Time in Seconds	Per Cent Fast	Time in Seconds	Per Cent Slow	Time in Seconds	Per Cent Slow
40.20	49.25	50.20	19.52	60.20	0.33	70.20	14.52
.40	58.51	.40	19.05	.40	0.67	.40	14.77
.60	47.78	.60	18.58	.60	0.99	.60	15.01
.80	47.06	.80	18.11	.80	1.31	.80	15.25
41.00	46.34	51.00	17.65	61.00	1.63	71.00	15.50
.20	45.63	.20	17.19	.20	1.96	.20	15.73
.40	44.93	.40	16.73	.40	2.27	.40	15.96
.60	44.23	.60	16.28	.60	2.59	.60	16.20
.80	43.54	.80	15.83	.80	2.91	.80	16.43
42.00	42.86	52.00	15·38	62.00	3.22	72.00	16.66
.20	42.18	.20	14.94	.20	3.53	.20	16.89
.40	41.51	.40	14.50	.40	3.84	.40	17.12
.60	40.85	.60	14.07	.60	4.15	.60	17.35
.80	40.19	.80	13.64	.80	4.45	.80	17.58
43.00	39.53	53.00	13.21	63.00	4.76	73.00	17.81
.20	38.89	.20	12.78	.20	5.06	.20	18.03
.40	38.25	.40	12.36	.40	5.36	.40	18.25
.60	37.61	.60	11.94	.60	5.66	.60	18.47
.80	36.98	.80	11.52	.80	5.95	.80	18.70
44.00	36.36	54.00	11.11	64.00	6.25	74.00	18.92
.20	35.75	.20	10.70	.20	6.54	.20	19.14
.40	35.14	.40	10.29	.40	6.83	.40	19.35
.60	34.53	.60	9.89	.60	7.12	.60	19.57
.80	33.93	.80	9.49	.80	7.40	.80	19.79
45.00	33.33	55.00	9.09	65.00	7.69	75.00	20.00
.20	32.74	.20	8.69	.20	7.97	.20	20.21
.40	32.16	.40	8.30	.40	8.25	.40	20.42
.60	31.58	.60	7.91	.60	8.53	.60	20.63
.80	31.00	.80	7.53	.80	8.81	.80	20.84
46.00	30.43	56.00	7.14	66.00	9.09	76.00	21.05
.20	29.87	.20	6.76	.20	9.36	.20	21.26
.40	29.31	.40	6.38	.40	9.63	.40	21.47
.60	28.76	.60	6.01	.60	9.92	.60	21.68
.80	28.21	.80	5.63	.80	10.17	.80	21.88
47.00	27.66	57.00	5.26	67.00	10.44	77.00	22.07
.20	27.12	.20	4.89	.20	10.71	.20	22.27
.40	26.58	.40	4.53	.40	10.97	.40	22.38
.60	26.05	.60	4.17	.60	11.24	.60	22.68
.80	25.52	.80	3.81	.80	11.50	.80	22.88
48.00	25.00	58.00	3.45	68.00	11.76	78.00	23.08
.20	24.40	.20	3.09	.20	12.02	.20	23.28
.40	23.96	.40	2.74	.40	12.28	.40	23.47
.60	23.45	.60	2.39	.60	12.53	.60	23.66
.80	23.15	.80	2.04	.80	12.79	.80	23.86
49.00	22.45	59.00	1.69	69.00	13.04	79.00	24.05
.20	21.95	.20	1.35	.20	13.29	.20	24.24
.40	21.46	.40	1.01	.40	13.54	.40	24.43
.60	20.97	.60	0.67	.60	13.79	.60	24.63
.80	20.48	.80	0.33	.80	14.04	.80	24.82
50.00	20.00	60.00	0.00	70.00	14.28	80.00	25.00

Example. — If the revolutions to be made in one minute are completed in exactly 60 seconds the speed is correct and the per cent error is zero, but if the revolutions were made in 57 seconds then the meter is running 5.26 per cent fast; if completed in 58.4 seconds it is 2.74 per cent fast. When the time exceeds 60 seconds, the meter is slow. If it requires 63 seconds it is 4.76 per cent slow; if 64.6 seconds it is 7.12 per cent slow. The per cent error will be found in the column after the time in seconds. The seconds columns are divided into fifths of a second so as to conform to most stop watches whose seconds are split to fifths.

Formula for Testing Fort Wayne Type "K" Wattmeter.

The standard formula for testing all types and capacities when using indicating standards and stop watch is Watts $= \frac{\text{Rev.} \times 100 \times K}{\text{Sec.}}$.

Tables of Values of Constant "K" for Different Capacities, Type "K" Fort Wayne Single-Phase Meters.

(For meters whose serial number is 344,999 or less.)

Amperes.	2-Wire 50 V. "K."	2-Wire 110 V. "K."	2-Wire 220 V. "K."	3-Wire 220 V. "K."	2-Wire 550 V. "K."	2-Wire 1100 V. "K."	2-Wire 2200 V. "K."
3	...	9	18	18	45	90	90
5	9	9	18	18	45	90	180
7½	...	...	...	27	...	...	...
10	9	18	36	36	90	180	360
15	18	36	54	54	180	360	540
20	18	36	72	72	180	360	720
25	18	36	72	72	180	360	900
30	36	72	90	90	360	720	1,080
40	36	72	108	108	360	720	1,440
50	36	72	144	144	360	720	1,800
60	54	108	180	180	540	1,080	2,160
75	54	108	216	216	540	1,080	2,700
100	72	144	288	288	720	1,440	3,600
125	90	180	360	360	900	1,800	4,500
150	108	216	432	432	1,080	2,160	5,400
200	144	288	576	576	1,440	2,880	7,200
250	180	360	720	720	1,800	3,600	9,000
300	270	540	1,080	1,080	2,700	5,400	10,800
400	360	720	1,440	1,440	3,600	7,200	14,400
500	450	900	1,800	1,800	4,500	9,000	18,000
600	540	1,080	2,160	2,160	5,400	10,800	21,600
800	720	1,440	2,880	2,880	7,200	14,400	28,800
1,000	900	1,800	3,600	3,600	9,000	18,000	36,000

Use these Constants for High Torque Meters.

15	13½	27	54	54	135	270	540
30	27	54	90	90	270	540	1,080

Table of Values of Constant "K" for Different Capacities, Type "K" Fort Wayne Single-Phase Meters.

(For meters whose serial number is 345,000 or above.)

Amperes.	2-Wire 110 V. "K."	2-Wire 220 V. "K."	3-Wire 220 V. "K."	2-Wire 440 V. "K."	2-Wire 550 V. "K".	2-Wire 1100 V. "K."	2-Wire 2200 V. "K."
5	9	18	18	36	45	90	180
10	18	36	36	72	90	180	360
15	27	54	54	108	135	270	540
20	36	72	72	144	180	360	720
25	45	90	90	180	225	450	900
40	72	144	144	288	360	720	1,440
50	90	180	180	360	450	900	1,800
75	135	270	270	540	675	1,350	2,700
100	180	360	360	720	900	1,800	3,600
125	225	450	450	900	1,125	2,250	4,500
150	270	540	540	1,080	1,350	2,700	5,400
200	360	720	720	1,440	1,800	3,600	7,200
300	540	1,080	1,080	2,160	2,700	5,400	10,800
400	720	1,440	1,440	2,880	3,600	7,200	14,400
600	1,080	2,160	2,160	4,320	5,400	10,800	21,600
800	1,440	2,880	2,880	5,760	7,200	14,400	28,800

Table of Values of Constant "K" for Different Capacities, Type "K" Fort Wayne Polyphase Wattmeters.

(For meters whose serial number is 344,999 or less.)

Amperes Capacity.	Volts.					
	110 "K."	220 "K."	440 "K."	550 "K."	1100 "K."	2200 "K."
3	18	36	72	90	180	360
5	36	72	144	180	360	720
10	72	144	288	360	720	1,440
15	108	216	432	540	1,080	2,160
20	144	288	576	720	1,440	2,880
25	144	288	576	720	1,800	3,600
30	216	360	720	1,080	2,160	4,320
40	288	576	1,152	1,440	2,880	5,760
50	288	576	1,152	1,440	3,600	7,200
60	432	864	1,728	2,160	4,320	8,640
75	432	864	1,728	2,160	5,400	10,800
100	576	1,152	2,304	2,880	7,200	14,400
125	720	1,440	2,880	3,600	9,000	18,000
150	864	1,800	3,600	4,320	10,800	21,600
200	1,440	2,880	5,760	7,200	14,400	28,800
250	1,800	3,600	7,200	9,000	18,000	36,000
300	2,160	4,320	8,640	10,800	21,600	43,200
400	2,880	5,760	11,520	14,400	28,800	57,600
500	3,600	7,200	14,400	18,000	36,000	72,000
600	4,320	8,640	17,280	21,600	43,200	86,400
800	5,760	11,520	23,040	28,800	57,600	115,200
1,000	7,200	14,400	28,800	36,000	72,000	144,000

Table of Values of Constant "K" for Different Capacities, Type "K" Fort Wayne Polyphase Wattmeters.

(For meters whose serial number is 345,000 or above.)

Amperes Capacity.	Volts.					
	110 "K."	220 "K."	440 "K."	550 "K."	1100 "K."	2200 "K."
5	36	72	144	180	360	720
10	72	144	288	360	720	1,440
15	108	216	432	540	1,080	2,160
25	180	360	720	900	1,800	3,600
50	360	720	1,440	1,800	3,600	7,200
75	540	1,080	2,160	2,700	5,400	10,800
100	720	1,440	2,880	3,600	7,200	14,400
150	1,080	2,160	4,320	5,400	10,800	21,600
200	1,440	2,880	5,760	7,200	14,400	28,800
300	2,160	4,320	8,640	10,800	21,600	43,200
400	2,880	5,760	11,520	14,400	28,800	57,600
600	4,320	8,640	17,280	21,600	43,200	86,400
800	5,760	11,520	23,040	28,800	57,600	115,200

Formula for Testing Sangamo Wattmeters.

"K" equals watt-seconds per revolution of armature, 3600 watt-seconds being one watt-hour. The method of using these values of "K," the formula for obtaining correct speed at any load is simple. Thus if W equals observed watts of load, S equals correct time in seconds for one revolution; then S equals "K" divided by W. If S′ is the observed time in seconds for one revolution, the percentage of error equals S′ minus S, divided by S′. If this quantity is negative, the meter is fast, if the quantity is positive, the meter is slow.

NOTE. — The value of "K" as given below will also apply in all cases to the new alternating-current meter, type "F," except for the 5-ampere, 110-volt type, which will have "K" equals 1800, and for the 5-ampere 220-volt type, it will have "K" equals 3600.

Table of Testing Constants "K" for Sangamo Meters. Type "D" D. C. and Type "E" A. C.

Amperes.	100–125 Volts "K."	200–250 Volts "K."	500–600 Volts "K."
5	2,400	4,800	12,000
10	2,400	4,800	12,000
20	4,800	9,600	24,000
30	7,200	14,400	36,000
40	9,600	19,200	48,000
60	14,400	28,800	72,000
80	19,200	38,400	96,000
100	24,000	48,000	120,000
150	36,000	72,000	180,000
200	48,000	96,000	240,000

GRAPHIC RECORDING METERS.

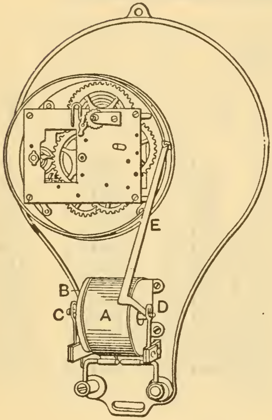


FIG. 47. Bristol Ammeter.

As the necessity of obtaining more accurate records of plant operation becomes more apparent, means of obtaining these records automatically are demanded. Several different forms have been developed by various manufacturers and those described herein are representative of American practice.

Bristol Recording Meters.

Figure 47 illustrates the Bristol Ammeter which has the same general appearance as the voltmeters and wattmeters. A is a stationary coil or solenoid through which passes the current to be measured; B is a thin disk armature of soft iron secured to a non-magnetic shaft which extends through the center of the solenoid A and is supported at its opposite ends on steel knife edged spring supports C and D. The recording pen E is attached directly to the spring support D and the point is arranged to lightly drag on a revolving chart, driven by clock-work, shown in illustration.

Operation. — As current passes through the coil A the magnetic field generated attracts the iron armature B drawing it directly toward the left hand end of coil A (when facing meter). This movement of B is, through

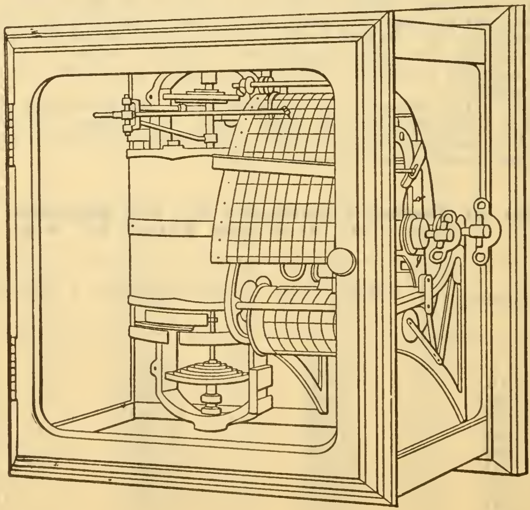


FIG. 48. General Electric Curve Drawing Meter.

its supporting structure, transmitted to the recording pen E, the point of which moves across the chart.

Voltmeter Construction. — The voltmeter construction is similar to that of the ammeter, with the exception that the iron armature B is replaced by a wire-wound armature which is connected in series with the stationary coil and through a resistance to line. Of course it should be understood that the stationary coils of ammeters are wound with comparatively heavy wire and the voltmeter coils with comparatively fine wire.

Single-Phase Wattmeters. — The wattmeter construction is similar to that of the voltmeter, except that the stationary coil is wound with wire of sufficient capacity to carry the current to be measured. The moving coil is, through a resistance, connected directly across the line, or, in high-capacity alternating-current circuits is operated from the secondary of a voltage transformer.

General Electric Graphic Recording Meters.

Figure 48 illustrates the G. E. "Curve Drawing Instruments." The meters are made as ammeters, voltmeters, single-phase and polyphase wattmeters, all having the same general appearance.

Principle of Operation. — The voltmeters and wattmeters work upon the well-known "Siemens Dynamometer" principle, employing fixed and moving coils. The ammeters are of the "Magnetic Vane Type," employing an iron armature suspended within two fixed coils which carry the current to be measured.

Construction. — Fig. 49 illustrates the measuring elements of an ammeter in which —

AA = Fixed coils connected in series.
B = Iron armature suspended between coils AA.
C = Guide bearing for lower end of shaft D.
D = Suspended shaft carrying armature B, control spring E and pen supporting arms.
E = Control or restraining springs.
F = Suspension wire carrying moving element.
G = Supporting frame carrying pivoted pen arm H.
H = Spring controlled pen arm pivoted at I and carrying glass pen K.
I = Pivoted support for pen arm H.
J = Control spring holding pen against the record chart L.

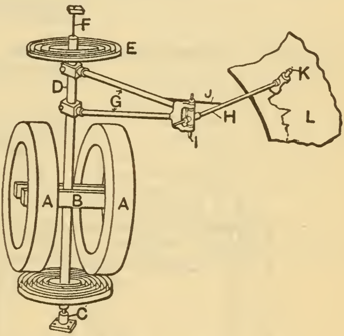


FIG. 49.

K = Recording glass pen bearing on chart L.
L = Record chart driven by clock mechanism (not shown).

Action of Meter. — The armature B is so located in relation to the fixed coils AA that when current flows through them it is attracted by the magnetic field and tends to rotate the suspended element. This movement causes the recording pen K to move across the chart L, against the restraining action of the control springs E, which tend to return the pen to zero position. The turning or actuating force of the armature is thus balanced against the coercive force of the control springs and their point of balance is a measure of the current flowing through the coils.

Westinghouse Graphic Recording Meters.

Figure 50 illustrates the Westinghouse "Relay Type" Graphic Recording Meters. The meters are made as voltmeters, ammeters, single-phase and polyphase wattmeters, power factor and frequency meters.

Construction.—The construction of a voltmeter is diagrammatically shown in Fig. 51 in which the various elements of the meter are designated as follows:

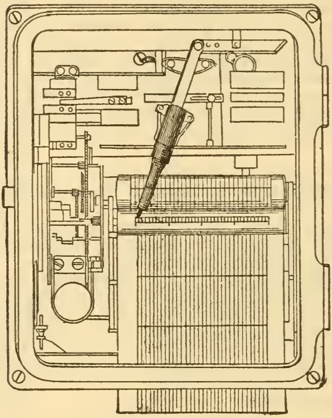


FIG. 50. Westinghouse Graphic Recording Voltmeter With Indicating Dial.

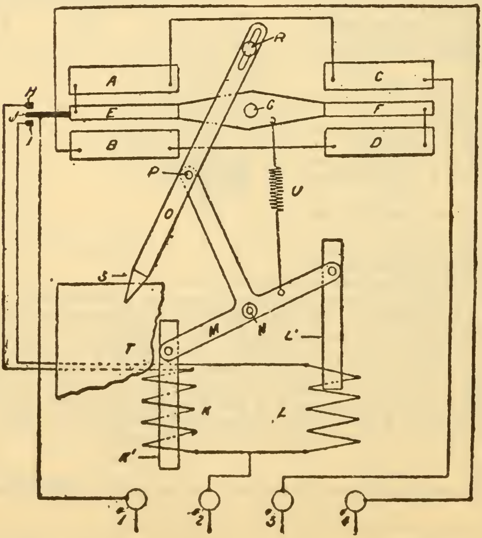


FIG. 51. Diagrammatic Sketch of Westinghouse Graphic Voltmeter.

A—B—C—D = Fixed coils.
E—F = Movable coils mounted on supporting structure pivoted at G.
G = Pivoted support of E—F.
H = Upper adjustable relay contact.
I = Lower adjustable relay contact.
J = Movable relay contact attached to movable element E—F.
K = Pen actuating electromagnet (left hand).
K′ = Iron core of K.
L = Pen actuating electromagnet (right hand).
L′ = Iron core of L.
M = Arm supporting iron cores pivoted at N and connecting O by pin bearing P.
N = Pivoted bearing for M.
O = Pen arm connected to M by pin bearing P and provided with guide slot at upper end which bears on stationary guide pin R.
P = Pin bearing connecting M and O.
R = Stationary guide pin for O.
S = Recording pen arranged to pass across a suitable moving record paper T.
U = Helical spring connecting movable coil system and movable pivoted supporting arm M.

Action of Meters. — The system of fixed and measuring coils is so arranged that when current flows through them the left-hand coil E is repelled by A and attracted by B, the right-hand coil F being repelled by D and attracted by C. Assuming the recording pen to be at zero position on the chart and connection made to relay and measuring circuits through binding posts Nos. 1, 2, 3 and 4, it will be seen that the movable system will take up a position which will force contact J against contact I. A circuit will thus be completed through the right-hand solenoid L and the electromagnetic attraction will cause the core L′ to move downward, which movement will turn M about its axis and through its connection with O cause the pen to move across the chart toward full scale position. This movement of M places tension on the spring U and continues increasing this tension until the core has travelled a sufficient distance to place such a tension on U that it balances the torque of the movable measuring system E—F and draws the contact J away from I.

The entire moving system, including solenoids, pen arm and measuring coils remains in the position last assumed when the "relay" circuit was broken and the pen continues to draw a line which represents the voltage current or wattage values as the case may be.

TELEGRAPHY.

REVISED BY CHARLES THOM.

IN this chapter only the instruments used in telegraphy will be noticed; and these, with their connections, in theoretical diagrams only. For the various details, whose presentation would defeat the purpose of clearness in this compilation, readers are referred to various works on telegraphy. Lines, batteries, etc., are each treated in other chapters.

AMERICAN, or CLOSED CIRCUIT METHOD.

The following diagram shows the connections of the Morse system of single telegraphy, as used in the United States. The terminal stations only are shown, and in one case the local circuit is omitted. Several interme-

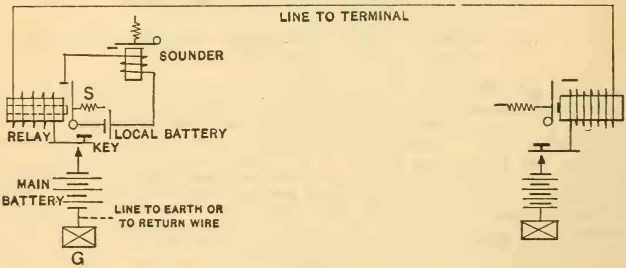


FIG. 1.

diate stations (in practice 25 is not unusual) may be cut in on one circuit; all the instruments working in unison, in response to one key only.

In Fig. 1 at either end is a key which, when open, allows the now unattracted armatures to be withdrawn by the retractile spring, S. Closing the key restores the current to the relays, attracts the armatures to the front stop; the local circuit through the relay points is closed, and the signal is heard on the sounder. The attracting force of spring, S, is less than that of the relay cores as energized by the current from the battery used for a given circuit. It can, by "pulling up" on the spring, be made greater; in which case the given current is ineffective to close the relays, and if the tension of spring, S, is maintained, battery must be added to close the relays. It is possible, therefore, by means of spring, S, to make a comparatively weak current ineffective to close the relay points. The significance of this will appear later in connection with the quadruplex.

EUROPEAN, or OPEN CIRCUIT METHOD.

The following diagram shows the connections of one terminal station with the line connecting to the next. The ground plates may be dispensed with if a return wire from the next station is used, thus forming a metallic circuit.

This method of connecting Morse apparatus is used mostly in Europe, and has two advantages over the American method.

a. The battery is not in circuit except when signals are being sent.

b. When the key is closed and the current admitted to line, the coils of the relay are cut out of the circuit, thus lessening the hindrance to the flow of current.

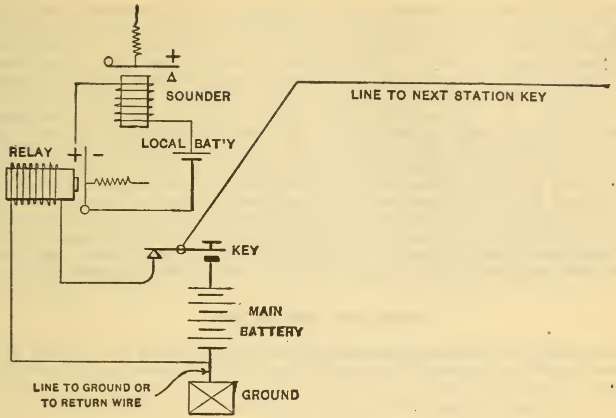


FIG. 2.

REPEATERS.

In practical telegraphy, the high resistance of the line wire between the terminal stations, and imperfect insulation permitting leakage in damp weather, make it inexpedient to attempt to transmit signals over circuits whose lengths have not well-defined limits. But a circuit may be extended, and messages exchanged over longer distances by making the receiving instrument at the distant terminal of one circuit do the work of a transmitting key in the next. The apparatus used for this purpose is called a repeater, and is usually automatic, in a sense which will appear later on.

From among the scores of repeaters, selection must be made of representative types, — the three in most general use

Milliken Repeater.

The following diagram illustrates the theory of the Milliken repeater, which is in general use in the United States and Canada. The essential feature of every form of automatic repeater is some device by which the circuit into which the sender is repeating not only opens when he opens, but closes when he closes.

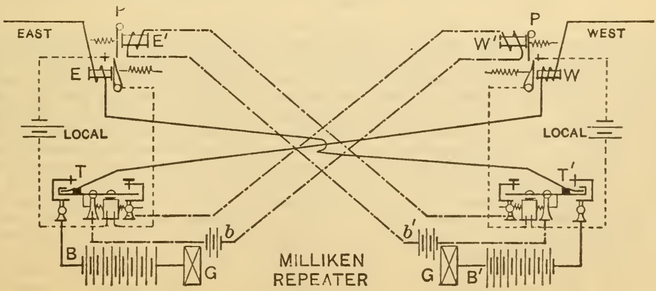


FIG. 3.

In the diagram is represented the apparatus of a repeating station in which appear the instruments and three distinct circuits in duplicate, viz.: the east and west main line; east and west local (dotted); east and west extra local (dash and dot). Starting with both "east" and "west" keys closed and the line at rest, battery *b′*, whose circuit (dash and dot) is complete through transmitter, *T′*, energizes extra magnet, *E′*, attracts the pendent armature, *P′*, leaving the upright armature free, the pendent armature, *P*, being similarly held by battery, *b*. In operation, the distant east opens his key, relay, *E*, opens, then transmitter, *T*, through whose tongue and post passes the west line, which opens, and would open relay, *W*, and therefore transmitter, *T′*; but at the moment transmitter, *T*, opens, the extra local circuit (dash and dot) opens, releasing pendent armature, *P*, which is drawn by its spring against the upright armature holding closed the points of relay, *W*, and transmitter, *T′*, and therefore the east line, which passes through its tongue and post. When the distant west breaks and sends, the action begins with the west relay instead of east, and follows the same course.

Ghegan Repeater.

In repeaters for lines worked single, the characteristic is a device in the repeater which holds closed the main line on which the sending is being done,

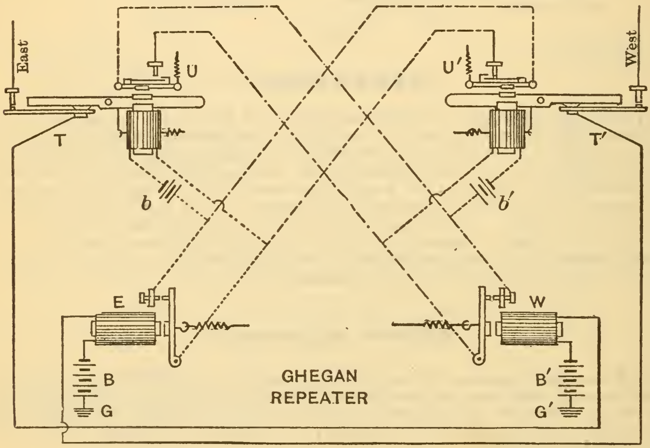


FIG. 4.

while the distant relay on the second main line records that sending; the parts arranged to effect this result should act quickly on the "break" and a little slowly on the "make" of the main line current — "break" and "make" being the technical terms respectively for the opening and closing of the circuit. A form of repeater intended to effect in a high degree this result, called from its inventor the Ghegan, is shown in theory in the diagram, Fig. 4. The characteristic instrument is a transmitter having a second armature-bearing lever placed above the first one in such a position that one electromagnet serves to work both; the upper armature forms a back contact simultaneously with the opening of the transmitter, and it inclines to preserve the contact at *U′* until the regular local circuit (dotted) has been closed at the local points in relay *E*; the action is therefore quick or slow as occasion requires. As in the Milliken and Weiny-Phillips, there are three pairs of circuits; the main lines (solid black); the local circuits (dotted); and the shunt circuits (dot and dash). When relay *W* open it releases the armature of transmitter T'; through its tongue and post passes the west wire which opens, releasing the armature of relay E, and opening its local points. At the same time upper armature U' flies against its back contact and completes a shunt circuit by which battery b holds transmitter T closed; and the wire passing through its tongue and post is kept intact. Reverting to the position of the instruments in the diagram, the distant east is supposed to have opened his key. This opens relay W, which opens transmitter T' (both armatures); the drop in the lower armature opens the west main line, which opens relay E and its local points; but, as just explained, the circuit of battery b is now complete through the dot and dash lines, so that transmitter T is held closed and the east line is kept intact by its tongue against the stop. When the distant west breaks, the armature of relay E remains on its back stop, and, on the first downward stroke of the upper armature of transmitter T', the local circuit of transmitter T is broken, and at its tongue and post the east line opens. The east sender, thus warned, closes his key; the sender at the distant west takes the circuit, and action similar to that just described begins with relay E, and follows a like course.

Weiny-Phillips Repeater.

A theoretical diagram of the Weiny-Phillips repeater is given herewith. It is in general use by one of the principal telegraph companies, and is

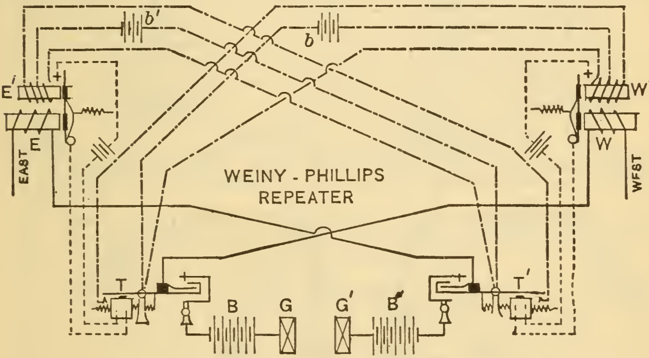
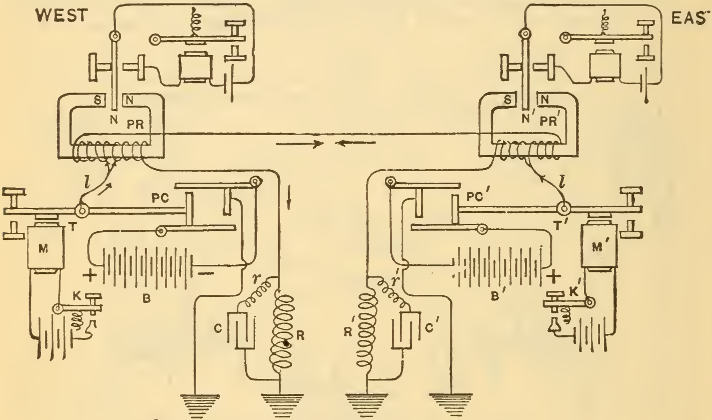


FIG. 5.

introduced here because it involves the principle of differentiation in magnet coils, which plays so important a part in duplex telegraphy. As in the Milliken, there are three distinct circuits in duplicate; and in the diagrams the parts performing like functions in the two types of repeaters are similarly lettered. The connections and functions of the main line (solid black) circuits and of local (dotted) circuits are identical with those of the Milliken. But instead of the extra magnets and pendent armature of the latter, we have a tubular iron shell enclosing a straight iron core and its windings, the combination of shell and straight core performing the same functions as the usual horse-shoe core. The turns of wire around the core of the extra magnet are equally divided, and the current traverses the two halves in opposite directions. Such a core is said to be differentially wound, because the core is energized by the *difference* in strength of the currents in the coils; but when the coils are equal in resistance, the equal currents, passing in opposite directions around the core, neutralize each other. If one of the coils is opened, the core at once becomes a magnet capable of holding the armature at the moment when, the repeater in operation, the "east" station opens his key, opening relay E; then transmitter T; then opening the "west" wire, which would open relay W, transmitter T', and therefore the east wire; but the opening of transmitter T' is prevented by the energizing at the critical moment of core W', one coil of which is opened when transmitter T opens. When the distant west breaks and sends, the action begins with the west relay instead of the east, and follows the same course.

Duplex Telegraphy.

That method of telegraphy by which messages can be sent and received over one wire at the same time is called duplex; and the system in general use, known as the polar duplex, is illustrated in the accompanying diagram. In single telegraphy all the relays in the circuit, including the home one, respond to the movements of the key; the duplex system implies a home relay and sounder unresponsive, but a distant relay responsive to the movements of the home key; and this result is effected by a differential arrangement of magnet coils, of which the extra magnet coils in the Weiny-Phillips repeater furnished an example. A current dividing between two coils and their connecting wires of equal resistance will divide equally, and passing round the cores, will produce no magnetic effect in them. This condition is established when the resistance of the wire marked →← in the diagram



THEORETICAL DIAGRAM OF POLAR DUPLEX
BALANCING SWITCH OMITTED
FIG. 6.

is balanced by the resistance of a set of adjustable coils in a rheostat marked R. This is called the ohmic balance (from ohm, the unit of resistance); and the static balance is effected by neutralizing the static discharge on long lines by means of an adjustable condenser C, and retardation coil r, shunting the rheostat as shown. In the single line relay the movement of the armature is effected by the help of a retractile spring in combination with alternating conditions of current and no current on the line. In the polar relay the spring is dispensed with, and the backward movement of the armature is effected, not by a spring, but by means of a current in a direction opposite to that which determined the forward movement. This reversal of the direction of the current is effected by means of a pole-changer, PC, whose lever, T, connected with the main and artificial lines, makes contact, by means of a local circuit and key, K. with the zinc (−) and copper (+) terminal of a battery alternately. The usage in practice is zinc to the line when the key is closed; copper, when open. The law for the production of magnetic poles by a current is this: When a core is looked at "end on," a current passing round it in the direction of the hands of a clock produces south-seeking magnetism, S; in the opposite direction, north-seeking magnetism, marked N. A springless armature, permanently magnetized and pivoted, as shown in the drawing, will, if its free end is placed between S and N magnetic poles, be moved in obedience to the well-known law that like poles repel, while unlike poles attract each other. The "east" and "west" terminal is each a duplicate of the other in every respect; and a description of the operation at one terminal will answer for both.

Under the conditions shown, the keys are open; and the batteries, which have the same E.M.F., oppose their copper (+) poles to each other, so that no current flows in the main line. But in the artificial line the current flows round the core in such direction as, according to the rule just given, to produce N and S polarities as marked, opening the sounder circuits at both terminals. If, by means of key, K', the pole-changer, PC', of "east" station is closed, the connections of battery, B', are changed; it is said to be reversed; and it now adds its E.M.F. to that of battery B, the current flowing in a direction from "west" to "east"; i.e., from copper to zinc. But the current in the main line is to that in the artificial as 2 to 1; and if the relative strength of the resultant magnetic poles is represented by small type for that produced by the current in the artificial line, and by large type for the main, the magnetic conditions can be graphically shown, as they are produced on each side of the permanently magnetized armatures marked (N) and (N'). In relay, PR', it is Sn (N') sN, causing it to remain open; in relay PR it has changed to Ns (N) nS — just the reverse of that shown in the diagram — the relay therefore closes, and the sounder also. If key, K, of the west station is closed at the same time, the batteries are again placed in opposition, but with zinc (−) poles to the line, instead of, as in the first instance, copper (+) poles. The result is no current on the main line; but the current in the artificial lines, flowing in the direction from the ground (whose potential is 0) to the zinc (−) of the batteries, the magnetic condition at "east" station is represented by n (N') s, which closes relay, PR'; and at "west" station by n (N) s, which closes relay PR. The conditions necessary to duplex work, viz., that the movement of key, K', should have no effect on relay, PR', but should operate the distant relay, PR, are thus fulfilled, and the transmssion of messages in opposite directions at the same time is made practicable. In the case of the Wheatstone Automatic duplex this exchange goes on at high rate of speed, the maximum rate being 250 words a minute.

There have already been traced out the magnetic poles formed in the inside ends of the relay cores as the result of three possible combinations of current: (1) copper to line at each end; (2) zinc at east, copper at west end; (3) zinc to line at each end.

One other possible combination remains to be traced out with reference to the poles formed; it is shown in Fig. 7, where the duplex is represented in a form more nearly approaching that which obtains in practice. At the west, or Pittsburg end, zinc is to the line; at the east, or New York end, it is copper; the effect on the distant relay in each case is indicated in the drawing. For the sake of clearness the local systems are omitted; at each terminal the artificial circuit is represented by a dotted line; the main line by solid black; the relays with their windings are shown in a manner fitted for tracing the magnetic effects. Representing the polarity of the armatures by (N) and (S), and the magnetic condition of the cores in the manner adopted in the preceding paragraph, it must be understood that the point of view is midway between the cores. The direction of the current on the main line in this diagram is from New York to Pittsburg. At the New York end the direction of the current in the artificial line is from the battery to the ground; at the Pittsburg end the current sets in from the ground to the zinc pole of the dynamo. In the Pittsburg relay the magnetic conditions, beginning with the lowest core, are Ns (N) nS; the large letters are the poles produced by the main line current; the small are those resulting from the current in the artificial line whose direction is from ground to dynamo; the armature is drawn upward and the relay opens, as shown. In the New York relay, the magnetic conditions (lower core first) are Ns (S) nS; the armature is drawn down and the local points closed.

Other details of the duplex are apparent on examination of the diagram. The two boxes with disks on the top are rheostats; each contains a number of coils in series for making the resistance of the artificial line equal to that of the main. Under the rheostats are the condensers for eliminating the effects on the relay of the static discharge of the line. At the New York end is a chemical battery with the old style of pole changer; when open, as shown, it sends copper to the line, and puts zinc to the ground; when closed it puts zinc to line and copper to ground. At the Pittsburg end is shown an entirely different arrangement; it is the one now almost universally in use. Two dynamos furnish the current; the positive pole of one is grounded;

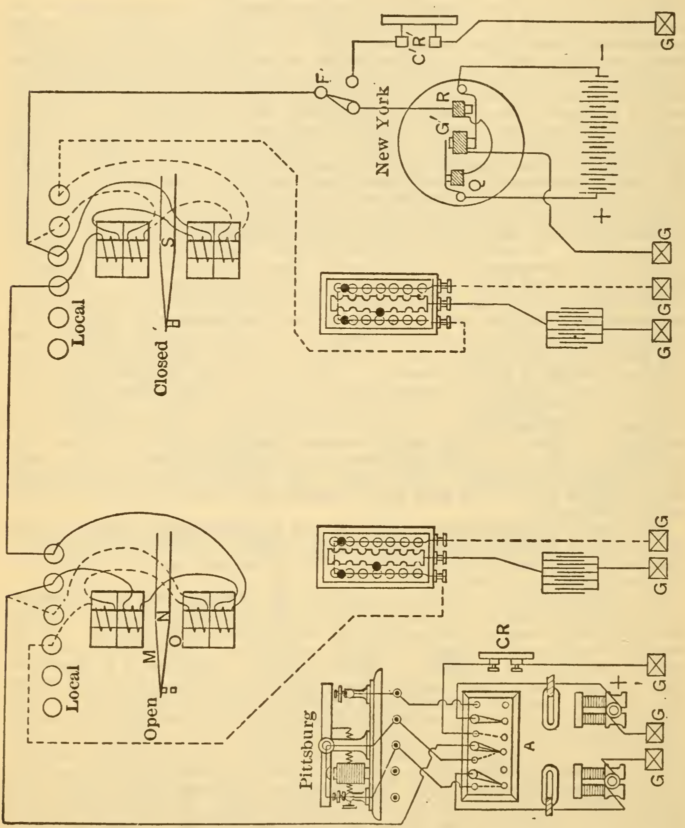


Fig. 7.

the other pole is led through a safety lamp to a cut-off switch, thence to the pole changer which sends zinc to the line when closed. Of the other dynamo the negative pole is grounded; the copper current goes to the right-hand post of the pole changer, which is very much simpler in form than the old style. The balancing switches, omitted from Fig. 6, are shown marked *A* and *F*; by means of these when the lever, say *F*, is thrown to the right, the main line wire is detached from the pole changer and passes through a compensating resistance to the ground.

Duplex Loop System.

For many years after the introduction of the duplex and quadruplex the number of lines operated by those systems was small; but with improvements in the material for wires and in line construction the number gradually increased until now nearly one half the wires of the two leading companies are utilized for one system or the other; and of the wires thus operated the working sets, to the extent of nearly one half, are assembled in main offices, and the wires themselves are worked, by what are called loops, from branch offices located mostly in the different exchanges. The apparatus and connections by which the service of the duplex is extended to a branch are therefore an essential part of multiplex telegraphy. Fig. 8 is a diagram of the duplex loop system; the places of polar relay, pole changer and rheostat are indicated; the main line connections shown in Figs. 6 and 7 are omitted; and the local connections which are entirely omitted from

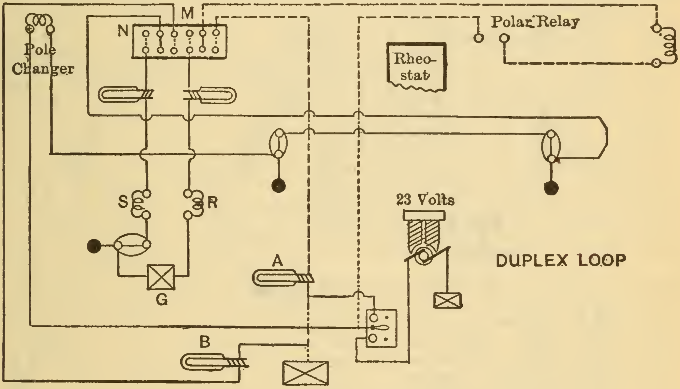


Fig. 8.

Fig. 7 are here inserted; so that Figs. 7 and 8 combined give a representation of the working duplex. The polar relay controls the local circuit, passing through its points; the thumbscrews mark the joining of the office wires with those of the instrument; the electromagnet of the pole changer is controlled by means of two keys whose connecting wires join those of the electromagnet at the thumbscrews. A sounder, a six-point switch, a three-point switch, two lamps, and a 23-volt dynamo complete the outfit for the main office. The current is led first to the three-point switch where it divides; one circuit, called the receiving side, may be traced (dotted line) through the points of the relay, through the sounder, to a lever in the six-point switch which, if turned to the right, conducts the current through a lamp to the ground. The other circuit, called the sending side, may be traced (solid line) through the magnet of the pole changer, through two keys, thence to a lever in the six-point switch which, turned to the right, similarly conducts the current through a lamp to the ground. There are therefore two grounded circuits, with connections as described, the current for which and for many like circuits is supplied by one dynamo. In the six-point switch are shown other two points; to one, marked *M*, is connected a wire extending to a distant branch office, through a sounder therein, thence to the ground; to the other point, marked *N*, is connected a wire similarly extended through a sounder and key, thence to the ground. These connections completed, the levers of the six-point switch may be turned from right to left; the use of the duplex is then extended to the branch office; the polar relay works the sounders in both main and branch office; the key in the branch controls the electromagnet of the pole changer in the main office. The lamps *A* and *B* are in the main office local circuits, and compensate severally for the resistance of the two extensions when the loop is cut out.

Half-Atkinson Repeater.

The description of the duplex local (office and branch) system prepares the way for an interesting form of repeater by means of which the offices on a single wire of considerable length may repeat into, i.e., alternately send and receive on, a duplex wire or one side of a quadruplex. This apparatus

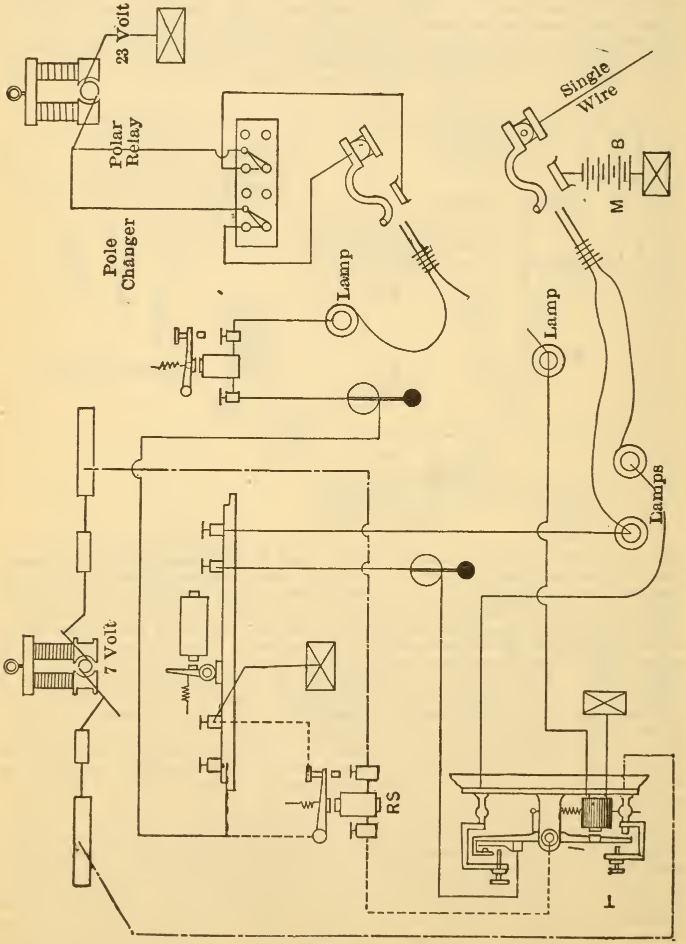


FIG. 9.

is named by prefixing the word "half" to whatever form of single line repeater is used; e.g., half-Milliken, or half-Ghegan. To present as many different forms of repeaters as possible within the limits of this article, the diagram (Fig. 9) shows a half-Atkinson. In the upper right-hand corner is represented in skeleton form the duplex local system just described, together with the jack in the loop switch for the placing of the repeater wedge. The apparatus of the repeater is seen to be a transmitter in the lower left corner, a common relay of 150 ohms resistance, two sounders, two keys, lamps, and a small dynamo. In the lower right corner is a jack to which on one side is connected the single line to distant points; on the other side is the main battery. With the wedge, as indicated, inserted in the jack, the main line circuit can be traced from the battery *MB* through the post and tongue of the transmitter, through the key and magnet coils of the relay, thence back to the jack and main line "out."

In addition to the main line circuit there are four others; two of them are extensions of the 23-volt system of the duplex; of these one has in circuit a pole changer, lamp, sounder, and the local points of the common relay, and terminates in a ground; this arrangement places the pole changer in the control of the common relay. The other circuit has within it the local points of the polar relay, lamp, the electromagnet of the transmitter, and terminates in a ground; this arrangement places the transmitter (and the single line which passes through its post and tongue) in the control of the local points of the polar relay. Of the local circuits of the repeater proper, one (marked dot and dash) extends from one pole of a 7-volt dynamo through the lower post and lever of the transmitter, through the coils of a repeating sounder *RS*; thence back to the other pole of the dynamo; another circuit (dotted) runs through the lever and back stop of *RS*, making connection, as shown, with the local points of the common relay. On the base of the relay the connecting posts on the right join the coils of the relay with the main line wires; the posts on the left connect with the local points of the relay. When the transmitter is open the sounder *RS* is open; the lever makes contact on the back stop, and completes a circuit in which is the electromagnet of the pole changer.

Suppose all the circuits closed and ready for work. When a distant office on the single line writes, he operates the relay through whose local points passes the pole changer circuit; he controls the pole changer and, therefore, the relay at the distant end of the duplex. When the distant office on the duplex writes, he operates the polar relay whose local points control the electromagnet of transmitter *T*, through whose tongue and post passes the single line. He thus controls every relay on the single line circuit; the response of the pole changer to his own sending (which it is the purpose of the repeater to avoid) is prevented by the bridging of the local points of the common relay through the lever and back stop of *RS*. The distant station on the duplex may thus communicate with any office on the single line, and conversely.

The action of this repeater can be utilized to repeat from one single line into another; when so arranged it is known as the Atkinson repeater, and it is the standard of one of the leading companies.

Duplex Repeater.

In wires worked in the duplex or quadruplex system, the static capacity of the wire, which plays little if any part in the operation of circuits by the single method, places a limit on the length of the continuous circuit. But the distance between working stations can be greatly extended by the use of repeaters in which, by an arrangement perfectly simple, the pole changer of a second circuit is controlled by the relay points of the first. The longest regular circuit in the United States is that worked between New York and San Francisco, with six repeaters.

The work of the repeater in this and many other duplex circuits has been facilitated by the recent introduction of the J. C. Barclay pole-changing relay. It consists of a polar relay so constructed that two armatures, insulated one from the other, move on a common arbor; one armature controls the local circuits; to the other is attached the main line which makes contact on front and back stop with the poles of the battery; it is thus a polar relay and pole changer combined.

The Stearns Duplex.

The operation of differential relays like *M* in the diagram of the quadruplex, by alternations of "no battery" and "battery," is the principle of the Stearns duplex, which, as the first condenser-using, and therefore static-eliminating duplex in the world, has a certain historic interest. In February, 1868, there were in use by the Franklin Telegraph Company a duplex set New York to Philadelphia, and another to Boston; and in August, 1871, by the Western Union Telegraph Company, a duplex, New York to Albany — all without condensers. In March, 1872, the Stearns duplex, with condenser, went into operation between New York and Chicago, but it has been superseded by the polar system.

Reverting to the diagram, the pole changer with its adjuncts, and the polar relay of the quadruplex, are omitted; one pole of the battery is

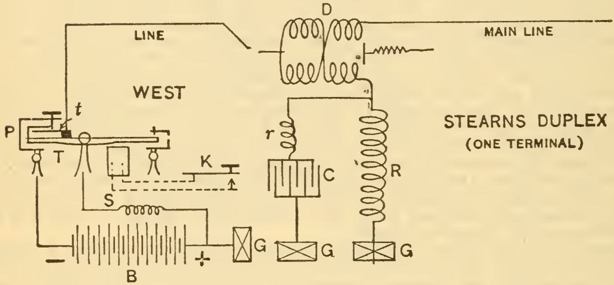


Fig. 10.

grounded, and the lever of transmitter, *T*, is grounded through a resistance equal to that of battery, *B*. This grounds the line through tongue, *t*, and leaves the battery open at the post, *P*. The "east" station (not shown) is a duplicate of the "west," and the control of relay, *D*, by the distant transmitter, *T′*, may be traced as follows. Suppose distant transmitter, *T′*, sends copper to the line when closed, the current dividing equally between the main and artificial lines in distant relay, *D′*, has no effect upon it; but at the west station there is no current in the artificial line in relay, *D*, so that the current in the main line closes it. Open the key, *K′*, and the line is grounded through the lever of transmitter, *T′*; battery *B′* is open, and there being no current on the wire, relay, *D*, is open in response to the opening of distant key, *K′*. Let transmitter, *T*, now be closed, and trace the control of relay, *D*, by the distant key, *K′*. The current, which now flows from the ground through the lever of open transmitter, *T′*, to the zinc pole of battery, *B*, is neutralized in relay, *D*, by an *equal* current flowing from the ground through its artificial line in the opposite direction around its cores, so that relay, *D*, remains open. Now close distant transmitter, *T′*, and the current in the artificial line (i.e., through the rheostat, *R*) of relay *D* is overpowered as to its effects by a current on the main line of twice its strength, and relay *D* is closed. It is thus shown to be controlled by the distant key, *K′*, irrespective of the position of home key, *K*, and the conditions necessary to duplex telegraphy are met.

QUADRUPLEX.

The *quadruplex* system of telegraphy allows of two messages being sent in either direction, over the same wire, and at the same time. In theory it is an arrangement of two duplexes, so different in principle as to permit of their combination for the purpose designated. If the accompanying diagram of the quadruplex is examined, there will be noticed in it the

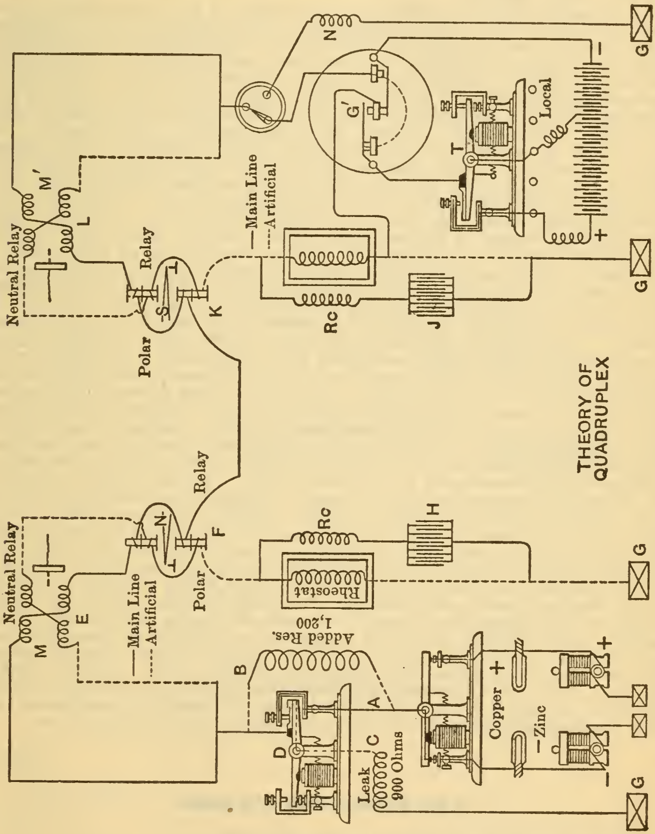


FIG. 11.

pole changer, polar relay, and all the apparatus of the polar duplex. The polar relay, K, at the "east" station will respond to signals sent by the pole changer, at the "west" in the manner described in the paragraph on the Polar Duplex, so long as the working minimum of current is maintained. This working minimum can be doubled, trebled, or quadrupled without appreciable difference to the polar relays. In the paragraph on Single Telegraphy, the operation of the single relay, fitted with a retractile spring, was effected by opening and closing the key; or, in other words, by alternating periods of "no current" and "current" on the wire. It was further stated, in anticipation of its introduction at this point, that the spring could be so adjusted that a weak current, though flowing all the time through the coils, would not close it. To effect the closing an increase of battery, and therefore of current strength, is necessary, so that the relay, instead of, as in the first instance, responding to alternating periods of "no current" and "current" could be operated by alternating periods of "weak current" and "strong."

The diagram, Fig. 11, illustrating the theory of the quadruplex, will be seen on examination to be a combination of the polar and Stearns duplexes, each of which has already been described. The operation of the Stearns duplex in combination differs from that described in connection with Fig. 10, only in that there is always on the wire a minimum of current sufficient to operate the polar side of the quadruplex; the neutral relays M and M', identical with that marked D in Fig. 10, are operated by alternating periods of "weak" current and "strong," after the manner of the Stearns. In practice the weak current is technically called the "short end"; the strong, the "long end"; and the diagram shows how, with different methods of current production, viz., the chemical battery and the dynamo, the proportioning of the current in the ratio usually of 1 to 3 is effected. The clock-face pole changer operates, as already described, to send when open (see diagram) copper to line and zinc to the ground; when closed, zinc to the line and copper to the ground. If the connections of transmitter T are traced it will be seen to admit to the pole changer one third of the battery when open, and the entire battery when closed; in other words, the movements of the transmitter determine a "short" or "long" end to line. At the left-hand terminal transmitter D effects a like result but by different means. In connection with the transmitter are two sets of resistance coils, so proportioned that when transmitter D is closed all the current from the dynamo goes to line; when open, one third of it goes to the line and two thirds is "leaked" off to the ground. One pole of each dynamo is grounded; the other is connected through a lamp to the pole changer in such a way that the rule "zinc to the line when closed, copper when open" holds good. The main line is shown in solid black; the artificial in dotted lines; the rheostats and condensers with their retardation coils marked RC are identical in principle with those shown in the polar duplex. In the diagram transmitter D with its companion pole changer is closed; transmitter T with its pole changer is open; the effect of these conditions is respectively to close relays M' and K, and to open relays M and F; the reasons for these results have already been set forth in detail in connection with the polar and Stearns duplexes, so that it is not necessary to repeat them here. In short, there is in the quadruplex a pair of polar relays which respond to changes in the *direction*, not in the strength of the current; and a pair of neutral relays, which respond to changes in the *strength*, not in the direction of the current. The diagram shows the apparatus in its simplest form; there are a number of details in connection with its operation, the complete connections for which are rather too complicated for this book. On page 199 of Mavers's *American Telegraphy* will be found a diagram embodying the full scheme of connections; and Thom and Jones' *Telegraphic Connections* contains diagrams and detailed descriptions of the systems in general use.

TELEGRAPH CODES.

Morse, used in the United States and Canada.
Continental, used in Europe and elsewhere.
Phillips, used in the United States for "press" work.

Dash = 2 dots.
Long dash = 4 dots.

Space between elements of a letter	= 1 dot.
Space between letters of a word	= 2 dots.
Interval in spaced letters	= 2 dots.
Space between words	= 3 dots.

Letters.

	Morse.	Continental.
A	. —	. —
B	— . . .	— . . .
C	. . .	— . — .
D	— . .	— . .
E	.	.
F	. — .	. . — .
G	— — .	— — .
H	. . . .	. . . .
I	. .	. .
J	— . — .	. — — —
K	— . —	— . —
L	——	. — . .
M	— —	— —
N	— .	— .
O	. .	— — —
P	. . . . .	. — — .
Q	. . — .	— — . —
R	. . .	. — .
S	. . .	. . .
T	—	—
U	. . —	. . —
V	. . . —	. . . —
W	. — —	. — —
X	. — . .	— . . —
Y	. . . .	— . — —
Z	. . . .	— — . .
&	. . . .	

Numerals.

	Morse.	Continental.
1	. — — .	. — — — —
2	. . — . .	. . — — —
3	. . . — .	. . . — —
4	. . . . —	. . . . —
5	— — —	. . . . .
6	. . . . . .	— . . . .
7	— — . .	— — . . .
8	—	— — — . .
9	— . . —	— — — — .
0	——	— — — — —

Punctuation, etc.

	Morse.	Continental.
. Period	. . — — . .	. . .
: Colon	— . — . . .	— — — . . .
:— Colon dash		
; Semicolon	. — . — .	— . — . — .
, Comma	. — . —	. — . — . —
? Interrogation	— . . — .	. . — — . .
! Exclamation	— — — .	— — . . — —
Fraction line	.	
— Dash		
- Hyphen		— . . . . —
' Apostrophe		. — — — — .
£ Pound Sterling		— . — . .
/ Shilling mark		
$ Dollar mark		
d Pence		

	Morse.	*Continental*
Capitalized letter		
Colon followed by quotation: "		
c cents		
. Decimal point		
¶ Paragraph	—— —— —— ——	
Italics or underline		- - —— —— - ——
() Parentheses	- —— - - ——	—— - —— —— - ——
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	Phillips.
. Period	- - —— —— - -
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:— Colon dash	—— - —— - —— - -
; Semicolon	- - - - -
, Comma	- —— - ——
? Interrogation	—— - - —— -
! Exclamation	—— —— —— -
Fraction line	-
— Dash	—— - - - —— - -
- Hyphen	- - - - - —— - -
' Apostrophe	
£ Pound Sterling	- - - - - - —— - -
/ Shilling mark	- - —— ——
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Abbreviations in Common Use.

Min. Minute.
Msgr. Messenger.
Msk. Mistake.
No. Number.
Ntg. Nothing.
N.M. No more.
O.K. All right.
Ofs. Office.
Opr. Operator.
Sig. Signature.
Pd. Paid.
Qk. Quick.
G.B.A. Give better address.

Bn. Been.
Bat. Battery.
Bbl. Barrel.
Col. Collect.
Ck. Check.
Co. Company.
D.H. Free.
Ex. Express.
Frt. Freight.
Fr. From.
G.A. Go ahead.
P.O. Post Office.
R.R. Repeat.

WIRELESS TELEGRAPHY.*

REVISED BY FREDERICK K. VREELAND.

IN consequence of the rapid changes which the art of wireless telegraphy is undergoing, it is impracticable to give here more than an outline of the principles involved, with descriptions of a few typical forms of apparatus. For further details the reader is referred to the more complete works on the subject.

Wireless Telegraphy, as it is practiced to-day, is based upon the fact that an electrical oscillating system, when suitably proportioned, may become the source of electromagnetic waves, which radiate through space like light waves, and which have the power of exciting oscillations in a conductor on which they impinge.

Electrical Oscillations. — The essential elements of an oscillating system are a capacity and an inductance, and means for charging the capacity and allowing it to discharge through the inductance. Fig. 1 represents such a system, in which the capacity C may be a Leyden jar, and the inductance L a coil of few turns of coarse wire. A is a pair of knobs separated by an air gap, and I an induction coil. When the coil I is set in operation the jar C is charged until its potential is sufficient to break down the air gap G. When a spark occurs, the air gap becomes a good conductor, and the jar discharges through the inductance L.

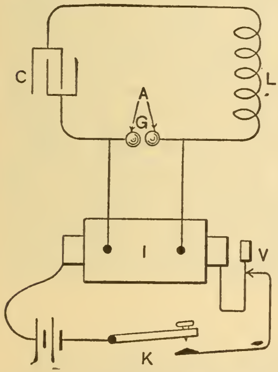


FIG. 1. Closed Oscillating Circuit Operated by an Induction Coil.

If the ohmic resistance is not too high the discharge is oscillatory, and the current surges through the circuit with a frequency

$$N = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}},$$

or, if R is small,

$$N = \frac{1}{2\pi\sqrt{LC}},$$

where

N = Frequency in cycles per second.
L = Inductance in henrys.
C = Capacity in farads.
R = Resistance in ohms.

If $R > 2\sqrt{\frac{L}{C}}$, N becomes imaginary, and the discharge is undirectional.

The frequency is usually very high; for example, if C = .005 microfarad and L = .02 millihenry, — figures which roughly represent the case cited, — N will be 500,000 cycles per second.

Electromagnetic Waves. — Such a closed circuit oscillator may produce very powerful inductive effects, but it gives off little energy in radiation. It may be converted into a good radiator by separating the conductors of the capacity, so that the electrostatic field which lies between

* Many of the illustrations for this chapter are taken from *Maxwell's Theory and Wireless Telegraphy*, by L. Poincaré and Frederick K. Vreeland, through the courtesy of the McGraw Publishing Company.

them may spread out into space instead of being concentrated in the glass of the jar.

Figure 2 shows an open circuit oscillator as used by Hertz in the discovery of electromagnetic waves in space. Here the capacity between the spheres S_1 and S_2, and the inductance of the short rod joining them, are both small, and the frequency is correspondingly high, say 50,000,000 cycles per second.

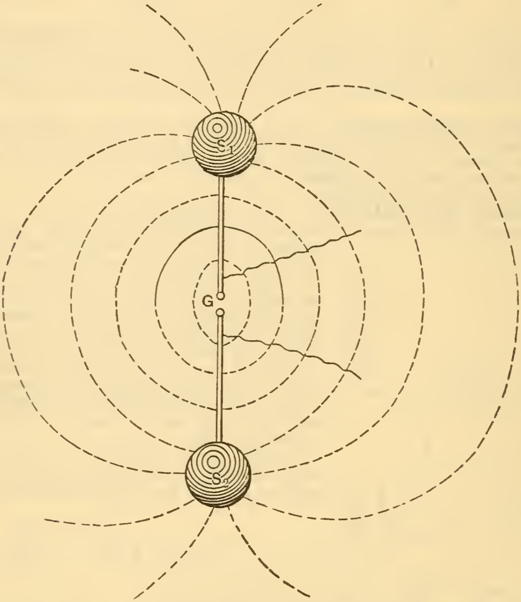


FIG. 2. Open Circuit "Dumb-bell" Oscillator, showing Electrostatic Lines at the Moment Before the Air-gap Breaks Down.

The high frequency combined with the open character of the circuit makes this oscillator a good radiator. The dotted lines (Fig. 2) represent the electrostatic field just before the air gap breaks down. When the spark occurs and the oscillations commence, these electrostatic lines shrink back

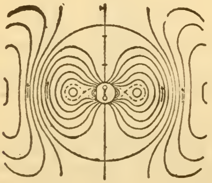


FIG. 3. Field surrounding a dumb-bell oscillator when in operation. At the moment illustrated the spheres are discharging and the lines within the large circle show the beginning of a half wave about to be detached. Outside the circle the preceding half wave is started on its journey through space. The oscillator is shown, greatly reduced, within the small circle. (After Hertz.)

into the oscillator; but the shrinking is so sudden that portions of them are snapped off, as it were, forming closed loops (Fig. 3), which go off into space with the velocity of light (300,000 kilometers per second) expanding vertically as they go, and carrying energy with them. This is repeated in each half oscillation, until all the energy is radiated or wasted in internal losses.

The rapidly moving electrostatic lines carry with them a magnetic field, whose lines of force form coaxial circles with centers in the axis of the oscillator, expanding continuously as ripples expand about a pebble thrown into the water. Their relation to the electrostatic lines is shown in Fig. 4.

This combination of electrostatic and magnetic fields, traveling outward with the velocity of light, constitutes an electromagnetic wave. When such a wave encounters a nonconducting obstacle it passes through it without interference, but if the obstacle be a conductor, the magnetic lines cutting it induce currents which absorb energy from the wave. If the obstacle be large, such as a sheet of metal, the wave is completely cut off and reflected as from a mirror; if the obstacle be a wire parallel to the axis of the oscillator, it becomes the seat of secondary oscillations, like those in the oscillator, but weaker. Any instrument capable of detecting these oscillations may be used as the receiver of a wireless telegraph system, of which the oscillator is the transmitter.

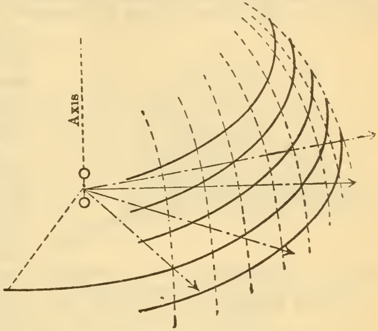


Fig. 4. A Portion of the Spherical Wave-front proceeding from an Oscillator. The Full Lines Indicate the Magnetic Force, the Broken Lines the Electric Force. The Direction of Propagation is Perpendicular to Both of these, and is therefore Radial.

The Antenna. — The Hertzian oscillator shown in Fig. 2 is operative only over short distances. The energy of the waves is limited by the small capacity of the oscillator, and waves of such high frequency are readily absorbed by obstacles. In actual practice the oscillator takes the form of a vertical wire or *antenna*, supported by a mast, and grounded at the lower end through a spark gap (Fig. 5).

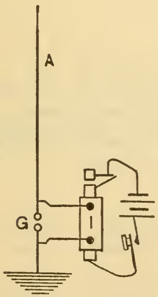


Fig. 5. Transmitter with Simple Antenna.

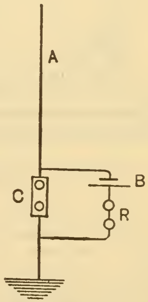


Fig. 6. Receiver with Simple Antenna and Coherer.

This is equivalent to half of a Hertzian oscillator, the lower half being removed and replaced by the earth. The capacity and inductance are distributed along the whole length of the wire, and the law of their distribution is such that the wave-length is four times the height of the antenna. Thus with a wire 50 meters high the wave-length would be 200 meters, and the frequency = velocity ÷ wave-length, would be $\frac{300,000,000}{200}$ = 1,500,000 cycles per second.

A free Hertzian oscillator emits free Hertzian waves, which travel through space like light. A grounded oscillator gives off grounded waves (Fig. 7). They are half waves, whose electrostatic lines, instead of being self-closed, terminate in the earth, to which they are inseparably bound. Instead of traveling always in straight lines, they must follow the contour of the conducting surface over which they slide, and so they may cross mountains or travel about the earth.

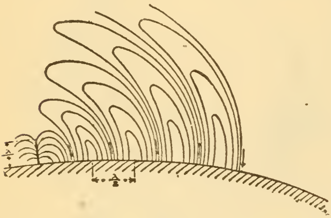


Fig. 7. Propagation of Grounded Waves from an Antenna over a Curved Surface.

In gliding over the conducting surface of the earth they are accompanied by alternating currents in the surface. These currents waste energy in overcoming the ohmic resistance of the surface, with the result of diminishing the intensity of the waves. For this reason the propagation is much better over water or moist ground than over dry or frozen ground whose resistance is high.

A further cause of attenuation of the waves exists in the space through which they travel. When the sun is shining the air becomes ionized, in which state it is partially opaque to the waves and they are more or less absorbed. Where the distance of signaling is great the difference between the strength of signals in the day and their strength at night is sometimes very marked.

With a grounded transmitter, a grounded receiver is used (Fig. 6). This is another vertical antenna A, with a detector C, connected in series near the ground. B is a battery and R a relay or telephonic receiver.

The Coherer. — One of the best known detectors of electrical oscillations is the coherer. A typical form is shown in Fig. 8. T is a glass tube in which are two tightly fitting silver plugs, E and E', attached to leading-in wires. The ends of the plugs are about .5 millimeter apart,

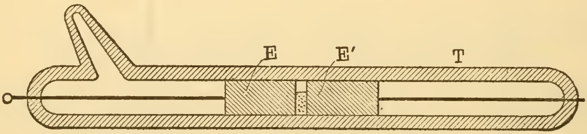


Fig. 8. Coherer — Longitudinal Cross Section.

and the space between them contains a mixture of silver and nickel filings, with sometimes a trace of mercury. The tube is then exhausted and sealed.

Normally, the filings lie loosely together, and present a high resistance. The coherer is practically open circuited, but under the influence of the electrical oscillations the filings cohere, and the resistance falls at once to a few hundred ohms. If the coherer be connected in circuit with a battery and a sensitive relay (Fig. 9), this drop in resistance will operate the relay and give a signal.

The filings continue to cohere after the cessation of the impulse that affected them, but they may be separated by a mechanical shock. Ordinarily an automatic tapper is arranged to strike the tube whenever the relay gives a signal, and so restore it to its sensitive condition, ready for the next impulse.

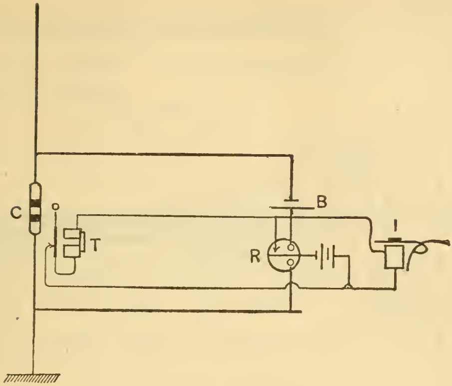


FIG. 9. Arrangement of Coherer *C* with Battery *B* and Relay *R* *I* is a Recording Instrument, and *T* an Automatic Tapper.

SYNTONIC SIGNALING.

A simple grounded antenna has a definite natural period of vibration, but its tendency to adhere to this period is weak, and it may execute forced vibrations over a wide range of frequencies. Thus a given receiving antenna will respond to the radiations of various sending antennæ, with only a slight preference for radiations whose period is the same as its own. Such an antenna constitutes a simple "responsive" system, which is adapted to use on shipboard or between ships and shore, where it is desirable that any station may communicate with any other station in the vicinity.

When a number of stations are so close together as to interfere with each other, a responsive system is not suitable, but the apparatus must be made selective, so that any given pair of stations may intercommunicate without interference from the others. The most usual way of securing selectivity is by applying the principle of Electrical Resonance or Syntony.

An electrical oscillating circuit may be so constructed as to make it a stiff vibrator, i.e., the positiveness of its vibration period may be greatly increased, so that it will respond readily to vibrations having its own natural period but will be little affected by impulses of a different period: just as a stretched string will respond to a sound to which it is tuned, but not to sounds of different pitch.

Damping. — The criterion of sharp resonance is a persistent oscillation in both transmitter and receiver. In the transmitter there is a certain initial supply of energy stored in the antenna or other charged condenser, and this energy is gradually expended in radiation or in resistance of the conductors and spark gap and other internal losses. The rate at which the stored energy is expended determines the "damping" or rate of decay of the oscillation. In the receiver, energy is received by the antenna and consumed in doing useful work in the detector, or wasted in ohmic and other losses. To secure a large resonant accumulation of energy, all these losses should be reduced to a minimum. In other words, the damping of both transmitter and receiver must be small. A simple antenna is a poor oscillator because its energy is radiated rapidly, and the amplitude of its oscillations decreased at a corresponding rate. The curve (Fig. 10) represents the strongly damped oscillation of a dumb-bell oscillator (Fig. 2) as determined by Bjerknes. The amplitude falls to $\frac{1}{10}$ of its initial value after nine oscillations. The oscillation of a simple grounded antenna may decay even more rapidly still, and this is why sharp resonance is impossible between two such simple oscillating systems.

A closed oscillating circuit (Fig. 1) may be made quite a persistent vibrator, as little energy is lost in radiation, and the damping of the oscilla-

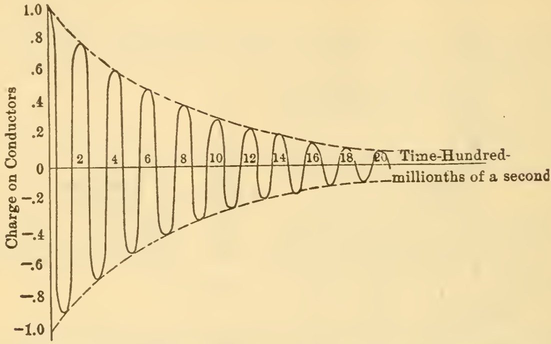


Fig. 10. Discharge Curve of Dumb-bell Oscillator.

tions is due mainly to the ohmic resistance of the circuit. The oscillation of such a system is represented by the equation

$$q = Q \frac{\sqrt{\beta^2 + \gamma^2}}{\gamma} \epsilon^{-\beta t} \cos(\gamma t + \alpha)$$

where t = time,
Q = initial charge of condenser, when $t = o$,
q = charge after time t,

$$\beta = \frac{R}{2L},$$

$$\gamma = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}},$$

$$\alpha = \tan^{-1} - \frac{\beta}{\gamma},$$

R being the resistance in ohms (or in absolute units).
L being the inductance in henrys (or in absolute units).
C being the capacity in farads (or in absolute units).

The expression $\cos(\gamma t + \alpha)$ determines the frequency of the oscillation, $N = \frac{\gamma}{2\pi}$, and is represented by a simple harmonic curve, while the exponential factor,

$$\epsilon^{-\frac{R}{2L}t}$$

determines the damping, and is represented by the logarithmic curve shown in dotted lines in Fig. 10.

For $t = T$, a complete period, the exponential term becomes

$$\epsilon^{-\frac{R}{2L}T}$$

which is the ratio of any two consecutive maxima. The exponent $\frac{R}{2L}T$ is the natural logarithm of this ratio, and is called the "logarithmic decrement." (According to the convention of some writers, the logarithmic decrement is defined as the logarithm of the ratio of two consecutive *turning points*, and hence has half the above value.)

In a persistent vibrator of high frequency the ratio $\frac{\beta}{\gamma}$ is small, and the equation may be written,

$$q = Q\epsilon^{-\beta t} \cos \gamma t,$$

or

$$q = Q\epsilon^{-\frac{R}{2L}t} \cos \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \cdot t.$$

This form is more convenient than the complete equation, and is sufficiently accurate for practical purposes.

Skin Effect. — The value of R as here used is quite different from the resistance as measured by ordinary methods, owing to the fact that such rapidly oscillating currents are confined to a thin superficial layer on the outside of the conductor. The thickness in centimeters of the skin measured to the point where the current density is $\frac{1}{\epsilon}$ of its value at the surface, is,

$$S = \sqrt{\frac{\sigma}{4\pi^2\mu N}},$$

where σ = specific resistance of conductor,
μ = permeability of conductor,
N = frequency of oscillation,

and the effective resistance of the skin is equivalent to the resistance for a continuous current of a shell whose thickness is,

$$S' = \frac{S}{\sqrt{2}} = \sqrt{\frac{\sigma}{8\pi^2\mu N}}.$$

For copper σ = 1600 C. G. S. units, and $\mu = 1$. If the frequency be 3,000,000 ~ per second the effective thickness S' of the equivalent shell will be .0026 cm. or about .001 inch.

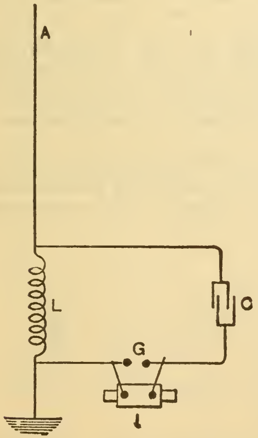


FIG. 11. Antenna with Closed Oscillating Circuit Directly Connected.

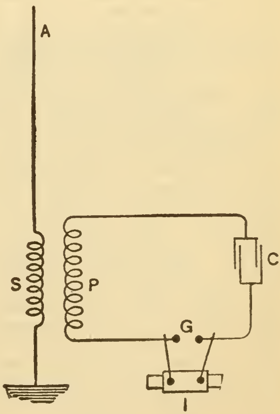


FIG. 12. Closed Oscillating Circuit Coupled to Antenna Through a Transformer.

Syntonic Apparatus. — Two closed circuit oscillators may exhibit very sharp resonance — a slight variation in the capacity or the inductance of either circuit will throw them out of tune — but they cannot affect each other at any great distance owing to their poor radiating and absorbing powers. To make them available for signaling, they are coupled, each to an antenna. The coupling may be effected by a direct electrical connection across an inductance coil or auto-transformer as in Fig. 11, or through an air-core transformer *PS* (Fig. 12). Such a compound oscillating system combines the virtues of its two component parts. The closed oscillating circuit stores energy in its large-capacity condenser to maintain the oscillation, and this energy is fed out slowly to the antenna, which radiates it into space. In the receiver, the process is reversed: the antenna absorbs energy from the passing wave train and communicates it to the closed resonant circuit, which is tuned to respond to impulses of the desired frequency.

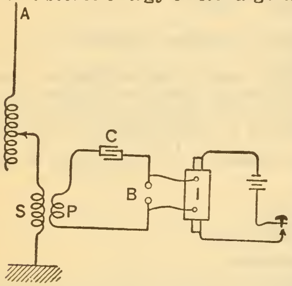


FIG. 13. Inductively Coupled Transmitter with Tuning Coil in Antenna Circuit.

To obtain the best results in both transmitter and receiver, the closed circuits should be tuned to the same natural frequency as their respective antenna circuits. For this purpose a variable inductance *L* (Fig. 13) is often placed in the antenna circuit, and thus a given receiver or transmitter may be tuned to a variety of frequencies, irrespective of the height of the antenna.

TRANSMITTERS.

The simple antenna system of Figs. 5 and 6 has been almost entirely superseded by the compound oscillating system, even where selectivity is not important, because of the far greater intensity of radiation that may be obtained with the compound oscillator. With the simple antenna the energy of a wave train, such as that illustrated in Fig. 10, consists entirely of the energy which is stored up in the antenna at the moment the spark occurs. This energy depends upon the capacity of the antenna and the potential to which it is charged. As the voltage that may be successively used is limited and the capacity of an antenna is comparatively small, the energy of the wave train is not sufficient to carry it over a long distance. Where a compound oscillator is used, however, the condensers may have a capacity many times as great as that of the antenna, and the power of the apparatus is greatly increased.

A typical form of transmitter with compound oscillating circuit is shown in Fig. 13, when *I* is an induction coil controlled by a sending key and discharging across a spark-gap *B*. *CPB* is a closed oscillating circuit comprising a battery of Leyden jars *C* and the primary *P* of an air-core transformer, whose secondary *S* is connected to the antenna *A* and to ground. Both primary and secondary of this transformer consist of a few turns of stout copper wire or cable, and the whole is immersed in a vessel of oil. *L* is an additional inductance coil, whose number of turns may be varied, inserted in the antenna circuit to facilitate tuning. By varying this inductance and the capacity of the condenser *C* the two circuits may be tuned in unison with each other and with the receiving apparatus.

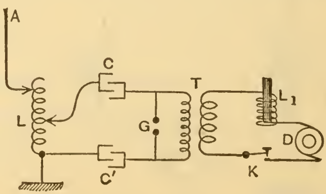


FIG. 14. Transmitter with A. C. Supply.

Transmitters with A. C. Supply. — A more powerful form of transmitter is shown in Fig. 14. Here the power is derived from an A. C.

generator D which feeds an ordinary A. C. transformer T wound for a secondary voltage of about 20,000 volts and immersed in oil. This takes the place of the induction coil of Fig. 13 for feeding the oscillating circuit $GCOC'$. The oscillating circuit is coupled to the antenna through a single coil L having adjustable terminals, which performs the double function of auto-transformer and tuning coil. It thus serves the same purpose as the transformer PS and the inductance L of Fig. 13.

If the alternator were directly coupled to the transformer shunted by a spark-gap the apparatus would not operate satisfactorily owing to its tendency to form a hot, low-frequency arc across the gap. As long as this arc continued it would be impossible to charge the condensers to a sufficient voltage to excite oscillations. To prevent this arcing a large adjustable self-induction L_1 is inserted in the primary circuit of the transformer. This chokes down any sudden rush of current when the air-gap breaks down

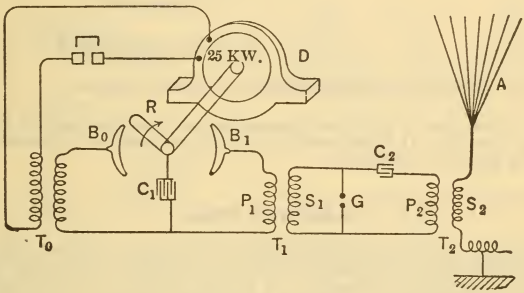


Fig. 15. High-power Transmitter.

and allows the arc to extinguish itself so that the condensers may be charged anew. When the apparatus is suitably adjusted it is possible to obtain several sparks to each alternation of the supply current.

High-power Transmitters. — Where very intense radiation is required, as in transatlantic work, still more powerful apparatus is used, such as that shown in Fig. 15. The source of power does not directly excite the active oscillating circuit, but is used to set up low-frequency oscillations in a primary oscillating circuit, which acts as a secondary source of power at high voltage to supply the active circuit. D is an A. C. generator whose voltage is stepped up to, say, 20,000 volts by the transformer T_0. R is a rotating arm geared to the shaft of the generator, and passing within sparking distance of two metallic sectors, B_0, B_1. When the arm comes opposite the first sector, B_0, a spark leaps across and charges a large condenser, C_1. When the arm reaches the second sector, B_1, this condenser is discharged through the primary, P_1, of an air-core transformer, T_1. Oscillations are set up in the primary oscillating circuit $C_1B_1P_1$, but they are of comparatively low frequency, owing to the large capacity and inductance of the circuit. They are stepped up to a very high voltage by the transformer, T_1, and serve to charge the smaller condenser, C_2, of the active oscillating circuit, C_2GP_2. This condenser discharges across the spark-gap G, and sets up a new series of oscillations, of the same high frequency as that of the antenna circuit, AS_2, to which the circuit C_2GP_2 is coupled by a second air-core transformer, T_2. The large condenser, C_1, is thus charged at a moderate voltage, and its energy is radiated at a suitable working frequency, which would be impracticable if the condenser were simply included in the working circuit in the usual way.

Ungrounded Transmitters. — The distinctive feature of this system is the fact that the antenna is not grounded (Fig. 16), but is connected to a capacity area *K*. This is made in the form of a metal cylinder with rounded

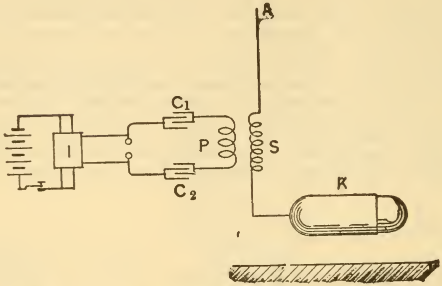


FIG. 16. Transmitter with Artificial Ground.

ends, made in two parts which telescope one over the other, so that its capacity may be varied. It forms with the earth a condenser, which serves the purpose of a ground connection.

RECEIVERS.

The principles which govern the design of a syntonic receiver are similar to those which obtain in the case of the transmitter, but their practical application is somewhat different. In the transmitter a considerable supply of energy is stored in a charged condenser, and this energy takes the form of powerful oscillating currents in the transmitter circuits. These currents are surprisingly heavy — an induction coil fed by a few cells of storage battery may generate currents of several hundred amperes, representing an activity of many horse-power. To carry such currents efficiently heavy conductors are required, and circuits of large capacity and small inductance are desirable in order that the requisite energy may be handled at practicable voltages. In the receiver, however, the amount of energy received from the incoming waves is exceedingly small, and the currents induced are correspondingly feeble. Where a coherer — a potential-operated device — is used for detecting the oscillations, the voltage applied at its terminals should be made as large as possible. Hence the oscillating circuits are made with small capacity and large inductance. and their ohmic resistance may be quite large without seriously increasing the damping of the oscillations. (See Fig. 17.)

But where the sharpest selectivity is required it is of the utmost importance to make the resistance as small as possible so as to diminish the damping, for a strongly damped receiver circuit is not only incapable of sharp resonance, but it requires a close coupling to the antenna circuit to secure the necessary strength of signals. The sharpest resonance is secured with a loosely coupled system, for there the oscillating circuit is comparatively free from the disturbing influence of the strongly damped antenna circuit; but loose coupling diminishes the intensity of the secondary oscillations, and requires a strongly resonant oscillating circuit to give readable signals. Usually a compromise is required, and the closeness of coupling is made adjustable by varying the distance between the primary and secondary coils, so that loose coupling may be used when the sharpest selectivity is required, or stronger signals may be secured by bringing the coils in closer inductive relation.

Coherer Receiver with Jigger. — This receiver (Fig. 17) is designed to give a high voltage at the coherer terminals. *A* is the receiving antenna, which is grounded through an inductance *L* and the primary J_1, of a transformer of special construction, which is called a "jigger." J_2 is the secondary of this transformer, to whose outer terminals the coherer T is connected. The secondary coil J_2 is broken in the middle and the inner terminals thus formed are connected to a condenser C, and also to the relay and recording apparatus.

The peculiar construction of the jigger is shown in Fig. 17, which represents half of the coil in longitudinal cross section. j is a glass tube on which is wound a single layer j_1 of primary winding. $j_2 j_2$ are the two halves of the secondary winding, which is represented diagrammatically, each of the zigzag lines on the diagram representing a layer of winding. The inner layer has the greatest number of turns, and the number of turns decreases in the successive layers to the last, which has only two or three turns. j_3 is the condenser, from which wires lead out to the relay and auxiliary apparatus.

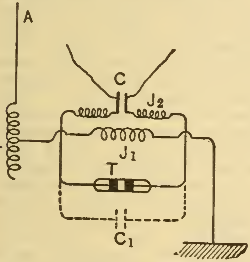


Fig. 17. Coherer Receiver with Jigger.

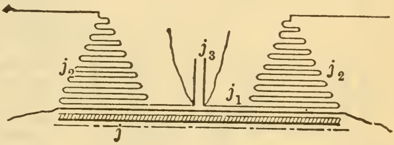


Fig. 18. Method of Winding Jigger.

The secondary winding has a large number of turns of fine wire, and its distributed capacity and inductance are such that it has a natural period of vibration, when connected to the coherer, equal to that of the antenna circuit and of the incoming waves. It is thus, to a certain extent, syntonic in its action, and it has the further advantage of stepping-up the voltage of the receiver oscillations and thus increasing their effect on the coherer. As the capacity of a coherer is a rather uncertain and variable quantity, a condenser C_1 is sometimes shunted across its terminals to make the apparatus more definitely selective.

Receiver with Low-resistance Detector.—The peculiar arrangement of the last-described receiver is due to the practically open-circuit character of the coherer. When low-resistance detectors are used they may be inserted in series in a simple resonant circuit as shown in Fig. 19. M is an air-core transformer whose primary coil is connected in series with the antenna, A. The secondary is connected in a closed oscillating circuit including the condenser C, which is preferably adjustable for purposes of tuning, the detector D and sometimes an additional inductance coil L. The transformer M is preferably a loosely coupled one, as the low-resistance character of the oscillating circuit permits comparatively strong resonant currents to be induced by a feeble electromotive force. The coils are usually mounted so that the distance between them may be varied, to adjust the coefficient of coupling.

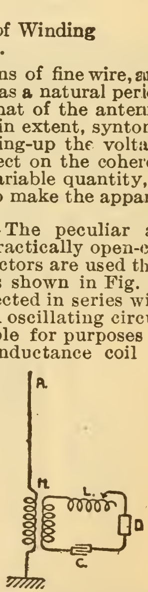


Fig. 19. Receiver circuits with Detector in series.

Receiver with Shunted Detector.—Another arrangement, which permits a high degree of selectivity while not requiring a detector of especially low resistance, is shown in Fig. 20. Here the oscillating circuit SC is closed upon itself and the detector D is shunted across the condenser. This arrangement may be adapted to detectors of widely varying characteristics; thus, if the detector is one which requires a high voltage to operate it, the condenser C is made of small capacity and the inductance is made correspondingly large. If, on the other hand, the detector has comparatively low resistance, the oscillating circuit is made of large capacity and low resistance, so that it may be robbed of considerable current without greatly increasing the damping. The particular detector shown in the figure is the electrolytic ("polariphone") cell described below. *B* is a local battery and *F* is a potentiometer for adjusting the voltage applied to the cell. *C'* is a large condenser which permits the flow of the oscillators to the detector while preventing the short-circuiting of the battery through the coil *S*.

DETECTORS.

Anti- and Auto-Coherers. — Besides the typical filings coherer above described, many other forms of coherer have been devised. Some owe their distinctive characteristics to the material of which they are made. For instance, if carbon grains be used instead of metallic filings the operation of the coherer is reversed, i.e., the apparatus is normally a fairly good conductor, but on the receipt of a signal its conductivity is destroyed. Detectors of this type are called *anti-coherers.* The De Forest "Responder" acts in a similar manner. Two electrodes of tin or other suitable metal are immersed, close together, in a poorly conducting liquid, such as glycerine containing a trace of water, in which are suspended minute particles of metal. Under the influence of a local battery these particles form conducting bridges or "trees" reaching across between the two electrodes, and completing the circuit through the battery and a telephone. When oscillations are passed through the apparatus the bridges are disrupted, the conductivity is destroyed, and a sound is produced in the telephone.

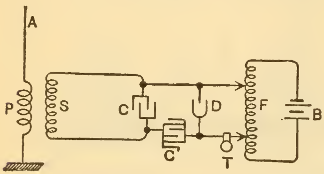


Fig. 20. Receiver Circuits with Shunted Detector.

Other modifications have for their object the abolition of the tapper, and give rise to the class of *auto-coherers,* whose action is entirely automatic. A globule of mercury in light contact with electrodes of iron or carbon constitutes an effective form of this device.

Various mineral substances also have been found to be more or less effective as detectors of high-frequency oscillations. For example, if a crystal or fragment of carborundum magnetite or metallic silicon be clamped between a pair of metallic terminals its resistance is altered when the oscillations are caused to pass through it. When properly constructed such detectors are quite sensitive.

An improved form of mercury auto-coherer is shown in Fig. 21. A disk of steel *a* rotates in light contact with a globule of mercury *b* contained in a

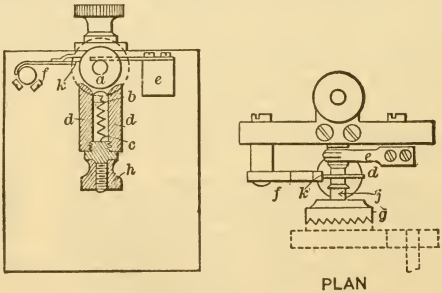


Fig. 21. Mercury Auto-Coherer.

cup *d*, which constitutes one terminal of the apparatus. The spring *e*, bearing on the shaft *j* which carries the disk *a*, constitutes the other terminal. The disk *a* is normally separated from the mercury by a thin film of oil, but under the influence of oscillations the insulation is broken down and the circuit is completed through a telephone or a siphon recorder. The steel disk is rotated by clockwork so as to present a continuously fresh surface to the mercury, and to break the contact as soon as the signal ceases. The edge of the disk is kept clean by a wiper *k*.

Magnetic Detectors. — A very sensitive detector has been produced by utilizing the changes in the magnetic state of iron which are

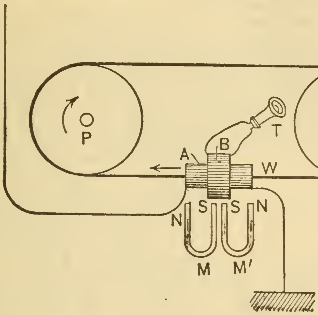


Fig. 22. Magnetic Detector.

caused by rapidly oscillating currents. If a core of iron wires be placed in a slowly varying magnetic field, the magnetization will lag behind the magnetizing force on account of the hysteresis, or "magnetic friction," of the metal. But if a rapidly oscillating current be passed through a coil surrounding the iron, the hysteresis is reduced and a sudden change in the magnetization occurs. This change in magnetization may be caused to induce an E.M.F. in a second coil surrounding the core, and thus operate a telephone receiver in series with this coil.

Fig. 22 shows one form of the apparatus. *W* is a stranded belt of fine iron wires passing over the pulleys *PP′*, which are driven by clockwork. *MM′* are permanent magnets which supply the field to induce a continuously varying magnetization in the moving core *W*. *A* is a coil of copper wire through which the oscillations are passed, encircling the core *W*, and *B* is a second coil in which currents are induced to operate the telephone *T*.

Electrolytic Detectors. — Another detector, which is extremely sensitive, depends for its operation on the changes in polarization of a specially constructed electrolytic cell which are caused by oscillations passing through it. The cell (patented by Andrew Plecher) consists of a minute anode of insoluble material such as platinum, and a larger cathode, immersed in a suitable electrolyte. When such a cell is connected across a source of E.M.F. greater than the decomposition E.M.F. of the cell, a current will flow and the cell will become polarized, opposing a counter E.M.F. to the passage of the current. If the E.M.F. across the cell be so adjusted that the cell is polarized to the proper critical point, it becomes remarkably sensitive to external impulses. The oscillations from an antenna passing through it have the effect of partially or completely depolarizing the minute anode, and a large momentary increase in the local current occurs, with the effect of repolarizing the cell to its sensitive point, ready for the next impulse. These changes in the local current are used to operate a telephone or other receiver.

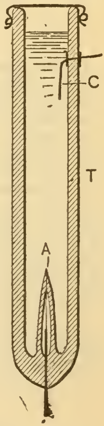


Fig. 23. Electrolytic Detector — Cross Section.

A convenient form of the cell is shown in Fig. 23, and the connections of its battery, etc., are shown in Fig. 20. *T* is a glass tube containing the electrolyte, *C* is the cathode of stout platinum wire, and *A* is the minute anode, both sealed by fusion into the glass. The anode is a fine platinum wire, .001 inch diameter or even less, sealed into the capillary tip of a small glass tube and then ground down flush with the surface of the glass, leaving only the end exposed. The area of anode surface is thus of the order of a millionth of a square inch. In the connection diagram (Fig. 20) *D* is the detector proper, *F* an adjustable inductive resistance or potentiometer, to regulate the voltage, and *T* a telephone.

Hot-Filament Detectors.— Another type of detector owes its existence to the peculiar properties of an incandescent body when placed in a rarified gas. Under such conditions the incandescent body emits negatively charged corpuscles or electrons, which are free to move about in the rarified gas, thus rendering it a more or less good conductor. If, for example, an incandescent lamp filament be mounted in its exhausted bulb in close proximity to a plate of metal connected to a third terminal, and a battery be connected between this terminal and one of the terminals of the filament, a current will flow from the battery through the gas. If now electrical oscillations be caused to pass through the tube between the filament and insulated plate, the conductivity of the tube is altered and variations of the current from the battery occur corresponding to the presence or absence of the oscillations. Fig. 24 shows a hot-filament detector *D*, connected across the condenser *C* of a closed oscillating circuit *SCC'*, which in turn is coupled to the antenna *A* through a transformer *PS*. The filament of the detector is heated by a battery *B* and the local receiver circuit, including a second battery *B'* and a telephone receiver *T*, is connected between the insulated plate *W* and the positive terminal of the filament.

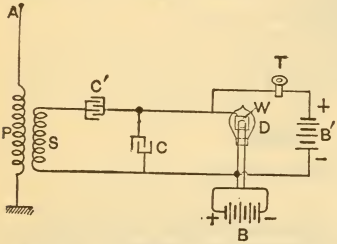


Fig. 24. Hot-Filament Detector.

Undamped Oscillations.

It has been pointed out above that a prime requisite of a selective signaling system is a transmitter whose oscillations are not strongly damped. An ideal transmitter for this purpose is one in which the oscillations are absolutely undamped; that is, they are high-frequency alternating currents of constant intensity. Such a transmitter, besides making possible the highest degree of selectivity, possesses other advantages: for example, the continuous character of the oscillations enables a given amount of energy to be transmitted at a very much less intensity than is required with a strongly damped oscillator, which emits very intense radiations for a brief space of time, with long intervals of inactivity when no energy is radiated at all. Furthermore, the radiation from an undamped oscillator, being continuous, may be stored up cumulatively in the receiver, so that a signal of very feeble intensity maintained for a comparatively long time will have a relatively powerful effect on the receiver.

All these and other considerations point to the undamped oscillator as an important factor in the future of wireless telegraphy. Already such oscillators have been produced and applied to practical work, but it is impracticable in this section to discuss them in detail.

TELEPHONY.

REVISED BY J. LLOYD WAYNE, 3D.

THE electric speaking telephone was invented by Alexander Graham Bell (then of Boston) in 1876. While exciting great interest in scientific as well as popular circles, it bade fair to be little more than a scientific toy until the intercommunicating or exchange idea was brought forward. It is in this connection that the telephone is of primary importance to-day, the number in use running well into the millions.

Scope of Word Telephone. — At first a single instrument of Bell's type at each end of the line served all purposes. Now commercial telephony has rendered it necessary to universally associate with these primary instruments several other pieces of apparatus, and the scope of the word telephone has been broadened to include all this allied apparatus of the telephone or subscriber's set.

Requirements for Operation. — The fundamental problem of the telephone is really more one of acoustics than of electricity, and because of this all attempts to solve the problem failed until it was approached from a purely acoustic standpoint. In order to understand the requirements of operation it is necessary to understand the nature of sound and speech.

Sound is propagated by means of vibrations of a purely physical nature, the vibrations of the various particles of the sounding body being so timed

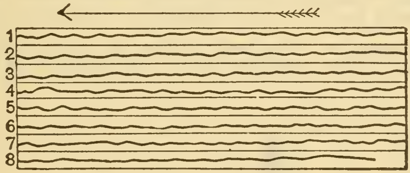


FIG. 1. Phonogram of the Word "Hello."

that there results a progressive wave motion. It is such a wave motion impinging upon the ear-drum and forcing it into a sympathetic vibration that is recognized as sound. Sound has three fundamental properties, — loudness, pitch, and timbre or quality. Loudness depends upon the energy of the vibrations, pitch depends upon the rate of vibration — thus, the vibrations per second — while quality depends upon the kind of vibration the individual particles are performing.

If the character of the vibrations is such that the wave follows a simple sine law, a fine tone is produced. Every other kind of sound is produced by a wave more complicated than that of a pure tone. Each source of sound produces a wave form characteristic of that sound. Sounds vary in quality from the pure tone to the most discordant noises, but there is no generally recognized point of transition from one to the other.

Speech consists of a proper combination of many sorts of sounds varying from pure tones to mere noises and hisses, intermingled in a proper order, and each given a proper relative pitch.

The requirements for operation of the telephone are that any series of sounds spoken at one end of a line shall be transmitted to the other end and there given out correct in relative pitch and in quality. The term relative pitch is used, as a corresponding change in the pitch of all sounds has no distorting effect more than the difference between a low-pitched and high-pitched voice. Loudness is also of little moment, so long as sound leaves the receiver in sufficient volume to be heard.

Means of Transmission. — With the electric telephone, transmission is accomplished by means of electric current waves sent out along a conducting line from the station at one end to that at the other end. For perfect transmission such electric waves are exact equivalents, except in energy, of the sound waves producing them, the strength of the electric current having at each instant direct relation to the sound vibrations. The periodicity of the current waves must at each instant correspond to the pitch of the sound, while the succeeding instantaneous magnitudes of the current must be such that the quality factor of the sound waves is virtually pictured electrically. From this it will be evident that the telephone current is a vibratory or alternating current of extremely complex character. This must be continually borne in mind as one of the most essential factors to be contended with in telephone transmission. All the properties of alternating currents, of power magnitudes, and frequencies bear directly upon the subject of telephone transmission in greater or lesser degree.

ELEMENTS OF TELEPHONE SET.

The telephone set, in addition to the various enclosing boxes, the mounting backboards and wiring, usually includes the following elements:

1. Receiver or telephone proper.
2. Transmitter and current supply.
3. Induction coil.
4. Hook or automatic switch, or a hand switch.
5. Call receiving apparatus.
6. Call sending apparatus.

The design and function of these elements differ materially for different systems. In some cases it is even practicable to dispense with one or even two of them.

The Receiver. — The Bell receiver is universally used, it being thus far the only really practicable type. It consists of a permanent mag-

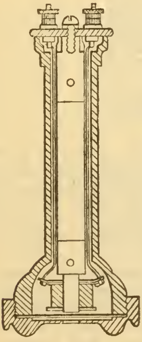


FIG. 2. Single Pole Receiver.

FIG. 2a. Magnet of Single Pole Receiver.

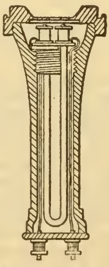


FIG. 3. Double Pole Receiver.

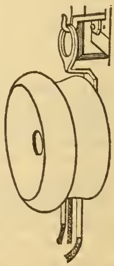


FIG. 4. Watch Receiver.

net of bar steel, either straight or U-shaped, so mounted as to exert a polarizing influence upon an electromagnet, before the poles of which latter an iron diaphragm is mounted. For convenience these elements are assembled within a casing of one of the well-known forms, such as shown in Figs. 2, 3, and 4.

In all commercial forms, the electromagnets are made quite short and are mounted directly upon the permanent magnet. The cores are of soft iron and are almost completely covered by the coil. In single-pole receivers (see Fig. 2), but one end of the bar magnet is used, one coil and extension pole sufficing. For such the permanent magnet is usually compound, and the coil and pole circular in section. In double-pole receivers (see Fig. 3) both poles of the permanent magnet carry soft iron extensions, both cores and coils being of oblong section.

The soft iron diaphragm of circular shape about $\frac{1}{40}$ of one inch in thickness and 2 to $2\frac{1}{4}$ inches in diameter is secured by its edges in a manner to clear the soft iron extension cores from $\frac{1}{64}$ to $\frac{3}{64}$ of an inch. The magnet thus exerts a continual pull upon the diaphragm, tending to distort it, concave inwards. When the alternating telephone currents are admitted to the receiver coil, part of each wave assists the permanent magnet by its electromagnetic influence, increasing the attraction and causing the diaphragm to further approach the magnet. That portion of the current of opposite sign detracts from the magnetic pull and allows the diaphragm to recede from the magnet. The diaphragm thus takes up a vibratory motion corresponding to the electrical waves supplied to the coil, and it imparts motion to the surrounding air, which results in sound waves.

Receiver casings are of various shapes, the shape being determined by the size of the parts and the dictates of convenience. The most usual form is the hand type shown in Figs. 2 and 3. The second common type is the "watch-case receiver" shown in Fig. 4 and used where a small instrument is required. Lastly, there is the head telephone, in shape much like the watch-case receiver, but provided with a spring head band to hold it to the ear, leaving the hands free. The shape of the air space between the diaphragm and the aperture in the ear-piece of a telephone is of prime importance. This air space is now universally made shallow, from $\frac{1}{32}$ inch to $\frac{1}{16}$ inch in depth, and of an area nearly equalling that of the diaphragm. A relatively small hole connects the air space to the outside air.

Many kinds of receiver are now manufactured and are upon the market. Detailed descriptions of these may be found in the trade catalogues, the later works on the telephone, and in a series of articles by A. V. Abbott in the *Electrical World and Engineer*, Vol. XLII.

Magneto Transmitters. — The ordinary receiver will also operate as a transmitter, and it was thus originally used by Bell. It is so miserably inefficient in this rôle, however, as to have been almost immediately superseded by the battery transmitter. There are, however, some house-telephone systems and private lines which employ two Bell instruments in series, as receiver and transmitter respectively. When so used the diaphragm of the transmitting instrument should be much heavier and larger than for receivers if the best results are to be produced. At times the operation of the receiver as a transmitter is of material advantage, as one may so use it by talking sufficiently loud, when the regular transmitter is out of order and unusable. In this case it is, of course, necessary to shift the receiver from ear to mouth and *vice versa*, as the case demands.

Battery Transmitter. — The battery transmitter depends for its operation upon what is known as the microphonic action of a loosely formed electrical contact. It is found that if a source of steady or constant electric potential, such as a battery, be applied to a loose contact, within limits the current which will flow will be in exact proportion to the pressure between the contact points. If, therefore, one contact point be held stationary and the second be clamped lightly between it and a diaphragm vibrating under the influence of a sound, the pressure between the contact points will vary with the motions of the diaphragm to produce current fluctuations exactly corresponding to the sound vibrations. It was at once found that under no circumstance must an actual rupture of the circuit be allowed to occur at the loose contact. It was also found that carbon of all conductors could be subjected to the greatest extremes of pressure within the range of true microphonic action, and because of this property it is largely used for transmitter electrodes.

Single-Contact Transmitter. — Of the early successful transmitters, the Blake is by far the most important, obtaining at one time almost universal use, although it is now almost obsolete. In this transmitter the microphonic action took place at a single contact point between a globule of platinum, driven by the diaphragm, and a button of carbon.

Both electrodes were spring-mounted, tending to bear against each other normally, this tendency being augmented by the pressure of the diaphragm. While excellent for clearness, the Blake transmitter could be used for but comparatively short lines, because of the fact that its contact is only suitable for comparatively weak currents. A good idea of the arrangement of the parts of this transmitter may be obtained from Fig. 5.

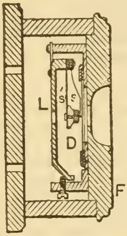


FIG. 5. Section of Blake Transmitter. *D*, diaphragm ; *S*, carbon spring ; *S'*, platinum spring; *L*, iron bracket; *F*, adjusting screw.

Multi-Contact Transmitters.— The multiple contact transmitter of the Rev. Mr. Hunnings was the successor of the Blake transmitter. This transmitter having undergone numerous modifications and improvements culminated in the "Solid-Back" type, developed by Anthony White.

In all transmitters of the Hunnings type the microphonic button consists of two electrodes, between or surrounding which is a mass of granulated carbon approaching gunpowder in appearance. The electric circuit is from one to the other electrode through the granular mass. As long as the granular carbon is kept in a condition of looseness or "lightness," such a transmitter with its multitude of microphonic contact points, some in series and some in parallel connection, is ideal. The resistance of such a transmitter is capable of a change, many times that of a single contact, it being practically impossible to actually break the electric circuit. Unfortunately it has proved to be almost impossible to keep the mass of granular carbon in a loose condition, there being a tendency to a "packing" which rapidly reduces the efficiency. The solid-back transmitter largely owes its success to its ability to withstand this packing tendency.

Description of "Solid Back" Transmitter.—The casing of the transmitter is usually the only part in view, the operating parts being within it. The transmitter front is supported by the gong-shaped back, and carries all the parts. This front is very stiff, and the mouthpiece of hard rubber screws into it. The aluminum diaphragm lies in a receptacle cut for it in the rear of the front. This diaphragm has a rubber band snapped over its periphery, an anulus of rubber being thus formed upon each face of it. This provides an insulated cushion seat for the diaphragm. Damping springs with soft rubber cushions at their tips, serve to hold the diaphragm securely and at the same time prevent its assuming any but forced vibrations.

In Fig. 7 is shown the various parts of the microphone button. The electrode chamber is formed out in a single piece, an insulating lining of varnished paper covering its cylindrical side walls. The back electrode is composed of a carbon disk soldered to brass mounting piece, the finished piece being secured in the bottom of the chamber by its screw stud. The front electrode is also a disk of carbon soldered to a brass mounting, and an auxiliary diaphragm of mica is provided to carry it and at the same time seal the chamber. The mica diaphragm *m* is perforated and slips over the shoulder *p*, being clamped by the nut *u*, which screws down upon the shoulder.

The chamber is now charged with granules, the front electrode is placed in position and the edge of the auxiliary mica diaphragm clamped tightly by the clamp ring *c*, which screws down upon the chamber. The granules of carbon are insulated from the side walls of the chamber and the front electrode is insulated by the mica mounting, so that an electric circuit may be led through the button from electrode to electrode.

The completed button is now secured between the main diaphragm and a heaving bridge piece which spans the receptacle in the rear of the front piece. The stud *W* (Fig. 6) has a seat in the bridge, while the front electrode is secured to the center of the diaphragm by the stud and nuts shown in Fig. 6. When everything is adjusted, a set nut clamps the stud *W* in place. A small flexible insulated wire extends from the front electrode to an insulated terminal upon the bridge piece, the metallic body serving as a terminal for the rear electrode.

The vibrations of the diaphragm are communicated to the front electrode by the pin, which forms a rigid connection between them. The electrode, having a certain freedom of movement within the little chamber, varies the pressure on the layer of carbon granules between it and the back electrode thereby setting up the usual variation of resistance required in a carbon transmitter. The design of the instrument is very good. The two electrodes, being of carbon, highly polished, make excellent contact with the carbon granules, thus affording the best opportunity for wide variation of resistance under vibration, while the carbon electrodes, being soldered to brass disks, have good metallic contact obtained with the two sides of the primary circuit. The "packing" difficulty is nearly obviated in this form of transmitter. The space in the chamber is but partially filled with carbon, and the space around the edges of the electrodes contains a certain quantity of it, which is not directly in the circuit, and does not become heated by the current. Any expansion of the granules immediately between the electrodes through heating causes a displacement of part of the heated carbon into the cooler. When the transmitter is out of circuit and cools off, the granules tend to resettle into their original position.

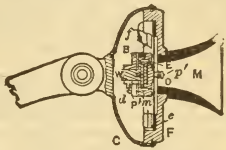


FIG. 6. Section of Solid-Back Transmitter. *M*, mouthpiece; *D*, diaphragm; *E*, front electrode; *B*, back electrode; *W*, electrode chamber; *P*, metal bridge piece; *d*, set screw; *m*, mica washer; *p*, threaded pin on front electrode; *e*, rubber band; *f*, damper; *C*, case; *F*, cover.

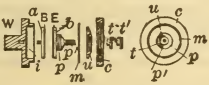


FIG. 7. Details of Solid-Back Transmitter. *W*, electrode chamber; *i*, insulating lining; *B*, back electrode; *a*, brass backing; *E*, front electrode; *b*, brass backing; *p*, thread for nut *U*; *m*, mica washer; *u*, nut for clamping *m* in place; *p'* thread for *t* and *t'*; *c*, cover of *W*; *TT*, nuts for clamping front electrode to diaphragm.

The chamber containing the working-parts of the instrument is extremely small. By unfastening the screws which hold the cover, the entire transmitter can be withdrawn, the connecting cord joined to the insulated binding-post having first been disconnected. On account of the smallness and delicacy of the parts, great care is required in handling the transmitter when assembling or taking apart. When properly set up, it needs no adjustment; and indeed there is nothing that can be adjusted unless some radical defect exists. Figs. 6 and 7 show the details of construction by means of a section of the transmitter mounted, and a section of the various parts of the chamber, and a front view of the chamber.

The following dimensions give an idea of the sizes of the parts of the carbon button of the solid-back transmitter.

Separation of electrodes	.05 inch.
Diameter of front electrode	.66 inch.
Diameter of back electrode	.69 inch.
Diameter of chamber	.75 inch.
Thickness of paper lining	.005 inch.
Thickness of mica diaphragm	.010 inch.

Weight of carbon granules used — Approx. 400 mgms.
Diaphragm of aluminum, $2\frac{1}{2}''$ dia., $.02''$ thick, varnished on one side.

The solid-back transmitter is most efficient when the diaphragm is in a vertical plane, but the efficiency is not much changed so long as the displacement from the vertical is not great. As the diaphragm approaches the horizontal position the transmitter not only loses its efficiency, but there will be much confusion and distortion of the sound, and at times the transmitter may be wholly disabled, the cause of this being that the chamber is but partially filled with granules, and the carbon may fall almost or entirely away from the upper electrode.

Commercial "Solid-Back" Transmitter.— The solid-back transmitter manufactured by some companies for the open market is practically a duplicate of the above, except as to unessential details. One notable exception is the inverted type of solid back devised by Mr. W. W. Dean. In this transmitter, the carbon retaining chamber is formed in the diaphragm, and, therefore, there is introduced by the vibration of the latter an additional tendency to shake up the carbon granules. In detail design and size of parts this transmitter adheres closely to the Bell "Solid-back" model.

"Corn Plaster" Type.— Another type of granular transmitter considerably used but not so good as the preceding, is that employing a felt washer as the containing chamber for the granular carbon.. Such a transmitter depends upon the elasticity of the felt to permit of the relative motions of the electrodes which close the chamber at the front and rear respectively.

"Packing and Unpacking."— A packed transmitter may be recognized by the dullness of the transmitted tone, the life being so far taken out of the tone at times as to render the words indistinguishable. To unpack a transmitter a slight jarring will at times suffice, this being best accomplished by striking the casing sharp, light blows with a hard object. The best transmitter may be packed by pulling the diaphragm forward either manually or by closing the mouthpiece with the lips and sucking. To avoid such abuse of the transmitter, mouthpieces are now provided with gratings in the front and air ducts at the base.

How to Use a Granular Button Transmitter.— The electrodes of the transmitter should always be in a nearly vertical plane. The lips should be placed close to the transmitter and the voice directed into the mouthpiece. As the weight of the parts to be moved is considerable, a large proportion of the energy of the voice must be expended upon the diaphragm. When used properly, a tone of voice, such as used in ordinary conversation. should be amply sufficient, and of this scarcely any need escape to the surrounding air.

Induction Coil.— When the battery transmitter was first introduced it was planned to connect it directly in the line in series with the battery and receiver. In this connection the total allowable resistance change in the transmitter is very small in comparison with the total line resistance, and therefore the corresponding current changes in the receivers are small and of little effect. Furthermore, the longer the line, the less proportional part of the total resistance is the changeable part of the transmitter resistance, and thus the longer the line, the less the possible transmitting effect.

To obviate this difficulty Edison introduced the induction coil connecting the transmitter and battery in circuit with the low-resistance primary and connecting the secondary in series with the telephone and line. With this arrangement, not only is the variable transmitter resistance made a large proportion of that of its circuit and this proportion made invariable with the length of the line, but also, by making the number of turns in the secondary winding large in comparison with those of the primary, the generated secondary voltage is made quite high, and thus suitable for long lines. There is yet another effect; viz.: the variable current of the transmitter circuit becomes transformed into a true alternating current.

Construction of Induction Coil. — The induction coil is almost invariably of the open magnetic circuit type. The core is composed of a bundle of annealed iron wire, upon which is wound the primary, usually of comparatively heavy, insulated copper wire, while the secondary of fine wire surrounds this.

Design of the Induction Coil. — Thus far no general method of computing induction coils has been developed, the best design for any work being found by a "cut and try" method. Usually each manufacturer has determined by a series of experiments, more or less elaborate, that a certain induction coil will give good results when coupled with his transmitter and receiver. He will then use this coil until something better is happened upon. Very few comparative tests of induction coils are upon record, and such as are, give no clew to any relation whatever between good transmission and the physical dimensions and electrical constants of the coil.

HOOK SWITCH.

After attempting in vain to use as a means of calling greatly magnified currents of the telephone type, produced by over-exciting the transmitter, there remained but two alternatives. Of these, one was to parallel the telephone line with a calling line, each line to carry currents of its own type; while the second was to use the telephone line in a double function, switching upon the ends either calling or talking apparatus as desired.

This latter method was used, hand switches being adopted until the forgetfulness of users proved that such were most unreliable, a talking and a calling apparatus being frequently inadvertently left connected together in a manner to defeat the whole system. The hook or automatic switch proved a fairly satisfactory means of overcoming this difficulty, being to-day in almost universal use. In the first place the switch lever is pronged to form a support for the receiver, and it should furthermore be about the only visible means of support for the receiver. When the weight of the receiver is upon the prongs, the lever is depressed so that the calling apparatus alone is connected to the circuits. On the other hand, when the hook rises in response to a spring, the receiver being removed, the switch operates to connect in the talking circuits.

Design of Hook Switches. — Hook switches are of many designs, each manufacturer producing his preferred idea. Many are of equal efficiency. The main points to be considered, are: first, to have the switch springs perform exactly the functions desired; second, to be sure that they perform no accidental and detrimental functions; third, to have the motion of the springs limited by positive stops; fourth, to be sure that the weight of the receiver is ample to actuate the switch; fifth, to have a sliding motion at the points of contact which should preferably be platinum tipped; and, sixth, to have the hook prongs so shaped as not to injure the receiver. In explanation of these points, it may be said that in usual systems, the switch lever on rising must connect two contact points to a third in common, as will be seen from later circuit sketches. In the depressed position sometimes it is merely necessary to break this connection, and sometimes in addition necessary to make a third connection. As to positive stops it may be said that when switch springs are allowed to come to a position of rest due to their own set, they are quite sure in time to have the position of normal set sufficiently disturbed to disarrange the apparatus. A sliding motion of the contacts over each other is desirable, as the contacts thus become largely self-cleaning. As to the hook prongs, it has probably been noted that nearly all are now provided with ring ends which cannot be forced against the receiver diaphragm.

CALLING APPARATUS.

Calling apparatus has been worked out upon several complete systems. The most obvious one, employing direct current from a battery with push buttons and vibrating bells, while still holding its own for the very short lines of some house systems and for toy lines, has proved unsuited for commercial telephony. This system will therefore be ignored here, but it will be mentioned in the sections on House or Interior systems.

For general commercial working the polarized bell, sensitive to alternating currents, has proved to be the best. To produce the alternating currents for actuating it, a magneto generator, *i. e.*, a dynamo having permanent magnets for fields, was long ago adopted, and this fact has given the name to this system, *viz.*, the "Magneto" system. Recently a calling system, a combination of battery and magneto calling has been extensively adopted. With this system, calls for the stations are made by means of the polarized bell with alternating current, while calls towards the central or interconnecting station are made by direct battery current operating an annunciator. The sending of the calling signal is effected by merely removing the receiver from the hook. This is the calling system employed with the now prevalent "common battery" system.

SERIES AND BRIDGING SYSTEMS DEFINED.

There are two methods of connecting calling apparatus into telephone circuits. The first of these is termed "series," and is that shown in Fig. 8, where it will be seen that the generator and bell are wired in series, and if there be an extension bell as in Fig. 9, this is connected in series also. In the "bridging" system, on the other hand, the generator and bell are

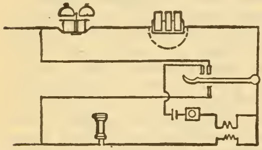


FIG. 8. Diagram of Connections of Series Magneto Bell and Telephone Set.

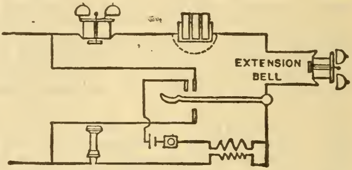


FIG. 9. Diagram showing Proper Connections of Extension Bell.

connected across the line in parallel, or, in other words, they are "bridged" across the line. In case there is but one wire used for the line, the earth serving for a return circuit, the bridges are made from the line to earth. Diagrams of bridging sets are shown in Figs. 10, 27, 28, and 58.

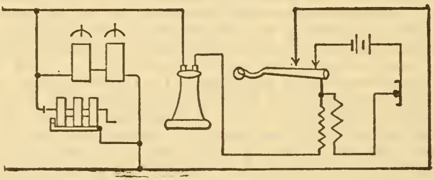


FIG. 10.

As the requirements for operation of the calling apparatus are very different in the series and bridging systems, it will be necessary, from now on, to point out the differences in the apparatus designed for them.

THE POLARIZED BELL.

The working parts of a polarized bell always include an electromagnet, a permanent magnet, a pivoted armature carrying a bell clapper, and two gongs. These may be disposed with reference to each other in a variety of ways, but always with the same result. It will, therefore, be necessary to consider the most general type only, a diagrammatical view of which type of bell is shown in Fig. 11, and a side view in Fig. 12.

The armature is pivoted to vibrate in front of the poles of the electromagnet, the pivot lying in a plane parallel to the pole faces, being midway between the two poles and so placed with reference to them that the armature cannot touch both poles at the same time. The permanent or polarizing magnet, usually a very broad U, has one of its poles secured to the middle of the yoke of the electromagnet, while the other extends to a point just beyond and over the middle of, but out of contact with, the armature. The coils of the electromagnets are connected directly together and to the wiring, without movable contacts of any kind.

When there is no current flowing in the coils, the electromagnet cores act merely as extensions of the permanent magnet, both poles of it becoming magnetized alike and of opposite polarity to that of the free end of the permanent magnet. The armature also becomes magnetized, but by induction, with two free and one consequent pole, the free poles being such that there is an attraction for each by the opposed core of the electromagnet. These attractions are not equal, except when the armature is exactly in its mid, an unstable, position. In any other position the attraction is greater for the nearer end of the armature than for the other. Thus the armature naturally comes to rest against one or the other pole, as the case may be. When alternating current is put on the line, the first impulse may do one of two things: it may be of direction such as to strengthen electromagnetically the pull of the pole upon which the armature is resting, by adding the effect of the current to that of the permanent magnet, while at the same time decreasing the effect of the other pole by a similar but subtractive effect; or the current being in the opposite direction may weaken the pull of the poles in proximity and strengthen that of those separated. It is this latter kind of impulse which starts the bell, for the armature will rapidly tilt in response to the changed attractions, only to be tilted back immediately by the succeeding current impulse of opposite sign. This action is

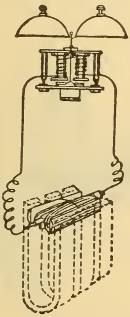


FIG. 11. Magneto-Generator and Bell.

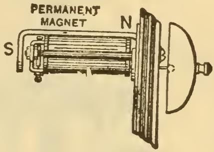


FIG. 12. Polarized Bell with Long Core for Ringer of Bridging Bell.

repeated for each reversal of the current, the armature and bell clapper making a double vibration for each cycle of the current.

For bridging working it will be seen that the bells are shunted directly across the talking instruments, and they must therefore be designed with reference to this effect. It has been found that with a resistance of winding of 1000 ohms, using No. 33 copper wire and cores about three inches long, the shunting effect is negligible even when a considerable number of bells are placed across the line. It is essential, of course, that the resistance be all or almost all wound upon the cores of the bell, as the telephone current being alternating the virtual resistance due to the inductive winding is far greater in effect than the ohmic resistance, and again, as the efficiency of the bells demands the greatest possible number of turns where effective in operating the armature.

For series systems the very opposite condition obtains, for not only is the bell always removed from influence upon the talking circuit, but economy demands that the resistance be kept low, especially where several pieces of apparatus are in series. Eighty ohms is the usual resistance for series bells, and the cores are made much shorter than for bridging bells.

Recently a type of bell known as "biased" bells has come into use for certain party line systems. Such bells have in addition to the features above mentioned, an adjustable spring which serves to give the armature a bias in one direction so that it will always come to rest against the same pole piece.

CONSTRUCTION OF MAGNETO GENERATOR.

As previously noted, the magneto generator is provided with a field by permanent magnets. From two to six U magnets are used, three being the most frequent number. These magnets are usually cold bent from bar steel approximately $\frac{1}{2}'' \times 1''$ in section, and after quenching in cold running water from a red heat, are magnetized by stroking. These magnets span a pole frame within which the armature turns. The armature is of the H. Siemens type, usually of cast iron, and wound full with fine wire. The number of turns of wire and the size of wire vary considerably with the use for which the apparatus is designed. The armature is driven by hand through a gear train arranged so that one will ordinarily drive the armature about 1000 revolutions per minute. At this speed the proper potential for operating the bells should be delivered. This latter ranges from forty volts up, series system machines usually generating a higher voltage and less current than those for bridging systems. One terminal of the armature is usually brought out through an insulated shaft pin to a brush, while the frame serves as the other terminal.

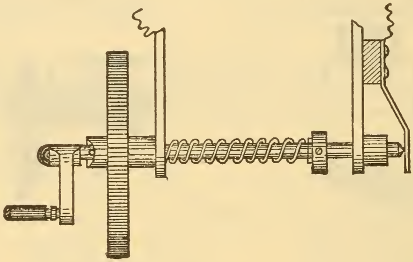


FIG. 13.

There are many points of design upon which considerable thought has been expended. Such is the interposition of a flexible spring coupling between the driving gear and the armature shaft to render the generator noiseless. Another is the proper proportioning of the span of the armature poles and the gap between the pole tips of the field to obtain the most effective wave form. It is generally conceded that these dimensions should be equal for best results. The automatic switch is still another feature. This is a switch so arranged that the generator is cut from circuit except when actually in use. For a series system cutting from circuit of course involves short-circuiting the generator, while for bridging systems the generator bridge must be opened. In some of the older telephone sets a push button serves in lieu of the automatic switch, and in still others the driving handle must be depressed to connect in the generator. In modern sets, some centrifugal or spring device integral with the driving mechanism automatically controls it. A prevalent type of automatic switch is shown in Fig. 13. Here the driving pin rides the sloping gear hub to move the shaft longitudinally to the left.

For the Common Battery system, as before mentioned, no generator is required. The bell, however, is exactly that already described. This system will be referred to more fully later, when its operation and circuits are described.

FACTORS AFFECTING TELEPHONE TRANSMISSION: INDUCTANCE, CAPACITY, RESISTANCE.

As mentioned earlier, the telephone current is an alternating current, and is therefore subject to all the influences of inductance and capacity. These are, moreover, exceedingly potent in their effects, because of the very high frequency of the telephone current, and because this current is made up of superimposed waves of many frequencies.

Inductance always tends to choke off alternating currents passing through it. While all lines have inductance, that with which we are most concerned is due to coils of wire about a core of iron. Such coils are variously called in telephony, choke coils, retardation coils, inductance coils, and, although not entirely properly, impedance coils. The inductance of a coil such as in a receiver or a bell magnet has a reducing effect equal to a long length of line; and a few small coils in series in a line, or one large one, will have the practical effect of so lengthening it, as to put the transmitting station beyond the reach of the receiving station. It is this choking effect of

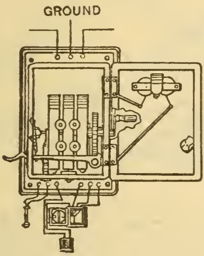


FIG. 14. Complete Magneto-Bell Post Pattern.

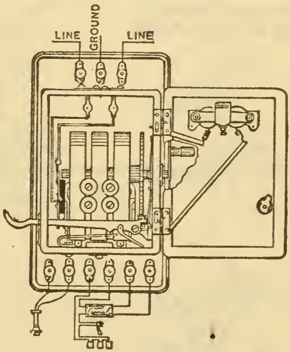


FIG. 15. The Bridging Bell.

inductance which renders the bridging bell practicable. Inductance has another effect, viz., it distorts and confuses transmission; the reason being that inductance chokes the higher frequency waves, i.e., the high tones, far more than the lower. Even when present in small degree, it gives the transmitted tone a "drummy" sound.

The effect of capacity or condensers is also twofold. Capacity placed or bridged across a line conducts the telephone current, but affords a freer path for the higher frequencies. It thus reduces the volume of the whole transmission and distorts by shunting out the high pitches. In series with a line the distorting effect of capacity is just the opposite of this. It obstructs the low frequency and permits the passage of a disproportionate quantity of high frequency current.

Capacity exists in its shunting relation, in all lines, because every pair of conductors forms a condenser. When capacity exists in series with a line it is in the form of a condenser of thin plates. It is used in this relation to the line whenever it is desirable to permit the flow of alternating current and to stop the flow of direct current. Similarly it must be understood that inductance coils can be used to permit the flow of direct currents and arrest the flow of alternating currents. Capacity and inductance are also used in conjunction, each to partially neutralize the effect of the other. An example of such a use is the shunting by a condenser of a relay the coil of which is necessarily included in series in a talking circuit for signaling purposes.

Resistance acts just as would be expected, to attenuate the telephone current. As all component periodicities are reduced equally, however, there is no distortion. Leaving out of consideration the conduction of direct currents, the only case in which resistance is of much importance is when it is combined with distributed capacity. For a long time Lord Kelvin attempted to apply his KR (capacity resistance) law to telephone lines, but this law has been found to not fit the case. The best light upon the subject seems to show that the combined effect of distributed capacity and resistance is nearer proportional to the square root of their product, thus, $a\sqrt{KR}$, rather than the product itself.

Besides these three most important factors, there are several other, though less important, effects. Among these there are losses due to Foucault or eddy currents, hysteresis losses, and reflection losses. These last

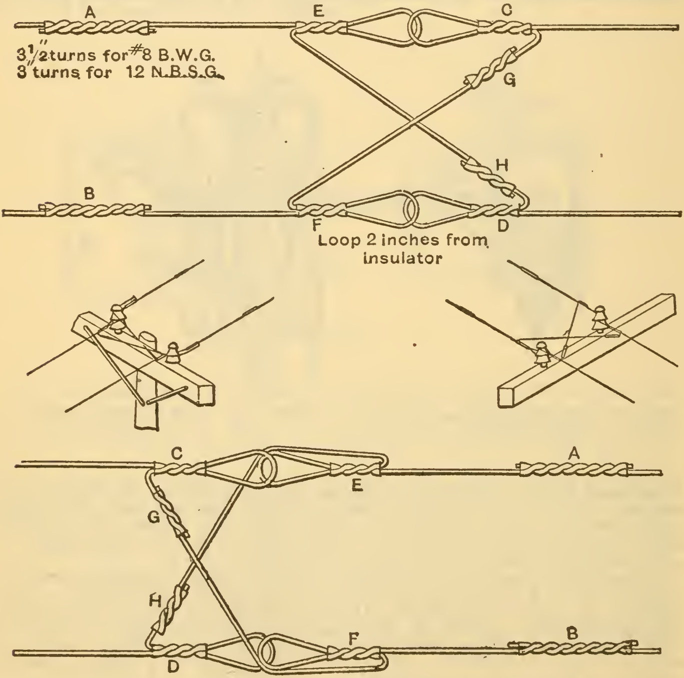


FIG. 16. Regular and Pole Transpositions.

occur when there is any abrupt and considerable change in the transmitting medium. Thus, for instance, where a line of almost no inductance is connected directly to a line of very high inductance, such as is used in the Pupin system of transmission. These reflections are analogous to the reflections of light and sound. In most telephone work little consideration is given to these last mentioned losses.

EARTH CURRENTS, INDUCTION, CROSS-TALK.

When the telephone was first adopted, all lines were worked as "grounded" circuits. That is, but one wire was used in connection with an earth return. As long as the lines were fairly short, and there was an inconsiderable use of the earth for a return for other systems, trouble was experienced due to disturbing earth currents only in times of general magnetic storms. Slight disturbances occurred, however, at all times.

It has been found that the earth is subject to continual potential fluctuations, usually minute, but changing with great rapidity. These cause disturbing currents to flow over grounded telephone lines. When neighboring trolley lines also use the earth as a return, grounded circuits become unbearable not only from the earth potential disturbances, but also from induction. This latter effect is due to a mutual inductive action between the telephone and neighboring wires. Induction may be due to electromagnetic or electrostatic effect. The former occurs when the varying field of force about a wire carrying a disturbing current, cuts and sets up a corresponding field about a parallel telephone wire. Electrostatic induction is caused by a series of rapid redistributions of the natural

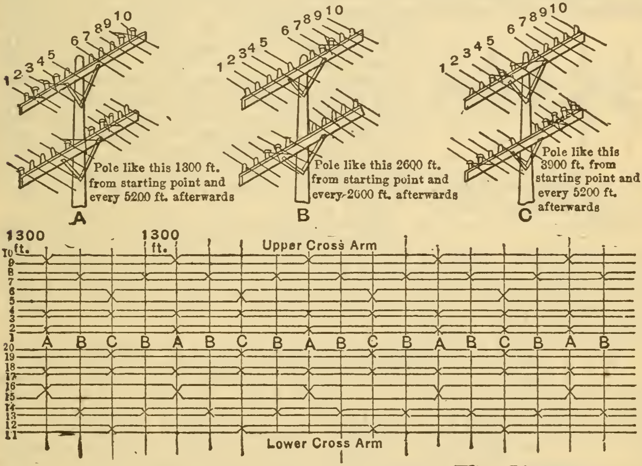


FIG. 17. Transpositions on Twenty-Wire Lines.

charges in the telephone line in the attempt to maintain a constant electrostatic balance in the neighborhood of the disturbing wire. That it is this latter effect to which most line induction may be traced was proved by J. J. Carty in a series of most interesting experiments, reported in 1889 to the New York Electric Club, and in 1891 to the American Institute of Electrical Engineers.

Cross-talk is the name given to induction or leakage from one telephone line to another. It is distinguished by the faint sound of voices.

Metallic Circuits. — With metallic circuits it is possible, though not always practicable, to do away entirely with disturbances. It is, however, almost always practicable to reduce disturbances to a point where they will not interfere materially with conversation. By metallic circuit is meant not merely a two-wire circuit without qualification, but it means an all-metallic line, both of whose limbs have the same and similarly distributed resistance, the same capacity, and the same insulation resistance. Moreover, both limbs should be equally exposed to all disturbing influences. With insulated wires this last condition is easily obtained by twisting the two wires about each other to form what is called a "twisted pair." With bare wires "transposition" must be resorted to.

Open Wire Circuits. — Open wire circuits are carried upon poles, or in cities, sometimes upon house-top fixtures, although this latter type of construction is rapidly disappearing. The principles underlying the construction of telephone pole lines are exactly similar to those for other lines. The factor allowed for wind-pressure and for weight of ice from sleet storms must, however, be proportionally greater than for most other kinds of lines, because of the large exposed surface of conductor.

Cross-arms for telephone lines are usually 10 or 6 pin, the wires adjacent to the pole being 16 inches apart and others 12 inches apart. Cross-arms are mounted two feet apart. Poles are usually set to give an average span of 130 feet, i.e., 40 poles to the mile.

The requirements for metallic circuits dictate that both wires of a pair shall be of the same diameter and material, and that they shall be placed in adjacent positions on the same cross-arm. Furthermore, at intervals the two wires must change places, in a manner such that both shall have the same average distance from all disturbing influences. This interchange of wires is termed "transposition." In case of extreme exposure, such as where telephone signal-wires are run upon the same poles as high-tension transmission lines, continuous transposition may be resorted to. Under ordinary conditions of telephone practice, it is found satisfactory, however, to transpose the wires upon a system which treats each two cross-arms as a pair, i.e., 20 circuits as a group, and which provides for the transposition of each with reference to its mate and to disturbing untransposed wires, at least once each mile. This brings "transposition poles" one quarter mile, or approximately 10 poles apart. A diagram of this transposition scheme is shown in Fig. 16.

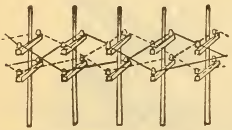


Fig. 18. English Method of Transposing Metallic Circuit.

Fig. 17 shows a diagram of this transmission system, a study of which will show that only those wires furthest apart in the group, transpose upon the same pole. For very long lines a further refinement must be introduced treating four cross-arms as a transposition group, for it has been found that cross-talk will occur between alternate arms of the two-arm system. Fig. 18 shows a method of continuous transposition.

Recently much of the transposition has been of a type known as single pin. This is much cheaper than that shown in Fig. 16. By this method a cross over of two wires is distributed over two spans of the line, the actual cross taking place at one pin of the middle pole. This pin is provided with a double groove transposition insulator, while its mate carries none. In the first span, one wire passes from its own pin position to the base of the glass in its mate's position. It then continues in this position while the mate wire passes over to the position in the second span vacated by the first wire. If both wires be tied to the same side of the insulator at the middle pole there is no danger of a short circuit.

The properties of conductors need not be discussed here. Suffice it to say that for open-wire circuits, iron, steel, aluminum, bronze, and copper have been used. Hard drawn copper is undoubtedly standard. Iron and steel are less satisfactory not only because of high resistance, but because of the difficulty of making good permanent joints, of deterioration, and of their highly magnetic properties with attending inductance.

CABLES.

Conductors laid up into cables were first brought into use to relieve congested or overcrowded pole lines. At first they were of small copper wire insulated with rubber or similar compounds. With the introduction of metallic circuits came the introduction of twisted pair cables. Such cables are of course relatively free from cross-talk so annoying with straight away cables. Because of the very high specific inductive capacity of rubber, and the proximity of the wires of a pair, so high a mutual electrostatic capacity was introduced as to greatly reduce transmission. For aerial lines, rubber cables are yet used in some localities, especially for emergency and temporary work. General practice has, however, substituted the cheaper and far better paper insulated cable for all uses.

Properties of Paper Insulated Cables. — Present day telephone cables are what are known as dry core cables, as the insulation is untreated paper, thoroughly dried. Strips of paper are loosely spiraled about the cable wire, and this is then twisted together in pairs with a lay approximating 3 inches. The pairs are then layed up in reversed layers to form a cylindrical core which is served with paper or cotton yarn or both. The core is then thoroughly dried by baking, and it is run directly from the kiln to the lead press which surrounds it with a moisture proof sheathing of either pure lead, or an alloy of lead with 3 per cent of tin, this alloy being tougher than pure lead.

The paper used is very porous, and being loosely wrapped the insulation about each wire is largely dry air, and it is this fact to which the low electrostatic capacity and the high insulation of such cable is due. The slightest moisture will greatly impair and may ruin paper cables and the core is so dry that sufficient moisture may be absorbed from the air to injure them. To prevent this, the ends of each length of cable are usually "filled" with paraffin for a few feet, and whenever a cable is cut at an unfilled spot, it is immediately "boiled out" by pouring over it hot paraffin-wax.

Probably the greatest number of cables now in use are of No. 19 B. and S. gauge wire, while of those being manufactured the greatest number are of No. 22 gauge wire. For long-distance lines cables have been used of Nos. 18, 16, 13, and 10 gauge.

Cables are known, according to their use, as aerial, distributing, underground, and submarine. Aerial cables are made as light weight as is consistent with durability. The usual sizes are from 15 to 100 pairs.

Distributing cables have a thicker sheath than aerial, but are made in about the same sizes. Underground cables are used in conduit beneath the streets. The usual sizes are from 100 to 300 pairs if the size of wire be No. 19, and 150 to 400 pairs if the wire be No. 22. Underground cables have been made up to 600 pairs, but such cables are not practicable at present for general use, as the allowable diameter of cable is limited, on the one hand, by the size of the conduit duct, usually 3 in. in diameter, and it is limited on the other by the electrostatic capacity. The smaller the cable of a given number of pairs the higher the capacity per pair.

Until recently submarine cables were all rubber covered and of not over 10 pairs. Now paper submarine cables of far better insulation, less electrostatic capacity, and a greater number of pairs of wires have been successfully developed. These cables are of from 30 to 150 pairs size. The lead sheath is usually thicker than for underground cables, and after being served with jute is covered with an armor of steel wires.

The following sample cable contract written by A. V. Abbott sets forth in tabular form the details of several types of cable.

SAMPLE SPECIFICATION FOR TELEPHONE CABLES.

(A. V. Abbott.)

Gentlemen: — Under the conditions hereinafter specified, please deliver the following enumerated telephone cables free on board cars at freight depot in ——————— reel, marked ———, containing ——— feet of No. ——— B. and S. gauge, ——— pair, aerial (or underground) paper cable, capacity ——— to ——— m.f. per mile, ——— inch plain lead (or with ——— per cent tin) at quoted price of ——— cents per foot ——— reel, marked ———, containing, etc.

Conductors. — Each conductor shall fully and throughout its entire length have the diameter corresponding to the gauge stated above, and shall be cylindrical and free from imperfections. The material of the conductors shall be soft-drawn copper.

Insulation. — Each conductor shall be insulated with one (or two reversed) wrapping of dry paper; the insulation of one conductor in each pair shall be colored blue and that of the other conductor red.

Number of Pairs. — Each cable shall have the number of pairs called for above, plus at least one extra or additional pair for each one hundred (100) or fractional part of one hundred (100) pairs of conductors called for.

Twisting. — The two wires of each pair shall be twisted together with a uniform lay, not to exceed approximately three inches for No. 19 B. and S. gauge and smaller wires, and approximately six inches for larger wires in a complete twist, so as to effectively prevent cross-talk.

Cabling. — The twisted pairs shall be laid up into a cylindrical core, arranged in reversed layers, so that the length of each complete turn shall not exceed thirty inches.

Sheath. — The core shall be incased in a cylindrical sheath of plain lead (or an alloy of lead and ——— per cent tin) of the thickness specified above. The sheath shall be free from holes or other imperfections and shall be of uniform thickness and composition.

Conductor Resistance. — Each conductor shall have a resistance equivalent to

not more than ... 25 ... ohms per mile of No. 16 B. and S. gauge cable;
not more than ... 31 ... ohms per mile of No. 17 B. and S. gauge cable;
not more than ... 38 ... ohms per mile of No. 18 B. and S. gauge cable;
not more than ... 47 ... ohms per mile of No. 19 B. and S. gauge cable;
not more than ... 59 ... ohms per mile of No. 20 B. and S. gauge cable;
not more than ... 95 ... ohms per mile of No. 22 B. and S. gauge cable.

All measurements to be made at 60 deg. F.

The conductivity of any wire shall be equal to at least 98 per cent of that of pure copper.

Insulation Resistance. — Each wire shall have an insulation resistance of not less than three thousand (3000) megohms per mile at 60 deg. F., when tested at the factory in the usual manner, and shall have an insulation resistance of not less than five hundred (500) megohms per mile at 60 deg. F., when installed, spliced, and connected to office terminals; each wire being measured against all the rest and the sheath grounded.

Electrostatic Capacity. — The electrostatic capacity of the wires shall remain inside the limits specified above (see p. 889). These limits to apply to measurements of each wire against all the rest and the sheath grounded and at a temperature of 60 deg. F.

Packing and Shipping. — The cable shall be delivered on reels in lengths specified above. At least eighteen inches of the inside end of the cable shall be brought out through the side of the reel so as to be accessible for testing. This end shall be securely boxed to protect it from mechanical injury. The outside layer of cable on each reel shall be properly wrapped, and each reel shall be incased in stout lagging. Each reel to carry in plain sight the company's name, the above specified identification mark, length and size of the cable.

Delivery. — Reel marked ———, shall be delivered at ————— on or shortly before —————190—. Reel marked ——— at ————— on or shortly before —————, etc.

Measurements and Tests. — The company reserves the right to send an inspector to the factory to be present during the process of manufacturing and to test the qualities of the materials used and the electrical properties of the cable before shipping. He shall have the power to reject any material or cable found defective. Such inspection, however, shall not relieve the manufacturer from furnishing perfect material and satisfactory work. Final measurements and tests are to be made after the cable is installed, spliced, and connected to office terminals. In case the cable falls so far short of the above specified requirements that the company is not willing to accept it, the manufacturer will be called upon to examine the work done by the company, and, if able, by remaking splices or repairing injuries to the cable received in handling and laying, to bring the cable up to the requirements; the cost of the work shall be borne by the company. If such work, however, does not bring the cable up to the requirements, and the cable is shown to be defective in material or work done by the manufacturer, then the manufacturer shall make the cable good by replacing as many lengths as may be necessary, and shall not be entitled to pay for work done in examining and remaking splices. The company will, if the manufacturer fails to do so, perform all the work of testing and remaking splices, and charge the cost of such work to the manufacturer in case the defect is found to be due to poor material or workmanship on the part of the manufacturer. The manufacturer shall be notified as soon as the company's inspector reports any defects, and he may have a representative present during such tests and work done by the company to detect or repair defects. The company reserves the right to have a representative present whenever the cable is tested or work is done by the manufacturer in repairing defects.

Guarantee. — The electrostatic capacity shall not increase, nor shall the insulation resistance decrease, beyond the specified limits due to defective material, manufacture of workmanship, for a period of ——— years after the cable has been installed.

Payments. — Payments for the cable shall be made within thirty (30) days from the receipt of a consignment, except that fifteen (15) per cent of the price of each consignment shall be held thirty (30) days after each separate consignment is installed and accepted by the inspector of this company, who shall make a written report accepting or rejecting the cable within twenty days after installation; in case of rejection a written notice and statement of the defects shall be sent immediately to the manufacturer, and if the manufacturer fails inside of ten days to remedy such defects they will be remedied by the company and the cost deducted from the final payments, or if the percentage is not sufficient to pay for such repairs the manufacturer must refund the difference.

(Signed)
———————————— Telephone Company.

SPECIFICATIONS FOR TELEPHONE CABLES.

Table I. — Capacity of Aerial Telephone Cables.

Revised by John A. Roebling's Sons Co.

Number of Pairs.	B. & S. Gauge.	Thickness of Lead, Inch Meas.	Capacity per Mile, Manufactured.	Approximate External Diameter in Mils.	Approximate Weight per Foot in Pounds.	Approximate Cost per Foot, f.o.b. Factory, in Cents (May, 1907).
10	19	$\frac{5}{64}$	.08 to .085	.800	.985	14.0
10	20	$\frac{5}{64}$	.085 to .09	.760	.9	12.3
25	19	$\frac{3}{32}$	.08 to .085	1.07	1.7	25.5
25	20	$\frac{5}{64}$	.085 to .09	.97	1.30	20.
25	22	$\frac{5}{64}$	.10 to .11	.76	.96	14.5
50	19	$\frac{7}{64}$	.08 to .085	1.41	2.7	42.5
50	20	$\frac{3}{32}$	.085 to .09	1.28	2.15	33.8
50	22	$\frac{3}{32}$	.10 to .11	.99	1.6	25.
75	19	$\frac{7}{64}$	.08 to .085	1.70	3.45	56.5
75	20	$\frac{7}{64}$	.085 to .09	1.56	3.08	48.7
75	22	$\frac{7}{64}$	.10 to .11	1.19	2.2	35.0
100	22	$\frac{7}{64}$	.10 to .11	1.35	2.68	43.

Table II. — Capacity of Underground Telephone Cables.

Revised by John A. Roebling's Sons Co.

Number of Pairs.	B. & S. Gauge.	Thickness of Lead, Inch Meas.	Capacity per Mile, Manufactured.	Approximate External Diameter in Mils.	Approximate Weight per Foot, in Pounds.	Approximate Cost per Foot, f.o.b. Factory, in Cents (May,1907).
25	19	3/32	.08 to .085	1.07	1.7	25.5
25	20	3/32	.085 to .09	1.	1.54	22.5
25	22	3/32	.10 to .11	.790	1.15	16.
50	19	7/64	.08 to .085	1.41	2.7	42.5
50	20	7/64	.085 to .09	1.31	2.45	37.
50	22	7/64	.10 to .11	1.02	1.86	27.5
100	19	1/8	.08 to .085	1.96	4.6	74.7
100	20	1/8	.085 to .09	1.81	4.1	64.5
100	22	1/8	.10 to .11	1.39	3.	46.5
150	19	1/8	.08 to .085	2.33	5.8	99.9
150	20	1/8	.085 to .09	2.16	5.2	86.3
150	22	1/8	.10 to .11	1.64	3.77	61.2
200	19	1/8	.10 to .11	2.24	6.1	116.
200	20	1/8	.10 to .11	2.1	5.47	99.
200	22	1/8	.11 to .12	1.84	4.45	75.1
250	22	1/8	.11 to .12	2.03	5.09	89.0
300	22	1/8	.11 to .12	2.21	5.7	102.
350	22	1/8	.11 to .12	2.3	6.3	115.
400	22	1/8	.11 to .12	2.5	6.8	122.

SIZES OF CABLES.

Conduits as now built readily take a 2½-inch diameter cable, and possibly one 2¾-inch; so by existing construction, cables are now limited to these sizes, and design must accommodate itself thereto. It appears desirable to have about seven varieties of cable for subscribers' lines, and three varieties of toll and trunk-line service. An appropriate set of cables is the following:

Purpose.	No. Pairs.	Size of Wire.	Capacity per Mile.
Subscribers' lines, distributing cable	10	19	.085
Subscribers' lines, distributing cable	30	19	.085
Subscribers' lines, distributing cable	50	19	.085
Subscribers' lines, main and distributing cable	100	19	.085
Subscribers' lines, main cable	200	20	.110
Subscribers' lines, main cable	300	20	.115
Subscribers' lines, main cable	400	22	.120
Subscribers' lines, main cable	600	24	.140
Trunk line cable	75	17	.065
Toll line cable	50	14	.050
Toll line cable	10	10	.035

ANNUAL EXPENSES OF TELEPHONE CABLES.

The following has been published as a basis for computation of the annual charges to be made against cables.

"Even with the utmost care, and in spite of the apparent protection offered by conduit and sheath, underground cables gradually fail. In some cases life is very long, but from one cause and another, owing to extension, necessary rearrangement of plant, etc., a thousand and one causes operate to injure the cable insulation and deterioration is inevitable and must be provided for, in the depreciation account.

"For underground main cable from 5 per cent to 7 per cent is a fair annual charge, while for laterals from 8 per cent to 10 per cent is essential. Aerial cable is much more exposed to injury than underground lines, for it is a constant prey to all sorts of additional destructive forces — sleet and wind storms, lightning, crosses with high-potential wires of all kinds; the small boy with a shot-gun or rifle, and hundreds of other influences constantly attack it. Moreover, aerial lines have a shorter life than underground ones, as being chiefly erected in districts which are growing rapidly they are soon superseded by conduit work. For these reasons an allowance of 10 to 12 per cent for depreciation for aerial cables is none too great.

"The maintenance to which cable wire is subjected will depend very largely upon the rate of growth in the exchange. Where this is rapid there is a constant necessity for rearranging and remodeling cable plant. Under such circumstances maintenance charges will vary from 2 per cent to 5 per cent on the cost of installation. For where growth is slow, and there is but little change in districts, maintenance may fall as low as from 1½ per cent to 3 per cent. With aerial cables 5 per cent for maintenance is the least charge which should be considered. Combining the charges for both depreciation and maintenance the annual expense for underground wire plant should be taken at from 5 to 10 per cent for main cables, from 10 to 15 per cent for laterals, and from 12 to 16 per cent for aerial cables."

Lightning Arresters. — Many telephone lines are exposed to lightning discharges and to accidental contact with wires carrying currents which would be destructive to the telephone apparatus and liable to cause fire. All of some lines are exposed while only short portions of others are. In both cases protection is needed although the best practice distributes it differently in the two cases. It is generally conceded that telephone cables run underground in subways wholly given up to telephone purposes are safe, *per se*.

It has been found that three different elements are necessary for complete protection. These are: first, an open space cut-out for grounding momentary high-potential discharges; second, a fuse of such caliber as to amply protect the line against abnormal currents; and third, a sneak current protector or thermal cut-out, which operates with a time factor, and protects the telephone apparatus from small currents, which by a gradual heating effect might destroy it.

For lines exposed throughout their length, complete protection demands all three types of safety devices on each wire, and at both ends of the line. For lines beginning in cable and with the outer end exposed, the central office end fuses are usually transferred to the outer end of the cable. It is found economical to terminate cables upon frames or strips designed to hold the various protective apparatus. At subscribers' premises the lines terminate upon a protector built up on a porcelain block, and arranged with binding posts for incoming and outgoing lines and for a ground wire.

Open space cut-outs almost always consist of two carbon blocks, the one grounded and the other connected to line. These are held tightly against either side of a small sheet of mica. This mica is perforated to permit of sparking between the carbons, and it is of gauge thickness such that 350 volts difference of pressure will strike across between the carbons.

Fuses are of various construction and capacity. Best practice prescribes a fuse between 3 and 6 amperes rating. Some prefer a fuse mounted upon a strip of mica which is provided with terminal pieces of copper, and some prefer tubular fuses. The tubular fuse has the advantage of quite effectually blowing out arcs, but it has the incidental disadvantage of at times blowing itself all to pieces upon a violent disruption.

The kinds of sneak current protector are now almost legion. All depend upon the gradual heating of some substance sensitive to heat, which gives way under some mechanical strain and opens or grounds the line. The early sneak current protectors were often called heat coils, as all contained a coil of fine wire, interposed in the circuit, which became heated upon the passage of current. Later blocks of carbon served as the heat generating member. In practically all cases certain of the parts are held in proper relation by fusible metal or fusible cement, and the mounting springs tend to disturb this relation. When the solder softens, the springs overcome the adhesion and thereby move the parts to open or ground the circuits. An old form is that shown in Figs. 19 and 20, wherein the softening of the solder permits the pin to slide within the coil under the pressure of spring B, which in following grounds the circuit. Many modern heat coils, while

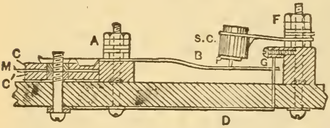


FIG. 19. Combination Protector. A, line-post; F, instrument post; B, German-silver spring; CC, carbon blocks; M, mica sheet; SC, sneak coil; P, releasing-pin; G, grounding-strip; D, ground wire.

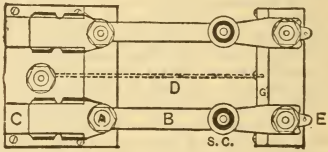


FIG. 20. Plan of Combination Protector.

different in detail, operate similarly. A disadvantage of this type lies in the necessity of reheating it for repairs. Recently several types of self-repairing protectors have been produced. One such has a star-shaped latch which, in releasing the grounding spring, resets itself while still warm. Another depends upon shearing a heat softened washer, which latter may be replaced by a new one at any time.

CLASSIFICATION OF TELEPHONE LINES.

Every telephone line may be included in one of three classes, according to the extent to which it may be interconnected with other lines.

Under the head "Private Lines" is included all lines which have no facility for interconnection. They may be direct, with but two stations, one at each end; or they may be provided with a considerable number of instruments located in different places. Private lines are largely used in cities by brokers, railways, etc., and in the country upon the premises of individuals or from farm to farm.

House or Hotel Systems include lines which are capable of interconnection, but which serve a very limited area, usually all within the premises of a single proprietor. Such systems have either one central switchboard, presided over by an attendant or of an automatic nature, or else have a switchboard at every station so that each user may perform his own switching. With this latter arrangement the system is termed "intercommunicating."

The third class includes the great bulk of telephone lines, namely those connected to an Exchange and capable of interconnection to not only all other lines of the system, but also through toll lines, to other exchange systems. Every exchange district has one or more central offices, where the switching operations necessary for interconnecting lines are performed. In each exchange system the lines are treated in groups according to the geographical location of their stations. The territory fed by each group is called a district. These vary in area according to the so-called telephone density.

THE CENTRAL OFFICE.

Every telephone district has its central office, from which all cables and lines in the district radiate, and where there are provided a switchboard for rapidly interconnecting lines for conversation and interconnecting frames where lines may be interchanged, or those which cross the district may be connected together from the approaching to the receding wire-route. The equipment of a central office is the result of gradual experience, one feature after another having been added as the demand for it arose.

For a small number of lines a switchboard of the utmost simplicity will suffice for interconnecting them. As soon, however, as the number becomes so large that it requires several operators to attend to their demands, there is difficulty in connecting together two lines appearing in front of two different operators and special provision must be made to handle such calls. Three general systems have been developed, the multiple, the transfer, and the automatic. These will all be briefly considered. First, however, it seems best to review the general requirements of operation and the method of handling calls upon small single operator switchboards.

REQUIREMENTS FOR SATISFACTORY OPERATION OF SWITCHBOARD.

A telephone switchboard system must be so designed that:

1. Every subscriber may signal the switchboard and give directions as to his wants.
2. Any line may be connected to any other line.
3. Any line may be signaled from the switchboard.
4. Every subscriber may signal for disconnection.

The rapidity, ease, and accuracy with which these operations may be carried on largely determines the value of the system, the only qualification being that the outlay to obtain speed shall be commensurate with the saving of operators' salaries and the advantage to the subscribers.

Small Switchboards. — The approved form for telephone switchboards is not far different at first sight from that of an upright piano. We have running along the front at mid-height a narrow keyboard, beneath which extends the supporting frame and above which extends the apparatus space. A view of a small switchboard for not over 100 lines is shown in Fig. 21.

In all manually "operated" switchboards the lines of the subscribers terminate in signals and in switch sockets, and there are provided flexible connecting conductors having terminals which register properly with the contacts of the socket switches. These socket switches are called "spring jacks," or, for short, "jacks," and they consist of a guiding thimble behind which are arranged contact springs of sheet metal. The flexible conductors are usually made in two lengths coupled together to form a pair of connecting cords, and there is associated with each such pair some switch by means of which the operator may connect her telephone set to them at will, and also means for applying ringing current to the conducting strands of the cords.

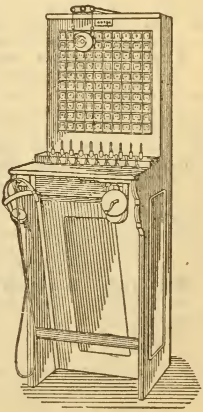
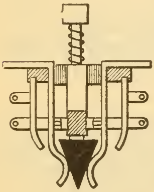


Fig. 21.

Thus far the description holds for all manually operated switchboards, but from this point a differentiation must be made between the various systems. For the present the magneto system only will be considered. For this system the switchboard signal for calling the attention of the operator is a "drop," a type of annunciator whose latch releases a falling shutter: hence the name.

When a subscriber desires connection, he drives his magneto and throws the drop. Thereupon the operator answers by selecting one of an idle pair of coils, and inserting it in the jack corresponding to the signal, and then connecting her telephone to that pair of cords. On ascertaining the number of the line desired, she takes the second cord of the pair, inserts it in the jack of the desired line, and pushes the ringing key to call the subscriber. She then disconnects herself from the cords and is ready to proceed with other connections. In all early switchboards, the operator was required to also restore the drop shutter by hand and she must still so do with many. There are, however, a number of admirable combined drops and jacks in use, where the act of answering a call by inserting a plug automatically restores the drop.

There is one more piece of apparatus which has not been mentioned. This is the "clearing-out" drop, which serves as a signal for disconnection when a conversation is finished. It is to throw this signal that one turns the magneto-crank before leaving the telephone. In operation the "clearing-out" drop is exactly like the calling or "line drop," and indeed, the line drop may serve as a clearing-out drop. As, however, a user may not always desire disconnection when he rings up central during a connection but may desire the further attention of the operator, whenever the drop falls, instead of disconnecting immediately, the operator must first inquire "Through?" or "Waiting?" Because of this, and because the listening key through which she must respond is associated with the cords, it has been found best to associate the clearing-out signal with the cords. Just



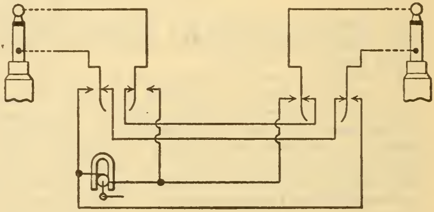


FIG. 22. Arrangement of Ringing Keys.

as with bells, drops may be made with high-inductance and connected directly across the line, or they may be made of low-inductance and become cut out during conversation. For clearing-out drops the former method is always used, while line drops are made both ways.

Arrangement of Ringing Keys. — It was stated above that in calling a subscriber an operator connects alternating-current to the connecting cords. This statement must, however, for accuracy be qualified, as were the current applied to both cords of the pair simultaneously, the fact that the receiver is off the hook at one of the connected stations would not only cause the disagreeable sensation to the listening subscriber of being "rung in the ear," but in addition the call would like as not fail, the bell of the called line being shunted by the low-resistance receiver. Because of these effects, ringing keys are made not only to connect ringing-current to the cord toward the called line, but also to separate the strands of this cord from those of its mate and the listening apparatus of the operator. The exact manner of accomplishing this result will be apparent from the circuit drawings.

Multiple Switchboard. — As soon as the number of subscribers is so large that the lines are spread out before several operators, if all of these operators are to make connection to any line, then either must two or more operators assist each other on some connections, or every operator must be given access to all lines. Both methods have been tried, and each has proved successful for a certain class of service. It is generally agreed, however, that the multiple switchboard, that in which every operator has access to all lines, is the more efficient. Switchboards of this type are made up of a number of sections or independent frameworks set side by side as though one continuous frame. Each such section accommodates two or three operators, and the keyboard is provided with a corresponding number of equipments. Above the keyboard there are arranged sets of jacks and signals, one set for each operator. These are connected to the group of lines which the corresponding operator must answer. Beside these, there is in each section another group of jacks called the multiple. This group contains as many jacks as there are lines entering the switchboard and each line is connected in every section to that jack having a position in the group corresponding to the number of the line. That every operator may have access to every line, a full group of multiple must be within her reach, and this fact limits the practical height and length of the group, and incidentally the maximum number of lines that can be accommodated upon a multiple switchboard.

As may be inferred, the connecting cords previously described serve as the means of making connection. As before the operator answers in response to a signal using the jack in her small or "answering jack" group

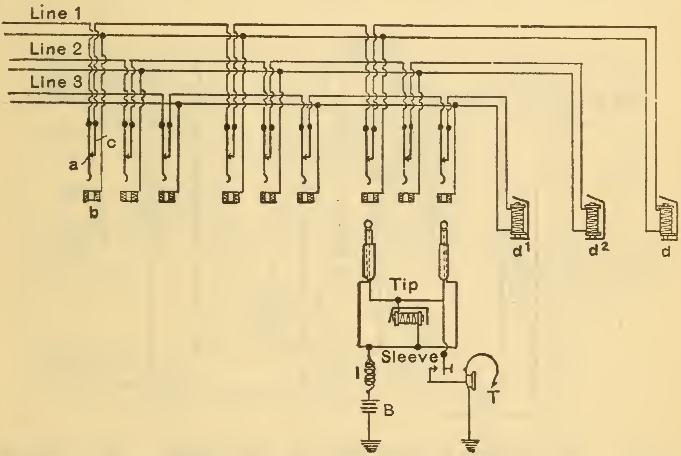


Fig. 23.

which corresponds to that signal. In calling the desired line she uses the nearest multiple jack bearing the number of that line. This may or may not be in the section before which she sits, for as the sections are placed side by side, the multiple is continuous from end to end of the switchboard, and it is often more convenient to reach into an adjacent section.

The Busy Test. — With a small switchboard it is at all times evident to the operator just which lines are busy. On the other hand with the multiple switchboard, each line being accessible to many operators, some sort of signal must be provided to indicate when a line is busy, as it is impractical to attempt to find out by direct inquiry. The well-nigh universally adopted "busy test" is an audible one, a click being sounded in the operator's telephone if she attempts to connect one of her cords to a busy line. The guide thimbles of the jacks are expanded to expose a considerable surface upon the face of the switchboard, and all thimbles of corresponding number throughout the switchboard are wired together. A test battery becomes connected to this conductor whenever a plug is in position in any of the jacks, this being the condition with the line busy. Now if a circuit containing a telephone be connected to one of the jack thimbles in a manner to complete the test battery circuit a click will be heard in the telephone. To simplify the movements of the operators the tips of the connecting plugs usually serve as the test connection. Thus if a line is called for, the operator selects her plug and touches it against the thimble of the nearest jack of the desired line. If the line be busy the click at once announces this fact positively. If no click is heard the line is free and the connection is completed by inserting the plug.

It is always a matter of perplexity to telephone users as to how operators may discover so quickly as to whether or not a line is busy, but from the above description it will be seen that the work of testing a line for busy is practically incidental to any attempt at making a connection with it, and well accounts for the quickness of the busy report.

Series-Multiple Switchboard. — The series-multiple switchboard was the first developed. The fundamental circuits of this system are shown in Fig. 23. The jack thimbles serve for the terminals of one wire of the lines, while a spring in each jack serves for the other. With this system a low-resistance drop is used and it must be cut off during con-

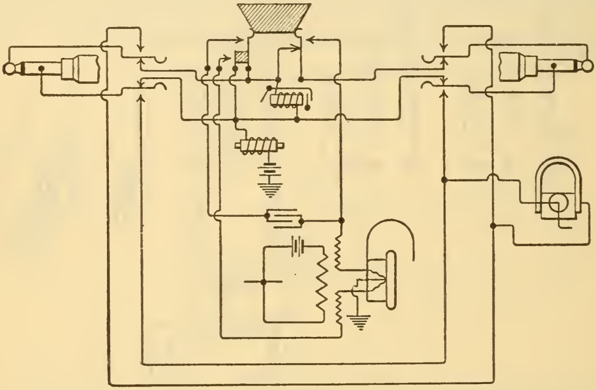


Fig. 24. Cord Circuits of Series-Multiple Switchboard. The Induction Coil and Receiver are each wound in Two Equal Sections that the Ground Connection may be made at an Inductively Neutral Point.

versation. This cutting-off is accomplished by the insertion of the plug, as it will be noted that one side of the circuit passes through a series of contacts. As a plug is pushed home, the contact spring *a* rides up, upon the point or tip of the plug becoming clear of the point *c*.

The busy-test battery with one pole grounded is shown at *B*. This must be connected to the thimble circuit which is already in use for talking-currents. The high inductance coil *I* is therefore inserted, to prevent the alternating talking-current from being earthed through the battery. It is evident how a contact between the tip of a plug and the thimble of a busy-jack completes the battery circuit.

This system has been extensively used and is not yet wholly superseded, yet it has never been entirely satisfactory. This type of board is especially susceptible to dust, because of the numerous contacts. Dirt in any one of these will reduce greatly the volume of sound transmitted. The busy test may become over-powered by extraneous currents due to accidental conditions of the line, either to make the test continuous and "false" or to countermand it. With this switchboard both effects are equally annoying, as in one case a desired connection cannot be completed, while in the other an existing one may be severed by a "cut-off" upon the insertion of a trespassing plug.

Branch Terminal or Bridging System. — The bridging or branch terminal switchboard overcomes these difficulties, but as originally designed the expense was greater than the betterment of service warranted. Bridging switchboards did not, therefore, come into general use until combined with the common battery and relay signaling. A few words as to the magneto bridging board will not be out of place. For this system, the jack thimbles are divided into two parts, the front one having the larger bore and being used solely for the busy test. The rear one serves as the line connection. The second line connection and two auxiliary connections are made through springs. Fig. 25 shows a part of a jack with a plug inserted. The plug has three parts: a tip, a collar, and a sleeve. The cord strands are connected to the tip and sleeve only. The collar serves merely as a short-circuiting piece between the auxiliary springs, and thereby connects the test battery which is wired to one of them to the test ring which is wired to the other. This may all be traced

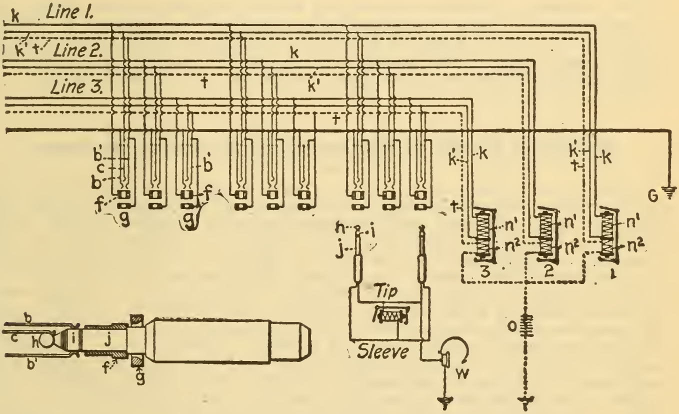


FIG. 25. FIG. 26.

from the circuit diagram wherein one of the jacks is lettered to correspond to the drawing of the plug and jack. The jacks have no cut-off feature, and thus the drops must be wound to high resistance and inductance. Furthermore, as the drops are connected to the talking-circuit and as those of different lines are mounted close together, they might be subject to mutual inductive effects to cause cross-talk, unless magnetically shielded. Because of this, the drop coils are encased in tubes of iron, which become entirely closed by the armature of the drop, and hence dispose of all stray field.

The omission of a cut-off feature also renders it necessary to lock the drop shutters during connection. Otherwise any slight current impulse, or any ringing-current sent upon the line, would throw not only the clearing-out drop but also the line drops. This would signal the answering operator of the called line, who has had nothing to do with the connection, and who in answering disturbs the call without the ability to assist in any way. The locking of drops is accomplished by an auxiliary coil which acts upon the drop shutter directly, to restore it and to hold it up. The current for this locking-coil is furnished by the busy-test battery, the circuit being closed by the plug collar just as for the busy test.

Transfer Systems. — Those systems in which each subscriber's line has but a single terminal jack, and two or more operators assist each other in completing connections, are called "transfer" systems. Probably the oldest is one in which each section of the switchboard accommodates 100 subscribers' lines, and there extends a series of transfer lines from each operator to every other. Upon ascertaining the number of a desired subscriber, out of reach, an operator selects a non-busy transfer line extending to the position at which the line of this number appears, and connects the calling subscriber thereto. By means of an order circuit with which she may connect herself at pleasure, and which connects directly with the head telephone of the operator at the desired section, she gives an order for the connection of the wanted line and the proper transfer line.

In another system the pairs of connecting cords of one position are connected to branch lines having single cords at each of several other sections, the transfers being made by means of these. In other systems the transfer lines have jacks at one end which multiple throughout the switchboard, while at the other end they have a single cord and plug at one position only.

The so-called "Express" system is a kind of transfer system where three operators assist in each connection. One responds to the signal by extending the calling line to a second operator who answers, ascertains the desired number, and orders a third operator to extend the line to her position. She then connects the two extended lines and is responsible for the call.

Relative Value of Multiple and Transfer Systems.

There is no transfer system where there is not some delay caused by the necessary co-operation of two persons, and although this delay may be slight where there are many connections to be handled, it may readily amount to the entire time of an extra operator. Furthermore, in times of excessive traffic due to a sudden emergency, this delay may result in the complete break-down of the system. The success of the transfer system is in direct relation to the efficiency of its auxiliary signals, which signals indicate at a glance the complete condition of the transfer lines, e.g., as to whether either or both ends are connected to subscribers, signals for connection, for disconnection, to indicate mistakes, etc. The advantage of the transfer system in comparison with the multiple system is its cheapness. The cost of apparatus with this latter goes up almost as the square of the number of subscribers and for a large switchboard is enormous. A 1000-line multiple switchboard having 200 answering jacks in a section, will require 5 sections of multiple plus an extension for each end operator of $\frac{1}{3}$ of a multiple. This amounts to 5700 multiple jacks. Add to this 1000 answering jacks, gives a total of 6700. Contrast this with a 5000-line board, which, by the same reasoning, has 25 sections and 133,300 jacks. Consider that these jacks must all be cabled together and some idea of the vast cost may be obtained. This cost must be offset by the efficiency of operation, and that it is so offset is best testified to by fact that practically all the large manual switchboards thus far installed are of the multiple type.

ONE CENTRAL OFFICE vs. SEVERAL.

Most of the larger cities now have several central offices each with its own switchboard, yet the lines of all must be interconnected almost as often as those of the same office. Connections between two different offices must be handled by some transfer method involving two operators, with the consequent delay, and it would, therefore, seem at first sight advisable to concentrate all lines in one switchboard. That for a small community this is the case can hardly be questioned, but as the territory reached grows the cost of the wire plant for the lines increases so fast that the division of territory becomes imperative.

It may not be apparent as to why the establishment of additional central offices effects a saving, as lines must be provided between these. However, it must be understood that there is never more than a small percentage of the lines of a system in use at once, and it is only necessary to provide sufficient tie lines, trunk lines as they are called, to continuously take care of this percentage. The usual maximum number of connections provided for in designing a switchboard is about 20 per cent of the total number of lines. Where there is more than one central, it is usually assumed that the number of calls local to each switchboard will be a slightly greater proportion of the whole number of calls than the ratio of the number of its subscribers to the total number in the system.

Leaving out of consideration the question of economy there is another ample reason for several offices in some cities. This is that there is no type of switchboard which can accommodate satisfactorily a sufficient number of lines. Switchboards designed for an ultimate of 10,600 lines are now in use, but this seems to be about the practical limit, although in a number of cities the number of lines is far greater than this.

TRUNKING.

Those calls which involve two central offices are termed "trunk calls," and the ratio of the total number of these to the total number of calls expressed as per cent of the whole is called the "trunking percentage." This of course varies from zero where there is but one switchboard, to well up to 90 in the largest cities. When the trunking percentage is over 50 this kind of traffic becomes the more important, and every effort must be made to handle it quickly and positively, and without too great expense either for lines or operators.

The most efficient method thus far devised is that known as the calling-circuit method. By this method each central has two kinds of trunk lines, termed respectively outgoing and incoming trunk lines, and each is used exclusively for calls in the direction its name indicates. Of course the incoming lines at one central are but one end of lines outgoing from some other central. The switchboard at each central is divided, one part being termed the subscribers' switchboard and the other the incoming trunk switchboard. The outgoing trunks terminate in jacks and multiple throughout the subscribers' sections, forming a group usually placed beneath the multiple line jacks, but above the answering jacks and signals. These outgoing lines do not appear at all on the incoming sections which have the subscribers' line multiple only. At these latter sections the incoming trunks terminate at the keyboard in single plugs and cords. Besides the trunk lines there are wires called calling-circuits which extend between each two offices, from the subscribers' board at one to the incoming trunk board at the other. At the subscribers' switchboard the calling-circuits are available to every operator, and she may connect her telephone set to any one of them at will, by merely depressing one of a group of calling-circuit keys. The other ends of the calling-circuits connect directly with the telephone sets of the operators who manipulate the incoming trunk switchboard; each calling-circuit terminating at that position where the corresponding group of incoming trunk lines terminates.

Method of Operating Circuit Trunks.

When a subscribers' operator at one central receives a call for a line of another central, she depresses the proper calling circuit key, and speaking directly to that trunk operator facing trunks from her own office, gives the number desired. The distant operator can tell at a glance which trunks are not in use, because the plugs of such are at the keyboard. She selects one and assigns it by giving its designating number. Upon hearing this assignment the subscribers' operator proceeds to connect the calling subscriber to the nearest jack of the outgoing trunk, which bears the same designation.

In the meantime the trunk assigning operator has with the plug of the incoming trunk tested the line of the asked-for subscriber of her district, and either connected the trunk thereto, and rung the subscriber, or he being busy has connected a hum or other busy signal to the trunk to signify this fact.

It must be understood that the incoming trunk operator can never talk to any of the subscribers, i.e., she cannot talk upon any of the lines but merely upon her calling circuit.

Auxiliary Trunk Signals.

A circuit trunk system will only work satisfactorily when equipped with certain auxiliary signals. One of these has already been mentioned. This is the busy signal. Sometimes this is an audible signal and sometimes a visual signal such as the flashing of a lamp. Such signals are introduced upon the trunk by the insertion of the trunk plug in a jack to which the signal currents are wired.

Sometimes a phonograph is used. This repeats, "The line is busy; please call again," or some similar phrases. Such an arrangement includes a telephone set, the transmitter of which is agitated by the phonograph reproducer.

The disconnect signal is an almost indispensable auxiliary. It usually takes the form of a small incandescent light in front of the trunk operator. This glows when a trunk is to be disconnected from a line. As the trunk operator cannot listen on a trunk, she has no means of discovering just when a conversation is completed. The subscribers' operator can, however, listen, and she has in addition, her regular clearing-out signals. Upon discovering or being notified that a conversation is completed, she clears the cords from the jacks without reference to the trunk operator. The disconnect signal lamp near the plug socket at the incoming end of the trunk glows at once, indicating to the trunk operator which connections she must take down.

Ring Down or Common Trunks.

Such an elaborate trunking system as that just described is, of course, economical only when the number of calls between two offices is considerable. This is evident when it is understood that two lines, viz., the calling-circuits, are required solely for carrying out the system. When the traffic is small, but one group of trunks is used. These trunks end in jacks and signals at both ends. When a call must be passed over such a trunk, the operator tests through the group until she finds a trunk not busy, and then rings upon it. This throws the distant signal. When the distant operator answers, the call is passed to her and handled by her as though direct from a subscriber. Such a call, involving two pairs of connecting cords, has, of course, two clearing-out drops as disconnection signals. This system is much slower than the circuit system.

COMMON BATTERY SYSTEM.

As mentioned in the description of telephone instruments, in some systems the individual transmitter batteries are replaced by a storage battery, located at the central office, which serves for the entire system. Such systems are variously called Central Energy, Central Battery, or Common Battery Systems. There have been suggested a number of different ways of applying the current from the common battery to the uses of the transmitter, but the only one of practical importance thus far is that in which the current is applied to the transmitter directly, the circuits being variously arranged to permit of this.

One of the primary features of all common battery systems is the use of direct current or battery signaling from the subscriber to the central office. This permits of the omission of the hand generator, as all signals to the central office whether for connection or disconnection are made by the mere closing or opening of the line circuit.

Rudimentary Common Battery Circuits.

In the two circuit diagrams herewith given are shown the rudiments of two common battery systems. In the first (Fig. 27) are shown two lines connected together and supplied from a common battery. In this system the transmitter and receiver at the substation are shown in series. This is a practical method of connection, but has been largely superseded by others giving more powerful results. The ringing keys at the central are omitted from the circuit to simplify the diagram, but they are wired exactly as earlier described. The battery is connected to the line through the retardation coil. The left-hand receiver is shown off the hook and the battery circuit is complete, flowing out through the signal. This signal being energized raises its target above the shield. The right-hand instrument has not yet responded and its circuit is open at the hook switch. No current flows through the bell circuit because of the condenser. The right-hand signal target is behind the shield.

Suppose the response of the right-hand station to be made, current will then flow steadily to both stations. This steady current will magnetize the core of the retardation coil. Now when any sudden change in the resistance of one line is made, due to the agitation of the transmitter, there will be a simultaneous change in the current to the other. The reason for this is twofold; first, there is a reapportionment of currents between the lines due to the resistance change ; and secondly, the rapid change of current affects the magnetization of the coil, causing either inductive discharges to the line, or absorption of the current as the case may be. Additional pairs of lines may be wired off the battery from additional coils, as indicated, up to the current capacity of the battery.

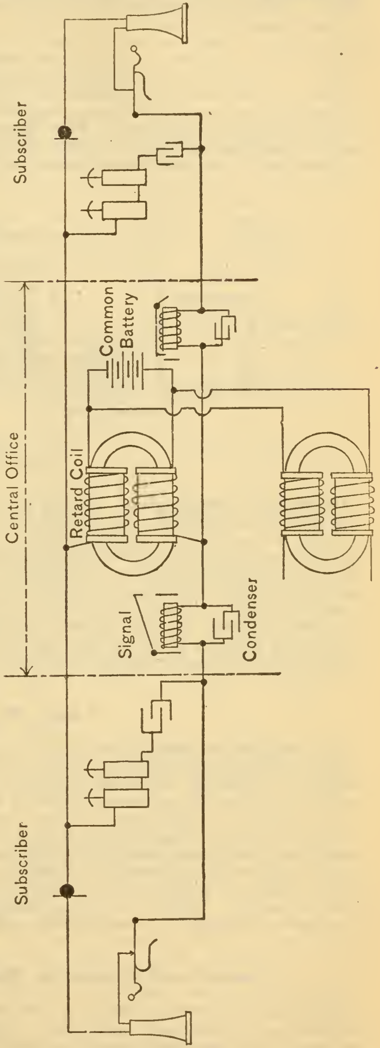


FIG. 27.

In the second circuit (Fig. 28) it will be seen that the arrangement of the subscribers' instruments is considerably changed, an induction coil being used. Another difference lies in the substitution of a sort of quadruple wound transformer, called a repeating coil, for the retardation coil. It is mere chance that the retardation coil and series connected instruments should be associated, as these instruments will work equally well when wired to a repeating coil, provided the parts be properly proportioned.

The operation of the repeating coil is almost self-explanatory, the current changes in one pair of coils being inductively repeated by the other through electromagnetic induction. The distinction between an induction coil and a repeating coil lies in the fact that the latter has a ratio of transformation of unity, i.e., all its coils have the same number of turns.

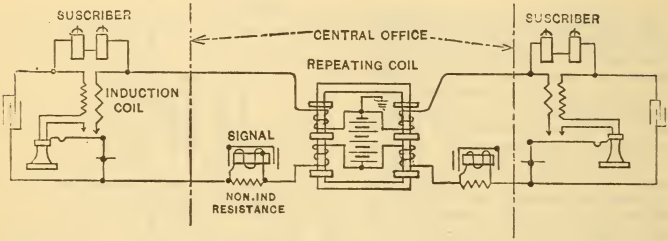


Fig. 28.

With this repeating coil system as with the other, many lines may be simultaneously supplied by the same battery, each pair of lines, however, having an individual repeating coil. The battery must be of extremely low internal resistance, for otherwise the varying currents supplied to one line might cause a corresponding potential fluctuation at the battery terminals; and thus cause minute current fluctuations on all lines connected thereto. The result of this is battery cross-talk, or battery noise. A storage battery of large current capacity has proved best, this usually consisting of from 11 to 25 cells according to the circuit system used, the corresponding mean voltages ranging from 24 to 52.

Lamp Signals.

The magnetic signals shown thus far are likely to be replaced by incandescent lamps controlled by relays. These latter are similar to telegraph relays in function, although usually of far more compact design. The contacts of the relays control circuits local to the central office, which include miniature incandescent lamps, the glowing of which gives the signals.

Sockets of the general appearance of jacks are used as receptacles for the lamps, which are generally of tubular form. The lamps carry terminals which register with terminal springs in the sockets. As a cover for the lamp socket, a bull's-eye of opalescent glass is mounted with the convex side outwards. This, by internal reflection, glows throughout, and renders the light visible from a considerable angle.

Circuits of Common Battery Switchboards.

Common battery switchboard systems are now of many types, and new schemes are continually appearing. All, however, may be referred back to one of the two fundamental schemes. The first switchboards to meet general adoption had jacks wired on the bridging system, each of which has two spring and one thimble contact. Three wires run throughout the board for each line, and this has led to the name "three-wire" system, this name having been given in distinction to a later "two-wire" system.

Each system has many modifications and developments to fit different conditions and the different ideas of various inventors. It is possible, however, to consider here but one system of each kind, and these with regard to fundamentals only.

Three-Wire System.

The subscriber's line circuit is bridged to the multiple and answering jacks and in addition is carried to two contacts of a relay, called a "cut-off" relay. The armature of this relay is arranged to cause the opening of two independent circuits when the relay is energized. From the cut-off relay contacts the branch circuit leads on one side directly to the battery, while on the other it is carried to the coil of a single contact relay and thence to battery. This latter relay is called the "line" relay, and it is evident that it will be energized whenever the telephone is removed from its hook if the contacts at the cut-off relay be closed.

Associated with the answering jack of the line is a lamp signal whose circuit is controlled by the line relay.

The cord circuits for interconnecting lines are used as with the switchboards already described. There is, however, a most admirable feature added. This is what are called the supervisory signals, by means of which an operator may know the instant that a conversation is completed.

These supervisory circuits are controlled jointly by the third-wire circuit, in which they are wired, and by relays wired directly in the talking-circuit. Referring to the circuit diagram, the battery circuit may be traced through the repeating coil and supervisory relay to the plug, jack, and subscriber's instrument. It is also evident that the rapidly alternating current will be greatly attenuated in passing through the inductive winding of the relay unless some shunt circuit is provided about it. This is usually done, the relay winding being the combination of a non-inductive and an inductive winding in parallel. A condenser will serve as a shunt, and many consider this the more desirable arrangement.

The supervisory lamps are designed to operate upon 12 volts, one half the battery potential. There must be placed in series with them a resistance equal to that of the lamp, approximately, 120 ohms. This is made up as follows: 83 ohms of resistance coil, and 30 ohms in the cut-off relay winding, with an allowance for 7 ohms in the wiring. Under these circumstances, the lamp glows. If now the supervisory relay close the shunt circuit about the lamp, the combined resistance of shunt (40 ohms) and lamp is but 30 ohms. The total resistance is then 150 ohms, corresponding to a pressure at the lamp of but $\frac{30}{150}$ or $\frac{1}{5}$ of the battery voltage, too little to affect the lamp.

The progress of a call may now be traced. The receiver being removed from the hook at the calling station, the line lamp lights, calling attention. The operator responds with a plug and cord. The corresponding supervisory light fails, for as soon as its circuit is closed the shunt becomes operative, as the receiver is off the hook and current flows through the supervisory relay.

At the instant of inserting the plug, the cut-off relay is energized and breaks the circuit of the line relay, cutting it off the line. The line lamp of course goes out. Incidentally the busy test battery is put upon the jack thimbles, as these are at a potential corresponding to the drop of potential in the cut-off relay, viz., 4 volts.

The operator, using her listening key, ascertains the desired number and connects to that line and rings. As long as the station fails to answer, the corresponding supervisory lamp remains aglow, as the shunt circuit is open. When the receiver is removed from the hook, the shunt closes. It must be noted that the cut-off relay of the called line operates upon the insertion of the calling plug in its jack, and thus there is no possibility of affecting the line lamp of this line.

Trunking is accomplished by exactly the same methods as with magneto systems. The circuits used are so various that it is useless to attempt to choose one as standard. One of the most interesting features largely adopted with circuit system trunks is that of through supervision. By this is meant that the subscriber's operator, at whose position the call is

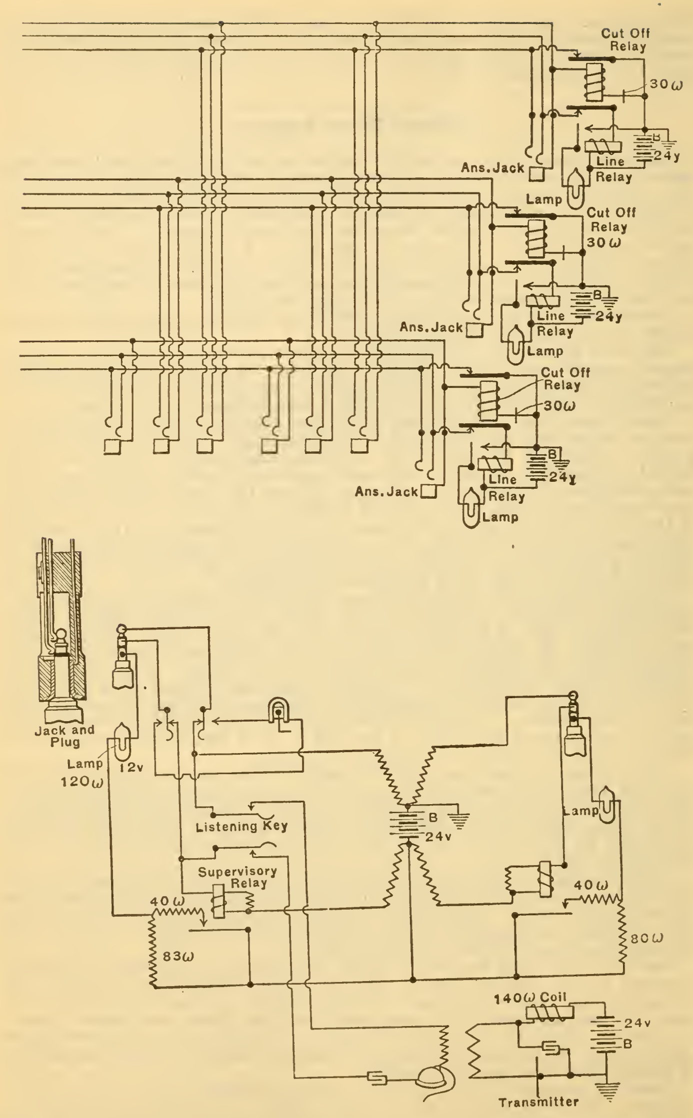


FIG. 29. Circuits of Three-wire System. Batteries *B*, *B*, *B*, are one and the Same Battery.

first received, has in her lamps a direct indication of the position of the hook switch of a subscriber of another central office connected through a trunk line.

Two-Wire Systems.

There are so many different schemes for two-wire systems and this system is of such recent introduction that it is difficult to select any one which might be considered standard. One of the earlier types is shown,

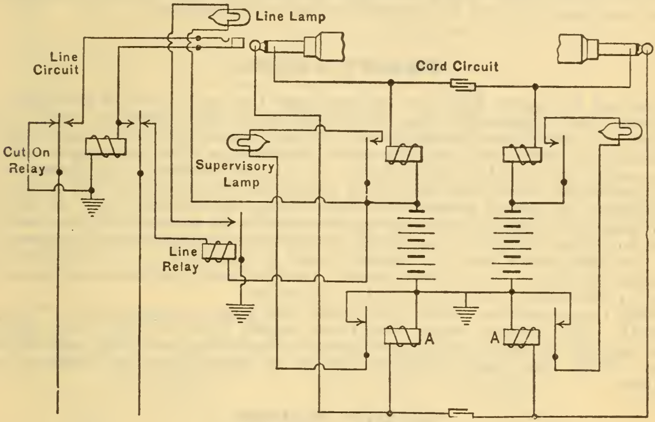


FIG. 30 Circuit of Two-wire System. Relays *A*, *A*, serve as Retardation Coils.

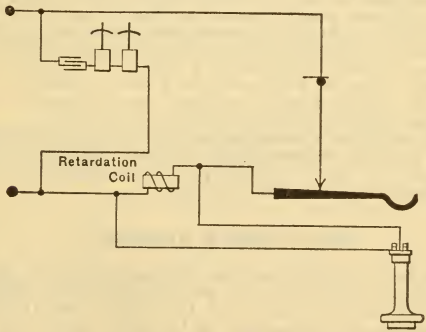


FIG. 31. Recent Common Battery Subscriber Set Circuit.

however, in Fig. 30. The cut on relay severs the connection between the line relay circuit and the line, and at the same time connects this latter to the jack circuits. The supervisory circuit is self-evident. It might seem that the contact with the jack thimble, in testing for busy, might interfere with a conversation by shunting off part of the current. This is avoided by reducing the shunted current to the smallest amount and making this effective in a very sensitive relay. This relay in turn closes a circuit which clicks the receiver. This test apparatus and the ringing and listening keys are not shown in the diagram.

Common Battery Instrument Circuits.

The circuits of instruments are also of many sorts. One kind largely used is shown in connection with Fig. 28. In this the induction coil primary and secondary have a ratio of turns of 1 to 2, and of resistance of 2 to 1. The transmitter affects the repeating coil directly, and in addition through the induction coil causes a more intense current to be sent out on the line.

Another type of circuit is shown in Fig. 31. Here the coil shunted about the receiver serves as a low-resistance path for the transmitter current, while the voice currents find a path through the receiver.

PARTY LINES.

Demand for party lines has existed since the early days of telephony. Nothing really successful was accomplished in this direction until the advent of the Carty bridging-bell. With series bells good party-line service with a two-wire line is out of the question, as all voice currents must necessarily traverse the bell-magnets of all idle stations. The bridging-bell, previously described, connected across the line-circuit and of so high impedance as not to appreciably shunt the voice-currents, can be used for a number of parties up to twenty or more so far as electrical considerations go. Practically the number of stations is limited, for with the unmodified bridging-bell a code of signals must be resorted to, to distinguish between stations. As all bells respond to all signals, confusion and annoyance to subscribers limits the number of parties.

With the magneto system the signal, one ring, is reserved for calling central. The stations must then have signals from two up; and when their number is large, a differentiation is made between long and short rings. With the common-battery system all signals may be assigned to stations.

Selective Systems.

Before the bridging-bell was introduced, attempts were made to solve the party-line problem by some sort of selective device, which, by responding to a code of signals, would succeed in ringing the desired party to the exclusion of others. At first all systems were what are now known under the generic name — "step-by-step systems." Each station has a point switch, the arm of which is driven by a motor. The motor is controlled from central, and drives its mechanism in a series of steps.

All motors run synchronously and they are arranged to connect the bells one after the other in operative relation to the line.

Another and later type of selective system has been developed, in which the bells work entirely independently of each other and of any motor device, the selection of any particular bell being dependent upon the combination of currents sent out upon the line.

Step-by-Step Systems

Probably hundreds of step-by-step mechanisms have been invented, but it can scarcely be said that any are in general use. Both spring and electrical motive power have been tried, but the fact that this system places all the more complicated apparatus at the subscriber's station, where it is most troublesome to all concerned to get at it for repairs and adjustment, weighs too heavily against all step-by-step systems.

Two-Party Selective Systems.

The simplest selective system is the two-party system, largely used by the Bell companies. In this system one bell is wired to ground from each side of the line, bridging-bells being used. In ringing a party the ringing current is connected to ground on the one hand and the proper side of the line on the other.

Four-Party Systems.

Four-party systems seem to be the most popular, and there have now been many schemes for accomplishing selection. The so-called Newburgh system uses what are termed "biased" bells. These are polarized bridging-bells with the armatures biased to always come to rest in the same position. The biasing means is usually an adjustable spring acting upon one end of the armature. Two such bells are wired to ground from each side of the line. The currents used are impulse currents of one sign only, being comprised of a series of half waves of alternating current separated by an equal period of no current. Two of the bells, one on each side of the line, are connected to respond to positive impulses only and to fail on negative impulses, these latter merely assisting the spring to hold the armature stationary.

After an armature has been moved by a current impulse of the proper sign, the spring returns the armature during the period of no current. The other two bells are similarly arranged, but are connected to respond to negative currents.

For the common-battery system the Newburgh system becomes modified as it will not do to have permanent grounds upon the line, and the insertion of a condenser will not help matters as it converts the impulse currents to alternating currents to which all bells are responsive. The

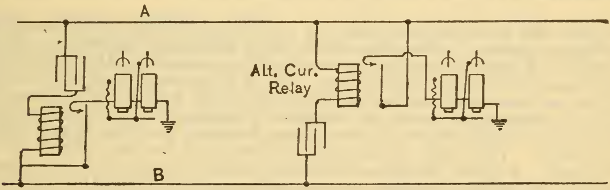


Fig. 32. Four-Party Newburgh System Arranged for Common Battery, Two Stations wired from Line *A*, and Two from *B*.

arrangement usually adopted is indicated in Fig. 32. The relays at all stations are in series with condensers and all operate irrespective of the kind of current impulses. These relays connect the bells to line and that responsive to the impressed current rings.

There are other four-party systems in which the bells respond to changes of frequency of the current, the bells being wired with such combinations of inductance and capacity as to make the response and failure positive. Other systems use combinations of direct with alternating currents, while at least one, the "B.W.C.," which at one time bid fair to be very popular but which has now largely gone out of use, depends entirely upon various combinations of direct currents.

Method of Obtaining Impulse Currents.

The impulse currents for the Newburgh system are obtained from the ringing generator by the use of an auxiliary two-part commutator one segment of which is connected to one of the usual alternating-current terminals and the other of which is either left blank or connected to the other alternating-current terminal, if this latter be grounded. Two brushes diametrically opposite each other bear upon the commutator, and these are adjusted with reference to the field so that the passage from one seg-

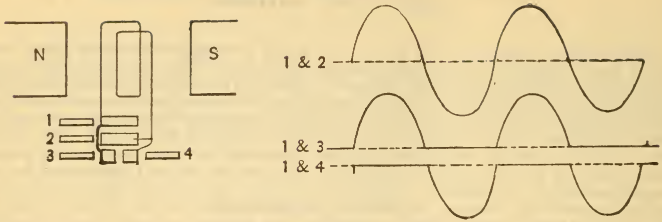


Fig. 33. Arrangement of Generator for Obtaining Impulse Currents.

ment of the commutator to the other occurs just at the zero or point of reversal of the alternating wave.

Between either commutator brush and a collecting ring an impulse current can be obtained.

CENTRAL OFFICE APPARATUS AUXILIARY.

Besides the switchboard there is in every central office considerable auxiliary apparatus. The size of the office generally determines the kind required. Of such apparatus, in every office of any size, the main distributing frame is of prime importance. As it is imperative that all stations be given as near continuous service as possible, and as it is always distasteful to subscribers to have a change of number, it is found necessary to have some flexible link in the wiring between the line cables and the switchboard. The main distributing frame provides the facility for this connection. A steel framework carries strips of terminals, to some of which the switchboard cables are connected and to others the line or outgoing cables are connected, each pair of wires being assigned and connected to one pair of terminals according to some carefully planned scheme. A flexible or temporary connection, usually termed a "cross connection" is run from any one pair of terminals to any other, as the service may require. Main distributing frames are usually arranged with two accessible sides. The terminals upon one side are vertical and are supported from a set of uprights so as to form a series of vertical runways between the terminal strips. On the other side the terminals and framework are usually arranged in horizontal planes that horizontal runways may be formed. With such construction, wire may be run with the greatest ease between any two terminals.

Of late years it has been considered good practice to use the main frame as a support for the central office thermal cut-outs and carbon plate arresters, the vertical side of the frame having arrester mountings substituted for the simple terminals. The strips of arresters are often called arrester bars.

The intermediate distributing frame has only come into universal use lately. It is similar in construction to the main frame, but its purpose is to provide a flexible link between the multiple and answering jacks. It is clearly impracticable to have the multiple jacks arranged in any order save that indicated by the line numbers. The wiring of these jacks is therefore made permanent once for all. On the other hand it frequently becomes necessary to change the position from which any line is answered, in order to properly distribute the work between the different operators. For example, Nos. 1 to 50 may call frequently enough to require two operators to properly care for them; while Nos. 50 to 150 may require but one operator. It would clearly be impossible to distribute answering jacks and signals to meet such conditions while designing a switchboard. The question of distribution must be met by the intermediate frame. The multiple jack wiring connects to one side, and that for the answering jacks and signals to the other, and the cross connection serves to connect any answering jack to any multiple jack. It is of no moment that answering jacks be placed in an order having no relation to the line number, for they are never sought for by number, but only in response to an associated signal.

Of the other apparatus the most important is the power plant. In magneto offices this comprises a small four-volt storage battery, sufficient to energize the operators' transmitters and to operate miscellaneous signal lamps and magnetic signals. A power-driven generator for charging the battery and power-driven ringing machines are also required.

For common battery offices the battery is usually of from 16 to 52 volts and of large capacity. The charging generators must be correspondingly large, having sometimes as great as 20 kw. output, which at low voltage means a big and heavy machine.

It might seem at first thought that the battery could be omitted as generators must be provided to charge them, the generators being used directly. Unfortunately the difficulty of making a generator which will produce a current sufficiently smooth to permit of any service whatever without a battery is so great that the use of the battery is a necessity. The battery smooths out the irregularities caused by the commutation of the generator, which irregularities, of no moment at all in any other service, are entirely disastrous to telephony because of the noise introduced.

AUTOMATIC EXCHANGE SYSTEMS.

There are in operation quite a number of automatic exchange systems. These range in size from accommodations for a few lines, to a capacity approaching 10,000 lines. The subscriber's instrument for all automatic systems is provided with a numbered dial and a movable indicator. This latter is set in some manner to indicate the number of the line desired. When released it returns automatically to zero and in so doing, through the agency of auxiliary contacts, it causes a selecting apparatus at the central office to make connection between its line and the desired line.

Almost all automatics depend upon the multiple principle. Each line is assigned a switching mechanism before the moving switch arms, of which are arrayed contact points for all other lines in the district. There is thus one multiple for each line. The multiple line contacts are arranged in consecutive order. For small systems they are often placed as radii of a circle over which the contact arms move. In such systems the motor for the switch arm requires but one motion, that of revolution. In other small systems the contacts of the multiple are arranged in a single row. The switch motion then becomes a simple longitudinal one. As the capacity grows, the multiple contact points assume the form of a superimposed series of rows, the contact of each line occupying a position which can be located by its co-ordinates. The tens of the number usually correspond to the vertical and the units to the horizontal co-ordinate. For such systems the moving switch arms require two motions. If the points be arranged upon a plane surface, these motions are an elevation and a transverse motion. If the contacts be arranged upon the inside of a cylinder the motions are elevation and rotation.

Suppose with such a system Number 79 is desired. Seven elevating impulses will be sent so that the switch arm will traverse the vertical co-ordinate. Then nine transverse or rotating impulses will cause the arm to traverse the horizontal or units ordinate and rest upon the point 7–9.

A second system, more akin to a manual switchboard, has been invented. In this system the lines have each but one set of terminals, but there is provided a system of circuits corresponding exactly to the cord circuits of manual switchboards. The starting of a call causes one of these circuits to first become connected to the calling line and then to the called line which is automatically rung up.

When automatic systems are used for a great number of lines the method of completing calls, while becoming little more complicated for the user, becomes excessively more so at the switchboard. It is not possible to attempt to explain here the scheme of operation, nor is it possible to consider the details of any of the smaller systems.

SIMULTANEOUS USE OF LINES.

Efforts have been made to use telephone lines for two distinct purposes, simultaneously, in two ways. The first has been but partially successful and contemplates sending more than one telephone message at a time. The second, very successful, and in everyday use permits of the simultaneous transmission of telegraph and telephone messages.

Duplex and multiplex telephony depends upon the arrangement of the various instruments with regard to the conductors so that each telephone

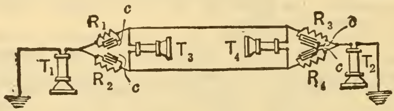


Fig. 34. Duplex Telephony.

connects equipotential points of the system with respect to all other instruments save its mate. Thus in Fig. 34, if the resistance and capacity upon the upper branch of the parallel line equal exactly that of the lower line, both in value and distribution, the terminals of both T_3 and T_4 will connect equipotential points with respect to instruments T_1 and T_2. Similarly will

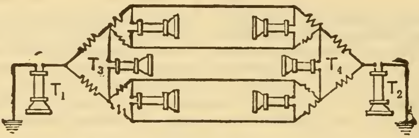


Fig. 35. Multiplex Telephony.

T_1 and T_2 connect equipotential points with respect to T_3 and T_4. So also in the multiplex circuit it will be found that equipotential points are used. Retardation coils serve better than resistances, in such systems, as these may be connected to form an inductive path for currents, the passage of which should be resisted to prevent loss of volume and to form a non-inductive path for those currents which should be conducted.

The difficulty with such systems has lain in the inability to make the two sides of the various lines exactly alike, with the result that the supposed

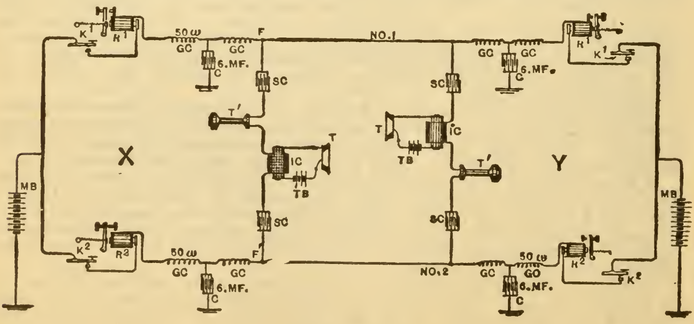


Fig. 36.

equipotential points were not such. Under this condition the two circuits overlap and cross-talk.

The method employed for rendering telegraph signals of no effect upon telephone lines has involved the rounding of the telegraph current impulses to such an extent that there is no change abrupt enough to affect the telephone. The first system was invented by Van Rysselberghe and after modification is used to-day. Such a system is indicated in Fig. 36, taken from Maver's American Telegraphy. It will be seen that one pair of wires provides simultaneously for one telephone and two telegraph messages.

Another system in use sometimes called "Simplex," provides for but one message of each kind for each two wires. Simultaneous telegraphy and telephony is used extensively on long distance lines, and the application of this system is called "compositing," while the coils, condensers, etc., are called a "composite set."

LIMITS OF TELEPHONIC TRANSMISSION.

The limiting distance through which commercial telephony is practicable is as yet an unknown quantity. Every few years the idea becomes general that the working limit has been reached, when some new invention or construction permits of a further extension. The limit for the magneto transmitter was extended by the Blake transmitter, and then by the solid back type. The bipolar receiver has replaced the single pole. Dry and LeClanche batteries were superseded by the more powerful and steadier Fuller cell and this in turn by the storage battery of practically constant strength. In the direction of the line the grounded circuit gave way to the metallic and the iron and steel wire to hard copper. This latter has been used in constantly increasing sizes until the commercial limit seemed to be reached at number six B. & S.

The most obvious way of increasing volume is improvement in the sensitiveness of the transmitter and receiver. Improvements in this direction have been at a standstill for some years. Nothing has been found to better the solid back, except increase of current, and the effect of this is temporary only, resulting disastrously very soon. Improvements in the receiver, on the other hand, prove a disadvantage at once, as with a sensitive receiver the effect of line disturbances grows at a rate entirely incommensurate with the increase in volume of transmission.

Another method of extending the limit for speech transmission attempted almost since the beginning of telephony is the use of a repeater, in a manner exactly similar to that which has worked so successfully in telegraphy. Up to this time, however, no success has been met with along this line. No repeater has as yet been developed which does not do at least as much harm as good.

Within the last few years an entirely new means of improving the efficiency of transmission has appeared. This, briefly, consists in the change of the electrical characteristics of the line by means of auxiliary inductances or capacities or auxiliary conductors in a manner such that the telephone currents are transmitted with better efficiency.

The first method to be developed was that invented by Dr. M. I. Pupin and termed "loading." Dr. Pupin showed how coils of certain known inductance can be spaced along a line and thereby improve its efficiency. The adaptation of such a system of course requires much study and experiment. Coils must be designed which are non-interfering and the energy absorbing properties of which are sufficiently reduced so that there is a net gain in transmission. Lines are now in use equipped with this system, but it can scarcely be said to have passed the experimental stage. The improvement in transmission thus far is, as far as can be learned, about as 2½ to 1, when all conditions are normal. When, however, the insulation of a line is reduced irregularly as by moisture, the effect upon a loaded circuit is at times very disastrous.

Two later systems have been invented. One of these involves putting condensers in series with the line and inductances across the line, at regular intervals. This system has as yet been placed upon no practical basis.

The second of these systems has been developed in theory to the most encouraging state. It may be termed the method of "distributed shunts."

The theoretical condition to be fulfilled is that of equal velocity of transmission for waves of all frequency; thus the condition for no distortion of the wave forms. The inventor has found that to fulfil this condition he must increase the inductance of the copper line by plating it with magnetic material such as nickel or an alloy of iron and nickel and that it must be shunted at stated intervals. The shunts consist of graphite or other non-inductive resistances of many thousand ohms resistance each; spaced at equal intervals of from one to several miles.

NOTES ON COST OF TELEPHONE PLANT.

That the cost of telephone switchboards for large central offices increases faster than the number of lines is of course evident from what has been said concerning switchboards. It must be pointed out, however, that even when the plant is considered as a whole, the cost for large plants is greater per station than for small. The following by H. S. Kerr in the *American Electrician* may throw some light on this subject.

"The cost of a telephone plant can be estimated approximately on the basis of the number of instruments installed. An exchange of 500 telephones installed within a radius of 1½ miles without any conduit or cable work, but with up-to-date pole-line construction, will cost about $65 per instrument; this will come so near to the actual cost that a company may base its calculations on it with a degree of certainty. As the number of telephones increases, that radius or distance from the exchange will also increase, and, therefore, the cost per instrument. In estimating on a plant of 1000 telephones some aerial cable and more substantial construction must be taken into consideration as well as more costly equipment; consequently, there will be a material increase in the cost per instrument; without conduit work a safe approximate figure would be $85 per instrument within an ordinary radius.

"When an exchange has more than 1000 subscribers, and quick, strictly modern service is required, necessarily it must be equipped with central energy and multiple switchboards, and in towns where electric light and railways are used many additional appliances are required to neutralize the interference from the heavy circuits. Where it is necessary to construct conduits it is not safe to allow less than $100 per instrument for the installation. In large cities where 5000 to 10,000 subscribers are connected up, the cost would approximate from $150 to $200 per instrument."

Besides the interest on the investment, maintenance and depreciation are of vital importance. Something has already been said with regard to the maintenance and depreciation of cable, but further opinion may be of value. In 1899 the Michigan Board of State Tax Commission arrived at the following schedule of depreciation for various telephone equipment.

"Poles and cross-arms, accepting about twelve years as the average life of a pole, a depreciation was allowed of eight per cent per annum; underground conduits, two per cent; underground and aerial cables, lead-covered and rubber, ten per cent; subscriber's station equipment, ten per cent; switchboards, ten per cent. For copper wire in use one year or less, its full value will be taken; for two years and less than three years, two and one-half per cent; for three years and less than five years, five per cent; for five years and less than ten years, ten per cent; for ten years and over, twenty per cent. This makes an annual average of about eight per cent."

PRIVATE LINES, INTERCOMMUNICATING, AND HOUSE SYSTEMS.

(Condensed from articles by W. S. Henry in *Amer. Elec.*, 1900).

Thus far only the central office system has been considered. For Private Lines, Intercommunicating, and House Systems, very different apparatus and circuits are used. Such systems have been well described in the technical press and it therefore seems sufficient to review briefly a series of articles treating of such systems.

Private telephone systems may be divided into *series party lines*, *bridging* *party lines*, *intercommunicating systems*, and *small central switchboard systems*. As the last system differs practically only in size from the regular central station system no description of it will be undertaken here. In these systems either magneto or microphone transmitters may be used, and the signaling apparatus may be either magneto bells and generators or the common vibrating bell and battery.

Where microphone transmitters or vibrating bells are employed, the batteries may be distributed among the various stations or, in some cases, all concentrated at one place. It is generally desirable although not really necessary, so to arrange the circuits that the bell at the calling station, or the home bell as it is called, should ring when calling up another station. This assures the person signaling that his own circuit and probably the

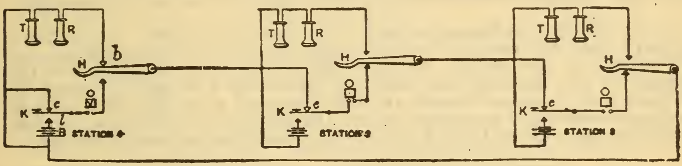


FIG. 37. Series System with Magneto Transmitters and Signaling Batteries.

whole system is in working order, and that his call is being transmitted to the desired station.

One of the simplest telephone systems comprises magneto instruments connected in series in one line. Fig. 37 shows an arrangement of this kind requiring at each station two magneto instruments; *T* is the transmitter and *R* is the receiver. An ordinary vibrating battery bell, *V*, a battery, *B*, of two or more cells, and a hook switch, *H*, complete the equipment. When the receiver, *R*, is hanging on the hook, the line is connected to the lower contact; when the receiver is removed, a spring pulls the lever up against

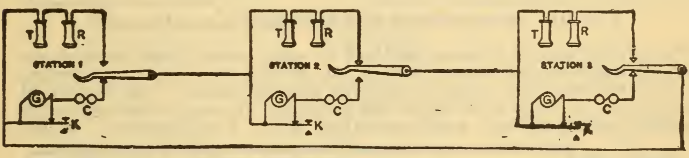


FIG. 38. Series System with Magneto Transmitters and Generators.

the contact, *b*. The smaller auxiliary switch, *l*, is arranged to normally rest on the contact, *c*. It may be pressed down upon *d*, but when released it should be returned to *c* by a stiff spring.

In Fig. 38 a very similar arrangement is shown, the only difference being the use of magneto generators, *G*, in the place of the signaling batteries, *B*, of Fig. 37, and the substitution of magneto bells for the simple bells used in the first system. The signaling key, *K*, has only the upper contact, to normally short-circuit the generator, *G*, as indicated in the sketch. Some automatic arrangement may of course be used.

The above described systems are known as *series party lines*, meaning that all of the stations connected up are in series with each other. When this arrangement is used, even for a small number of stations, the bell magnets should have as low resistance and as few turns of wire on them as possible, in order to reduce the impedance of the circuit; and the generators should be wound with rather fine wire, because the current generated must pass through all of the bells in series.

In order to avoid forcing the talking current through the magnets of the signaling bells, the latter may be "bridged" directly across the circuit, as shown in Fig. 39, in which case the bells may be wound for high resistance and impedance so that the talking currents will pass them.

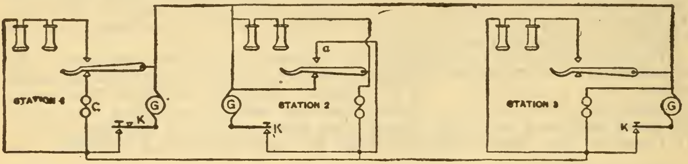


FIG. 39. Bridging System with Magneto Transmitters and Generators.

In Fig. 39, three different methods of bridging are shown. At Station 1 the bell is removed entirely from the circuit when the receiver hook is up; at Station 2 the bell remains constantly across the circuit in series with the transmitter and receiver, but when the hook is up it is short-circuited by the hook and its upper contact through the wire, *a*; at Station 3 the bell remains permanently connected across the circuit, and when the receiver hook is up the transmitter and receiver are connected in parallel with it.

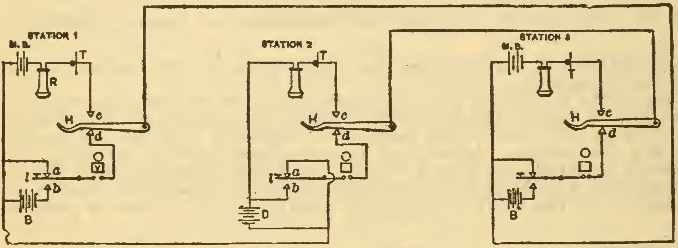


FIG. 40. Series Systems with Microphones and Batteries.

Fig. 40 shows the simplest method of using microphone transmitters. The instruments are a transmitter, *T*; an ordinary receiver, *R*; a vibrating bell, *V*, and one or two separate batteries at each station. The battery, *B*, is used only for ringing the bells; the battery *M.B.*, only for operating the microphone transmitters, and the battery *D*, for both purposes. In this

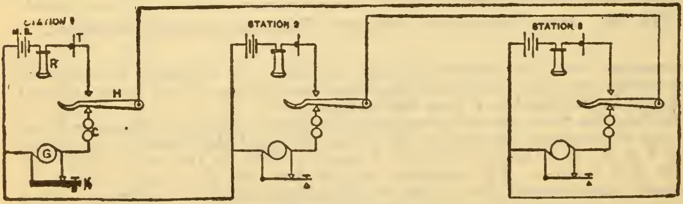


FIG. 41. Series System with Microphones and Magnetos.

arrangement, as well as in the one shown by Fig. 41, the microphones, receivers, and microphone batteries are directly in series with the line, no induction coils being used.

Instead of vibrating bells and batteries for ringing, we may use a polarized bell, *C*, and a generator, *G*, as shown in Fig. 41.

A better arrangement is to use high-impedance bells bridged across the two-line wires, as shown in Fig. 42. The generator, as is the case in Fig. 39, is normally on open circuit.

Three bridging methods are shown. At Station 1 some of the current from the battery, *M.B.*, can flow through the bell when the receiver is off the hook, but this will do no harm; in fact, it may be beneficial, for it allows a larger direct steady current to flow through the microphone. The fluctuations in the current produced by the microphone cannot pass through the bell-magnet coils, but will pass through the line circuit on account of the lower impedance of the latter. At Station 3 the bell is cut out when the hook switch is raised, and at Station 2 both the generator and bell circuits are cut off by raising the hook. An extra contact, *d*, is required at these two stations, but on the other hand there are two bells

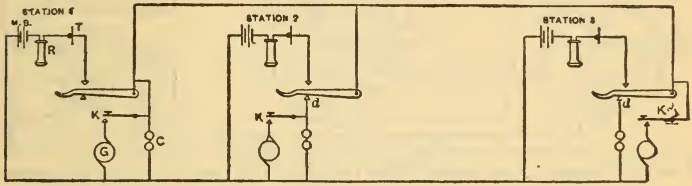


Fig. 42. Bridging System with Microphones and Magnetos.

less across the circuit to form shunts or leaks for the current when two parties are conversing. On the whole, the arrangement at Station 3 is the best of the three.

Fig. 43 represents a series party system (corresponding with that which was shown at Station 1 in Fig. 40) in which a battery, *B*, and vibrating bell, *V*, are used for signaling, and an induction coil, *I*, is added to the speaking apparatus. The primary of the induction coil is in series with the microphone transmitter, *T*, and its battery, *M.B.*, and the secondary is in series with the telephone receiver and the line.

The connections at Stations 1 and 2 are identical; when the receiver hook, *H*, is down the talking instruments are entirely cut out, and when it

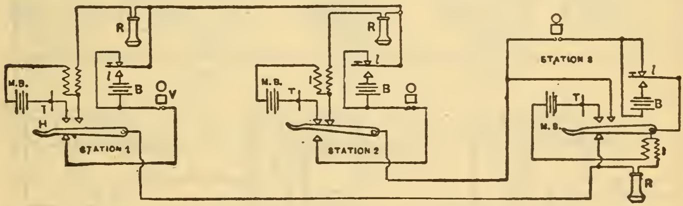


Fig. 43. Series Party System, with Induction Coils and Signaling Batteries.

is up the signaling key, battery, and bell are thrown out of circuit and the main circuit passes through only the telephone receiver and the secondary of the induction coil. At Station 3 the connections are different; when the receiver hook is down the telephone receiver and secondary of the induction coil are merely short-circuited, while the transmitter, its battery, and the primary of the induction coil are open-circuited. When the hook is up, the talking instruments are connected up for service and the signaling part of the apparatus is short-circuited. Fig. 42 corresponds with Fig. 43, except that magneto-generators, *G*, and magneto-bells, *C*, have been substituted in the place of the signaling battery and vibrating bells shown in Fig. 43. The station connections correspond also, the receiver hook, *H*, at Stations 1 and 2 being arranged to throw in and out of circuit the talking apparatus and the signaling apparatus, while the hook at Station 3 merely short-circuits the signaling apparatus or the receiver circuit, according to its position. This arrangement is the preferable one of the two, for the reason that faulty switch contacts at the receiver hook will not open the circuit so that there will always be a continuous line through which one may signal.

A simple system installed where there was considerable noise, dirt, and vibration, is represented diagrammatically by Fig. 45. Here, there are three line wires, *a*, *b*, and *c*, the line *c* forming a common return for both the

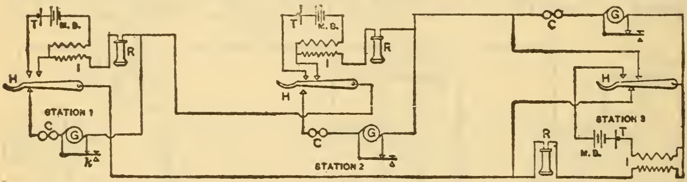


FIG. 44. Series Party System Using Induction Coils and Signaling Magnetos.

signaling and the talking circuits, *a* and *b*, on which the apparatus is arranged in series. In this system the talking line is never open-circuited, the telephone hook, *H*, serving to merely short-circuit the receiver and the secondary of the induction coil when down, and to remove the short-circuit and close the local circuit of the transmitter and induction coil primary when up. It is obvious that the middle line wire, *c*, gives a free path to the talking current, instead of its being forced through the signaling bells. Such an arrangement facilitates the separation of the signaling and talking apparatus, so that the call bells can be located where they can be easily heard while the transmitter and receiver may be put in a sound-proof closet. The

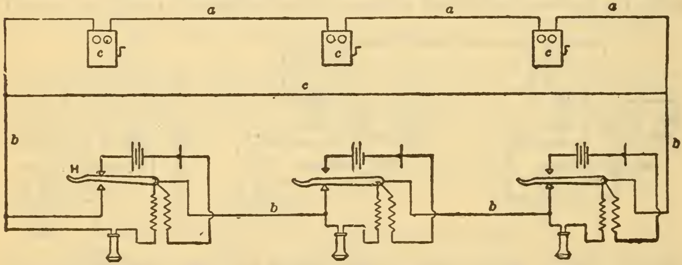


FIG. 45. Three-Wire Series Party System.

disagreeable noises due to induction from lighting or power circuits may be overcome by using a twisted three-conductor cable between stations. Such an installation is greatly superior to the series system shown by Figs. 43 and 44.

Fig. 46 shows a series system in which one battery is used both for signaling and for talking. In this system the connections are alike at all stations; when the receiver hook, *H*, is down and the signaling key, *l*, is up, there are included in the line circuit only the vibrating bells. Depressing the signaling key, *l*, puts the battery in the line and causes all the bells to ring. It is preferable to have the batteries so connected up that if two or more signaling keys should be depressed at once the batteries will agree in polarity. When the receiver hook is up the battery is connected in series with the transmitter and the primary of the induction coil, while the signaling key and bells are thrown out of circuit and the telephone receiver and secondary winding of the induction coil are included in the line, as shown at Station 3.

In this, as in previous series systems, with the exception of Fig. 45, the talking current must flow through the signaling bells at idle stations. The advantage of the system is obviously that it eliminates half the batteries, only the one battery being used at each station for both signaling and talk-

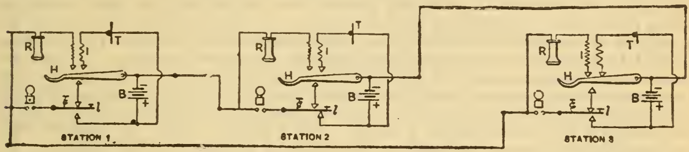


Fig. 46. Series Party System Using One Battery at each Station for both Talking and Signaling.

ing. As in all series systems where vibrating bells are used, the vibrators should be short-circuited on all bells except one.

The best method for connecting a large number of telephones on a single system where only two line wires may be used is to bridge them, as shown in Fig. 47. The dots *A* and *A′*, represent the binding-posts of each complete outfit. The bells are permanently bridged between the two line wires at Stations 1, 2, and 4, irrespective of the position of the receiver hooks. The

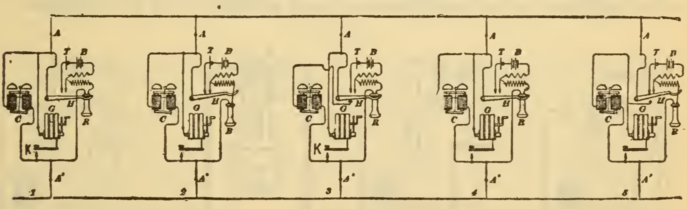


Fig. 47. Bridging Party-Line System; Three Arrangements of Station Instruments.

magneto-generator is also bridged across the two line wires in an independent circuit, which is normally kept open either by a push-button, *k*, or by an automatic device on the magneto spindle.

At Station 3 the magneto-generator is bridged permanently across the line as in Stations 1, 2, and 3, but the bell is connected across only when the receiver hook is down, being thrown out when the hook is up. At Station 5 the bell and generator are bridged across the line wires when the receiver hook is down, and are cut out entirely when it is up. At all of the stations a third bridging circuit includes the receiver and the secondary winding of the induction coil in series, this circuit being open when the receiver hook is down and closed when it is up. The hook also closes the local transmitter circuit in the usual way when it is up and opens it when it is down. The connections shown at Stations 3 and 5 possess the advantage of cutting out their signaling bells entirely when the receiver hooks are up, instead of leaving the bells shunted across the line continuously, as is the case at Stations 1, 2, and 3.

COMMON RETURN INTERCOMMUNICATING SYSTEMS.

An intercommunicating system may be defined as a system having three or more telephones connected to the same system of wiring in such a manner that one may from any station call up and converse with any other station, without requiring any central-station switchboard whatever. Intercommunicating systems require one wire from each station to every other station and at least one more wire running through all the stations. Where vibrating bells and one common ringing battery are employed, at least two more wires than there are stations are necessary. At each station there must be a switch of some kind whereby the telephone at each station may be connected to any one of the wires belonging to the other stations. Intercommunicating systems are very practical and satisfactory up to fifteen or even twenty stations; beyond that, the large number of wires running through all stations makes the cost of the system increase rapidly, especially when the stations are some distance apart. For a large number of stations well scattered, a simple central-station switchboard system is preferable.

Fig. 48 shows a very common but not a good method of interconnecting a number of telephones, where each station is equipped with ordinary series bells and magneto generators. Theoretically any number of telephones may be connected on such a system, but practical consideration would place the limit at about twenty. In this figure there are four stations; at Nos. 1, 2, and 4 the telephone connections are drawn in full, while at No. 3 is shown the telephone outfit as it usually appears. There are four individual line wires, numbered 1, 2, 3, and 4, and a common return wire. Thus there is one more wire than there are stations, and all these wires run through all the stations, each wire being tapped at each station and not cut. At each station there is one ordinary telephone instrument consisting of the usual talking apparatus, magneto-generators and polarized bells. Below each telephone there is an intercommunicating switch, the buttons of which are connected to the respective line wires, and the common return wire. When not in use the switch at each station should remain on the home button.

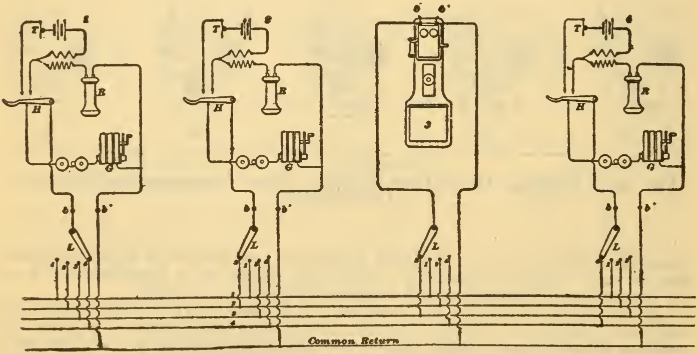


FIG. 48. Intercommunicating System, with Magneto Signaling Generators and Polarized Bells.

With all the levers in this position, a person at any station can call up any other station by moving the switch lever to the button connected with the individual line of the station desired, and turning the generator handle; only the bells at the home station and at the station called up will ring. The ringing and talking currents pass through only the instruments at the stations in communication. After finishing the conversation, the switch lever at the home station must be returned to its home position, otherwise the system will be crippled.

In Fig. 49 is shown a method of wiring the intercommunicating switch that avoids the principal objection mentioned in connection with Fig. 45, that is, the failure to return the switch to the home position does not leave the station so that it cannot be called up. Only four stations are shown, but the system can be extended to include as large a number as may be desirable. The usual telephone sets, consisting of a microphone transmitter, induction coil, receiver, hook switch, two cells of battery, a series magneto-generator and polarized bell, are included in the outfits indicated by T_1, T_2, etc. The inside connections of these telephones are the same as shown in the preceding figure.

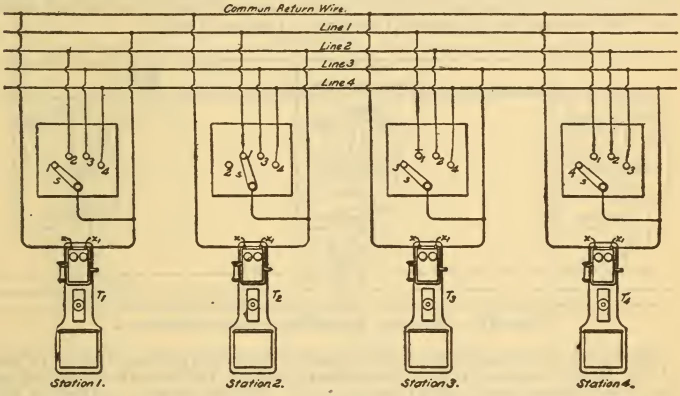


FIG. 49.

In Fig. 49 one binding-post of each telephone is connected to the common return wire, and the other binding-post is connected to both the lever arm, *s*, and the individual line wire belonging to that particular station.

The home button in this last system is the first on the left and is not connected to anything; it is really a dummy button, but it should be there by all means, for the lever, *s*, of the switch should always be returned to it when the original calling party leaves the telephone. If all switch arms, *s*, are on the home buttons it will be found that the circuits of all instruments are open and no bell will ring, no matter what generator is turned. If Station 2 desires to call Station 1 it will be necessary to first move the switch arm, *s*, at Station 2 to button 1.

Fig. 50 is a system similar to that shown in Fig. 49, but arranged for vibrating bells and one common calling battery, CB, in place of magneto-

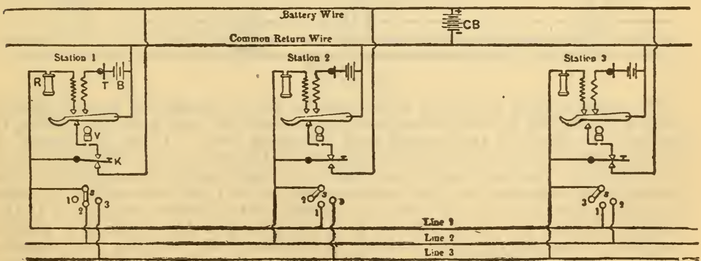


FIG. 50. Common Signaling-Battery System.

generators and polarized bells. A battery is used at each station for operating the transmitter. This is probably the best arrangement of batteries for such a system where vibrating bells are used. This system requires one more wire than that shown in Figs. 48 and 49 where magneto-calling apparatus is employed; thus there are two more wires throughout than there are stations. The calling battery, CB, must be connected to the two wires shown, but it may be located at any convenient place. In this arrangement only the bell at the station called will ring, the bell at the calling station remaining silent. If the bells are not arranged in this manner, the vibrators on the two bells that happens to be connected in series when making a call might interfere more or less with good ringing. Furthermore, it would not do to short-circuit any of the vibrators, because there is no telling which two stations may be connected together in making a call.

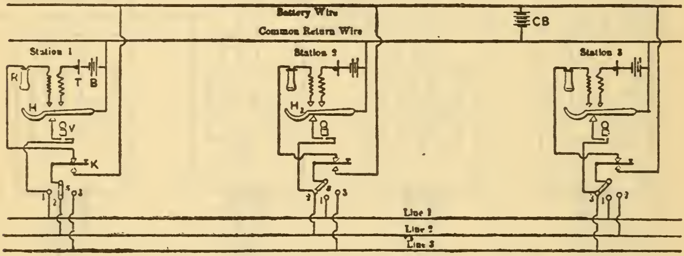


FIG. 51. Common Signaling-Battery System.

Trouble is experienced with intercommunicating systems similar to that of Fig. 50 by reason of the user carelessly leaving the selective switch S, off the home button after using the telephone. Fig. 51 shows a method of wiring such a system which obviates to a considerable extent this trouble. Here, the vibrating bell is permanently connected to the home button, and the pivot of the switch, S, is connected to the arm of the push-switch, K. Any station can still be called up, no matter on what button its switch, S, may be left.

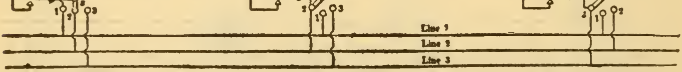


FIG. 52.

The same system of wiring employed in Fig. 48 is applied to the system shown in Fig. 52, in which magneto-generators, G, and polarized bells, C, are used in place of the battery and vibrating bells. There is no need of having a push button or automatic shunt on the generator, although it will do no harm. The generator is normally on open circuit because one of its terminals is connected to the under contact of the push switch, K. In order to call up a station, the switch, S, is placed on the button belonging to the station desired, the push switch, K, depressed, and the generator handle turned. Since no common battery is employed for ringing, this system requires one less wire through all the stations than the preceding arrangement.

In Fig. 53 is shown an arrangement in which one conveniently located common battery, C B, supplies current for ringing and also for all transmitters. No matter where the lever of the selective switch is left, the bell can still be rung, but conversation cannot be carried on until the switch at the station called is returned to the home button. This system includes a piece of apparatus at each station that has not been required in any of the systems previously described, to-wit: the impedance coil E. Where a common battery supplies all the local microphone circuits with current in systems of this kind, there is very apt to be cross talk between two pairs of telephones that may be in use at the same time, in which case the battery will be supplying current to four microphones.

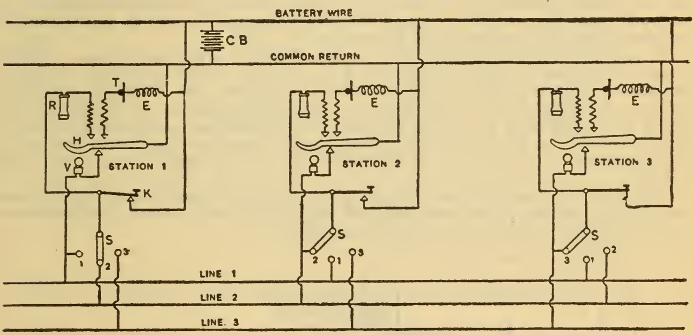


FIG. 53. Common Battery System with Impedance Coils.

The cross talk is due to the variation in the fall of potential along the battery and common return wires.

The cross talk may be greatly reduced by using batteries of very low internal resistance, such as storage cells, and making the common return and battery wires extra large, that is, small in resistance, so that the variable fall of potential through the battery and in these two wires may be small. However, it is impractical to make the resistance of these two wires low enough, especially where they are of considerable length, to eliminate all cross talk.

Another way to reduce the trouble from cross talk is to insert an impedance coil in each microphone circuit, as shown in Fig. 53. This makes the impedance of each microphone circuit large compared to that of the two lines and battery, and in order to get the same current as before in each microphone the e. m. f. of the battery must be increased. These impedance coils reduce the efficiency of the system, but the reduction in cross talk compensates for this loss to a great extent.

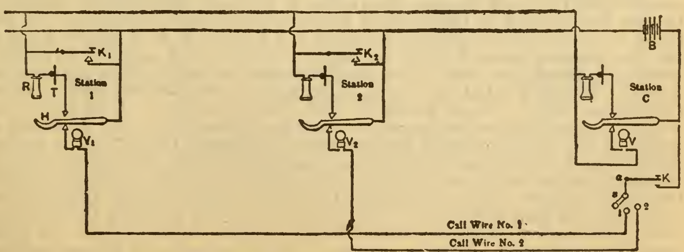


FIG. 54. Radial System; Selective at One Station Only.

It sometimes occurs that a system is required to be so arranged that one station can call up any one of the others, but the others can call up and converse with the first station only. Fig. 54 is a diagram of such a system; Station No. 1 or No. 2 can call up station C by merely depressing the push switch K1 or K2, but they cannot call up or converse with each other. Station C by means of the switch, S, and push, K, can call up either Station No. 1 or No. 2. There are only two wires that must run through all the stations. There is one wire, however, from Station C to each one of the other stations. These wires, Call Wire No 1 and Call Wire No. 2, are used only when Station C calls up one of the other stations. One wire could be made to answer if there was no objection to having all but the home bell ring when Station C makes a call. In this case a certain number of rings would be necessary for each station except C, and the one common call wire would be connected to the signaling key at *a*, Station C, and there would be no need of the switch, S.

As arranged in the diagram, the push switch, K, is normally open. When Station C desires to call Station No. 2, for instance, the switch, S, must be turned to button 2 and the push switch, K, depressed. The one common battery, B, furnishes current for all ringing and talking. At each station there is an ordinary receiver, microphone transmitter, and vibrating bell. There is only one bell in circuit when a call is made so that each bell must have a vibrator. It makes no difference upon what button the switch, S, is left.

In the systems so far described there is nothing to prevent the intercommunicating switch from being left off the home button when the conversation is finished and the receivers hung up.

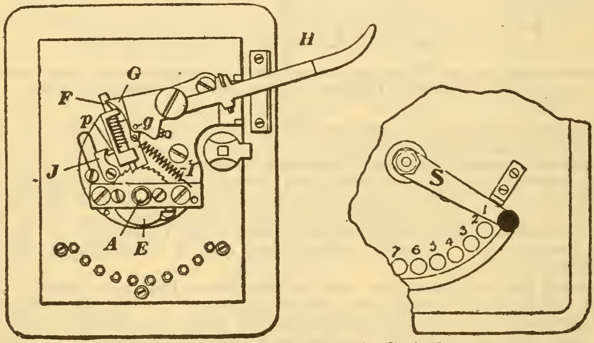


FIG. 55. Ness Automatic Switch.

An example of a device obviating this trouble is the Ness automatic switch, illustrated by Fig. 55, arranged so that the replacing of the receiver upon the hook causes the switch to fly back to its home position. In the engraving S is the lever of the selective switch, adapted to be rotated over the various contact buttons, 1, 2, 3, etc. It is mounted upon a shaft, A, passing through the front board of the box and carrying a ratchet-wheel, E, inside the box. This ratchet-wheel is held in any position to which it may be rotated by a pawl, F, and thus prevents the lever S, from turning backward. Upon the short arm of the hook lever, H, is pivoted a dog, G, adapted, when the receiver is removed from the hook, to engage a notch in the pawl, F; when the receiver is replaced, the dog, G, is pulled upwards and lifts the pawl out of the engagement with the ratchet-wheel, allowing a spiral spring around the shaft, A, to return the switch lever, S, to the home button. After raising the pawl out of the notch on the ratchet-wheel the dog slips out of the notch on the pawl, thus allowing the latter to return into contact with the ratchet-wheel in order to be ready for the next use of the telephone. In order, however, that the pawl may not engage the ratchet-wheel before the lever, S, has fully returned to its normal position, a second dog, J, is provided which is pressed by a spring so as to occupy a position under the pin, *p*, carried on the pawl, F, thus holding it out of engagement with the ratchet-wheel until the rotation of the lever is completed. At this point a pin on the farther side of the ratchet-wheel pushes the dog, J, out of engagement with the pin, *p*, and allows the pawl, F, to drop into contact with the ratchet-wheel.

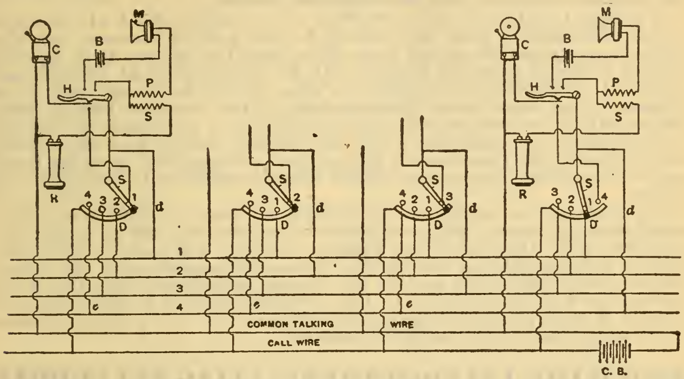


FIG. 56. Common Signaling Battery System; Individual Talking Batteries.

In Fig. 56 are shown the circuits of a four-station system using one common battery, CB, for ringing up the various stations, each station having an ordinary vibrating bell, C. The circuits of Stations 1 and 4 are shown in full, while those of the intermediate stations, being exactly the same, are partially omitted. It will be noticed that the switch lever, S, at each station is connected with the line wire bearing the same number as that station, by means of the wire, *d*. Each line wire is also connected at each of the stations not bearing its own number with a button on the switch of

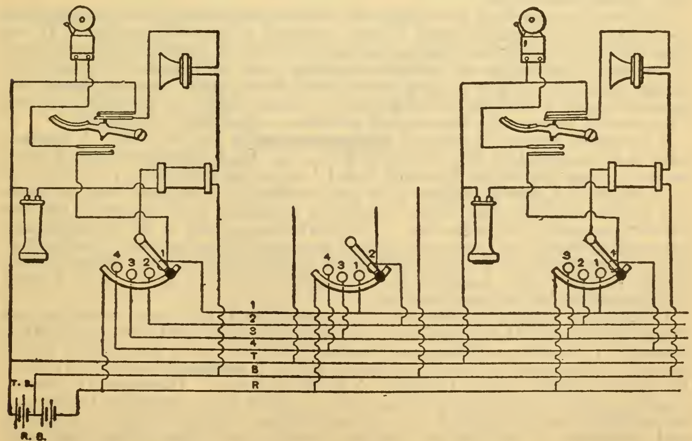


FIG. 57. System having Common Talking and Signaling Battery.

that station which does bear the same number in the manner previously described, by means of the wire, *e*. In this common-battery call system two additional wires are run, one being termed the "call wire" and the other the "common talking wire." The call wire and the talking wire are connected through the calling battery CB, as shown. It is evident that the number of wires passing through all the stations will be two more than the number of stations, irrespective of that number.

If Station 4 desires to call up Station 1, for example, No. 4 will turn his switch lever until it rests upon button 1, then a slight pressure upon the switch knob causes the switch lever, S, to touch the contact strip, D, completing a circuit from the battery, CB, to contact strip, D, lever, S, and button, 1, at Station 4; line wire, 1, wire, *d*, switch, H, and bell, C, at Station 1, and back to the battery through the common talking wire. When both subscribers remove their receivers from the hooks, the circuits are completed over line wire 1 with the common talking wire as a return. At the close of the conversation the receiver is simply hung upon the hook, and the automatic mechanical device returns the lever to the home position.

Fig. 57 shows the application of the Ness automatic switch to an intercommunicating system, using one common and centrally located battery for supplying both the ringing and talking current. The section, TB, of the battery supplies all the microphone transmitter circuits, and the whole battery, RB, supplies the current for ringing the ordinary vibrating bells that are used in this system. In this arrangement it is evident that the number of wires passing through all the stations will in any size of system be three in excess of the number of stations.

TWO-WIRE INTERCOMMUNICATING TELEPHONE SYSTEMS.

By H. S. Webb.

By a two-wire intercommunicating telephone system is meant one that has two wires for each telephone station in addition to the two wires used in common by all the stations in some systems for signaling purposes only. The object of using two independent wires for each telephone station is to eliminate cross-talk.

In a single wire system if one wire in use by one pair of telephones overlaps the wire in use by another pair of telephones, there is very apt to be more or less cross-talk.

This can be avoided by using for each conversation two independent wires; that is, by using what is here termed a two-wire system. If the wires for an intercommunicating system are run in cables, each pair must be twisted together, as in telephone cables used in complete metallic exchange systems. If not in cable then the different pairs must be fairly well separated, and if two pairs run parallel to each other for any distance the wires should be properly transposed in order to eliminate cross-talk.

A two-wire system is shown **diagrammatically** in Fig. 58. A contact piece, *e*, is fastened to, but insulated from, the hook switch, in such a manner as to close the circuit between *d* and *f* when the telephone receiver rests on the hook. A double switch, *S*, is also required. The latter may be made in a variety of ways, but is here shown in a simple form in order that the connections may be clearly seen. The two levers *m*, and *n*, are mechanically fastened together so that moving one handle will move both levers; but the two levers must be insulated from each other; *P* is a simple push-button switch. One common and centrally located battery, *RB*, is used for ringing the bell at any station.

To call up a station the switch, *S*, is turned until the straps, *m* and *n*, rest on the buttons of the number of the station desired and the push-button pressed. It makes no difference whether the receiver at the station where the call originates is on or off the hook, nor is it necessary for the switch at the station called to be at the first, or home, position. However, the levers, *m* and *n*, at the station called, must rest on their home positions before any conversation can be carried on. When ringing, only one wire of a pair is used, the wire, *V*, serving as a common return; but when conversing, both wires of one pair are in use, and neither wire, *W*, nor *V*, is used; thus there can be no cross-talk due to induction. The ringing current may cause slight trouble from induction, as it traverses but one wire of a pair. By means of a double contact push-button switch even the ringing current can be made to flow through both wires of one pair and all danger of induction troubles be eliminated.

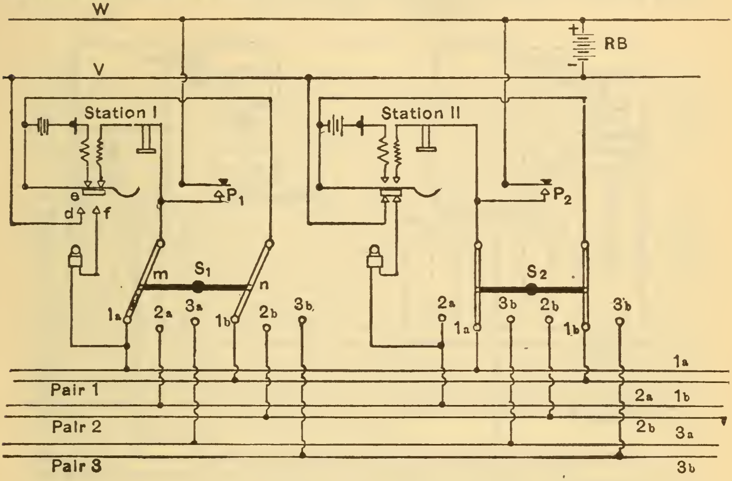


FIG. 58. Two-wire Telephone System.

Such an arrangement is shown in Fig. 59. The wiring at Station 1 is so arranged that the station can be called up from any station, no matter in what position the intercommunicating switch S_1 may have been left.

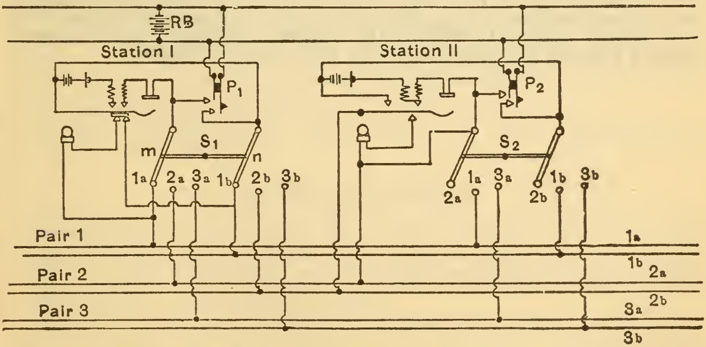


FIG. 59. Two-wire System with Automatic Switch.

However, the wiring at this station has been purposely so arranged that the switch must be returned to the home position before anything can be heard in the receiver.

When automatic switches are used the switch is automatically restored to the home position when the receiver is hung up. At Station 2 in Fig. 59 the connections are also suitable for use with an automatic switch.

If magneto bells and generators are included in each telephone set instead of an ordinary vibrating bell, then the ringing battery and the two battery wires will not be required, and the connections would be as shown in Fig.

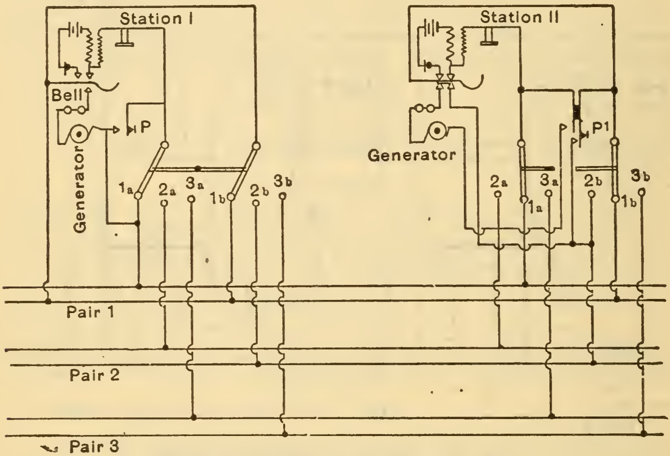


FIG. 60. Automatic Telephone System with Magneto Bells.

60. This arrangement requires only one pair of wires for each telephone. At Station 1 the wiring is so arranged that only a simple push-button, *P*, is required for ringing purposes, while the wiring at Station 2 requires a double contact push, *P* 1. The wiring at this latter station may give a more evenly balanced system, but does not seem to possess much superiority over that at Station 1, which is the simpler. At Station 2 an insulated contact piece on the under side of the hook switch is required.

USES OF ELECTRICITY IN THE UNITED STATES ARMY.

REVISED BY GRAHAM H. POWELL.

THE use of electricity is prevalent in nearly every branch of the military art, being employed in the operation of searchlights, manipulation of coast defense guns, ammunition hoists; in range and position finders; for field and fortress telephones and telegraphs; for firing guns, submarine and subterranean mines, and the control of dirigible torpedoes; while electrically operated chronographs are utilized in the solution of ballistic problems.

In March, 1906, the President submitted to Congress the report of the National Coast Defense Board, appointed in the previous year "to recommend the armament, fixed and floating, mobile torpedoes, submarine mines, and all other appliances that may be necessary to complete the harbor defense" of the United States and its insular possessions. That board made the statement in its report that "Electricity has become of vital importance to an efficient system of gun defense."

The following were the general recommendations of that board so far as electrical appliances are concerned:

1. That the electrical power for fortification and defense purposes be furnished by an adequate steam-driven, direct-current producing central power plant, all machinery to conform in type to approved commercial standards.
2. That each battery or group of batteries, depending upon local conditions, be equipped with direct-current generators, gas or oil engine driven, installed as a reserve to the central plant.
3. That searchlights, except such as are in close proximity to the central plant, be provided with and operated by self-contained units.
4. That the torpedo casemates be equipped as heretofore with independent power for submarine-mine purposes, as an integral part of the submarine-mine defense.
5. That when alternating currents are essential, they should be obtained, if practicable, from direct current by means of a suitable converter; or, if more economical, by a separate alternating unit.
6. That the current from the fortification central plants, when not needed for fortification service, may be used for garrison purposes when such distribution does not require too large an increase in the size and number of units.
7. That if garrison service requires alternating current, this should be supplied by the central plant, either through a suitable converter or from alternating current units specially installed for the purpose in the central station; such increase, however, and all additional cost due to post lighting being a charge against the proper appropriation.
8. That uniformity of types and accessories is desirable.
9. That all electrical power plants for the use of fortifications shall be operated by the Artillery.

SEARCHLIGHTS.

Searchlights are used both as offensive and defensive auxiliaries; defensive when used by shore fortifications to light channels or by a vessel to discover the approach of torpedo boats; offensive when used as "blinding-lights" to smother the light of an approaching vessel and confuse her pilot.

The accompanying illustrations show the searchlight manufactured by Schuckert & Co. of Nurnberg, Germany.

The lamp is placed on top of the two lowest longitudinal rods of the casing, and is held in place by four lugs, two on each side. The carbon holders reach upward through a slit in the casing, and there is a small wheel in rear for moving the light parallel to the axis of the reflector for the purpose of focusing it. The trunnions of the casing are fastened to two longitudinal rods on each side, parallel to the axis of the cylinder, and can be moved forward or back so that the casing and what is carried with it will have no pre-

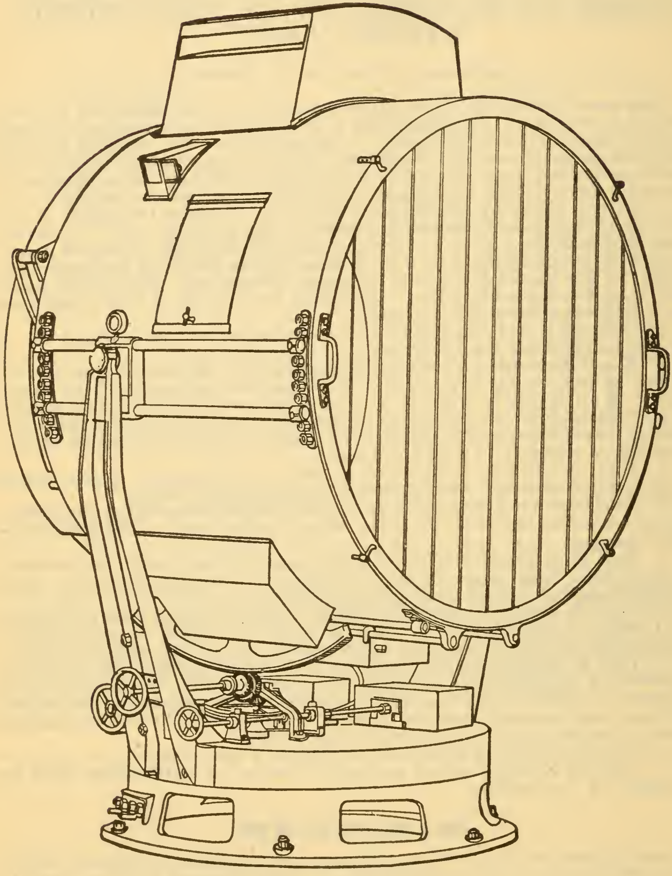


FIG. 1. Schuckert Searchlight.

ponderance. The trunnions are supported in trunnion beds in the ends of supports which project upwards from the racer.

The elevating arc is attached to another longitudinal rod beneath the cylindrical casing and is capable of adjustment on this rod. Engaging in this arc is a small gear attached to a horizontal shaft passing through the right trunnion support and carrying a small hand wheel. This small hand wheel is for the purpose of elevating or depressing the light rapidly.

The light may be elevated or depressed slowly by means of a small hand wheel attached to another horizontal shaft in front of the one just described. This shaft near its center carries a worm, engaging in a worm wheel on a vertical shaft, to which is also attached a bevel gear. This gear engages in another, which is attached to the quick-motion shaft, but is free to turn about it until it is connected with the elevating gear wheel by means of a friction clamp. The relation between the worm and worm wheel is such that a slow motion is obtained.

The racer rests upon live rollers and is joined by a pintle to the base ring.

Attached to the base ring is a toothed circular rack, into which on the outside a gear wheel attached to a vertical shaft engages. This vertical shaft projects upward through the racer and carries a worm wheel, which engages in a worm carried on a horizontal shaft having a hand wheel. The worm wheel is entirely independent of its vertical shaft, except when connected with it by means of a friction clamp. When so connected, by turning the hand wheel the light is traversed by a slow motion. To traverse the light rapidly, the friction clamp is released and the light turned by hand, taking hold of the trunnion supports. One of the ends of the slow motion elevating and traversing shafts is connected with a small electric-motor, which is encased in a box on top of the racer. By means of these motors the motion of the searchlight can be controlled from a distant point. A switch is provided with contacts so arranged that the current can be passed into the armatures of the motors in either direction, so as to obtain any movement the operator may desire. The current needed for the movement is obtained from the lines supplying the current used in the light itself. The current is brought to the motors by means of contact points, bearing on circular contact pieces attached to the racer.

The reflector is a parabolic mirror embedded in asbestos in a cast-iron frame, and is held in place by a number of brass springs. The frame of the reflector is fastened to the overhanging rear ring of the casing with studs and nuts, the overhanging part of the ring protecting the reflector from moisture. In order to enable the operator to observe the position of the carbons and the form of the crater while the apparatus is in use, small optical projectors are arranged at the side and on top of the casing, which enables images of the arc as seen from above and from the side to be observed. When the light is properly focused the positive carbon reaches a line on the glass on top of the casing.

There are two screws on the positive carbon holder which enable the end of this carbon to be moved vertically or horizontally to bring it to a proper adjustment.

In consequence of the ascending heat the carbons have a tendency to be consumed on top ; and to avoid this there is placed just back of the arc and concentric with the positive carbon a centering segment of iron, attached to the casing, which, becoming magnetic, so attracts the current as to equalize the upward burning of the carbons. In taking the light out of the casing this centering segment must be unfastened, and swung to the side on its hinge.

An example of the method of calculating the intensity of the light sent out by the mirror follows:

Diameter of parabolic mirror, 59.05 inches.
Diameter of positive carbon, 1.5 inches.
Diameter of negative carbon, 1 inch.
Power consumed, 150 amperes × 59 volts.
Maximum intensity of rays impinging upon the mirror, 57,000 candle-power.
Average intensity of rays impinging upon mirror, 45,600 candle-power.
Diameter of crater, 0.905 inch.

Intensifying power of the mirror $\frac{D^2}{d^2} = \frac{(59.05)^2}{(0.905)^2} = 4{,}253.$

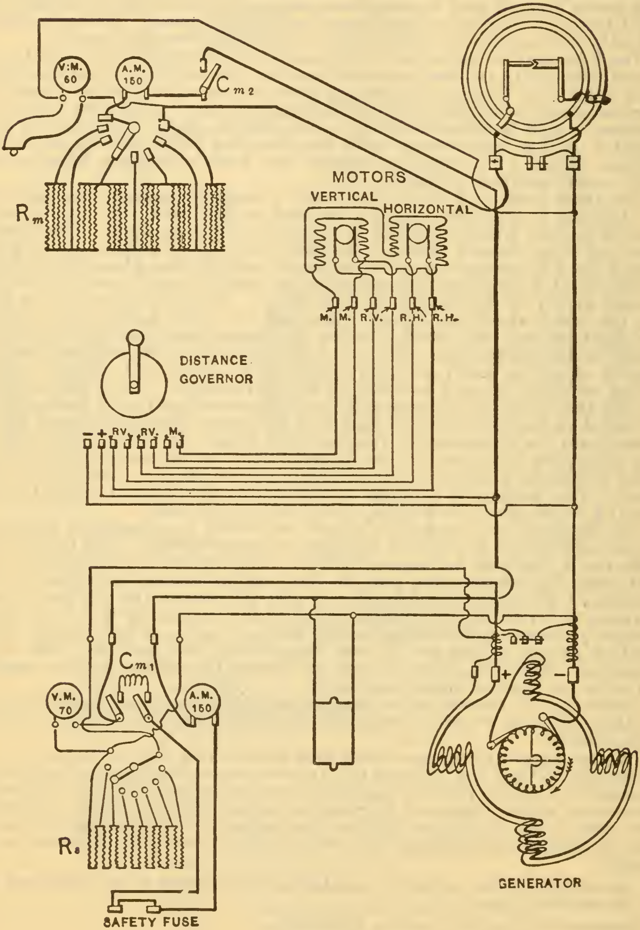


FIG. 2. Diagram showing Searchlight Connections.

DATA RELATIVE TO SEARCHLIGHTS.

Diameter of Mirror D in mm.	Strength of Current in Amperes.	Potential in Volts.	Watts.	Standard Candle-power in one Watt.	Intensity of Rays Impinging on Mirror in Candle-power.		Average Intensity of Rays Reflected by Mirror in Standard Candle-power.	Diameter of Crater d in mm.	Intensifying Power of Mirror $\frac{D^2}{d^2}$.	Intensity of Ray of Light Sent out by Mirror in Candle-power.	Focal Distance of Mirror in mm.	Dispersion.	Field of Illumination at 1000 m. in m.
					Maximum.	Average.							
	20	43.5	870	4	3480	2780	2500	9.3	1845	4,635,000	180	2° 58′	51
400	25	44	1100	4.6	5000	4000	3600	9.4	1811	6,490,000	180	2° 59′	52
	30	44	1320	4.8	6300	5000	4500	9.5	1773	8,000,000	200	2° 43′	47
	20	43.5	870	4	3480	2780	2500	9.3	2341	5,850,000	200	2° 40′	46
450	30	44	1320	4.8	6300	5000	4500	9.5	2244	10,600,000	200	2° 43′	48
	40	45	1800	5.14	9250	7400	6660	10.	2025	13,500,000	200	2° 52′	50
	40	45	1800	5.14	9250	7400	6660	10.	3600	24,900,000	250	2° 18′	40
600	50	46	2300	5.35	12,300	9800	8820	10.9	3030	26,700,000	250	2° 30′	44
	60	47	2820	5.55	15,500	12,400	11,160	12.1	2459	27,200,000	250	2° 47′	48
	60	47	2820	5.55	15,500	12,400	11,150	12.1	3840	42,300,000	310	2° 16′	39
750	75	49	3675	5.8	21,200	17,000	15,300	14.3	2744	42,300,000	310	2° 38′	46
	90	51.5	4680	6.	28,100	22,500	20.300	16.7	2020	42,300,000	310	3° 6′	54
	100	53	5300	6.05	32,000	25,700	23,130	17.5	2640	61,000,000	380	2° 43′	47
900	125	55.5	6660	6.23	41,500	33,200	29,880	20	2030	61,000,000	420	2° 44′	48
	150	59	8900	6.45	57,000	45,600	41,040	23	1530	61,000,000	420	3° 8′	55
1100	150	60	9000	6.5	58,000	46,400	41,750	23	2287	96,000,000	520	2° 32′	44
1500	150	60	9000	6.5	58,000	46,400	41,750	23	4300	180,000,000	650	2° 2′	36

Total intensity of light sent out by mirror, 45,600 × 4,253 = 194,000,000 candle-power.

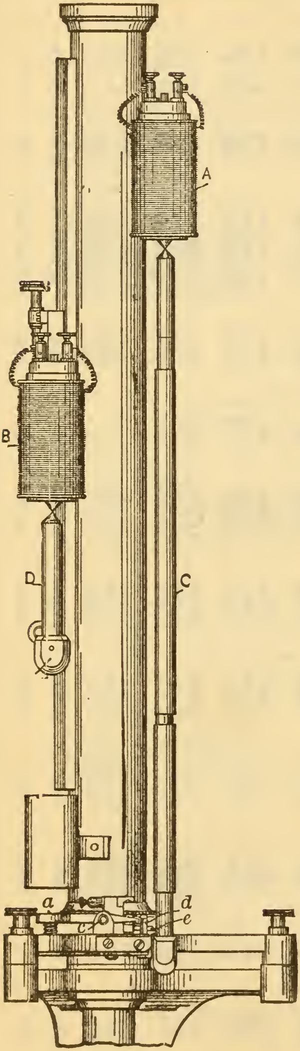


FIG. 3.

The focal distance of the mirror is 25.5 inches.

The dispersion angle of the concentrated beam is 2° 2′.

The diameter of the illuminated area at a distance of 1,111 yards is 84 yards.

The resistance R_m on the switchboard at the light is in series with the main current for the purpose of regulating the amperage at the lamp. The voltmeter at the lamp should indicate about 60 volts. The connection of the distance governor with the two motors for elevating and traversing is also shown.

Until recently the largest searchlight built was the one that was on exhibition at the Paris Exposition of 1900 in the section "Navigation de Commerce et Armées de Terre et de Mer," which was 6 feet 6 inches in diameter, and gives a beam of 316,000,000 candles. This was slightly exceeded by the 80-inch projector of the General Electric Co. at the Louisiana Purchase Exposition.

The table on preceding page gives data in regard to searchlights of various sizes.

CHRONOGRAPHS.

In the experimental work of testing guns, etc., it becomes necessary to ascertain the velocity of projectiles, both while passing through the bore of the gun and during flight. Chronographs of various sorts are used for this purpose.

In order to ascertain the velocity of a projectile during flight, two screens or targets are set up in the course of the projectile, generally 100 feet apart. These screens ordinarily consist of a frame of wood carrying a number of small parallel copper wires. The breaking of the wires in the successive frames by the projectile causes the interruption of the current through the instrument, and thus registers the time of flight between the screens.

Probably the best-known instrument of this class is the one invented by Captain Le Boulengé of the Belgian artillery, which was afterwards modified by Captain Breger.

Boulengé Chronograph.

This instrument depends for its accuracy upon the law of falling bodies or the acceleration due to gravity, namely, 32 feet per second.

It consists of a vertical column (Fig. 3) to which are affixed two electromagnets; the right-hand one, *A*, is actuated by the current of the first frame and supports an armature C_1, called the chronometer; the left-hand magnet, *B*, is actuated by the current of the second frame, and supports an armature *D*, called the registrar.

The chronometer C is a long, cylindrical brass tube terminating at its upper extremity in a piece of soft iron, and bearing at its lower extremity a steel bob. It is surrounded by a zinc or copper cylinder called the recorder. The rupture of the first target causes the demagnetization of the magnet A, releasing the rod C. The registrar D is of the same weight as the chronometer, and is a tube with soft iron and bob. The cores of the electromagnets and the soft iron of the armatures terminate in cones slightly rounded at their vertices in order that the armatures when suspended can take a vertical position.

When the registrar is set free by the rupture of the second target it strikes a horizontal plate (a), which turns upon its axis (c) and releases the spring (d). The spring is furnished with a square knife (e), which strikes the recorder and leaves an indentation upon it.

If the two currents be ruptured simultaneously the indentation is found upon the recorder at a height h, indicating that since the chronometer commenced to fall the time t has elapsed. $t = \sqrt{\frac{2h}{g}}$.

It is evident that t is the time required for the apparatus to operate; it is a systematic retardation inherent in the instrument.

A special device, called the disjunctor, permits the simultaneous rupture of the circuits to be produced, so that the time t is always known.

A very simple device is resorted to in order to render it constant. If the current of the registrar is not ruptured until after that of the chronometer, and if an interval T has elapsed between these ruptures, the time during which the chronometer will fall before receiving the indentation of the knife will simply be augmented by t, and calling H the height of the indentation, we will have

$$t + T = \sqrt{\frac{2H}{g}}.$$

Thus the determination of an interval T always comprises two operations: the measurement of the time (t) required for the instrument to operate, and that of the time $t + T$. The difference of these two measurements gives the time sought. This indirect method of ascertaining the result is the characteristic feature of the instrument and explains its accuracy. When the rupture of the currents is produced by the projectile the portion (D) of the trajectory between the targets is regarded as rectilinear and the mean velocity V is

$$V = \frac{D}{\sqrt{\frac{2}{g}(H-h)}}.$$

With the time known that the projectile takes to pass between the two screens, the velocity in feet per second, the usual mode of indicating, is readily obtained.

The arrangement of the circuit must vary according to circumstances, and no particular system can be prescribed. The general arrangement, however, is shown in the sketch,

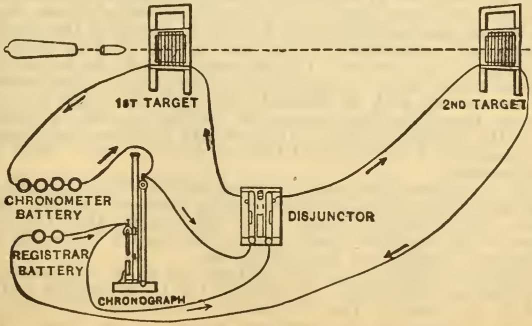


FIG. 4. Connections of Boulengé Chronograph.

Schultz Chronoscope.

The Boulengé chronograph measures velocity at one point only, but it is frequently necessary to measure the velocity of the same projectile at different points, as in determining the laws of the resistance of the air to its motion, or in ascertaining the velocity of a projectile at different points in the bore of the gun.

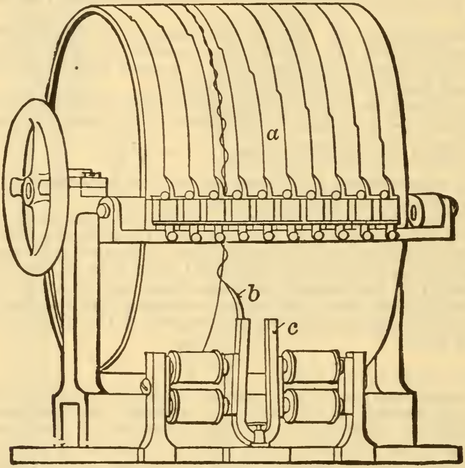


FIG. 5. Schultz Chronoscope.

For such purposes an instrument must be used which will give a scale of time of such length that all the phenomena may be registered upon it.

There are several instruments of this class, of which the best known is the Schultz chronoscope. In this instrument a drum (*a*), one meter in circumference, and covered with a coating of lamp-black, is driven by the means of a clock movement and weight, so as to revolve once per second and at the same time slowly advance longitudinally. In front of the drum, mounted on a support and actuated by two magnets, is a standard tuning-fork (*c*), vibrating 250 times a second; on one link of this fork is a quill (*b*) which traces a line on the blackened surface of the drum, and therefore will record 250 complete vibrations for every revolution of the drum.

A microscope with micrometer (not shown in drawing) is also attached to the support fork; and each vibration of the fork, traced on the drum in form of a curve, can be subdivided in 1000 parts, thus allowing readings to be made to $\frac{1}{250000}$ of one second. On the support with the tuning-fork is a small pointer which traces a straight line on the drum. This pointer has an electrical connection with an accurate chronometer which at every half second closes the circuit and causes the pointer to make a succession of records on the revolving drum. These marks serve as starting-points to count the number of vibrations of the tuning-fork, and to check them up every half-second.

In order to measure the velocity of projectiles, the gun must be fitted along its bore with special electrical circuit breakers, usually placed one foot apart. Each circuit breaker is so constructed that the current is interrupted as the projectile passes, but is made again before the projectile reaches the next breaker one foot further on.

These breakers, with appropriate battery, are all in one circuit with the primary of an induction coil. One terminal of the secondary of the coil is grounded to the frame of the chronoscope, while the other terminal consists of a fine point near the blackened surface of the drum. Therefore, when the primary circuit is opened by the first circuit breaker along the bore of the gun, the spark induced in the secondary of the induction coil jumps from the points to the revolving drum, leaving a distinct mark on the blackened surface. As the next circuit breaker in the gun is passed the spark again passes to the drum, and this operation is repeated for every breaker along the gun bore. Thus on the drum, alongside of the indications made by the tuning-fork, will be recorded a succession of spots at certain distances from each other. The time elapsing between any two of these spots can be calculated directly from the record which the tuning-fork made, and thus the time (measured to the $\frac{1}{250000}$ part of a second) taken by the projectile in passing a known distance along the gun barrel calculated. — *Electrical World and Engineer*, June 23, 1900.

Schmidt Chronograph.

This is a portable instrument, and while probably not so accurate as the Boulengé instrument, is sufficiently so for the every-day work of the proving ground.

The chronograph is composed of the following principal parts (see Figs. 6 and 7):

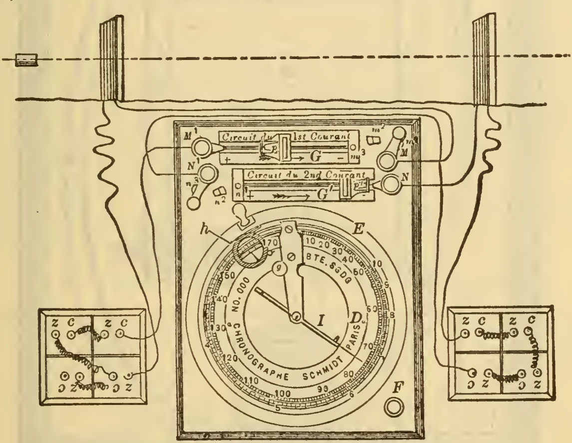


FIG. 6. Connections of Schmidt Chronograph.

The balance-wheel *A*, with its spring and needle.

The electromagnet *B*, which holds the balance-wheel at the starting-position and releases it the instant the first current is broken.

The electromagnet *C*, with its mechanism, which stops the balance-wheel the instant the second current is broken.

The dial *D*, graduated for velocity readings.

A circular frame *E*, for setting the instrument at zero.

The button *F*, reëstablishing the current in the magnet *C*.

The rheostats *G* and *G'*, with their resistance coils for regulating the currents.

The balance-wheel, made of nonmagnetic metal, is about 2½ inches in diameter and mounted on the axis *o*, which is held by two strongly made bridges fastened to the face plate of the instrument. The pivots of the axis are set in jeweled bearings. The spiral spring *H* is fastened to the bridge and axis as in ordinary chronometers.

The needle *I* is composed of two parts, as shown in Fig. 8. One part, *a*, of bronze, is fastened rigidly to the axis; the other, *b*, a steel spring, is fastened at one end to *a*, the free end being limited in its motion by two small pins set into *a*.

The electromagnet *B*, which holds the balance-wheel at the starting-point, is operated by the current passing through the first screen, and is mounted on the face plate so that the core is radial with referènce to the balance-wheel. The core of the magnet projects beyond the coil and acts upon the small armature *c*, mounted on the rim of the balance-wheel.

The electromagnet *C*, with its mechanism operated by the current passing through the second screen, stops the balance-wheel the instant the

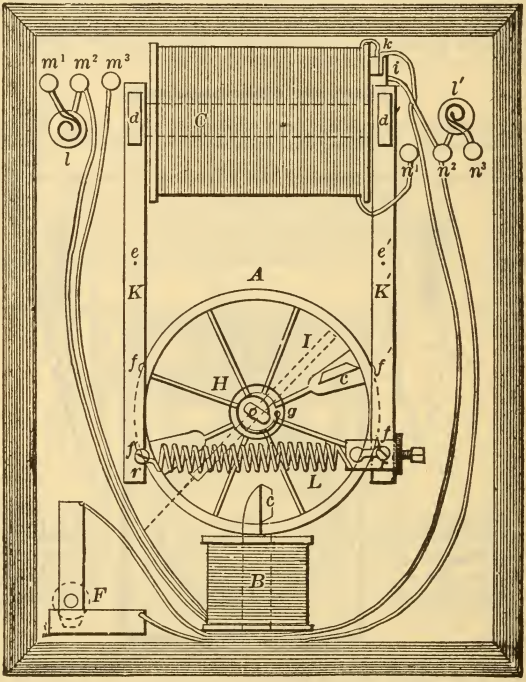


Fig. 7. Interior Schmidt Chronograph.

current is broken. This magnet is somewhat larger than the other, and is placed tangentially with reference to the balance-wheel. It acts upon the two armatures *d*, *d′*, placed opposite the extremities of the core. These armatures are fastened to the ends of the two levers *K*, *K′*, which are

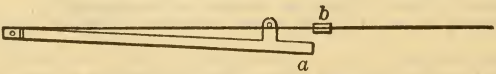


Fig. 8. Construction of Needle.

mounted on the axis *e*, *e′*, parallel to the axis of the balance-wheel and similarly supported. The other ends of the levers are joined by the coiled spring *L*, with its adjusting-screw. Set in the levers near this end are four pins, *f*, *f*, *f′*, *f′*, that ordinarily, due to the tension of the spring, bear against the rim of the balance-wheel, holding it fast. When the current passes through this magnet, the armatures on the levers are attracted by the core, the spring is elongated, and the pressure of the pins upon the balance-wheel is released. When the current is broken the armatures are released, and the tension of the spring closes the pins upon the wheel. To insure effective action the pins are accurately set and the rim of the wheel is milled.

The face of the chronograph is a graduated dial concentric with the balance-wheel axis. When the wheel is held at its starting-point the needle points at the zero of the graduation. The scale in black indicates the time in thousandths and two-ten-thousandths of a second. Another scale, in red, gives the velocity directly in meters per second when the screens are placed 50 meters apart.

The dial is covered with glass enclosed in the circular metal frame *E*. A pin *g*, fixed in the glass, is used to set the needle at zero by turning the frame, to which is also fastened the lens *h*, to facilitate reading. This lens is provided with two pointers so placed that the reading is always taken in the vertical plane.

The button *F* is for the purpose of reëstablishing the current through the magnet *C* after it has once been broken. Pressing the button closes the circuit; the magnet then attracts the armatures *d*, *d′*, fixed to the ends of the levers *K*, *K′*. This motion of the levers brings the small spring *l*, mounted on *K′*, in contact with the projection *k*, thus forming a circuit, through which the current continues to flow after the pressure on *F* has been released. This contact is broken by the motion of the lever when the current is interrupted by the shot. This arrangement prevents the current from passing through the magnet and releasing the balance-wheel before the circuit is closed by pressing the button *F*, even though the broken screen is repaired, and gives the operator time to take the reading and prepare for the next shot. This is especially important when targets that close the circuit automatically are used.

The rheostats for regulating the currents are placed above the dial, their resistance coils being inside the case. One binding-post of each rheostat is provided with a circuit closer for passing the currents through the resistance coils or directly into the rheostats.

The Squire-Crehore Photo-Chronograph.

This instrument was designed to overcome the minute errors inherent in other forms of chronographs, such as the inertia of the armature, the time required to magnetize iron, or in instruments employing a sparking device, the fact that successive sparks do not proceed from the same point by identically the same path.

The agents employed in this instrument are light and electricity. Briefly stated, a ray of light from an electric arc is reflected upon a revolving photographic plate. The interposition of the shadow of a tuning-fork gives on the plate a curve which is used as a scale of time.

In the path of the beam of white light is placed a Nicol prism in order to obtain a beam of plane polarized light. This prism is made of two crystals of Iceland spar, which are cemented together by Canada balsam in such a way as to obtain only a single beam of polarized light. The crystal is a doubly refracting medium; that is, a light beam entering it is in general divided into two separate beams which are polarized and have different directions. One of these beams in the Nicol prism is disposed of by total reflection from the surface where the Canada balsam is located, and the other emerges a completely polarized beam ready for use.

A second Nicol prism exactly like the first is now placed in the path of the polarized beam. This second prism is called the "analyzer," and is set so that its plane is just perpendicular to that of the first prism, called the "polarizer," so that all the light vibrations not sorted out by the one prism will be by the second. In this position, the planes being just perpendicular to each other, the prisms are said to be "crossed," and an observer looking through the analyzer finds the light totally extinguished as though a shutter interrupted the beam.

By turning the analyzer ever so little from the crossed position, light passes through it, and its intensity increases until the planes of the prisms are parallel, when it again diminishes; and if one of the prisms is rotated there will be darkness twice every revolution. In order to accomplish this same end without actually rotating the analyzer, a transparent medium which can rotate the plane of polarization of the light subject to the control of an electric current is placed between the two prisms. The medium used is carbon bisulphide, contained in a glass tube. To produce a magnetic field in the carbon bisulphide, a coil of wire through which passes an electric current, is wound around the glass tube. When the current ceases the carbon bisulphide instantly loses its rotatory power, and the ray of light is free to pass through the prisms.

Breaks in the current are made in the same way as in other ballistic chronographs. This instrument is not now in use, but the foregoing description is given as showing the development of such devices. For a complete description of this instrument, with an account of experiments, see *The Polarizing Photo-Chronograph*, *John Wiley & Sons*, *New York*.

MANIPULATION OF COAST-DEFENSE GUNS.

Until recently the carriages for the larger caliber of guns were manipulated only by hand-power, but tests having demonstrated the utility of electric power for this purpose, such carriages are now equipped with motors for the purpose.

In disappearing carriages of the type in use in the United States, the operations to be performed are those of elevating and depressing, traversing, and the retraction of the gun from the "in battery" position to that assumed after firing. This recoil position is normally obtained by the discharge of the gun operating through recoil cylinders and a counterweight, the latter being principally for returning the gun to the firing position. However, it is frequently desirable, or necessary, to retract the gun without firing the piece, and for this purpose wire ropes are attached to hooks on the gun levers near the trunnions of the gun, the opposite ends winding on drums.

The electrical equipment consists of the following apparatus:

Traversing Motor. — A 4 horse-power, totally enclosed motor, 110 volts, and having a speed of about 565 revolutions per minute. This motor has a pinion upon its shaft which engages directly with a gear upon the traversing crank shaft.

Elevating-Depressing and Retraction Motor. — A single motor is used for all of these operations. It is rated at 4 horse-power, 110 volts, and speed of 625 r.p.m.

A lever carries an idler gear so that the motor shaft may be thrown into mesh with either the gear on the retracting or that on the elevating crank shaft.

Both traversing and elevating motors are shunt wound, the fields being energized directly from the switchboard and the armatures being operated by individual controllers.

The two controllers, one for the traversing and one for the elevating-retracting motor, are placed side by side on a frame bolted to the working platform in rear of the left standard of the carriage. Each controller shaft has a vertical extension reaching to a convenient height above the sighting platform from which the controllers may be operated if desired, though only one set of handles is provided, to avoid the possibility of attempts to maneuver the carriage from two different points.

In the side and rear elevations (Figs. 9 and 9a) *A* is the elevating and depressing hand-wheel, *B* the retracting hand-wheel, with lever *C* carrying idler gear between them; *D* is the traversing crank shaft, *E* controllers, *F* controller extension shafts, *G* sighting platform, and *H* wire rope for retracting.

The motors heretofore described are bolted to a bed plate inside the chassis and immediately in rear of the hand wheels.

ELECTRIC FUSES.

It is often necessary to fire at a distance from the gun, as in experiments, and for this purpose the electric fuse offers the safest, simplest, cheapest and most effective means of firing high explosives or large charges of powder, and the only means of igniting separate charges simultaneously for greater destructiveness, or a single charge from a distant point, or at a required moment, or under water.

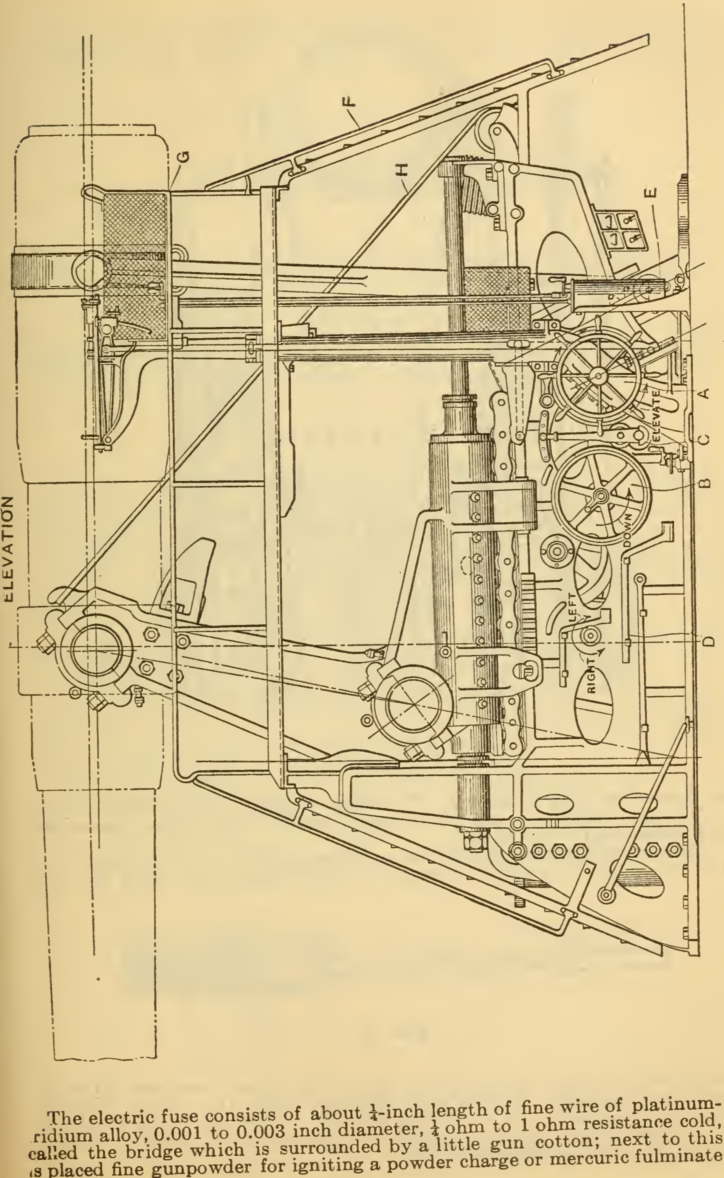


FIG. 9. (See View of Rear on next page.)

The electric fuse consists of about ¼-inch length of fine wire of platinum-iridium alloy, 0.001 to 0.003 inch diameter, ¼ ohm to 1 ohm resistance cold, called the bridge which is surrounded by a little gun cotton; next to this is placed fine gunpowder for igniting a powder charge or mercuric fulminate

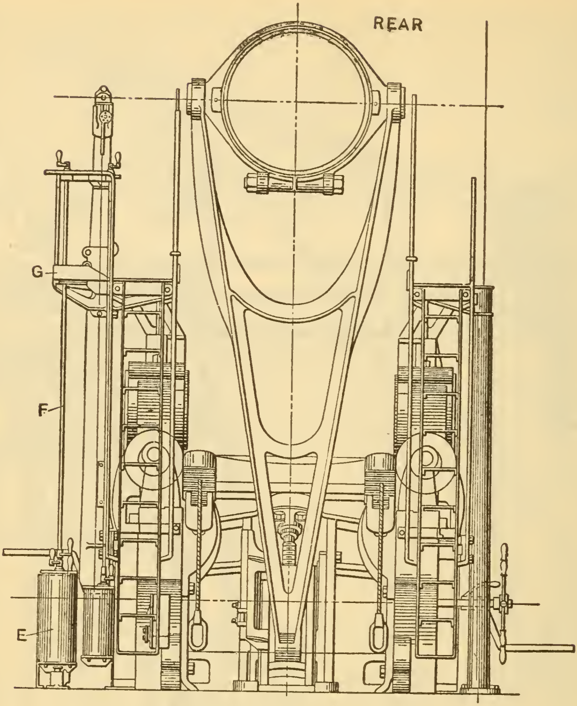


FIG. 9a. Rear.

for detonating high explosives. The whole is fixed within a copper case. An electric current of specified strength reddens the bridge, ignites the gun cotton, and fires the fuse.

The commercial fuse (Fig. 10) has a copper shell *A* with corrugation to hold more firmly the sulphur cement *F* which seals up the open end and

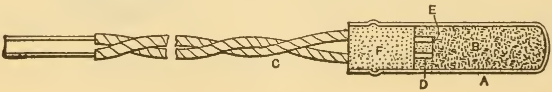


FIG. 10.

holds firmly in place the fuse wires. *B* is the chamber containing 20 to 50 grains of fulminate. A little gun cotton surrounds the bridge which is soldered to the bared ends of the fuse wires *D*. The wires, 4 to 40 feet long, have cotton covers soaked in asphalt for ordinary outdoor, work and gutta-percha covering for submarine work.

The United States Navy electric fuse (Fig. 11) has the copper case in two parts which screw together, $\frac{3}{16}$ inch. The upper or inside part holds 35 grains of the fulminate. The lower, open at both ends, is filled with

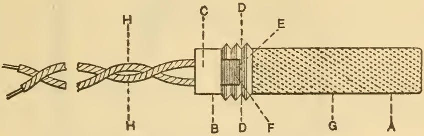


FIG. 11. *A*, lower tube; *B*, upper tube; *C*, plug of sulphur and glass; *D*, bridge legs; *E*, bridge; *F*, gun cotton; *G*, fulminate; *H*, fuse wires.

sulphur and glass, which holds fixed in place the wire ends and bridge. When the fulminate is dry, the spaces in both parts are filled with dry pulverulent gun cotton and the parts are screwed together.

DEFENSIVE MINES.

A mine is a charge of explosive contained in a case which is moored beneath the surface of the water or buried beneath the soil. The mines laid and operated in and around seacoast fortifications are for the most part defensive in their character, fixed in position, and hidden.

A defensive mine is either self-acting, — a mine which, once placed, ceases to be under control, and is fired by means within itself, mechanical or electrical, — or controlled, a mine fitted with electrical apparatus, which enables a distant operator to ascertain its condition, and to fire it at any time; it may also be fired automatically.

A controlled mine may be fired in four different ways : (*a*) by contact with the mine only ; (*b*) at will of the operator only ; (*c*) by contact and will, both of which are necessary ; (*d*) by observation from two stations.

A controlled sea mine may be either a buoyant mine whose case floats 3 or 4 feet beneath the surface, and contains both the charge and electrical apparatus, or a ground mine. The latter is in two parts: one a case containing the charge and fuse, rests on the bottom ; the other, containing the electrical apparatus, floats 3 or 4 feet beneath the surface.

Copper wires lead to two or three Sampson-Leclanché cells, which are put in circuit with the torpedo casemates of the fortification.

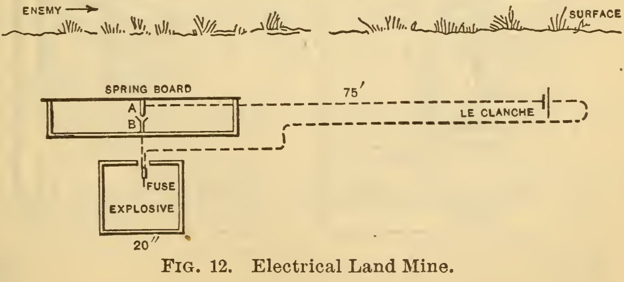


FIG. 12. Electrical Land Mine.

The sketch shows a self-acting electrical land mine, and is self-explanatory. By using three lead wires the mine may be fired by the enemy's contact with it, or by the operator at the station.

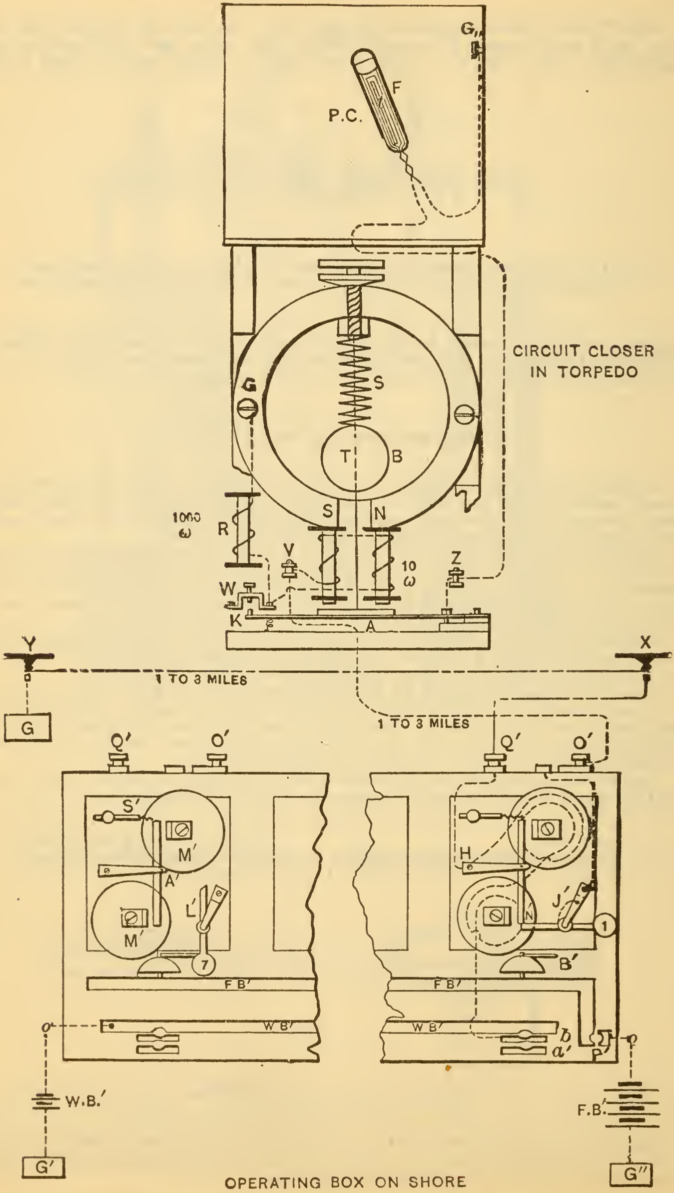


FIG. 13. Diagram of torpedo circuit closer and connections.

Circuit Closer in Torpedo. (See Fig. 13.)

NS, circular permanent magnet with attached electromagnets N and S.

A, armature whose adjusting spring near K holds it away from the magnet, while a weak current flows in through the electromagnet coils in a direction to assist the permanent magnet. But if a stronger current flows, the armature is attracted, and sticks to the magnet, until a reverse current is sent in. The spring then draws the armature away, and breaks the contact of the circuit closer K on W.

B, a brass ball ¾ inch diameter, held by spiral S.

T, a silk thread running through the vertical axis of the ball from adjusting screw to the armature. When the vessel strikes the mine the brass ball being knocked sidewise pulls, by means of the string, the armature against the poles where it sticks.

R, 1000-ohm resistance coil, which is cut out of the mine circuit by the contact of K on W.

PC, priming-charge.

F, fuse.

Operating-Box on Shore.

WB′, watching-battery of gravity cells and brass bar.

FB′, firing-battery of Sampson cells and brass bar.

P′, firing-plug.

M′M′, ordinary electro-magnet, 100 ohms. (See Relay No. 7.)

A′, armature pivoted at the center. (See Relay No. 7.)

S′, spring holding armature back against a weak current. (Relay No. 7.)

L′, shutter arm pivoted above its center of gravity. When set as in relay No. 1, shutter-arm L′ makes electrical connection with the armature at N′; when armature is attracted it releases L′, whose lower end strikes a bell, and makes electrical contact with the firing-bar at B′.

b, terminal of mine circuit which may be plugged to WB′.

a, terminal for testing-set.

o, *o*, two reversing-keys.

X and Y are two stations, 1 to 3 miles apart, each having a key and an observer of the mine field.

Operation.

The torpedo having been planted and connected with its relay, whose shutter-arm L′ is set as in relay No 1, a small steady watching-current flows through G′, WB′, *b*, M′M′, H, N′, J′, O′, V, coil S, coil, N, W, R (1,000 ohms), G to G′ again. The direction of the current is such as to preserve the magnetism of the magnet. If the circuit closer is accidentally closed (indicated by a change of the resistance in the circuit) it can be opened by using the reversing-key from shore.

The fuse F may be fired in four ways: —

(*a*) *By contact with the mine only.* Insert firing-plug P′. When a vessel strikes a mine the brass ball B in the circuit-closer is thrown aside, closing K on W and thus short circuiting R. The watching-current, thus made stronger, flows from coil N through K, A, Z, fuse, $G_{\prime\prime}$ to G′. Coming from gravity cells it cannot fire the fuse, but is strong enough to operate the relay and drop L′, which throws in the firing-battery. A strong current now flows through G″, FB′, P′, B′, J′, O′, V, coil S, coil N, W, K, A, Z, F, $G_{\prime\prime}$ to G″ again, and fires the fuse.

(*b*) *At will of operator only*, who may at any time drop the shutter arm L′ by hand and insert the firing-plug. The firing-current is strong enough, even through R in the torpedo, to close K, short-circuiting R, and to fire the fuse.

(*c*) *By contact with the mine and at operator's will.* Remove firing-plug P′. The watching-current flows as above in (*a*). When the vessel strikes the mine L′ drops, striking the bell, when the operator inserts P′, throwing in the firing-current which fires the mine.

(*d*) *By observation from two stations;* shutter arm L′ set, and firing-plug P′ in. When a hostile vessel appears over the mine from the position of X the observer closes his key. Y has like instructions. When both keys are closed the main part of the current from WB′ flows through G′, WB′, *b*, M′M′, H, Q′, X, Y, G, to G′ again, drops the shutter-arm and fires the mine.

For obvious reasons the foregoing is not a description of the service circuit closer, but the principle of construction and operation of the mines of all countries are much alike.

Fortress Telephones and Telegraphs.

Covering as it does a considerable area, the modern fortification must have its several units within instant communication, in order to insure that concert of action so necessary to a successful command. The fort commander must communicate his orders to the battery commanders, and they in turn transmit the necessary commands to the gun commanders; and while much time and ingenuity has been spent in devising means of communication through the medium of printing and dial telegraphs, the telephone is to-day practically the universal method of communication from one part of a fire command to another. As ordinary commercial telephones are employed, no special description of them need be given in this section. The telephone is however, at best, but an unsatisfactory method of communication, and will be rendered more so by the noise and confusion of battle.

Field Telephones and Telegraphs.

For communicating in the field operations of an army, where portability is of primary consideration, several forms of apparatus have been devised by the Signal Corps.

Field Telegraphy. — This outfit is contained in an oak case $13\frac{1}{2} \times 7 \times 8\frac{3}{4}$ inches, with a leather carrying strap, and weighs 18 pounds.

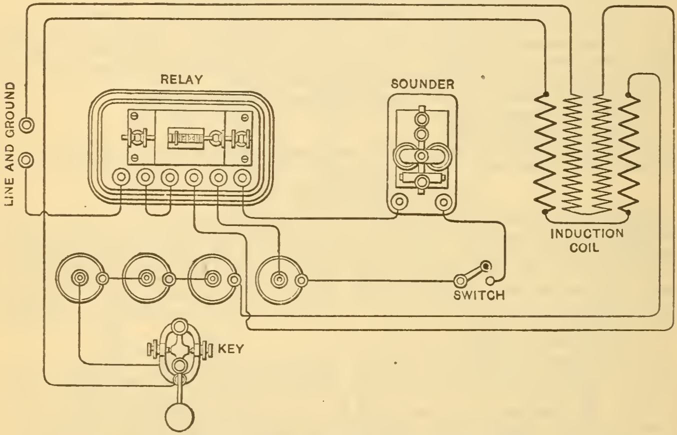


Fig. 14. Wiring Diagram Field Induction Telegraph.

It is operated by means of an induction coil, the ratio between the primary and secondary wiring being 100 to 1. The magnetic circuit is broken at one end to give increased speed. A polarized relay is used. The line battery consists of three No. 5 dry cells, giving $4\frac{1}{2}$ volts. This apparatus works successfully for 250 to 300 miles over No. 9 galvanized iron wire. Fig. 14 shows the circuit.

Field Telephone. — Outfit is contained in an oak carrying case, $10 \times 5\frac{3}{4} \times 10$ inches, and weighs 20 pounds; has a hand set receiver and transmitter, and magneto call. Two No. 6 dry cells are used for transmitting circuit.

Field Buzzer. — This is a combined telephone and telegraph instrument, working on principle of self-induction. Interruption is very rapid, giving a high-pitched note. Telephone receiver is used for sounder when employed as a telegraph instrument. This is a very efficient instrument and will work over a line through which ordinary instruments cannot possibly operate. Has been operated over line of 30 miles of bare wire lying on ground and practically short-circuited all the way; also over 18 miles with breaks in line totaling 20 feet. The outfit is contained in a leather carrying case $10\frac{1}{2} \times 5\frac{1}{4} \times 8\frac{1}{2}$ inches, and weighs 11 pounds.

Telephone Switchboard. — The Signal Corps also employs a portable telephone switchboard, mounted on a tripod and weighing about 75 pounds. This has a capacity of 10 lines, cordless connection and magneto call. It can be set up in a few minutes.

Wire. — Three different grades of wire are used. One form consists of 2 strands of steel and 1 of copper, cotton covered, weighing about 12 pounds to the mile, carried on reels of one-half mile. Another grade consists of 11 strands of steel and 1 of copper, rubber covered and braided. This is capable of standing very rough usage. A third type of wire, but little used on account of its weight, consists of 19 strands of steel and one of copper.

THE TELAUTOGRAPH.

In the transmission of ranges and azimuths from the observers, where great accuracy is required, the telautograph is largely employed. The following description of this instrument is taken from "Handbook for the Use of Electricians," Government Printing Office, 1904.

Description, Principles, and Operation.

Transmitter. — By means of two light rods attached to the transmitting pencil near its point, the arbitrary motions of writing or drawing are resolved into simple rotative or oscillatory motions of two pivoted arms, located on either side of the writing platen. These arms are included in the line circuits and carry at their extremities small contact rollers which move to and fro upon two rheostats, or resistance coils, these being so connected through the arms to the line and to the source of energy as to act both as adjustable shunts and as rheostats in the line circuits. By this method the voltage supplied to the line is made to vary with the position of the pencil upon its writing platen, and definitely variable writing currents are transmitted.

Receiver. — The receiver principle is equally simple. The variable line currents coming in over the line wires are led through two vertically movable coils, each suspended in a strong uniform magnetic field by a well-sweep arrangement, from which they derive the name of "buckets."

Each coil is supplied with an adjustable retractile spring which tends to oppose the movement of the coil downward through the field. It is evident that for given values of the line currents each coil will have a definite position in its respective magnetic field, depending upon the tension of its retractile springs. The vertical motions of these receiver "buckets," due to the varying line currents, are used to cause rotative motions in two pivoted arms, similar to those at the transmitter, which motions, through another system of light rods, compel the receiving pen to exactly reproduce the motions of the transmitting pencil.

To accomplish the pen-lifting at the receiver an automatic device is used, consisting of an induction coil at the transmitter, having two secondary windings and performing the double function of pen-lifting and reducing friction. The primary circuit of this coil is entirely local at the transmitter, and includes an interrupter and a shunt circuit controlled by the platen.

The vibratory secondary currents are superimposed upon the writing currents, and serve to keep the receiving pen in continual though imperceptible vibration, reducing friction in the moving parts to a minimum. The normal writing pressure of the pencil upon the transmitter platen opens the shunt circuit and causes an increase in the strength of the secondary vibrations. This operates a vibratory relay inserted in one of the line circuits at the receiver, opens a local circuit, and causes the armature of the pen-lifting magnet to be released and the pen is allowed to rest upon the paper.

Lifting the transmitting pencil from the platen decreases the strength of the vibrations, closes the local receiver circuit, and the pen-lifting magnet attracts its armature and raises the pen clear of the paper.

The shifting of the paper at the transmitter is done mechanically by means of the master switch. The same motion of the switch operates an electromagnetic device over one of the line wires, which automatically and positively shifts the paper at the receiver a corresponding amount.

The paper, 5 inches wide, is supplied in conveniently detachable rolls, which are mounted in brackets attached to the backboard of the instrument. For signaling, a push button at the transmitter operates a call bell at the receiver.

The transmitting pencil is a simple adjustable lead pencil. The receiving pen is made on the principle of the ordinary right-line drawing pen, so

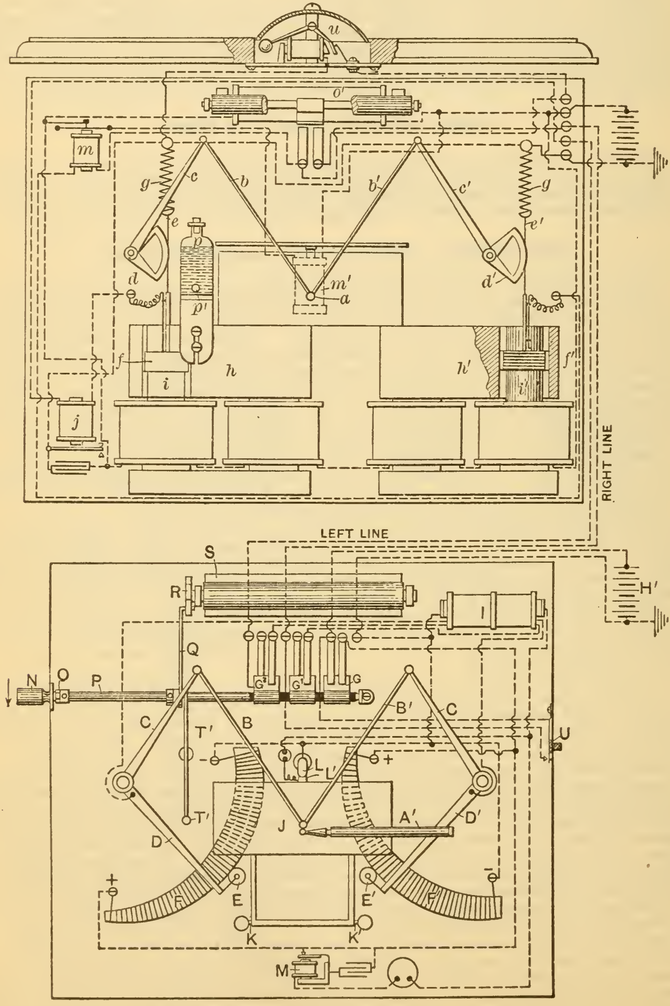


Fig. 15.

modified as to make perfect lines regardless of the direction of motion, and capable of holding an ample supply of ink.

The inking device consists of a bottle or supply well, with a hole and stopper for refilling, and also with a second small hole in the side of the well. This hole is below the surface of the ink, and the top of the well being corked and airtight, the ink is prevented from flowing out by the pressure of the external atmosphere.

The small hole is located at the unison point, and whenever the paper is shifted the pen returns to this position and automatically dips its point into the ink which stands at the mouth of the hole. Capillary attraction is sufficient to completely fill the pen, and, resting in the hole as it does, the point does not clog up with dry ink when not in use, but is always ready to start writing with a full fresh supply.

Explanation of Diagram. (Fig. 15.)

1. **Transmitter.** — The motions of the transmitting pencil *A* are conveyed through the pencil arms *BB′*, and pencil arm levers *CC′* to contact arms *DD′*, which carry contact rollers *EE′*, these contact rollers bearing upon the periphery of rheostats *FF′*, the terminals of these rheostats being connected through master switch *G* to the positive and negative poles of a suitable source of electrical energy, indicated by battery *H*. The contact arm *D′* is connected to the right line through one of the secondaries of the induction coil *I*, and through the right-line contacts *G′* of master switch, when the master switch is in the writing position as shown. The contact arm *D* is connected to the left line through the other secondary of the induction coil *I*, through the left line contacts *G*2 of master switch. The writing platen *J* is pivoted at *KK′*, and when pencil is off the platen closes upper contacts *LL′*, shunting resistance *l* around the primary winding of induction coil *I*. The vibrator *M* is in circuit with the primary of induction coil *I* and battery *H*, and rapidly vibrates, the current passing through the primary of the induction coil, thus causing a vibratory current to traverse the right and left line wires, the strength of this vibratory current depending upon the position of the platen *J*; when this platen is depressed by the pencil in the act of writing the shunt around the primary of induction coil *I* is open, consequently the strength of the vibratory currents on line is increased; this increased strength of vibration actuates the pen-lifting relay *m* (in receiver). The paper at the transmitter is shifted by moving the handle *N* of lever *O*, which is connected to shaft *P*, which carries the pawl *Q*, engaging the ratchet wheel *R*, mounted on shaft of paper-shifter roller *S*. Each movement of this handle *N* to and fro causes the roller *S* to rotate, which moves the paper forward. The shaft *P* also carries master-switch contact plates *G*, *G*1, *G*2, which open and close the line and battery circuits, according to the position of handle *N*; circuits being closed and instrument in sending position when handle *N* rests in position shown by arrow. The movement of the handle *N* in the opposite direction cuts the instrument out of circuit. The handle is locked in either position by lever *P*, and cannot be released except by pressing point of pencil *A* on button *T*. A signal-switch push button is shown at *U*; this switch when operated throws current of positive polarity through right line, which rings receiver bell, *u*, as hereafter described.

2. **Receiver.** — The motions of receiver pen *a* are caused to duplicate the motions of transmitting pencil *A* through the pen arms *bb′*, pen-arm levers *cc′*, which are mounted on shafts carrying sectors *dd′*. Light metal bands *ee′* are attached to the peripheries of sectors *dd′* and carry at their lower ends coils (or "buckets") *ff′*, and their upper ends are attached to springs *gg′*. The coils *ff′* are movable in the annular spaces between the poles of the magnets *h* and *i*, and *h′* and *i′*. Coil *f* is in circuit with Morse relay *j* and the left line, and coil *f′* is in circuit with pen-lifting relay *m* and the right line. As the transmitting pencil is moved its motions are transmitted to contact rollers *EE′*, the strength of current on line is varied, the currents becoming stronger as the rollers approach the positive ends of the rheostats *FF′*, these currents traversing line and passing through coils *ff′*, causing them to take different positions in the magnetic fields, opposing the pulls of the springs *gg′*, these springs being so adjusted that the position of the receiving pen in the writing field will always be the same as the position of the transmitting pencil on its writing platen.

3. The depression of platen J, causing a strong vibratory current to traverse line, causes the armature of pen-lifting relay m to vibrate and interrupt the circuit of pen-lifter m', thus releasing the armature of pen-lifter and lowering the pen-arm rest so as to allow the pen to come into contact with the paper. Upon raising the transmitting pencil from its platen the vibra-

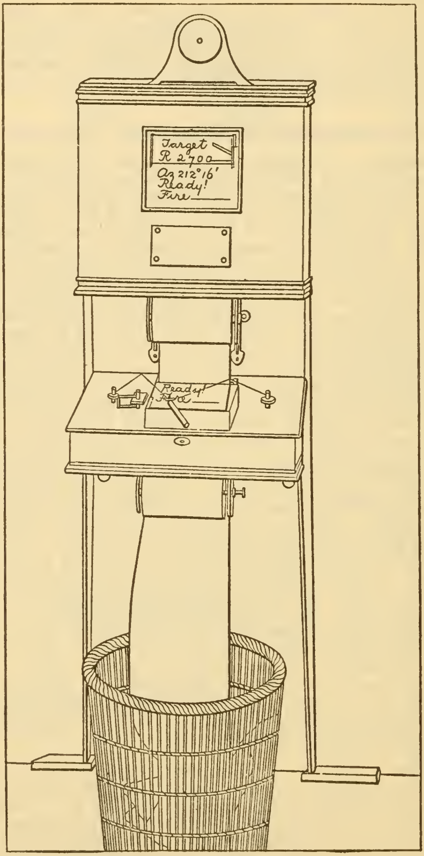


FIG. 16. Telautograph.

tory current will be weakened, the armature of pen-lifting relay m ceases to vibrate, closes the circuit of pen-lifter m', which attracts its armature and thus lifts the pen from the paper.

4. The paper-shifter o' is an electromagnetic device and is controlled by the Morse relay j, the armature of this relay closing the circuit of the shifter through its forward contact when the relay j is energized by line current through the master switch by the movement of handle N in the position shown by arrow.

5. The signal bell u, which is of low resistance, is thrown in parallel with the right-line coil, or "bucket" f', when no current is passing through the paper-shifter, consequently when signaling current passes over right line the bulk of the current passes through the bell, rather than through coil f'.

6. The ink well (an ordinary glass bottle) is shown at p, the receiver pen a entering the opening p' and receiving a fresh supply of ink every time the paper is shifted, the pen resting in this opening and in contact with the ink when the instrument is not in use.

Installing.

The instruments are furnished with a suitable backboard, the connections being made between the instruments and the circuits on the backboard by automatic contact pins, so that the instruments can be put on and taken off readily. The terminals on the backboard for connecting to line and battery are plainly marked so that the proper connections may be easily made.

Operation.

1. **To write.** — Depress button with pencil point and pull lever towards you a full stroke; release button with lever in this position, and write with firm pressure on paper.

2. **To shift paper.** — Depress button, holding it down until you have moved lever back and forth its full stroke as many times as you wish to shift paper, then release button with lever in position towards you.

3. **To hang up.** — Depress button, allowing lever to rest in position away from you. Always, after writing, leave the lever in position from you.

Care of Instruments.

The care of the instruments consists mainly in keeping the ink bottles properly filled with the ink which is supplied for that purpose, the occasional cleaning of the pen points, and the insertion of fresh rolls of paper which is supplied for that purpose.

WIRELESS TELEGRAPHY.

The wireless telegraph outfits used in the Army have been developed by the Signal Corps, and embody some of the best features of other systems. One of the most effective outfits is that designed to be carried on pack mules. For this purpose it is divided into three loads, each weighing approximately 150 pounds, the transmitting and receiving apparatus, the batteries, and the poles for aërial wires.

The transmitting and receiving apparatus is contained in a leatheroid trunk 30 × 17 × 14 inches inside measurement. Fig. 17 shows the wiring arrangement. Current is furnished from storage batteries or by hand generator. The storage battery consists of 8 cells of about 50 amp.-hour capacity. The ratio of the induction coil is about 1 to 200. About 16 volts are required in the primary. The key is an ordinary open circuit key with extra large platinum contact points. A special double head telephone receiver is used. Two types of detectors are employed, electrolytic and silicon. The electrolytic detector is similar to that used commercially, but differs in design. The silicon detector is that invented by G. W. Pickard in which the action is thermo-electric, and is in form of a brass contact resting on the silicon crystal, which is embedded in a brass cup.

The aërial wires are supported on a jointed pole 60 feet in height. The pole is hollow and is made of spruce in 9 sections, 6 feet 8 inches long and $2\frac{1}{4}$ inches in diameter. The aërial consists of 6 umbrella wires, 85 feet long, and 6 counterpoise wires, 75 feet long. The counterpoise is used in preference to ground. The aërial wires are formed of 42 strands of No. 33 phosphor bronze twisted around a hemp center. They have a tensile strength of 300 pounds and weigh about 7 pounds per thousand feet.

With a similar station receiving, this outfit has been successfully operated over a distance of 27 miles.

Kites are sometimes used for supporting the aërial wires, and with the height thus obtainable messages have been received over 600 miles.

Small wireless telegraph outfits have been made, weighing approximately 40 pounds, capable of covering 3 or 4 miles.

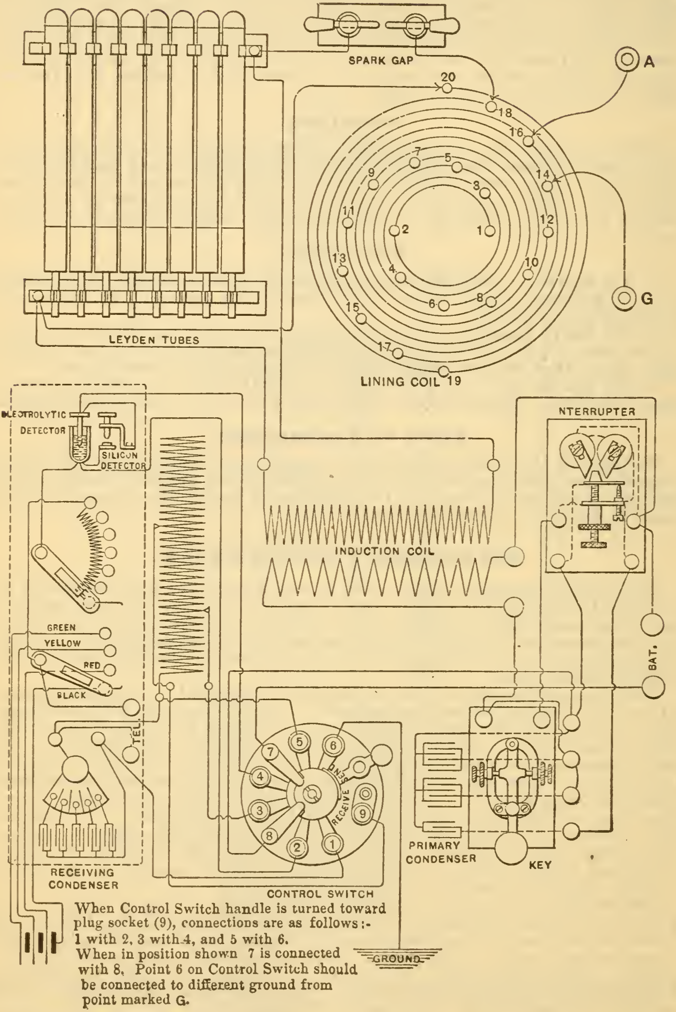


FIG. 17. Field Wireless Set-Pack. Trunk Type, Wiring Diagram.

ELECTRIC AMMUNITION HOIST WITH AUTOMATIC SAFETY STOP.

As its name implies this apparatus is used for raising ammunition from the magazines to the gun positions.

It is applied to two platforms, *G G*, Fig. 18, either of which is drawn upward, while the other descends, by a winch driven by a motor through worm or train gear. A 5-horse-power motor can raise 2,000 pounds counterweighted by 600 pounds of the other platform at the rate of 1 foot per second. The design is simple, inexpensive, and the motor and hoist are fairly well protected.

1. *M* is the motor with both series and shunt fields, the latter being excited when *MS* is closed. *RS* is a three-pole reversing switch shown in position for the right-hand platform to ascend.

2. The controller has a starting rheostat, *Rh*; a hand lever, *W;* a spring lever, *V;* an underload release, *UL;* and an overload release, *OL*. The

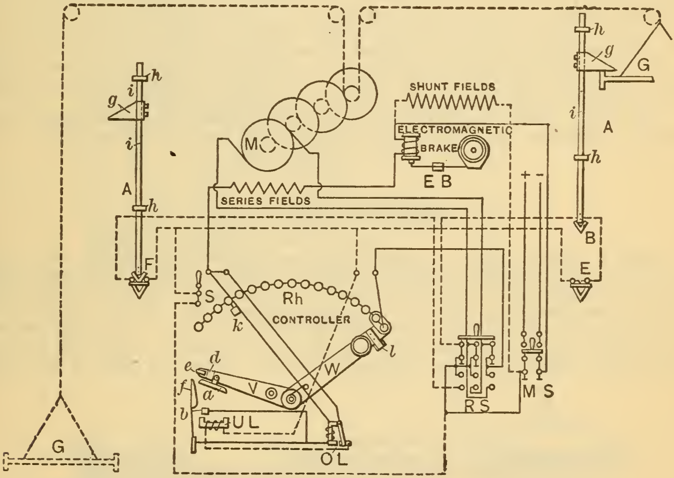


Fig. 18. Ammunition Hoist.

magnet *UL* depends for its excitation upon the voltage of the motor terminals and also upon the integrity of its circuit at any one of the four points *OL*, *RS*, *E*, or *F*. The main circuit from *MS* is through the electromagnetic brake *EB*, series fields *OL*, to the contact piece *b*, when the lever *V* is held down by *UL* magnet, the circuit is closed from *b* through *d*, *V*, *W*, *Rh* (or direct after the motor has attained full speed), to *RS*, *M* to *MS*.

3. The main circuit is broken either when the lever *V* is released (*e* and *f* taking the spark), or when *W* is moved to the left (*k* and *l* taking the spark). The lever *V*, when released by *UL*, is carried to the right by the spring at its axis until it strikes *W*. The rheostat may be designed for running the motor continuously at different speeds, or as a starting box not to be in the circuit longer than thirty seconds.

4. *S* is a baby switch held open by a spring. Its object is to close, if desired, the *UL* magnet circuit when open at *E* or *F*.

5. *A* and *A* are the devices for automatically breaking the circuit through *UL*, and thus the main circuit when the platform ascending strikes the lug *g*, which is adjustable on the bar sliding in guides *h*. On the lower end of

this bar an insulate copper wedge makes, when down, contact between two copper terminals at *E* or *F*, and breaks it when up, thus making or breaking the circuit through *UL*. *E* and *F* are alike and adjustable vertically 6 inches.

6. The right-hand platform is at its upper level, the left-hand is at its lower; the circuit through armature *M* has been broken and *V* is up against *W*. If now we try to start the motor without reversing *RS*, the circuit through *M* will still be open at *E*. But throw *RS* down and the circuit through *UL* will be closed at *F*, and the left-hand platform can be raised.

7. To start the motor at all, *W* must always be brought up to the left, pushing *V* before it until held by the underload magnet *UL*, then *W* may be moved to the right, closing the circuit first through *Rh* and at last without it.

8. When the left-hand platform, on nearly reaching its upper level, engages *g* and opens *F*, the main circuit will be opened at *b* and the motor will stop.

9. If it is necessary to move the platform farther up after the circuit has been broken at *E* or *F*, the switch *S* may be closed and the platform may then be moved by the motor. So long as *S* is closed *V* will not be released except for no voltage or overload.

10. The motor may be slowed down or even stopped by moving *W* to the left, provided *Rh* is large enough to carry the current.

11. The electromagnetic brake on the gear wheel next the motor armature automatically clamps it whenever the main current ceases and the motor stops. It gives a quick stop for heavy or light loads.

12. If the electric machinery is disabled the motor is quickly thrown out and the platform can still be raised by a crank handle and gearing.

NIGHT SIGHTS.

Electric night sights for rapid fire guns consist of a fitting and stem which can be inserted in the front sight bracket in place of the bead sight used in daylight. This fitting receives an encased white electric light which illuminates a glass cone set under a pierced cap, so that the point of the cone only is visible as a bead to be used in aiming. The light proper is shipped into a holder and down over two plug pins to the other end of which the cable wires are soldered (Fig. 19). The rear edge of the rear

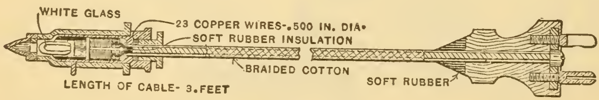


Fig. 19. Front Electric Light and Plug Connections.

sight ring is grooved and the groove baked full of scarlet enamel, which is illuminated by an encased red electric light, fitted similarly to the front light. Power is obtained from a battery consisting of ten O.K. dry cells, No. 4, $1\frac{3}{4}$ by $2\frac{1}{4}$ by $5\frac{3}{8}$ inches high. Four cells are connected in series through a rheostat to each lamp, a fifth cell in each case being held in reserve to put into the circuit when the four cells fail to give proper light.

For use at night, range finders are equipped with lights for illuminating the cross-wires of the instrument. The illuminating device consists of two small electric lamps in sockets attached to the rear, or eye-piece, end of the telescope, the beam of light from each lamp being reflected on the cross-wires by two small mica mirrors. The lamps are approximately $\frac{1}{2}$ c.p., and 4 volts. Power is obtained from the main lighting circuits through suitable resistance.

FIRING MECHANISM FOR RAPID FIRE GUNS.

The electrical power for firing rapid fire guns is obtained from two O.K. dry batteries, each consisting of eight cells in series. These batteries are not used simultaneously, but one is kept for use in case the other should fail. Each battery is stowed in a covered box, carried in brackets bolted to the side frames of the gun carriage. A third box is similarly carried for stowing the alternative firing cable. The battery carried on the left is ordinarily used to fire the piece through the pistol connection, while the one on the right is used with the alternative firing key.

One terminal of each battery is attached by a short cable to the frame of the carriage as an earth connection. The other terminal of the battery on

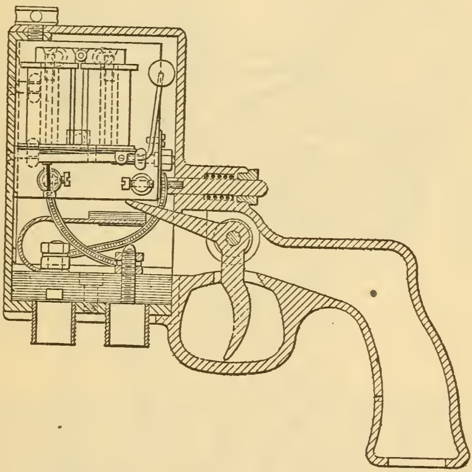


FIG. 20.

the left side of the frame is connected by a cable 4 feet long with the front nipple under the pistol (Figs. 21 and 22). When the trigger is pulled the circuit is completed to the rear nipple, from which a cable, 5 feet 5 inches long, passing under the cradle and through a twisted hook to the right side connects with the contact surface plug. This is bracketed to the cradle in such position that when the piece returns into "battery" from recoil, the contact pin, pressed out by a spring in the contact-pin plug, attached to and moving with the recoil band and piece, presses upon the contact surface of the plug before mentioned. The connection for the next shot is thus made.

From the contact-pin plug the firing-pin cable extends through a locking pin at the hinge of the breech mechanism to the firing pin, the last 10 inches being armored for protection (Fig. 22). To enable the cannoneer who fires the piece to ascertain whether the breech block is entirely closed and the connections otherwise complete, a buzzer is incased with the pistol, (Fig. 20) so that when the button over the trigger is pressed by the thumb a circuit is completed through a resistance coil, which permits just enough current to pass to sound the buzzer, but not enough to explode the primer, if kept on for an instant only. The ear must be held close to the buzzer

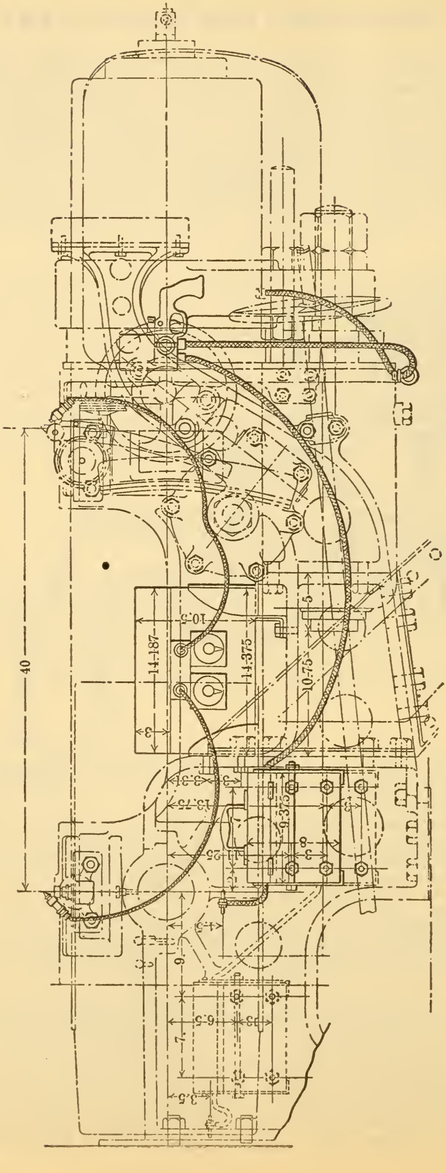


FIG. 21.

to detect the sound. When the trigger is pulled, a direct circuit is completed, permitting the full current from the battery to pass through the primer, thus firing the piece.

In case the pistol or its connections become short circuited, or the insulation fails, the cable can be quickly disconnected from the battery and firing

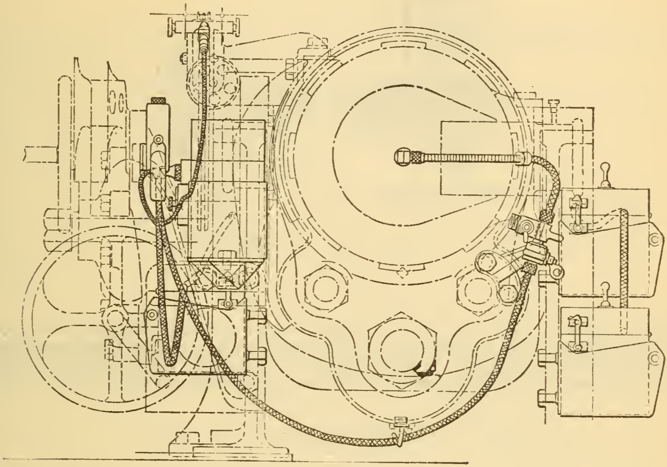


FIG. 22.

pin and the pistol lifted out of its slot. The surface-contact plugs are then disconnected by withdrawing the locking pins which engage with bayonet studs in the contact-plug block, after which another pistol and cables may be applied or the alternative firing key and cables used.

In the alternative battery, in the front box on the right side of the frame, the other terminal is directly connected with the firing pin through the

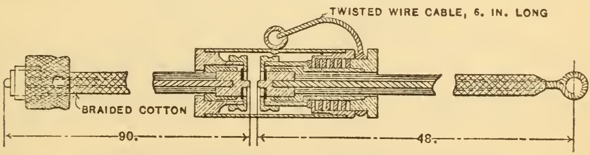


FIG. 23. Alternative Firing Key and Cables.

alternative firing key and cables about 11.5 feet long. The length of these cables is such that the key may be taken under the piece to the left side and used by the cannoneer who is aiming.

The alternative key (Fig. 23) consists of a tube into one end of which a cable end is coupled fast. The cable entering the other end is secured to a plunger which is held out by a coiled spring. When grasped in the hand with the thumb on the plunger end, the cable ends may be pushed together, completing the circuit. To guard against a premature discharge of the

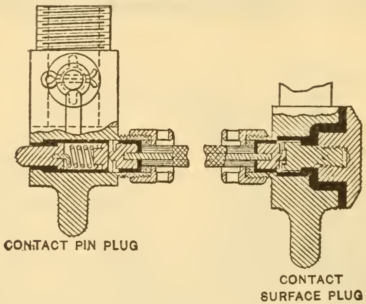


FIG. 24.

piece, a split key is wired to this firing key to prevent forward movement of the plunger, and this is kept pushed under the plunger head until the piece is about to be fired. Figs. 21 and 22 show the connections for both night sights and firing circuits, and Fig. 24 gives details of the contact plugs.

ELECTRICITY IN THE UNITED STATES NAVY.

REVISED BY J. J. CRAIN.

AT the present time (January, 1908) the standard practice on ships of the United States Navy is to use direct current, at 125 volts, distributed on the two-wire system. Previous to 1902 the standard was 80 volts, consequently many vessels have apparatus of that voltage.

A ship's installation is conveniently divided into dynamo room, lighting system, power system, and interior communication system. The wiring of each system is kept entirely separate from the other.

The dynamo room contains the generating sets, main switchboard, and sometimes condensers for the engines.

The lighting system supplies all ship's lights, searchlights, and signal lights. These are installed in two separate systems called "Battle Service" and "Lighting Service." Battle service comprises all lights necessary during action, and these lights are arranged so as to be invisible to the enemy. Lighting service comprises the additional lights necessary for ordinary habitation.

The power system supplies the various electric auxiliary machinery which at present consists of all ammunition hoists, turret turning gear, elevating and ramming gear for the larger guns, boat cranes, deck winches, ventilating fans, water-tight doors, and motors for driving line shafting in laundry and engineer's workshop. Anchor handling gear and steering gear are at present always steam driven, but electric devices are being experimented with. The auxiliaries in the engine and boiler rooms, consisting of numerous pumps and the forced draft fans, are all steam driven, except in a few vessels not yet finished where electric forced draft fans are being installed.

The interior communication system consists of various devices for transmitting signals and orders from one part of the ship to another. Most of these are electric, but in some cases they are paralleled by mechanical equivalents, as, for example, voice tubes paralleling telephones.

DYNAMO ROOM.

The generating plant is located in a compartment called the "Dynamo Room," which is under the protective deck and adjacent to the boiler rooms (when practicable), so as to secure a direct lead of steam pipes.

GENERATING-SETS.

The following are the principal requirements contained in the standard specifications for reciprocating generating-sets:

General Requirements.

Each set to consist of an electric generator direct-coupled to a steam engine, both mounted on a common bedplate.

The sets as a whole shall be as compact and light as is consistent with a due regard to strength, durability, and efficiency. The standard sizes, with their corresponding maximum allowable speeds, weights, and over-all dimensions are:

Size in kilowatts.	Revolutions per minute.	Weight in pounds.	Length in inches.	Width in inches.	Height in inches.
2.5	800	560	32	20	30
5	750	1,300	50	28	40
8	550	2,500	64	34	50
16	450	5,600	78	40	60
24	400	7,300	88	48	68
32	400	10,000	101	52	78
50	400	16,000	110	60	85
100	350	22,000	125	70	95

The design shall provide for accessibility to all parts requiring inspection during operation, or adjustment when under repair. Sets are to be designed to operate right-handed, i.e., counter clockwise when facing the commutator end, or left-handed, as required. The design to be preferably such that the same parts may be used in each, in order to avoid increase in number.

The sets must be capable of running without undue noise, excessive wear, or heating. Must be balanced and run true at all loads, up to 33⅓ per cent above rating; must be capable of running for long periods under full load and without continued attention.

Cast or wrought iron shall not be used for bearing surfaces, except in cases of cylinders, valve chests, and crosshead slides. Both upper and lower halves of main bearings to be removable without removal or displacement of shaft.

The driving shaft must be fitted with thrust collars or other suitable device which will prevent a movement of the shaft in the direction of its length, as might be caused by the rolling of the ship.

The combination bedplate to be a substantial casting, and provided with accurately spaced drilled holes for securing to foundation.

An oil groove of ample width and depth to be cast in the upper flange of bedplate, to be continuous around the engine, and to be provided with a stopcock for drainage. The lower side of the combination bedplate to be planed perpendicular to the line of stroke of engine.

Seats for all bolt heads and nuts to be faced. All nuts to be case hardened, and to be U. S. standard sizes. Where liable to work loose from vibration, nuts are to be secured by use of jam nuts and spring cotters. All bolt ends to be neatly finished.

The two halves of the main coupling to be either keyed to or forged solid with the engine crank and armature shaft. The coupling to be bolted together by well-fitted bolts, driving to be done by a cross key set in the faces.

Adjoining portions of the machinery shall be given corresponding marks whenever this may be desirable for insuring correct assembly.

Interchangeability among the different sets and their spare parts, of the same size and make, as furnished in any one contract, is required. This to be demonstrated as part of the final test for acceptance.

ENGINE.

Engines are to be of the automatic cut-off vertical enclosed type, designed to run condensing with maximum practical efficiency at all loads, but capable of satisfactory operation when running noncondensing, to be of sufficient indicated horse-power to drive the generator for an extended time at the rated speed, when said generator is carrying a one-third overload.

Sizes 2½ K. W., 5 K. W., and 8 K. W. to be simple engine, single or twin cylinder at the option of the contractor. Sizes of 16 K. W. and above to be cross-compound with cranks set at 180°.

The normal steam pressure under which the engine, running condensing with 25-inch vacuum, for different size sets, is to operate, and the maximum allowable water consumption per K. W. hour output of the set are:

K. W.	Normal steam pressure.	Water consumption per K. W. hour, full load.
2.5	100	105
5	100	90
8	100	65
16	100	44
24	100	40
32	100	37
50	100	35.5
50	150	33.5
100	150	31

In testing, corrections shall be made by calorimeter for entrained moisture. Superheating shall not be used in the test.

Engines must run smoothly and furnish the required power for full load at any steam pressure within 20 per cent (above or below) of those given in the above table, and exhausting to condenser at 25 inches vacuum; to furnish power for 90 per cent of full load at steam pressure 20 per cent below normal, and for full load at any steam pressure between normal and 20 per cent above normal, when exhausting with the atmosphere. Must be able to bear without injury the sudden throwing on or off of one and one-third times the rated full load of the generator, by making and breaking the generator's external circuit.

To be so designed that the work done by each cylinder, as shown by indicator cards, will be as nearly equal as practicable under all conditions of load. Indicator motions must be provided which will accurately reproduce the motion of the pistons at all points of the stroke. This will require, for cross-compound engines, the operation of the reducing motion for each cylinder from the crosshead or other moving part belonging to that cylinder.

Indicator piping to be installed in a manner to secure accuracy of indicator cards. Connections to be made at each end of each cylinder, and piped to a three-way cock in order that one indicator may be used for both head and crank ends of cylinder. Connections are to fit the standard indicators of the Bureau of Equipment.

The length of stroke of the engine to be not less than the diameter of the bore of the high-pressure cylinder.

The cylinders to be made of hard, close-grained charcoal iron, bored and planed true, of sufficient thickness for operation after reboring once, steam and exhaust ports to be short, of ample area and free from fins, scales, sand, etc. Cylinders to be fitted with the usual drain cocks, all drains to end in one outlet. In addition to these drains, relief valves are to be fitted to each end of each cylinder, and both high-pressure and low-pressure valves are to be free to lift from their seats to relieve the cylinder of water.

The low-pressure cylinder must be fitted with a flat, balanced slide valve; a piston valve on the low-pressure cylinder will not be accepted.

The pistons to be of cast iron or steel, strongly ribbed, light and rigid, and fitted with self-adjusting rings, each piston to have two or more rings. Rings to override counterbore of cylinders, to prevent wear to a shoulder.

Piston rods to be of forged steel securely fastened to pistons and crossheads. Crossheads to be of steel with adjustable shoes. Connecting rods to be of steel with removable babbitt-lined boxes for crank pins and bronze boxes for crosshead pins.

The crank shaft to be forged in one piece; counterweights for balancing reciprocating parts to be forged with it or securely fastened thereto. Valve rods, eccentric rods, and rocker shafts, as well as all finished bolts, nuts, etc., to be of best forged steel.

Lagging shall be fitted as extensively as practicable to cylinders, receivers, and steam chests. This shall be done after a preliminary run of the engine in order that any defects in castings or joints may be readily found. The arrangement for securing the lagging in place shall admit of its ready removal, repair, or replacement.

The steam and exhaust outlets shall be so placed as to admit of piping from either side with equal facility. Blank flanges shall be furnished complete when required to cover alternative outlets.

Throttle and exhaust valves to be 90-degree-angle valve, looking up, unless otherwise specified. Handwheels to be marked, indicating direction of turning for opening and closing. When so directed, larger sizes shall be furnished with by-pass valves for warming up cylinders.

The governor to be of the weight and spring type, arranged to operate the high-pressure valve by a shifting eccentric, thus automatically varying the valve travel and point of cut-off. No dashpots or friction washers shall be used in its construction.

The speed variation must not exceed 2½ per cent when load is varied between full load and 20 per cent of full load, gradually or in one step, engine running with normal steam pressure and vacuum. A variation of not more than 3½ per cent will be allowed when full load is suddenly thrown on or off the generator, with constant steam pressure either normal, or 20 per cent above normal; a variation of not more than 3½ per cent will be allowed when 90 per cent of full load is suddenly thrown on or off the generator, with constant steam pressure 20 per cent below normal, exhaust in both cases to be either into condenser or atmosphere. No adjustment of the governor or throttle valve during the test shall be necessary to insure proper performance under any of the above conditions.

The engine column to be designed to enclose all moving parts as far as practicable, or where weight may be saved, by using a wrought-steel frame with an enveloping enclosure of metal. Detachable hinged doors to be provided for examining moving parts while in operation. The design to eliminate all chance of oil or water leaking or being forced through.

Stuffing boxes for piston rods to be slightly longer than length of stroke, in order that no part of the rod exposed to the oil in the enclosure will enter the cylinder. Stuffing boxes for piston rods and valve rods to be accessible from the outside of the enclosing case of the engine.

A guard plate to be provided to prevent oil from being thrown against the lower cylinder heads and valve chests.

Engines are required to operate satisfactorily without the use of lubricants in the steam spaces. The lubrication for all other working surfaces shall be of the most complete character. No part shall depend on squirt-can lubrication.

Forced lubrication shall be used wherever practicable, which includes engine shaft, crank pins, crosshead bearings, eccentric, etc. The engine shall be capable of satisfactory operation with a low grade of lubricating oil, and the forced lubrication shall not be a necessary factor in its cool and satisfactory running. The intent of the forced lubrication is to reduce friction, noise, and attention required.

The pressure for such forced lubrication shall be approximately 15 pounds per square inch, and shall be between 10 and 20 pounds under all service conditions.

The bedplate is to contain a reservoir and cooling chamber of ample capacity, to be provided with a strainer which may be removed without interrupting the oil supply. The pump to be direct driven by a crank or eccentric on the engine shaft, construction to be simple and durable, and to include a proper guide or support for the plunger rod. The pump to handle clean oil only, not drawing from the top or bottom of reservoir.

To allow inspection while running, the engine crank is not to dip in oil in reservoir.

Fly wheel to be turned on face and sides, inner edge to be flanged to retain any oil which may drip thereon. Hub to be split and clamped to shaft by through bolts. A steel starting bar or its equivalent to be furnished in sizes of 16 K. W. and over, the fly-wheel surface to have not less than six holes for starting bar.

Mandrels, with collars, complete, shall be furnished for renewing white metal of all bearings so fitted.

GENERATOR.

To be of the direct-current, multipolar type, compound-wound long-shunt connection, designed to run at constant speed and to furnish a pressure of 125 volts at the terminals, at rated speed with load varying between no load and one and one-third times rated load.

The magnet yoke or frame to be circular in form, to have inwardly projecting pole pieces, and to be divided in half horizontally, in all generators above 5 K. W. capacity, the two halves being secured with bolts, to allow the upper half with its pole pieces and coils to be lifted to provide for inspection or removal of armature. Pole pieces to be bolted to frame, bolts to be accessible in assembled machine to enable removal of field coils without disturbing armature or frame. Magnet frame to be provided with two feet of ample size to insure a firm footing on the foundation.

Facilities for vertical adjustment of frame to be provided in sizes of 16 K. W. and above.

Armature spider to be designed to avoid shrinkage strains. To be accurately fitted and keyed to shaft and to have ample bearing surface thereon.

The disks or laminations to be accurately punched from the best quality thoroughly annealed electrical sheet steel, slots to be punched in periphery of laminations to receive armature windings. Disks to be magnetically insulated from one another, and securely keyed to spider or held in some other suitable manner to obviate all liability of displacement due to magnetic drag, etc. Space blocks to be inserted between laminations at certain intervals to provide ventilating ducts for cooling the core and windings.

Laminations to be set up under pressure and held securely by end flanges. Bolts holding these end flanges must not pass through laminations.

The commutator bars or segments to be supported on a shell, which must be either part of or directly attached to the spider, to prevent any relative motion between the windings and these segments. Bars to be of hard drawn copper finished accurately to gauge. Insulation between bars to be of carefully selected mica and not less than 0.03 inch thick, and of uniform thickness throughout.

Bars to line with shaft and run true, to be securely clamped by means of bolts and clamping rings. Bolts to be accessible for tightening and removable for repair.

Brushes to be of carbon. In sizes over 5 K. W. there shall be not less than two brushes per stud, each brush to be separately removable and adjustable without interfering with any of the others. The point of contact on the commutator shall not shift by the wearing away of the brush.

Brush holders to be staggered in order to even the wear over entire surface of commutator; the generator to be provided with some device for shifting all the holders simultaneously. All insulating washers and brushes to be damp proof and unaffected by temperature up to 100° C.

Finished armature to be true and balanced both electrically and mechanically, that it may run smoothly and without vibration. The shaft to be provided with suitable means to prevent oil from bearings working along to armature.

All copper wire to have a conductivity of not less than 98 per cent.

The shunt and series field coils to be separately wound and separately mounted on the pole pieces. The shunt and series coils, respectively, of any one set to be identical in construction and dimensions and to be readily removable from the pole pieces. The shunt coils as well as the series coils are to be connected in series.

In sizes of 15 K. W. and above a headboard is to be mounted on the generator containing the necessary terminals for main switchboard and equalizer connections, shunt and series field connections, pilot lamp, and, if specified, an approved type of double-pole circuit breaker whose range of adjustment shall cover from 100 to 140 per cent of rated full-load current of the generator. Field current not to be broken by the circuit breaker.

The field rheostat to be of fireproof construction suitable for mounting on back of switchboard, with handle or wheel projecting through to front, either directly connected or by sprocket chain, handle to be marked indicating direction of rotation for raising and for lowering voltage of generator. The total range of adjustment to be from 10 per cent above to 20 per cent below rated voltage, the variation to be not more than one-half volt per step at both full load and half load.

The compounding to be such that with engine working within specified limits, field rheostat and brushes in a fixed position, and starting with normal voltage at no load or at full load, if the current be varied step by step for no load to full load or from full load to no load, and back again, the variation from normal voltage shall at no point be in excess of 2 per cent.

The dielectric strength or resistance to rupture shall be determined by a continued application of an alternating E.M.F. for one minute.

The testing voltage for sets under 16 K. W. shall be 1,000 volts and for sets of 16 K. W. and above shall be 1,500 volts, and the source of the alternating E.M.F. shall be a transformer of at least 5 K. W. capacity for sets of 50 K. W. and under, and of at least 10 K. W. capacity for sets of greater output than 50 K. W.

The test for dielectric strength shall be made with the completely assembled apparatus and not with its individual parts, and the voltage shall be applied between the electric circuits and surrounding conducting material.

The tests shall be made with a sine wave of E.M.F., or where this is not available, at a voltage giving the same striking distance between needle points in air, as a sine wave of the specified E.M.F. As needles, new sewing needles shall be used. During the test the apparatus being tested shall be shunted by a spark gap of needle points set for a voltage exceeding the required voltage by 10 per cent.

With brushes in a fixed position there shall be no sparking when load is gradually increased or decreased between no load and full load; no detrimental sparking when load is varied up to one and one-third times rated load; no flashing when one and one-third load is removed or applied in one stage.

The jump in voltage must not exceed 15 per cent when full load is suddenly thrown on and off.

The temperature rise of the set after running continuously under full rated load for four hours must not exceed the following:

	Method of measurement.	Maximum allowable rise in °C.
Armature	Electrical	33⅓
Commutator	Thermometer	40
Field coils	Electrical	33⅓
Shunt rheostat	Electrical	75
Series shunt	Thermometer	40

The rise of temperature to be referred to a standard room temperature of 25° C, and normal conditions of ventilation. Room temperature to be measured by a thermometer placed 3 feet from commutator end of the generator with its bulb in line with the center of the shaft.

The generator to be capable of satisfactory operation for a period of two hours carrying one and one-third times its rated full load, and no part shall heat to such a degree as to injure the insulation.

Generators of the same size and manufacture to be capable of operation in parallel, the division of the load to be within 20 per cent throughout the range. The magnetic leakage at full load shall be imperceptible at a horizontal distance of 15 feet, measurements to be taken with a horizontal force instrument.

The minimum allowable efficiencies of the generators are as follows:

K. W.	Loads.			
	1⅓	1	¾	½
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2.5	78	78	76	73
5	80	80	78	75
8	84	84	83	80
16	87	87	86	84
24	88	88	87	85
32	88	88	87	85
50	89	89	88	86
100	90	90	89	87

Typical Results of Tests on Generating Sets Supplied under Above Specifications.

Size.	100 K.W.	50 K.W.	32 K.W.	24 K.W.
		31.5	35.0	33.4
Water consumption per K.W. hour ;	29.8	29.7	35.5	34.0
Normal steam and vacuum lbs.		28.2	35.6	34.1
Engine regulation %	2.77	1.35	1.9	2.5
Full load to no load	. . .	2.8	2.9	2.9
Normal steam and vacuum	. . .	2.66	2.	1.0
Engine regulation %	. . .	. . .	1.2	2.4
Full load to no load	. . .	2.65	1.96	3.0
20% above normal steam with vacuum	. . .	. . .	1.75	2.65
Engine regulation %	. . .	2.24	2.5	3.0
Full load to no load	2.8	3.17	2.09	3.6
20% below normal steam with vacuum	. . .	3.27	2.67	5.0
Generator efficiency %	91.3	89.5	88.8	88.2
Full load	91.7	89.1	89.1	88.6
		89.3	88.8	88.7
Temperature rise in	32.5	22.	20.8	25.1
Armature coils	33.3	18.	19.	20.1
By resistance, °C	. . .	24.8	22.	23.2
Temperature rise in	29.	24.	18.1	19.2
Field coils, shunt	31.	24.	26.7	21.3
By resistance, °C	. . .	30.7	20.8	19.0
Temperature rise	24.	24.5	13.	17.
Commutator	28.	23.	14.5	29.
By thermometer, °C	. . .	19.	15.	21.

SPECIFICATIONS FOR TURBO-GENERATING SETS.

Each set to consist of an electric generator driven by a steam turbine, both mounted on a common bedplate.

The set as a whole shall be as compact and light as is consistent with due regard to strength, durability, and efficiency. The maximum allowable normal speed, weight, and over-all dimensions are:

Size in K. W.	R.P.M.	Weight in lbs.	Length in inches.	Max. width over pipe connections.	Width in inches base.	Height in inches.
				inches.		
200	1700	25,000	150	100	75	87
300	1500	29,000	165	100	76	90

The design shall provide for accessibility to all parts requiring inspection during operation, or adjustment when under repair. Sets are to be designed to operate counter-clockwise when facing the steam inlet. The design to be preferably such that the same parts may be used in each, in order to avoid increase in number.

The sets must be capable of running without undue noise, excessive wear, or heating. Must be balanced and run true at all loads, up to 33⅓ per cent above rating; must be capable of running for long periods under full load.

Cast or wrought-iron shall not be used for bearing surfaces. Both upper and lower halves of main bearings to be removable without removal or displacement of shaft.

Suitable thrust bearings will be provided to prevent movement of the shaft in direction of its length as might be caused by rolling of the ship. Sets to be erected with shaft extending in a fore and aft direction.

The combination bedplate to be a substantial casting, and provided with accurately spaced drilled holes for securing to foundation. Provision will be made to receive duct from the ship's ventilating system.

Seats for all boltheads and nuts to be faced. All nuts to be case hardened and to be United States standard sizes. Where liable to work loose from vibration, nuts are to be secured by use of jam nuts and spring cotters. All bolt ends to be neatly finished.

Adjoining portions of the machinery shall be given corresponding marks whenever this may be desirable for insuring correct assembling.

Wrenches and lifting eyes to be furnished in sets as specified.

Canvas covers to be furnished for each set, engine covers and generator covers to be separate. To be made of Navy standard 8-ounce khaki cotton ravens (Specification 215) stitched together with a double seam.

If required in advance of delivery of set, templates of the combination bedplate or of the shunt field rheostat shall be furnished by the contractor free of additional expense. These may be of paper, full size, with dimensions entered complete in order to obviate errors due to shrinkage or expansion.

Interchangeability among the different sets and their spare parts of the same size and make as furnished in any one contract is required. This to be demonstrated as part of the final test for acceptance.

Spare parts supplied to be boxed and protected in accordance with "Specification 3B2" issued by the Navy Department, September 12, 1906.

The general appearance of the set resulting from design and workmanship must be of the highest character. Any defect not caused by misuse or neglect, which may develop within the first six months of service, to be made good by and at the expense of the contractor.

The works in which the construction of the contract is being carried on shall be open at all times during working hours to the inspection officer and his assistants. Every facility shall be given such inspectors for the proper execution of their work.

Copies of the original shop drawings of the generating set shall be furnished as part of the contract as soon as possible after said contract is awarded. Before final acceptance of generating set a complete set of first-class detail and assembly drawings on tracing cloth shall be supplied.

Turbine.

The turbine will be of the horizontal multi-stage type. It will be designed to run condensing with maximum practical efficiency at all loads. It will be of sufficient power to drive the generator for an extended time at the rated speed when said generator is carrying 1⅓ load.

The normal steam pressure under which the turbine will operate, and at this steam pressure the maximum steam consumption for various degrees of vacuum, is:

Steam K.W. pressure, normal.		Water consumption per K.W. hour, full load.			
		25 in. vac.	26 in. vac.	27 in. vac.	28 in. vac.
200	150	...	30½	28¾	27
300	200	...	28½	26¼	25½

These rates should be interpreted as dry saturated steam, steam pressure being measured at throttle and vacuum in exhaust casing. Superheating shall not be used in the test.

The turbine to run smoothly and furnish the required power for full load at any steam pressure within 20 per cent (above or below) of those given in the table, and exhausting to condenser at 25 inches of vacuum; to furnish power for 90 per cent of full load at steam pressure 20 per cent below normal, and for full load at any steam pressure between normal and 20 per cent above normal, when exhausting into the atmosphere. It will bear without injury the sudden throwing on or off of one and one-third times the rated load of the generator by making and breaking the generator's external circuit.

The steam outlets shall be so placed as to admit of piping from either side with equal facility. Blank flanges shall be furnished complete when required to cover alternative outlets, turbine to have exhaust outlet on right or left side as specified. All piping shall be firmly supported at points close to the turbine, so that the weight of same shall not effect the alignment of the parts involved.

Steam inlet valve shall be a combination throttle and emergency valve equipped with strainer intervening between valve and steam line. It will be connected to the emergency governor in such a way that it will automatically close if the speed of the turbine rises more than 15 per cent above normal. Flange drilling to conform with specifications of the Bureau of Steam Engineering.

The governor will be of the centrifugal type operating a series of valves.

Lagging to be fitted as extensively as practicable to turbine. It shall be done after a preliminary run of the turbine in order that any defects in casting or joints may be readily found. The arrangement for securing the lagging in place shall admit of its ready removal, repair, and replacement.

The speed variation will not exceed 2½ per cent when load is varied between full load to 20 per cent of full load gradually or in one step, turbine running with normal steam pressure and vacuum. A variation of not more than 3½ per cent will be allowed when full load is suddenly thrown on or off the generator with steam pressure constant between normal and 20 per cent above normal, a variation of not more than 3½ per cent when 90 per cent of full load is suddenly thrown on or off the generator with constant steam pressure at 20 per cent below normal, exhausting in both cases either into condenser or the atmosphere. No adjustment of the governor or throttle valve during the tests shall be necessary to insure proper performance under the above conditions.

The turbines will operate without the use of lubricants in the steam spaces. Forced lubrication will be used on all bearings. The bedplate will contain an oil reservoir from which oil will be drawn by a pump operating directly from the main shaft, and forced through the system. To be provided with a strainer which may be removed without interrupting the oil supply. The oil will be cooled by water which will pass through a coil around which the oil will circulate.

Mandrels, with collars, complete, will be furnished for renewing the white metal of all bearings so fitted.

The material and design of the turbine will be such as to safely withstand all strains induced by operation at the maximum steam pressure specified.

Generator.

To be of the direct current, multi-polar type, compound-wound long-shunt connection, designed to run at constant speed and to furnish a pressure of 125 volts at the terminals, at rated speed with load varying between no load and one and one-third times rated load.

The magnet frame will be circular in form; will have inwardly projecting pole pieces and will be divided in half horizontally, the two halves being secured with bolts to allow the upper half with its pole pieces and coils to be lifted to provide for inspection or removal of armature. The pole pieces will be bolted to the frame.

The magnet frame will be provided with two feet of ample size to insure a firm footing on the foundation.

Facilities for vertical adjustment of the frame will be provided.

The laminations for the armature will be accurately punched from the best quality, thoroughly annealed, electrical sheet steel, slots to be punched in the periphery of laminations to receive armature windings. The laminations will be insulated from each other and will be assembled on the spider or shaft and securely keyed. Space blocks will be inserted between laminations at certain intervals to provide ventilating ducts for cooling the core and windings.

Laminations will be set up under pressure and held securely by end flanges.

The commutator bars will be supported on the shell which will be keyed directly on the shaft so that no relative motion can take place between the windings and bars. The bars will be of hard drawn copper finished accurately to gauge. The insulation between bars will be of carefully selected mica not less than .03 inch thick. The bars will line with the shaft and run true and will be securely held in place by means of clamping rings.

The brushes will be of carbon. Each brush will be separately removable and adjustable without interfering with any of the others. The point of contact on the commutator will not shift by the wearing away of the brush.

Brush holders to be staggered in order to even the wear over entire surface of commutator; the generator to be provided with some devices for shifting all the holders simultaneously. All insulating washers and bushings to be damp proof and unaffected by temperature up to 100 degrees C.

Finished armature to be true and balanced both electrically and mechanically, that it may run smoothly and without vibration. The shaft to be provided with suitable means to prevent oil from bearings working along to armature.

All copper wire to have a conductivity of not less than 98 per cent.

For sets of 100 K.W. and less the shunt and series field coils to be separately wound and separately mounted on the pole pieces. The shunt and series coils, respectively, of any one set to be identical in construction and dimensions and to be readily removable from the pole pieces. The shunt coils as well as the series coils are to be connected in series.

A headboard will be mounted on the generator containing the necessary terminals for main switchboard, equalizing connections, shunt and series field connections, and pilot lamp.

The field rheostat to be of fire-proof construction suitable for mounting on back of switchboard, to be provided with handle or wheel projecting through to front, either directly connected or by sprocket chain, handle to be marked indicating direction of rotation for raising and for lowering voltage of generator. The total range of adjustment to be from 10 per cent above to 20 per cent below rated voltage, the variation to be not more than one-half volt per step at both full load and half load.

Operation of Generator.

The compounding to be such that with turbine working within specified limits, field rheostats and brushes in a fixed position, and starting with normal voltage at no load or at full load, if the current be varied step by step from no load to full load or from full load to no load, and back again, the difference between maximum observed voltage and minimum observed voltage shall not exceed 2½ volts.

The compounding and heat run (full load and overload) of the generating sets must be made with identical brush positions.

The dielectric strength for resistance to rupture shall be determined by a continued application of alternating E.M.F. of 1500 volts for one minute. Test for dielectric strength shall be made with the completely assembled apparatus and not with the individual parts, and the voltage shall be applied between the electric circuits and surrounding conducting material.

With brushes in a fixed position there shall be no sparking when load is gradually increased or decreased between no load and full load; no detrimental sparking when load is varied up to one and one-third times rated load, no flashing when one and one-third load is removed or applied in one stage.

The jump in voltage must not exceed 15 per cent when full load is suddenly thrown on and off.

The temperature rise of this set, after running continuously under full rated load with air of auxiliary ventilation at room temperature for four hours must not exceed the following:

	Degrees C.
Armature, by thermometer	40
Commutator, by thermometer	45
Series field coils, thermometer	40
Shunt field coils, resistance method	40
Shunt rheostat, resistance method	75
Series shunt, thermometer	40

The rise in temperature to be referred to standard room temperature of 25 degrees C. Room temperature to be measured by a thermometer placed three feet from commutator end of the generator with its bulb in line with the center of shaft.

A system of air ducts for the ventilation of armature and commutator shall be provided. This system shall be connected to the ship's ventilating system. The amount of air per minute required for the various sized sets will not exceed the following:

Size K.W.	Cubic feet air per minute.
200	2000
300	3000

The generator to be capable of satisfactory operation for a period of two hours carrying one and one-third times its rated full load; also full load continuously in a room temperature of 30 degrees C, without auxiliary ventilating system, and no part shall heat to such a degree as to injure the insulation.

Generators of the same size and manufacture to be capable of operation in parallel, the division of the load to be within 20 per cent throughout the range. The magnetic leakage at full load shall be imperceptible at a horizontal distance of 15 feet, measurements to be taken with a horizontal force instrument.

STEAM-PIPING.

The dynamo room is supplied by a special steam pipe which usually is so connected that it can take steam direct from any boiler or from the auxiliary steam pipe, it passes into a steam separator from which branches lead to each of the generating-sets in the dynamo room. This separator is drained by a steam trap which sends the water back to the hot well in the main engine room.

The exhaust pipe from each set joins a common exhaust which connects with the auxiliary exhaust service of the ship. If the sets are located below the level of the ship's auxiliary exhaust pipe, a separator is placed in the common exhaust pipe before it goes up and joins the ship's auxiliary exhaust. This separator is drained by a small steam pump, which is automatically started and stopped by means of a float in the body of the separator, which float starts the pump when the separator is full and stops it when empty.

In the latest vessels a separate condenser is installed in the dynamo room for the generating sets.

SWITCHBOARDS.

Switchboards are divided into:

(*a*) Generator boards.
(*b*) Distribution boards.

The generator boards are provided with two sets of bus-bars, one set for the lighting system, and the other set for the power system. The design is such that any of the generators can be operated singly or in parallel on either system. Fig. 1 shows diagrammatically the generator board used on the U. S. S. "Vermont."

Current is supplied to the different appliances by means of distribution switchboards, which have two sets of bus-bars, one for lighting and one for power, and are connected directly to the corresponding bus-bars on the main generator board. Feeders run direct from these distribution boards, each feeder being provided with a fused switch. Distribution boards are sometimes located at various parts of the ship and sometimes made continuous with the main board.

On several of the first vessels using electric turret turning gears on the Ward-Leonard system of control, a separate generator was used for each turret. This required an additional set of bus-bars on the generator switch-

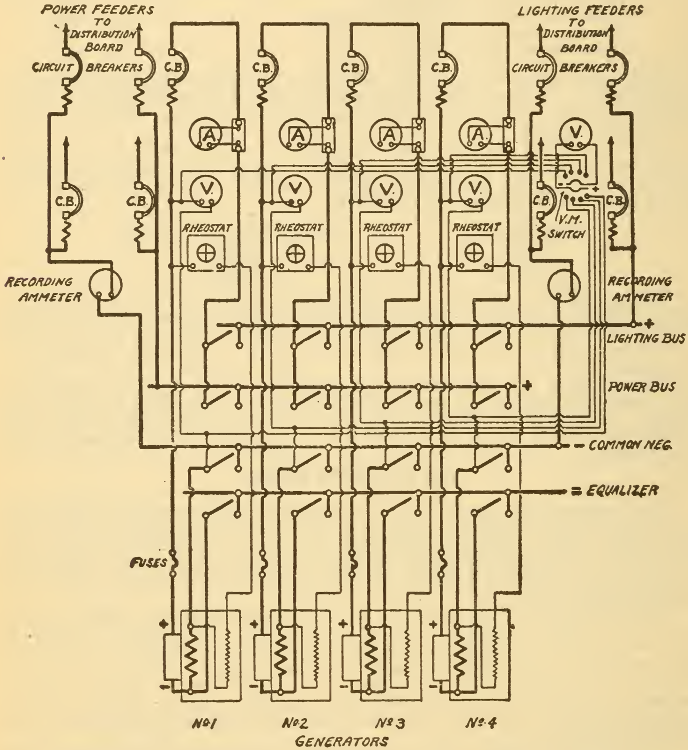


FIG. 1. Diagram of Vermont Generator Switchboard.

board for each turret. Fig. 2 shows the design as used on the U. S. S. "Illinois," except there are four more generators connected on exactly like the four shown. Each generator has a headboard carrying a double-pole circuit breaker, and clips for a series field short circuiting shunt used for turret turning. The diagram shows generators Nos. 1 and 2 operating in parallel on the power system, No. 3 alone on the light system, and No. 4 operating the after turret turning motors. It is to be noted that the three generators on the power and lighting systems have the right-hand blades of their triple pole field switches closed, giving self-excitation through the field rheostat, while the machine for turret turning has the middle blades closed, giving separate field excitation from the power bus-bars and through the field resistance attached to the controller in the turret.

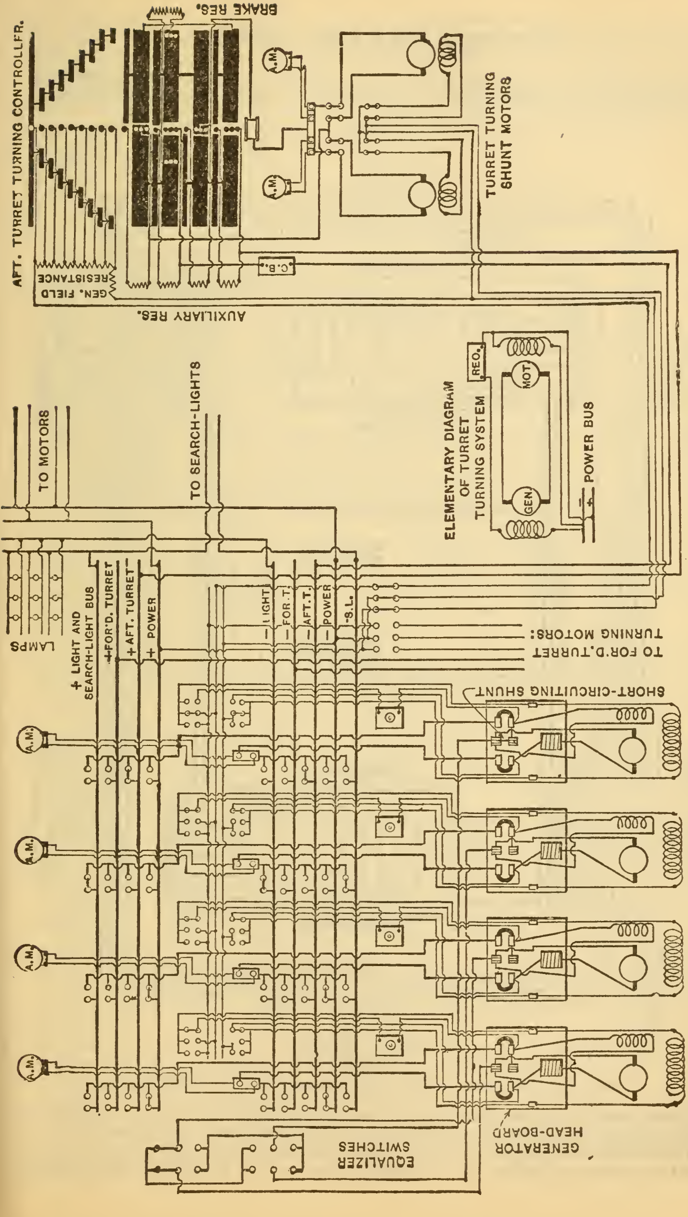


FIG. 2. Diagram of Generator Switchboard and Connections for Turret Turning System.

DOUBLE DYNAMO ROOMS.

Some of the latest ships have been designed with two complete generating plants each in a separate room, one forward and the other aft, so that any

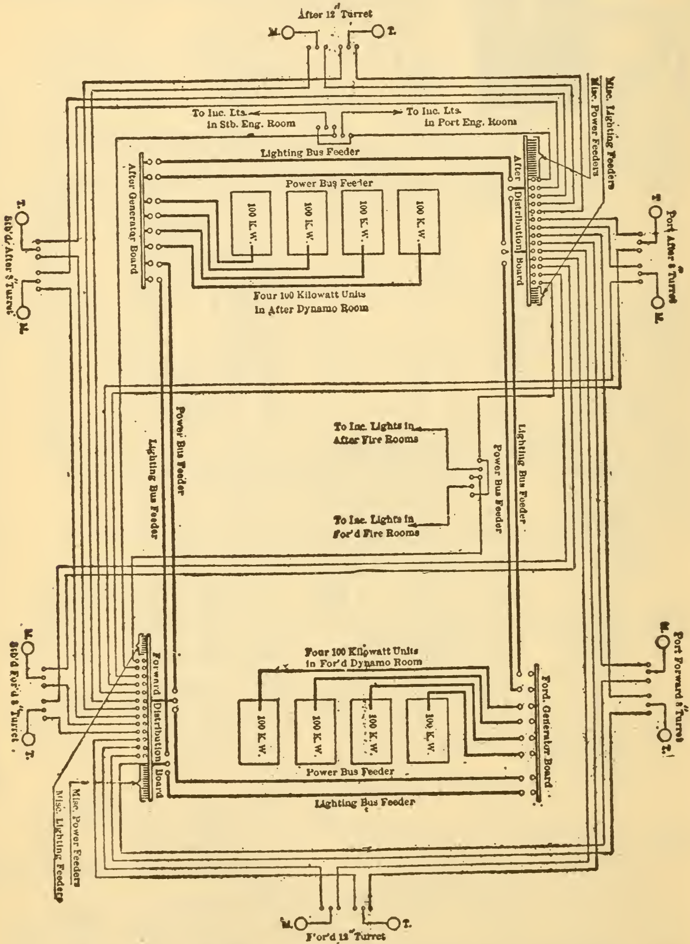


FIG. 3. Diagram of Double Dynamo Room Distribution.

accident disabling one plant will not affect the fighting ability of the ship. Each plant is of sufficient capacity to carry the entire working load.

The distribution is shown diagrammatically in Fig. 3. The generators in one room are controlled by the same board. The feeders to the various parts of the ship are supplied by the two distribution boards, one forward and one aft. Each of these distribution boards can take energy from either of the generator boards by means of transfer switches and interconnecting feeders.

The circuits supplying the lights in the engine and fire rooms, and the turret feeders are made double, one set running from each distribution board, and transfer switches provided at their ends; thus allowing these important parts to be supplied even if either dynamo room or either distribution board is destroyed.

WIRING.

Specifications.

The principal requirements of the Navy standard specifications for light and power conductors are:

All conductors to be of soft-annealed pure copper wire, and, unless otherwise specified, each wire to be thoroughly and evenly tinned.

All single strands must show a conductivity of not less than 98 per cent and the finished cable not less than 95 per cent of that of pure copper of the same number of circular mils.

All layers of pure Para rubber must contain at least 98 per cent pure Para rubber; must be concentric, of uniform thickness, elastic, tough, and free from flaws and holes.

All layers of vulcanized-rubber compound shall consist of the best grade of fine unrecovered Para rubber, mixed with sulphur and dry inorganic mineral matter only. The compound shall contain from 39 to 44 per cent, by weight, of fine Para rubber, and not more than 3 per cent, by weight, of sulphur. This sulphur shall be so combined with the Para rubber that not more than two-tenths of 1 per cent shall remain in the compound as free sulphur. The rubber shall be so compounded and vulcanized, that when test pieces taken from the wire (2 inches between jaws and $\frac{1}{2}$ inch wide when possible) are subjected to a tensile stress, they shall show a breaking strain of not less than 1,000 pounds per square inch, and shall stretch to at least three and one-half times their original length. The jaws will be separated at the rate of 3 inches per minute.

When test pieces, as described above, are subjected to a stress of 900 pounds per square inch for ten minutes, the compound shall be of such a character as to return to within 50 per cent in excess of its original length at the end of ten minutes after being released.

All layers of vulcanized rubber must be concentric, continuous, and free from flaws or holes; must have a smooth surface and circular section; and must be made to a diameter in the finished conductor as tabulated.

Measured dimensions "over vulcanized rubber" or "over tape" must come within $2\frac{1}{2}$ per cent of tabulated values, the departure in no case to exceed $\frac{1}{32}$ inch.

All layers of cotton tape must be thoroughly filled with a rubber-insulating compound, the tape to be of a width best adapted to the diameter of that part of the conductor which it is intended to bind. The tape must lap about one-half its width; must be of such thickness as to make dimensions conform to tabulated values, and be so worked on as to insure a smooth surface and circular section of that part of the finished conductor which is beneath it. The tape must not adhere to the rubber.

All exterior braid or braids must be closely woven, and all, except silk braid, must be thoroughly saturated with a black insulating waterproof compound which shall be neither injuriously affected by nor have injurious effect on the braid at a temperature of 95° C. (dry heat), or at any stage of the baking test, nor render the conductor less pliable. Wherever a diameter over outside braid is tabulated or specified, the outside surface must be sufficiently smooth to secure a neat working fit in a standard rubber gasket of that diameter for the purpose of making water-tight joints.

Measured dimensions "over braid" must come within 5 per cent of tabulated values, the departure in no case to exceed $\frac{1}{32}$ inch.

All wire and cable shall be subjected to a test for continuity and for insulating properties, the latter by measurement of insulation resistance and by high potential test on the entire length of the cables, either or both, as per the following table:

	Insulation resistance.	Test voltage, 30 minutes.
Lighting wire.		
Up to and including:		
500,000 c.m., single	1,000 megohms per knot	4,500
650,000 c.m., single	900 megohms per knot	4,500
800,000 c.m., single	800 megohms per knot	4,500
1,000,000 c.m., single	750 megohms per knot	4,500
All twin wire:		
Between conductors	1,000 megohms per knot	3,500
From conductors to ground	1,000 megohms per knot	3,500
Double conductor.		
Plain:		
Between conductors	1,000 megohms per 1,000 feet	2,500
Each conductor to ground	1,000 megohms per 1,000 feet	3,500
Diving:		
Between conductors	1,000 megohms per 1,000 feet	3,500
Each conductor to ground	1,000 megohms per 1,000 feet	3,500
Silk	No test	5,000
Bell wire	500 megohms per 1,000 feet	1,500
Bell cord	No test	5,000
Cable.		
Interior-communication cable:		
Between conductors	1,000 megohms per 1,000 feet	1,500
Each conductor to ground	1,000 megohms per 1,000 feet	3,500
Night-signal cable;		
Conductor for	1,000 megohms per 1,000 feet	3,500
Completed cable:		
Between conductors	1,000 megohms per 1,000 feet	3,500
Cable to ground	50 megohms per length	3,500

Tests for insulation resistance shall be made after immersion of wire (not less than three days after manufacture, the three days to be reckoned back from the end of the immersion period) in fresh water at a temperature of 22° C. for a period of twenty-four hours, the test to be made by the direct-deflection method at a potential of 500 volts after five minutes electrification.

High-potential tests shall then be made with the wire still immersed, the source of power supply to be a transformer of not less than 5 K.W. capacity. For double-conductor silk and bell cord the high-potential tests will be made with the dry wire freely suspended in the air.

Six-inch samples of wire, with carefully paraffined ends, shall be submerged in fresh water of a temperature of 22° C. for a period of twenty-four hours. The weight of the wire before and after submersion, deducting weight of copper and vulcanized rubber, will give the per cent of water absorbed by the braids. This shall not be more than 10 per cent.

A sample of suitable length (1 foot long for small wires) shall be exposed for several hours at a time, alternately, to a temperature of 95° C. (dry heat) and the temperature of the atmosphere, over a period of three days. The braid and insulation must then stand sharp bending to a radius of seven times the diameter without breaking or cracking. For twin conductor the minimum diameter will be used.

Unless otherwise called for, all wire supplies to be delivered in lengths of not less than 500 feet. To be delivered on reels of strong construction to admit of transportation to long distance, which reels on direct purchases will remain the property of the Government. The flanges of the reels to be at least 8 inches longer in diameter than the diameter through the coil. The loose end of the coil to be secured to prevent damage in transit.

To insure maximum flexibility, the pitch of the "standing" or "spiral lay" of all conductors so formed shall not exceed values tabulated:

Number of wires forming strand.	Length of pitch, expressed in diameters of individual wires.
7	30
19	60
37	90
61	120
91	150
127	180

When greater conducting area than that of 14 B. & S. G. is required, the conductor shall be stranded in a series of 7, 19, 37, 61, 91, 127, wires, or as may be specified, the strand consisting of one central wire, the remainder laid around it concentrically, each layer to be twisted in the opposite direction from the preceding; and all single wires forming the strand must be of the diameter given in the American wire-gauge table as adopted by the American Institute of Electrical Engineers, October, 1893.

Single Conductor.

TABLE OF STANDARD DIMENSIONS:

Approximate C. M.	Actual C. M.	Number of wires in strand.	Size of wire B. & S. G.	Diameter, inches.		Diameter in 32ds of an inch.		
				Over copper.	Over Para rubber.	Over vulcanized rubber.	Over tape.	Over braid.
4,000	4,107	1	14	.06408	.0953	7	9	11
9,000	9,016	7	19	.10767	.1389	10	12	14
11,000	11,368	7	18	.12090	.1522	10	12	14
15,000	14,336	7	17	.13578	.1670	10	12	14
18,000	18,081	7	16	.15225	.1837	11	13	15
20,000	22,799	7	15	.17121	.2025	12	14	16
30,000	30,856	19	18	.20150	.2328	12	14	16
40,000	38,912	19	17	.22630	.2576	13	15	17
50,000	49,077	19	16	.25410	.2854	14	16	18
60,000	60,088	37	18	.28210	.3134	15	17	19
75,000	75,776	37	17	.31682	.3481	16	18	20
100,000	99,064	61	18	.36270	.3940	18	20	22
125,000	124,928	61	17	.40734	.4386	19	21	23
150,000	157,563	61	16	.45738	.4885	20	22	24
200,000	198,677	61	15	.51363	.5449	22	24	26
250,000	250,527	61	14	.57672	.6080	24	26	28
300,000	296,387	91	15	.62777	.6590	26	28	30
375,000	373,737	91	14	.70488	.7361	29	31	33
400,000	413,639	127	15	.74191	.7732	30	32	34
500,000	521,589	127	14	.83304	.8643	34	36	38
650,000	657,606	127	13	.93548	.9667	38	40	42
800,000	829,310	127	12	1.05053	1.0818	42	44	46
1,000,000	1,045,718	127	11	1.17962	1.2109	46	48	50

All single-lighting conductors shall be insulated as follows:

First. A layer of pure Para rubber, not less than $\frac{1}{64}$ inch in thickness, rolled on. On the larger conductors this thickness must be increased, if necessary, to meet the requirements of paragraph 2 (*m*).

Second. A layer of vulcanized rubber.

Third. A layer of cotton tape.

Fourth. A close braid to be made of No. 20 two-ply cotton thread, braided with three ends, for all conductors under 60,000 circular mils, and of No. 16 three-ply cotton thread, braided with four ends, for all conductors of and above 60,000 circular mils. The outside diameter over the braid to be in conformity with that tabulated.

Twin Conductor.

TABLE OF STANDARD DIMENSIONS:

Approximate C. M.	Actual C. M.	Number of wires in strand.	Size of wire B. & S. G.	Diameter, inches.		Diameter in 32ds of an inch.						
				Over copper.	Over Para rubber.	Over vulcanized rubber.	Over tape.		Over 1st braid.		Over 2d braid.	
							One conductor.	Two conductors.	One conductor.	Two conductors.	One conductor.	Two conductors.
4,000	4,107	1	14	.06408	.092	5	6	12	8	14	10	15
9,000	9,016	7	19	.10767	.139	7	9	18	11	20	13	21
11,000	11,368	7	18	.12090	.156	8	10	20	12	22	14	23
15,000	14,336	7	17	.13578	.172	8	10	20	12	22	14	23
18,000	18,081	7	16	.15225	.190	9	11	22	13	24	15	25
20,000	22,799	7	15	.17121	.209	10	12	24	14	26	16	27
30,000	30,856	19	18	.20150	.243	11	13	26	15	28	17	29
40,000	38,912	19	17	.22630	.268	12	14	28	16	30	18	31
50,000	49,077	19	16	.25410	.298	13	15	30	17	32	19	33
60,000	60,088	37	18	.28210	.327	14	16	32	18	34	20	35

All twin lighting conductors shall consist of two conductors, each one of which shall be insulated as follows:

First. A layer of pure Para rubber, not less than $\frac{1}{64}$ of an inch in thickness, rolled on.

Second. A layer of vulcanized rubber.

Third. A layer of cotton tape.

Two such insulated conductors shall be laid together, the interstices being filled with jute, and covered with two layers of close braid.

Each braid to be made of No. 20 two-ply cotton thread, braided with three ends.

Methods of Installing Conductors.

Three methods of installing conductors are used.

1. Conduit; 2. Molding; and 3. Porcelain supports.

1. Conduit is the principal method, being used in almost all spaces below the protective deck, and wherever wiring is exposed to mechanical injury or the weather. Iron-armored conduit is used, except within 12 feet of the standard compass, where brass is used.

Conduit passing through water-tight bulkheads is made water-tight by means of stuffing-boxes and hemp-packing. Water-tightness is provided at the ends of conduit by a stuffing-box and a soft-rubber gasket, through which the conductor passes. Long lines of conduit passing through several water-tight compartments are provided with gland couplings at proper intervals, which divide the run into water-tight sections, thus preventing an injury in a flooded compartment from allowing the water to run through the conduit into another compartment. These gland couplings are also used where conduit passes vertically through decks.

2. Wood molding is used in living spaces but has been abandoned on the latest vessels. It consists of a backing piece fastened to the iron work of the ship, to which the molding proper is secured by screws and covered with a wooden capping-piece. Where leads installed in molding pass through water-tight bulkheads, a bulkhead stuffing-box is provided for water-tightness.

3. Porcelain supports are used in dynamo rooms and for the long feeders which are run in the wing passages where there is no danger of interference. Stuffing-tubes are used where the wires pass through bulkheads, the same as with molding.

Junction Boxes.

All conductors are branched by being run into standard junction boxes, which are usually provided with fuses. Where conduit is used these boxes are tapped, to have the conduit screwed into them; where molding or porcelain is used the boxes are provided with stuffing-tubes. The box covers are made water-tight with rubber gaskets; inside the fuses and connection strips are mounted on porcelain bases.

LIGHTING-SYSTEM.

Wiring.

The maximum drop allowed on any main is 3 per cent at the farthest lamp. Mains are required to be of the same size throughout, and to be of 1,000 circular mils per ampere of normal load.

Fixtures.

Most incandescent lamps are installed in air-tight glass globes of different shapes, depending upon position or location. Magazines are lighted by "Magazine Light Boxes," which are water-tight metal boxes set into the magazines through one of its walls, and provided with a water-tight door opening into the adjacent compartment, so that the interior of the box is accessible without entering the magazine. The sides of the boxes have glass windows, and each box is fitted with two incandescent lamps, each lamp having its own separate fused branch to the main, so that one lamp can be used as a spare.

"Switch Receptacles" containing a snap switch and a plug socket are provided for attaching portable lamps.

Lamps.

The principal requirements of the standard Navy specifications are:

Unit of Candle-Power. — The unit of candle-power shall be the candle as determined by the Bureau of Standards at Washington, D. C.

Photometric Measure. — The basis of comparison of all lamps shall be the same spherical candle-power. The normal candle-power referred to in these specifications shall be the mean horizontal candle-power of lamps having a mean spherical candle-power value of 82.5 per cent of the mean horizontal candle-power, which is the standard value for filaments of the oval anchored type.

For lamps having filaments giving a different ratio of mean spherical to mean horizontal candle-power, the horizontal candle-power measurement will be corrected by a reduction factor determined by the Bureau of Standards or other authority mutually agreed upon.

Test Quantity. — The test quantity shall consist of 10 per cent or more of any lot or package, and in no case be less than ten lamps.

From each package there will be selected at random the test quantity for the purpose of determining the mechanical and physical characteristics of the lamps, the individual limits of candle-power and watts per lamp, and finally the life and candle-power maintenance. These lamps will be known as the test lamps.

All lamps shall conform to the manufacturers' standard shapes and sizes of bulbs, and to the standard forms of filament, and the standard candle-power and watts per lamp.

All bulbs shall be uniform in size and shape, clear, clean, and free from flaws and blemishes.

All lamps, unless otherwise specified, shall be fitted with the standard Edison screw base, fitted with glass buttons, forming the insulation between contacts, and rendered impervious to moisture. The shells of the bases shall be of good quality brass, firmly and accurately fitted to the bulb with moisture-proof cement, and in length to conform to the National Electric Code of Fire Underwriters.

The lamp filament must be symmetrically disposed in the bulb and shall not droop excessively during the life of the lamp when the lamp is burned on test in the one horizontal position at a voltage corresponding to an initial specific consumption of 3.76 watts per mean spherical candle and without excessive vibration.

All filaments must be uniform and free from all imperfections, spots, and discolorations.

Leading in wires must be fused into the glass with the joints between copper and platinum wires bedded well within the glass; the wires to be straight, well separated, and securely soldered to the base and cap, without excess of solder and so threads of base are free from solder.

All lamps must have first-class vacuum, showing the characteristic glow of good vacuum when tested on an induction coil.

A printed label, showing manufacturer's name or trade-mark, voltage, and candle-power, must be placed on each lamp near base.

The lamps must be well made and free from all defects and imperfections, so as to satisfactorily meet the conditions of the lighting service.

If 10 per cent of the test quantity of lamps selected from any package show any physical defects incompatible with good workmanship, good service, or with any clause of these specifications, the entire lot from which these lamps were selected may be rejected without further tests when tests are made at the lamp factory. When the tests are made elsewhere, if the first test quantity prove unacceptable, 20 per cent more lamps will be selected from the package or lot of lamps, and should 10 per cent of this second lot of sample lamps be found to have any of the physical defects above mentioned, the entire lot from which these lamps were selected may be rejected without further test.

When tested at rated voltage the test lamps shall not exceed the limits given in schedule. If 10 per cent of test lamps from any package is found to fall beyond the limits stated, when tests are made at the lamp factory the entire lot from which these lamps were selected may be rejected without further test. When tests are made elsewhere, if the first test quantity prove unacceptable, 20 per cent more lamps will be selected from the package or lot of lamps, and should 10 per cent of these additional lamps be found to fall beyond the limits the entire package may be rejected without further test.

Life tests shall be made as follows: From each accepted package of lamps two sample lamps shall be selected which approximate most closely to the average of the *test quantity*. One of the two lamps thus selected will be subjected to a life test and designated as the *life test lamp*, the second or duplicate lamp being reserved to replace this *test lamp* in case of accidental breakage or damage during the life test. *The test lamps* shall be operated for candle-power performance at constant potential, average variations of voltage not to exceed one-fourth of 1 per cent either side. The voltage for each lamp shall be that corresponding to an initial specific consumption of 3.76 watts per mean spherical candle, or if tested upon a different basis, the results shall be corrected to a basis of 3.76 watts per mean spherical candle. If desired, the life tests may be made at such other watts per candle as may be mutually agreed upon.

Readings for candle-power and wattage shall be taken during life at the marked voltage of the lamps at approximately fifty hours, and at least every one hundred hours afterwards until the candle-power shall have fallen 20 per cent below the initial candle-power, or until the lamp breaks, if within that period. The number of hours the lamp burns until the candle-power has decreased to 80 per cent of its initial value, or until the lamp breaks, is known as the useful or effective life.

The average candle-power of lamps during life shall not be less than 91 per cent of their initial candle-power. In computing the results of test of a lot of lamps the average candle-power during life shall be taken as the arithmetical mean of the values for the individual lamps of the lot tested.

Lamps selected for the life test, which for any reason do not start on such test, shall be replaced by others.

Lamps which are accidentally broken but are burned out on test shall not be counted to diminish the average performance.

In case both test and duplicate lamps are broken or damaged before the life test is completed, the average performance of all lamps of the same class previously determined under the same contract shall be assigned to the package represented.

On all tests for determining average candle-power and life each package which will be affected by the results of test shall have at least one lamp on such test.

Accurate recording voltmeter records will be obtained during the test on lamps to show the average variation on the circuit.

When so tested the lamps shall average at least the values for useful life given in the tables on pages 1176 to 1178.

(*a*) Values for Oval Anchored Plain Standard Lighting Lamps.

Lamps of this type of voltages 105 and below, at 110, 120, and above, and also at 220, may have double the limits of variation in the initial limits specified for their respective classes.

Lamps and other types of filaments to give equivalent performances.

For lamps between 120 and 125 volts, the useful life values shall be 95 per cent of those given in the table, and for lamps between 126 and 130 volts the useful life values shall be 90 per cent of those given in the table.

(*b*) Values for Round Bulb, Tubular, and other Irregular Types of Lamps.

The individual limits for irregular types of lamps, such as round bulb and tubular lamps, shall be twice the individual limits given in the body of the preceding schedules for regular lamps of corresponding candle-power.

The individual limits for metallized filament and round bulbs primo types of lamps shall be 15 per cent above and 15 per cent below the mean candle-power rating, and 15 per cent above and 15 per cent below the mean total watt rating. The candle-power ratings referred to are the mean horizontal candle-power ratings of clear lamps without reflectors.

(*c*) Navy Special Lamps.

All lamps must conform in their general shape and form to drawing No. 7219–C, see Figs. 4 and 4a, and overall dimensions must not be exceeded.

Rejections and Penalties.

The failure of the lamps in any package to conform to the specifications as to mechanical and physical characteristics, or to initial limits, may cause the rejection of the entire package.

The failure of the lamps to give within 90 per cent of the values of useful life given in the tables may cause the cancellation of the contract.

Lamps which have not been used and are rejected under the terms of these specifications will be returned to the manufacturer at his expense, and no payment will be made therefor.

Prompt notice will be served upon the contractor of the test results on lamps that are rejected, or that fail to meet the specified requirements.

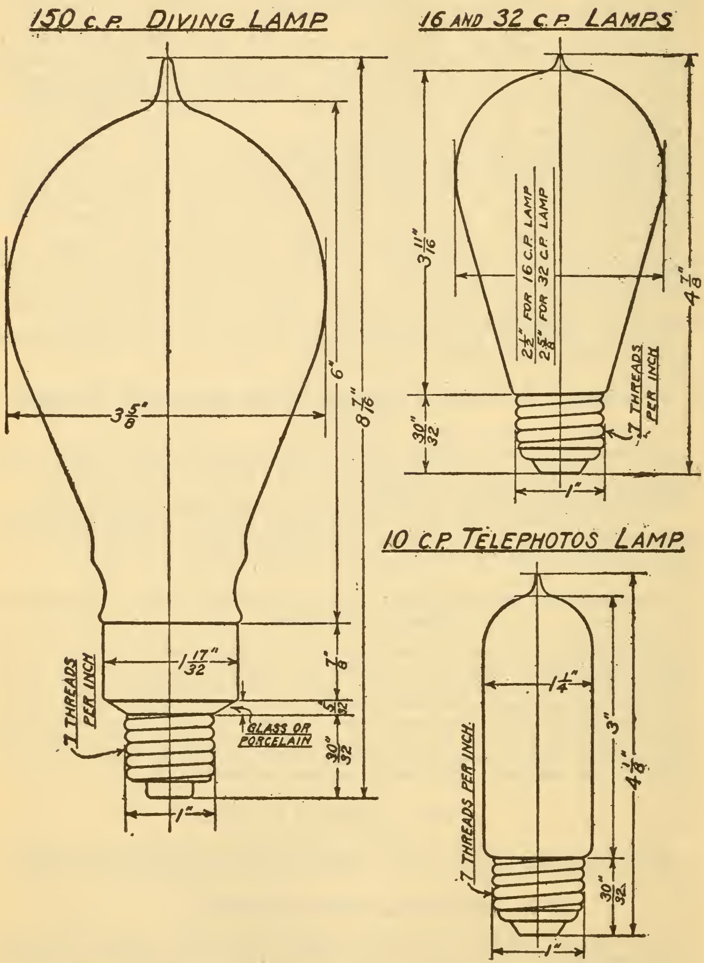


Fig. 4. Standard Incandescent Lamps as Covered by U. S. Navy Specifications.

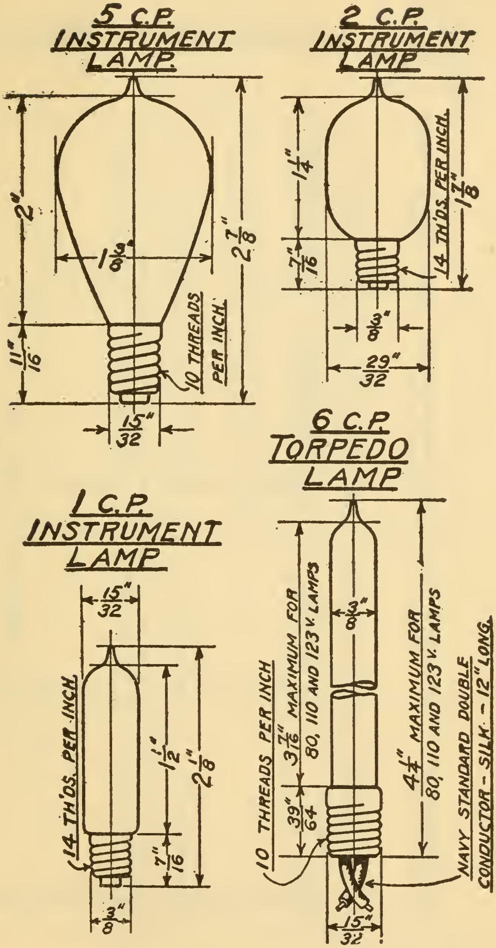


Fig. 4a. Standard Incandescent Lamps as Covered by U. S. Navy Specifications.

U. S. Navy Standards for 100-120 Volt Lamps.*

Rating.		Initial Limits.				Average Performance.
Rated candle-power, mean horizontal	Initial watts per mean horizontal candle	Individual candle-power limits	Mean candle-power limits	Individual watts per lamp limits	Mean watts per lamp limits	Useful or effective life in hours to 20 per cent drop in candle-power at 3.1 watts per candle
4	4.8	1c. p. above and 1c. p. below.	0.6 c. p. above and 0.6 c. p. below.	12 per cent above and 12 per cent below.	6 per cent above and 6 per cent below.	300
5	4.2	do	do	do	do	300
6	3.7	do	do	do	do	300
8	3.1	do	do	10 per cent above and 10 per cent below.	5 per cent above and 5 per cent below.	300
	3.6	do	do			330
10	3.1	do	do	do	do	330
	3.6	do	do	do	do	390
12½	3.1	do	do	do	do	390
	3.6	do	do	do	do	450
16	3.1	7½ per cent above and 7½ per cent below.	2½ per cent above and 2½ per cent below.	5.5 per cent above and 5.5 per cent below.	2½ per cent above and 2½ per cent below.	450
	3.5					420
20	3.05	do	do	do	do	420
	3.5	do	do	do	do	350
24	3.1	do	do	do	do	350
25	3.6	do	do	do	do	430
32	3.1	do	do	do	do	430
	3.6	do	do	do	do	400
50	3.6	do	do	do	do	300
75	3.6	do	do	do	do	. . .
100	3.6	do	do	do	do	. . .

* It is recommended that every effort be made to avoid ordering lamps of actual rated voltage of 105 and below, at 109, 110. and 111, 120 and above, and from 218 to 222, inclusive.

U. S. Navy Standards for 200-250 Volts.

Rating.		Initial Limits.				Average Performance.
Rated candle-power, mean horizontal	Initial watts per mean horizontal candle	Individual candle-power limits	Mean candle-power limits	Individual watts per lamp limits	Mean watts per lamp limits	Useful or effective life in hours to 20 per cent drop in candle-power at 3.1 watts per candle
8	4.4 4.4	2 c. p. above and 2 c. p. below.	1 c. p. above and 1 c. p. below.	15 per cent above and 15 per cent below.	7½ per cent above and 7½ per cent below.	120
10	4.25	. do	. do	. do	. do	130
16	3.8	15 per cent above and 15 per cent below.	7½ per cent above and 7½ per cent below.	12 per cent above and 12 per cent below	6 per cent above and 6 per cent below.	160
20	3.8	. do	. do	. do	. do	160
24	3.8	. do	. do	. do	. do	150
32	3.8	. do	. do	. do	. do	150
50	3.8	. do	. do	. do	. do	120

Values for Navy Special Lamps.

Description of Lamp.		Rating.		Initial Limits.		Average Performance.
Class	Type of filament	Rated candle-power, mean horizontal	Initial total watts	Individual candle-power limits	Individual watts limits	Useful or effective life in hours to 20 per cent drop in candle-power at 3.1 w. p. c.
Torpedo.						
6 c. p., 80 volts	Loop	6	30	33$\frac{1}{3}$ per cent above and 33$\frac{1}{3}$ per cent below.	25 per cent above and 25 per cent below.	1
6 c. p., 110 volts	do	6	30	do	do	1
6 c. p., 123 volts	do	6	30	do	do	1
Telephotos.						
10 c. p., 80 volts clear	Oval	10	36	25 per cent above and 25 per cent below.	17 per cent above and 17 per cent below.	160
10 c. p., 110 volts clear	do	10	36	do	do	160
10 c. p., 123 volts clear	do	10	36	do	do	160
Regular Navy Instrument.						
5 c. p., 80 volts	2 coil spiral.	5	19.5	30 per cent above and 30 per cent below.	25 per cent above and 25 per cent below.	150
5 c. p., 110 volts	do	5	19.5	20 per cent below and above.	15 per cent below and above.	100
5 c. p., 123 volts	do	5	19.5	25 per cent below and above.	20 per cent below and above.	70
Regular.						
16 c. p., 80 volts	Oval	16	56	25 per cent above and 25 per cent below.	17 per cent above and 17 per cent below.	450
32 c. p., 80 volts	do	32	115	do	do	300
32 c. p., 110 volts	do	32	115	do	do	300
32 c. p., 123 volts	do	32	115	do	do	300
Diving.						
100 c. p., 80 volts	Double loop.	100	250	30 per cent above and 30 per cent below.	25 per cent above and 25 per cent below.	...
100 c. p., 110 volts	do	100	250	do	do	...
100 c. p., 123 volts	do	100	250	do	do	...

Diving-Lanterns.

Diving-lanterns consist of a glass cylinder closed at each end with a metal cap, having the joint between the glass and metal packed with a soft-rubber gasket. On the inside of one of the caps is provided a standard marine lamp-socket for 150 candle-power incandescent lamp, to which is connected 100 feet of twin conductor cable, at the other end of which is connected a double pole plug for a standard marine receptacle.

When first submerged a considerable amount of moisture is deposited in the inside, which is drawn out through a small hole made water-tight by a screw with a rubber gasket.

Searchlights.

The requirements of the standard Navy specifications are:

It shall, in general, consist of a fixed pedestal or base, surmounted by a turntable carrying a drum. The base shall contain the turning mechanism and the electric connections, and be so arranged that it can be bolted securely to a deck or platform.

The turntable to be so designed that it can be revolved in a horizontal plane freely and indefinitely in either direction.

The drum to be trunnioned on two arms bolted to the turntable, so as to have a free movement in a vertical plane, and to contain the lamp and reflecting mirror. The drum to be rotated on its trunnions. The axis of the drum to be capable of a movement of not less than 70° above and 30° below the horizontal.

The drum to be thoroughly ventilated and well-balanced; to be fitted with peep sights for observing the arc in two planes, and with hand holes to give access to the lamp. It must be so designed that a parabolic mirror can be used, and means for balancing it must be provided.

The mirror to be made of glass of the best quality, free from flaws and holes, and having its surface ground to exact dimensions, perfectly smooth and highly polished. Its back to be silvered in the most durable manner; the silvering to be unaffected by heat. To be mounted in a separate metal frame lined with a non-conducting material, in such a manner as to allow for expansion due to heat and to prevent injury to it from concussion.

The lamp to be of the horizontal carbon type, and designed for both hand and automatic feed. The feeding of the carbons must be effected by a positive mechanical action, and not by spring or gravitation. It must burn quietly and steadily on a 125-volt circuit in series with a regulating rheostat, and shall be capable of burning for about six hours without renewing the carbons.

The front of the drum to be provided with a glass door composed of strips of clear plate glass. The door to be so arranged that it can be put in place on the drum easily and quickly.

Electrically Controlled Projector.

To be in all respects similar to the hand controlled, with the addition of two shunt motors, each with a train of gears; one motor for giving the vertical and the other the horizontal movement of the projector. The motors and gears to be contained in the fixed base, and to be well protected from moisture and mechanical injury. A means to be provided for quickly throwing out or in the motor gears, so that the projector can be operated either by hand or by motor, as desired.

The motors to be operated by means of a compact, light, and water-tight controller, which can be located in any desired position away from the projector. The design of the controller to be such that the movement of a single handle or lever, in the direction it is wished to cause the beam of light to move, will cause the current to flow through the proper motor in the proper direction to produce such movement. The rapidity of movement of the projector to be governed by the extent of the throw of the handle or lever. A suitable device to be included whereby the movement of the projector can be instantly arrested when so desired.

All projectors to be finished in a dead-black color throughout, excepting the working-parts, which shall be bright.

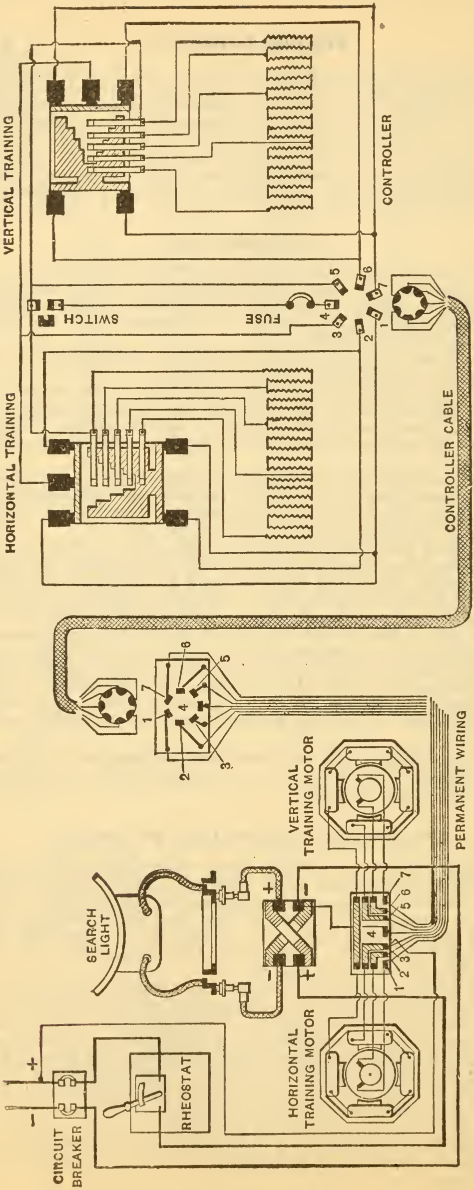


FIG. 5. Diagram of Connections for Electrically Controlled Searchlight.

The lamps to be designed to produce the best results when taking current as follows: 18-inch, 30 to 35 amperes; 24-inch, 40 to 50 amperes; 30-inch, 70 to 80 amperes.

The 18-inch projector shall project a beam of light of sufficient density to render plainly discernible, on a clear, dark night, a light-colored object 10 by 20 feet in size, at a distance of not less than 4,000 yards; the 24-inch projector, at a distance of not less than 5,000 yards; and the 30-inch projector, at a distance of not less than 6,000 yards.

The connections for the electrically controlled projectors as manufactured by the General Electric Company are shown in the diagram, Fig. 5. The fields of the two training motors are in series with each other and connected across the 125-volt circuit. Both horizontal and vertical training can be simultaneously produced. The controller-handle when released, is brought to the off position by springs and short circuits, both motor armatures thus stopping all movement.

The horizontal training motor drives through a worm gear, and the vertical motor through a revolving nut on a vertical screw shaft: all gearing can be easily thrown out for quick hand control.

The highest speeds are 360° in 30 seconds horizontally, and 100° in 60 seconds vertically. The motors may also be operated at four lower speeds.

The lamp has a striking magnet in series with the arc and feeding magnet in shunt with the arc. When the arc becomes too long, sufficient current is forced through the shunt feeding magnet to cause it to make its armature vibrate back and forth, and thus move the carbons together through a ratchet which turns the feed screws. The point at which the magnet will begin to feed is adjustable by means of a spring attached to armature. The feed screws are so proportioned that the positive and negative carbons are each fed together at the same rate that they are consumed, thus keeping the arc always in the focus of the mirror. Sight holes are provided through which the arc may be watched. A permanent magnet, fastened to the inside of the projector and surrounding the arc on all sides but the top, causes the arc to burn steadily near the upper edge of the carbons and in focus with the mirror.

The rheostat is located near the switchboard, and after being once set for proper working does not need to be again changed. Double-pole circuit breakers are used at the switchboards for switches.

SIGNAL LIGHTS.

Ardois Signals.

The Ardois signals consist of four double lanterns, each containing a red and a white light, which are hung from the top of the mast, one under the other and several feet apart. By means of a special controller any number of lanterns may have either their red or white lamps lighted, thus producing combinations by which any code can be signaled. The lamps used are clear, and the color is produced by having the upper lens which forms the body of the lantern colored red; the lower lens is clear.

The controller consists of eight semi-circular plates, with pieces of hard rubber set in the inner edges where needed, and a rotating center stud with eight plunger contacts rubbing on the edges of the plates. By suitably placing the pieces of hard rubber for any given position of the contacts, any desired combination of lights can be produced.

The operation consists in moving the arm carrying the contacts to the position desired (as shown by a pointer on an indicating dial) and closing the operating switch, when the proper lamps will light.

A later design is provided with a typewriter keyboard, the depression of any key making the proper contacts to light the lamps giving the combination corresponding to the character on the key.

Truck Lights.

The truck lights are lanterns of construction similar to the Ardois lanterns, mounted, one on the top of both the fore and main masts. By means of a special controller the red or white light in either lantern can be lighted.

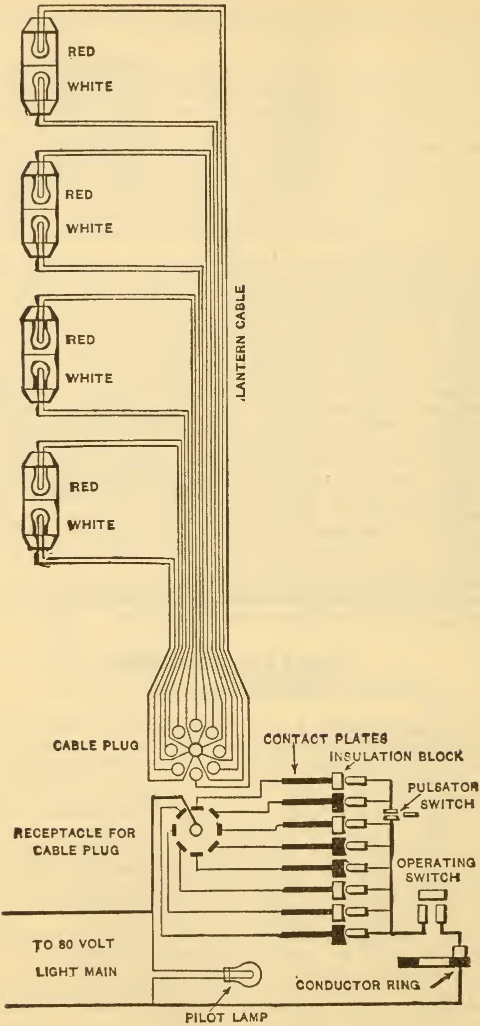


FIG. 6. Diagram of Ardois Signal Set.

POWER SYSTEM.

Motors are kept entirely separate from lights by the use of different bus-bars on the generator switchboard and distribution boards. Each motor or group of motors is supplied by its own feeder running from the distribution board, where it has its own fused switch. A maximum drop of 5 per cent is allowed.

Principal Requirements of Specifications for Motors.

Motors to be wound for 120 volts, direct current, for both armature and field windings, unless otherwise specified, and to be either series, shunt or compound wound, according to work they are to perform.

In sizes above 4 horse-power, motors to be multipolar; 4 horse-power or below may be bipolar. Motors to be as compact and light as possible, consistent with strength and efficiency. The method of running wires to motors to be in all cases by tapping conduit directly into the motor frames or into connection boxes attached to frames, as may be specified in each individual case; connection boxes for enclosed motors to be water-tight.

Enclosed motors should be provided with openings of sufficient size and number to give easy access to brush rigging, commutator, and field coils; such openings to be provided with covers and fastenings of approved design. The contact surfaces between these covers and motor frame should be flat machined surfaces, provided with rubber gaskets. Rubber gaskets for all water-tight work to be in accordance with the Navy standard specifications for the same as issued by the Bureau of Supplies and Accounts. All enclosed motors to be provided with drain plugs or cocks which will thoroughly drain out any water that may enter the motor casing.

The armature shaft to be of steel and strong enough to resist appreciable bending under any condition of overload, to have sufficient bearing surface and to be efficiently lubricated by grease or self-oiling bearings, or sight-feed oil cups, as occasion may require. Oil cups to be of size to afford lubrication for at least eight hours. A satisfactory arrangement to be made to prevent oil from running along the shaft or being spilled. Visual oil gauges to be provided for determining the amount of oil in pocket and drains for drawing oil prior to renewal.

To prevent deterioration from rust and corrosion, bolts for end brackets, all bolts and pins one-half inch diameter or less not in the magnetic circuit and such nuts and other special fittings as the Bureau may direct, will be of noncorrosive metal, rolled bronze or its equivalent.

All electrical connections to be designed with special reference to the prevention of their becoming loose from vibration or shock. All connections liable to become loose by vibration are to be provided with approved efficient locking devices.

All connecting pieces and other current-carrying parts to be so proportioned that no undue heating will occur when they are worked under the severest possible conditions.

All the field poles to be equally energized. In compound motors, series and shunt windings to be separate. The windings of armature and field to be well protected from mechanical injury, and to be painted with water-excluding material not soluble in oil or grease. No insulating substances to be used that can be injured by a temperature of 100 degrees C.

The armature to be of the ironclad type, built up of thin laminated disks of soft iron or steel of the very best quality, having the spaces between the teeth punched out of each separate disk and not milled after assembly.

The disks to be properly insulated from each other. The coils to be preferably of the removable type, and to be retained in slots of the armature body by maple wedges running full length of armature, or other approved method. No more than three band wires under poles will be accepted. Band wires must be of nonmagnetic material. The armature to be electrically and mechanically balanced. The winding at pulley end to be protected from oil in an approved manner. The commutator segments to be of pure copper, hard-drawn or drop-forged and tempered. The segments to be of ample depth and insulated from each other and the shell by pure mica of such quality as to secure even wear with the copper.

Brushes to be of carbon; current density in brushes must always be given and should be in accordance with the best practice. Special attention must be given to the selection of brushes, that their material may be homogeneous and the quality such as to give perfect commutation without cutting, scratching, or smearing the commutator. Brush holders to be readily accessible for adjustment and renewal of brushes and springs; to be entirely of noncorrosive metal and of the sliding shunt-socket type, in which the brush slides in the holder and is provided with a flexible connection between brush and holder. The springs are to be phosphor-bronze and shall not be depended on to carry current. Brush holders on all motors to be adjustable for tension, and on motors of five-horse-power and above to be adjustable for tension *without* tools, and so constructed as to permit of proper staggering of brushes. Brush holders for nonreversible motors of five-horse-power and above to be simultaneously adjustable for position, Proper position of rocker arm to be plainly marked. This position for reversible motors to give same speed in either direction.

Tests.

Contractors are required to afford facilities for inspection of apparatus during manufacture, if required.

Individual motors or small lots will be tested at the point of delivery, but all large lots of materials to be shipped to distant points will be tested at the works of the manufacturer. The contractor will provide all facilities, and have all the required tests made in the presence of an authorized inspector.

The contractor will present a certified record of such tests with the delivery. The tests to cover the following points:

(*a*) **Adjustment and Fit of Parts.** — The inspector to see that the materials and workmanship of all parts of the machine are of the best quality and satisfactory in every respect.

(*b*) **Mechanical Strength.** — The base, bearings, shaft armature, field magnets, and other main parts should not spring with any reasonable force that may be applied to them. The strength to resist strains due to centrifugal force to be tested by running armature without load for 30 minutes at double its rated speed for shunt motors and four times full load speed for series motors.

(*c*) **Balance.** — The perfection of balance of the armature to be tested by running the motor at its normal speed, at which speed the motor must not show the slightest vibration.

(*d*) **Noise.** — The motor to run at its full-rated speed and load without noise.

(*e*) **Sparking.** — Open motors to run without sparking from no load to full load without shifting the brushes and under all conditions of full and weak field when field regulation is used. Enclosed motors to 25 per cent overload.

(*f*) **Variation of Speed.** — For shunt-wound motors the variation in speed from no load to full load shall not be more than 12 per cent in motors of less than five-horse-power and not more than 9 per cent in motors of five-horse-power and above. Series and compound wound motors to make at rated outputs their rated speeds. The motor should be designed to obtain its rated speed when hot, with atmospheric temperature of approximately 25 degrees C., and the speed actually obtained on test at the end of the heat run must be within 4 per cent of the rated. The variation in speed due to heating shall not exceed 10 per cent.

(*g*) **Dielectric Strength.** — The test for dielectric strength to be made with a pressure of 1,500 volts alternating E.M.F. for 60 seconds, tested with a generator or transformer of at least 5-kilowatt capacity. The insulation resistance between windings and frame to be at least one megohm measured with 500 volts direct current.

(*h*) **Heating.** — The rise of temperature of the field windings above the surrounding air is to be measured by the resistance method according to the rules and coefficients adopted by the American Institute of Electrical Engineers, appended. The rise of temperature of all other parts to be by thermometer. The temperature of the room is to be read from thermometers, conditions of ventilation being normal.

The following are the maximum temperature rises allowed:

(i) Open-type motors designed for continuous work, eight hours' run with a rise of —
Commutator, 40 degrees C.
Field winding, 40 degrees C.
All other parts, 35 degrees C.

(ii) Enclosed motors designed for continuous work, eight hours' run with a rise of —
Commutator, 50 degrees C.
Field winding, 50 degrees C.
All other parts, 45 degrees C.

(iii) Intermittent-running motors will have heating limit and length of heat-run separately specified for each case.

The temperature rise of bearings shall in no case exceed 35 degrees C.

(*i*) **Efficiency.** — Motors must have the highest commercial efficiency for their size and speed. Each contractor must state weight and efficiency of motors at one-quarter, one-half, three-quarters, and full load. Preference will be given to lightest weight and best efficiency consistent with good design and the specific requirements. When thorough reliability and freedom from danger of breakdown are the prime requisites, as for turret-turning motors, boat-crane motors, etc., the maximum efficiency will not be insisted on.

(*k*) **Lubrication.** — The inspector will see that oil cups and wells of the specified capacity are provided and that all the necessary provisions are made for the supply and drainage of oil without injury to the electrical parts.

Electric brakes, solenoids, etc., to stand the same heat and insulation test as the apparatus to which they are attached. All spare parts to be subjected to the same tests as originals.

Most intermittent running motors, such as boat crane, deck winch, turret turning, etc., have the following heat tests:

Each motor shall be tested at the works of the maker by running for a continuous period of one hour at 120 volts at its rated output and speed, without increasing the temperature of the series field windings more than 70 degrees C., the shunt field windings 50 degrees C., the commutator 65 degrees C., the armature or any other part 60 degrees C. above the surrounding air.

Principal Requirements for Controlling Panels.

Controlling panels for installation in locations not exposed to the action of water outside of ammunition passages, handling rooms, etc., where powder is handled, may be of the nonflame-proof type, in accordance with the following specifications:

The panel to consist of a suitable insulating slate base with black polish finish, carrying a double pole main-line knife switch with enclosed indicating fuses, a starting arm with automatic no-voltage release and overload circuit breaker and the necessary resistances mounted at the back. A double pole circuit breaker with independently operating arms may be substituted for the line switch if desired. On panels where speed control by field resistance is required, suitable rheostat connections are to be provided, giving ample number of steps to secure smooth control and accurate adjustment, and must be a separate multipoint switch so arranged that the motor cannot be started on weak field. On panels where speed control by armature resistance is required, the starting arm must be so constructed that it will stay only on the contacts designed for continuous running.

For motors requiring more than 60 amperes of current, the starting arm must not be relied upon to carry the current in the running position. The starting resistance must not be left in series with the field on the running position; connections to be such that there shall be no disruptive discharge of the field on opening the circuit, either by opening the main-line switch, or by forcing the starting arm to the off position, and provision to be made to prevent arcing on the initial starting contact. Panel to be so connected that it shall be impossible to have full voltage on the field with the starting arm in the off position. Care should be taken in the design of the panel to see that there is no interference between operating parts, such as line switch, when opened, and starting arm. All magnet coils and all contact parts carrying currents must be renewable from the face of the panel without disturbing any of the rear connections. Panel to be mounted on a rigid box metal frame, with the top and bottom of solid sheet metal and the sides (if so desired) of perforated metal, which must extend the length and breadth of the slate and which must protect the connections and parts back of the panel; suitable lugs or extensions to be provided for supporting the frame. Hinged doors with composition lock and duplicate keys shall be provided over the face of the panel. No part on the face of the panel is to project beyond the edge of the panel.

The automatic no-voltage release must operate and either bring the starting arm to the off position or open the circuit breaker upon failure of voltage. The winding of the no-voltage release magnet must not be put in series with either the field winding or armature resistance. The automatic overload release must be of the nature of an ordinary spring operated circuit breaker, having the release mechanism operated by a positive hammer blow, delivered by a core or armature moved against the action of gravity, and must have its own independent contacts for opening the armature circuit; and it should open the circuit in case of overload under any condition, i.e., during ordinary running, during the act of starting the motor, or if the starting arm should become struck on any starting point and the current then switched on from the outside. For motors having a rated full load current of 50 amperes or less, the overload release may be of the interlocking type, in which case it must be so interconnected with the starting arm that it cannot be closed with the starting arm in any but the off position. For motors requiring more than 50 amperes, a single or double pole circuit breaker entirely separate from the starting arm must be used. An overload device which operates by short-circuiting or opening the circuit of the retaining magnet of the no-voltage release will under no conditions be accepted. The overload device is to be provided with renewable arcing contacts of carbon, to be adjustable and provided with a scale graduated from normal current to 100 per cent overload to facilitate adjustment to the desired number of amperes, and to be able to carry a current of 50 per cent in excess of the rated full-load motor current continuously without undue heating. The tripping device must be able to withstand severe shock without opening.

The insulating material used on the panel must be noncombustible, nonabsorbent, and not damageable by moisture or by heating to a temperature of 150 degrees C. The frame of the panel is to be insulated from the hull of the ship. All panels are to pass the same dielectric and insulation tests as the motors for which they are supplied.

All windings of magnet coils are to be run through an insulating varnish and the outside of the coils to be well varnished and taped. When continuously in circuit, the temperature rise of these coils must not be more than 40 degrees C. above surrounding atmosphere, measured by thermometer placed on the coil.

The main operating springs for the no-voltage release and the overload circuit breaker must be amply strong to prevent any sticking after the appliance has become worn or roughened. All flat springs are to be of phosphor-bronze and all helical springs of copper-plated steel. All contacts to be easily renewable from the face of the panel. The circuit is not to be opened on the rheostat contacts, and special arrangements to be made for opening the circuit and rupturing the arc independent of these contacts. All sliding brushes to be easily renewable and of the self-aligning, self-adjusting type, and able to ride over any projections standing one-sixteenth of an inch above the contact segments.

All operating parts to be strong and very substantial; thin sheet-metal stampings are not to be employed. All such operating parts which carry current to be copper or composition. Where the employment of oxidizable metal is necessary for magnetic purposes their surfaces shall be thoroughly protected against oxidation by copper-plating. Where used for other purposes to be very heavily coated with a nonvitreous enamel. The contact points to be of composition or copper, ample in size and well fitted on the surface and easily renewable. Panels should be as small and light as possible, consistent with other requirements.

All resistances and all insulation used on them and their connecting wires must be noncombustible, and the connecting wires must be capable of carrying their full current under all conditions of test and operation without becoming dangerously hot. All resistances to be of the unit type, so constructed and installed that they may be easily replaced and the whole rheostat readily removed from the casing. The method of mounting and insulating the resistances is to be such that the result of a burn-out would be practically the same as would occur with an entirely enclosed resistance, and no resistance is to be used until a sample has been submitted to the Bureau for test and approval. The capacity of all controlling panel resistances must be obtained without placing the coils in parallel with each other, unless each is capable of carrying full-line voltage. Starting resistances when cold must be capable of carrying 50 per cent overload in current for one minute, and 100 per cent overload for twenty seconds. Incandescent lamps or carbon shall not be used as resistance. Resistances must be mounted at the back of the panel upon the supporting frame, and not directly on the panel, for motors having a rated full load current over 50 amperes. For motors requiring 50 amperes or less, the resistance may be supported from the back of the panel by suitable brackets, if desired.

Water-tight, flame-proof panels will be used as directed in locations greatly exposed to moisture and where powder is handled, as ammunition passages, handling rooms, etc. They will, in general, consist of a cast metal, water-tight, flame-proof case containing the necessary resistances, connections, and operating parts, which must be controlled from without by means of rods or levers passing through approved stuffing boxes. The panels must contain within the casing at least the following parts: Resistances, circuit breaker or overload release, no-voltage release, reversing switch (when required), starting arm and contacts, and the necessary field contacts when necessary for variable speed motors. They will conform to the requirements for nonflame-proof panels as regards connections, capacity of resistance, construction of overload and no-voltage release, springs, contacts, etc., but such deviations from these requirements as may be absolutely necessary to simplify the construction of the panel and reduce its size and weight to a minimum will be considered.

The panel will be provided with suitable removable covers provided with clamping devices of approved construction, made water-tight by means of rubber gaskets, which will permit easy access to the interior. It must be strong and substantial in design, but of lightest weight and smallest dimensions consistent with other requirements. Suitable bosses for tapping conduit into casing to be supplied, the casing to be drilled and tapped after delivery. The casing is to be sufficiently water-tight to permit of immersion without leakage. Noncorrosive metal requirements will be strictly adhered to, and all operating levers passing through stuffing boxes will be of composition.

Turret-Turning Gear.

The following are the requirements of turret control:

First. Turrets to be able to be turned at a maximum rate of 100 degrees per minute, and at a minimum rate not exceeding one-fourth of a degree per minute, as large a number of speeds as possible (not less than 50) to be provided between the limits of one-fourth and 22 degrees per minute and a sufficient number of speeds between 22 and 100 degrees per minute to permit of smooth and easy acceleration. The total number of speeds to be not less than 70.

Second. Turret to be capable of acceleration at such rate that it can be started from rest and brought to its full speed of 100 degrees per minute in ten seconds of time, and while turning at its full speed of 100 degrees per minute to be able to be stopped in five seconds of time.

Third. At all speeds between and including one-fourth and 100 degrees the turret is to turn continuously throughout the arc of train on each controller position with practically no variation in speed due to increased load on the motors caused by allowable irregularities in track, gearing, etc.

Fourth. Turret to be able to be started and stopped ten consecutive times without turning through a total arc of train greater than five minutes.

There are four different systems in use at present:

1. Ward-Leonard System.
2. Rotary Compensator System.
3. Differential Gear System.
4. Mechanical Speed Gear.

1. The Ward-Leonard System was used on the first electrically operated turrets in the Navy. The actual connections and elementary diagram of the installation on the "Illinois" are shown in Fig. 2.

The motors are shunt wound, and have the fields constantly separately excited from the bus-bars of the ship's power system. A separate generator is required which cannot be used for any other purpose when used with the turret. The generator is also separately excited from the power bus-bars, but a variable rheostat, located in the turret, is connected in the shunt-field circuit. The brushes of the motor are directly connected to the brushes of the generator, and the generator is kept running at constant speed by its driving-engine. It is now evident that by varying the rheostat in the turret, the field excitation, and consequently the voltage produced by the generator, will be varied; and any variation in the voltage of the generator will produce a corresponding variation in the speed of the motor, which has a constant field from separate excitation. The direction of rotation of the motor is reversed by reversing the leads to the armature. The actual connections for the application of the above principles are shown in the main part of the diagram. Generator No. 4 is shown connected for operating the after-turret.

Closing the after-turret field switch and the center blades of the generator field switch separately excites the fields of the motors and generator from the power bus-bars. The regular field rheostat of the generator is entirely disconnected, and a rheostat located in the turret and operated by the turret-turning controller is used instead.

Closing the positive and negative single-pole switches on the after-current bus-bars connects the generator armature to the motor armatures, through a circuit breaker, the reversing contacts of the controller, and separate armature switches for each of the two motors, which are operated in parallel.

The controller has one shaft, at the top of which are located the connections for the generator field rheostat, so arranged that as the controller is turned either way from the off position the rheostat is gradually cut out; below are located the reversing contacts, which reverse the connections between the generator armature and the motor armatures; these contacts are so arranged that at the off position the motor armatures are entirely disconnected from the generator, and are short-circuited through a low resistance called the "Brake resistance." The effect of this brake resistance is to bring the turret to a quick stop when the controller is brought to the off position, as the motor armatures revolving in a separately excited field generate a large current, which passes through the braking resistance, and thus absorbs the kinetic energy of the turret, giving a quick and smooth stop. In parallel with each of the large main fingers of the reversing contacts is a small auxiliary finger and an auxiliary resistance connected to it. This auxiliary finger makes contact a little before and breaks it a little after the main finger, and thus reduces the sparking. The controller is also provided with a magnetic blow-out for reducing sparking at contacts.

When used on this system for operating a turret the generator has its series coil short-circuited by a very low resistance shunt, so that it has very little effect on the field excitation, but this resistance is so proportioned that enough of the total current generated by the generator will pass through the series coil to give a quick and positive start of the turret; because if the series coil is absolutely short-circuited, and only the separately excited shunt coil used, the time required for the field to build up is sufficient to make the starting of the turret very sluggish and irregular, and prevents very fine training from being obtained.

It is seen that the above-described arrangement requires a separate generator for each turret, and while operating a turret no power can be taken from the generator for any other purpose. The first ships to use electric turning gear had only two turrets, and two generators can easily be allowed for turret turning; but on the latest ships six turrets are used, and it is very undesirable to allow six generators for this purpose. To overcome this objection the Ward-Leonard method of control is obtained by means of a motor generator located at each turret, all of which take power directly from the main bus-bars of the dynamo room, thus materially reducing the required generator capacity. An elementary diagram of the arrangement is shown in Fig. 7. It will be noted by comparison with Fig. 2, that only two instead of five wires have to be run from the dynamo room to each turret.

The Ward-Leonard system will not give the large range and low speeds

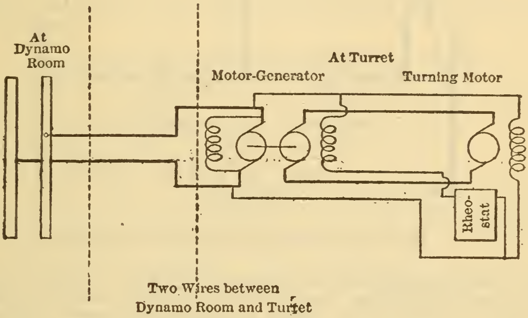


Fig. 7. Diagram of Motor Generator on Turret-Turning System.

now required by the Navy Department and therefore the other above-mentioned systems have been devised.

2. The Rotary Compensator System is shown in Fig. 8. A and B are the armatures of a motor generator balance set, called a Rotary Compensator Set. L is a large shunt motor geared directly to the turret. S is a small shunt motor the shaft of which carries a worm, W1, working in a worm wheel, W2, mounted on the shaft of L. This worm wheel is provided with a magnetic clutch D so that it can turn freely on the shaft of L, or be held to it. C is a contact in the controller which opens one side of the armature circuit of L. R is a field rheostat for A and B and is operated by the controller. With the connections as drawn in the diagram, B has a weak field and a low voltage, thus driving S at a low speed; S is driving L through the magnetic clutch and worm gear and thus turning the turret at a very low speed; C is open, so L turns freely, and does no work. As the controller is turned R is gradually inserted in the field of B, thus increasing the voltage and increasing the speed of S. When B has full field the magnetic clutch is opened and C is closed, thus transferring the load from S to L and permitting S to run free. At this time A has weak field and supplies a low voltage to L, and further movement of the controller brings the arm of R back to the first position, thus increasing the voltage of A and the speed of L, until A has full field and the turret is turned at full speed. At the period of transition when the load is shifted from S to L it is necessary that the ratio of the speeds of S and L shall be the same as the ratio of the worm gearing by which S drives L, so that the transfer will be made smoothly and without shock or change in speed of turret. In shutting down the above actions occur in reverse order. Reversing is accomplished by reversing the armature loads of the two motors, and in the off position the armature of L is short-circuited to produce a braking effect; these results are accomplished by controller contacts similar to those for Ward-Leonard System as per Fig. 2. This system is made by the General Electric Company.

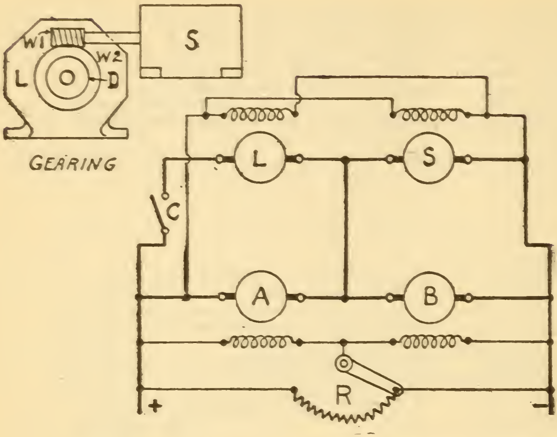


FIG. 8. Rotary Compensator Turret-Turning System.

3. The Differential Gear System is shown in Fig. 9. L and S are respectively large and small shunt motors running continuously on the supply main. They are both directly geared to a differential gear which is so proportioned that with L running at full speed and S at weak field the shaft A will stand still, but any change in their relative speeds will cause A to

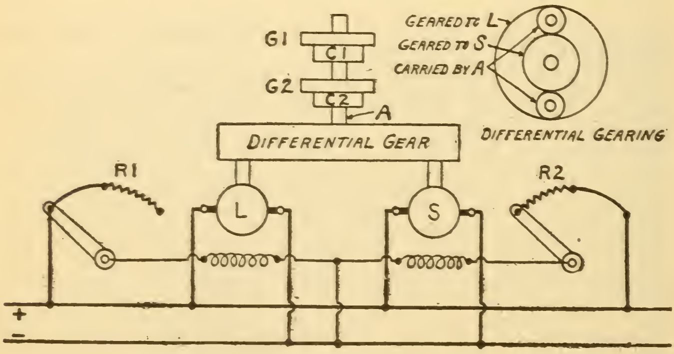


FIG. 9. Differential Gear Turret-Turning System.

rotate at a speed proportioned to the relative change. This change in relative speed is produced by the field rheostats R1 and R2 which are operated by the controller, and first decrease the speed of S by strengthening its field, and then increase the speed of L by weakening its field, thus giving the full speed range of the turret. The shaft A is geared to the turret through the gears G1 and G2, each of which is provided with a magnetic clutch C1 and C2. G2 is geared direct, and G1 through a reverse gear, thus accomplishing the reversing of the turret motion. The magnetic clutches are operated by contacts on the controllers. This system is made by The Cutler-Hammer Manufacturing Company.

4. The Mechanical Speed Gear System uses a continuously running, constant speed, shunt motor geared to the turret through the speed gear. The speed gear consists of a variable volume oil pump and an oil motor mounted in a common casing and provided with mechanical means for varying the volume of oil delivered by the pump per revolution and its direction of flow. The speed gear is made by the Waterbury Tool Company.

In all the above systems two sets of motors are usually provided and arranged so that by means of switches either set may be cut out and the turret operated by one set. Turrets carrying two 12-inch guns usually have two 25-horse-power main motors, and 8-inch turrets two 15-horse-power motors.

Loading and Training Gear for Guns.

Guns of 8-inch and over are elevated and rammed by power; smaller guns have hand gear.

Three kinds of elevating gears are in use:

1. Plain rheostat control with series motor.
2. Ward-Leonard control.
3. Mechanical speed changing gear with constant speed, shunt motor.

Rheostatic control with series motor as used in the first vessels does not give sufficiently close and even control. A 2½-horse-power, 300 r.p.m. motor with plain drum-reversing controller is used.

Ward-Leonard control as used is similar to that used for turret turning as shown in Fig. 7. The control obtained is quite satisfactory, but the complication is objectionable and there is not suitable space available in the turrets for the motor generators. Ten horse-power elevating motors and eight K.W. motor generators are used.

The latest vessels are using constant speed shunt motors and obtaining the control by means of mechanical speed gears as described above for turret turning.

Rammers consist of a telescopic tube worked through spur and chain-gearing by a 5 H.P., 775 r.p.m. series motor. A friction slip clutch is inserted in the gearing to prevent damage when the shell seats itself in the breech. Ordinary rheostatic control is used.

When ramming a shell but little power is required, as the shell slides along the breech, but as it is being forced to its seat at the end of the breech chamber a sudden rush of current of from two to three times the full-load current of the motor is produced.

AMMUNITION HOISTS.

Power ammunition hoists are of two kinds: first, those in which a car or cage is hoisted up and down by a line wound on a drum on the motor counter-shaft; and second, those in which the motor runs an endless chain provided with toes or buckets on which the ammunition is placed and conveyed up through a trunk.

Hoists for 12-inch and 13-inch Ammunition.

These hoists are of the first kind. The motor frame is provided with bearings for a counter-shaft, geared by a spur-gear and pinion to the armature shaft; on the counter-shaft is mounted a grooved drum for the hoisting-cable.

On the armature shaft is mounted a solenoid band-brake. The cores of the solenoid are weighted and attached to the brake-setting lever so that when free their weight is sufficient to hold the loaded car from falling; when the solenoids are energized the cores are drawn up and the brake released.

The controller is constructed so that on the off position the solenoids are not energized and the brake is set; but at all other points, both hoisting and lowering, the solenoids are energized and the brake released.

Shunt motors are used, and the control for hoisting is ordinary rheostatic; the resistance being put in series with the armature and gradually cut out, the field is always constantly excited as soon as the feeder-switch is closed. For lowering, the entire rheostat is thrown directly across the line, one armature lead connecting to one side of the line and the other lead gradually moved (as the motor is brought to full speed) from the condition of a short-circuited armature at the off position to direct connection to the other side of the line at the full on position; in all intermediate positions the armature is in shunt with a part of the rheostat. The object of this is to cause the armature to take current from the line and run as a motor when lowering a light load which will not overhaul, but to run as a generator and send current through the rheostat if the load is very heavy and overhauls the motor and gearing. In either case the speed will depend upon the amount of the rheostat that is in shunt across the armature. The off position of the controller short-circuits the armature, and since the fields are always excited, this gives a quick stop and also holds the load.

The 13-inch hoists of the U. S. S. "Kearsarge" and "Kentucky" use 20 H.P. motors running at 350 r.p.m., with a gearing ratio of 6.43 from armature to counter-shaft.

The load was, empty car 1,846 pounds, and full charge 1,628 pounds, or a total of 3,474 pounds.

The following average results were obtained when testing a hoisting full charge:

Hoisting-speed, feet per minute	180
Mechanical H.P. in load	18.96
Input of motor, E.H.P.	28.5
Total efficiency	66.6%

Motors were designed to be suspended under the turret, were entirely enclosed, and weighed 3,000 pounds complete with brake.

Hoists for 8-inch Ammunition.

Hoists for smaller ammunition are made and controlled in a manner similar to the above.

The 8-inch hoists used a 6 H.P., 375 r.p.m. shunt motor to hoist a total load of 910 pounds at 163 feet per minute.

Tests gave average results of —

Mechanical H.P. in load	4.5
Input of motor, E.H.P.	7.4
Total efficiency	60.8%

Endless Chain Ammunition Hoists.

These hoists run continuously, the ammunition being fed in as desired. The motor is geared to the chain sprockets by spur gearing, is shunt wound and is started and stopped by a controlling panel, which is provided with no-voltage and overload release, and a reversing-switch.

A solenoid brake is mounted on the armature shaft, and is set when the starting-arm is in the off position, but has its coils energized and is released when the arm makes the first contact in starting. At the full on position, part of the starting rheostat is in series with the brake, thus cutting down the current consumed by it. This does not affect the reliability of the brake, since the current required to hold up the cores is much less than that required to first start them, and at the start the full-line voltage is on the coils.

To lower ammunition the reversing-switch is thrown down, which reverses the connections to the motor armature, and puts in the armature circuit a safety switch. This safety switch is attached to the lever which operates the catch pawls in the hoist trunk. These pawls will allow ammunition to go up, but will catch and prevent it from going down, and are used to keep the ammunition from falling in case any part of the hoist should be shot away. When the pawl lever is thrown down it throws the pawls out of action, and allows ammunition to be lowered by reversing the motor; it also closes the safety switch which completes the armature circuit for the lowering position of the reversing-switch.

This style of hoist is used for all kinds of ammunition up to and including 7-inch. Packages are so made that they weigh about 100 pounds each. Motors from $2\frac{1}{2}$ to 3 H.P. output and about 400 r.p.m. are used. Height of

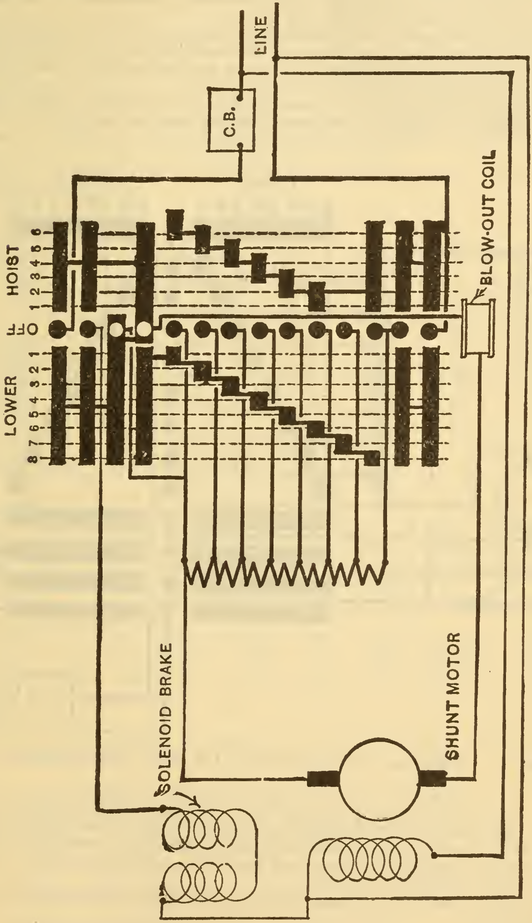


Fig. 10. Diagram of Connections for 13-inch Ammunition Hoist.

hoist varies from 10 to 40 feet, and about 12 packages per minute are hoisted. Mechanical efficiency from motor output to power in load varies from about 50% to 80%.

Ammunition conveyers, very similar to these hoists, are used to carry ammunition from some magazines to the foot of the hoist. The endless chain is horizontal, and no brake or safety switch is used.

BOAT CRANES.

For handling steam cutters and other boats a revolving crane having the general shape of a davit is used; it extends down to the protective deck, and has a steady bearing at each deck passed through, and the weight is carried by a roller thrust bearing. The operating machinery is carried on a circular platform fastened to the crane.

The standard specifications require the following control to be obtained:

The mechanical connections between the hoisting motor and its gearing and the electrical connections between motor and controller to be such that the following results are obtained:

I. No possible combination of manipulation of operating lever, opening of circuit breaker, or failure of current to allow any load to fall.

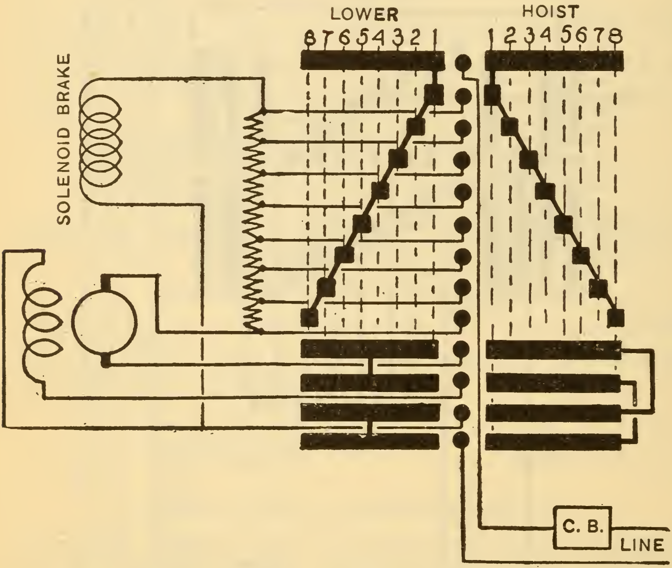


FIG. 11. Diagram of Connections for Boat Crane Motors.

II. The load to always stop and be held still immediately when the controlling or operating lever is brought to the off position during hoisting or lowering. The electric brake itself (in case of failure of mechanical brake) to be of sufficient power to stop and hold the maximum load at the off position or upon failure of current.

III. Maximum load not to lower while the controller operating lever is in any hoist position.

The control of the rotating motor must give the following results:

IV. Smooth starting and stopping must be obtained under all conditions of load and speed.

V. Crane must stop and be firmly held when the controller operating lever is brought to the off position.

VI. Swinging of the suspended load or rolling of the ship must not produce dangerous or excessive variations in the rotating speed.

Ordinarily two motions are provided, rotating and hoisting, and a separate motor is used for each; but sometimes a trolley is used so that the load can be moved radially; when used the trolley is operated from the hoisting motor, which is then provided with a change clutch in the gearing.

Plain series motors are used. The hoisting motor is usually geared to the drum by one pair of spurs and a worm, the worm wheel being fastened to the drum, and the pinion being on the armature shaft. At some convenient point in the gearing an automatic mechanical brake is inserted, which will only allow the load to lower when the motor is run by electric power in the lowering direction, and which absorbs the energy of the lowering load in friction. The design which at present has given the best results is that using friction disks and a follow-up screw similar to the brake used in the Weston triplex pulley block. A solenoid brake is also mounted on the armature shaft, which sets at the off position of the controller. The rotating motor is similar to the hoisting motor, but smaller. Cranes are required to rotate at the rate of one revolution per minute.

The sizes of motors used on the usual capacities of cranes on the latest vessels are as follows:

Capacity of Crane Pounds.	H.P. of Hoisting Motor.	H.P. of Rotating Motor.	Hoisting Speed, Feet per Minute.
33,000	50	30	25
17,000	30	20	25
10,000	30	20	40
5,600	20	15	40

Tests on typical cranes gave the following results:

No.	Load, Lbs.	Speed, Ft. per Min.	H.P. in Load.	Motor Input, E.H.P.	Efficiencies. Total.	Efficiencies. Motor.	Efficiencies. Gearing.	Weight Rotated, Lbs.	Rotating Speed, R.P.M.	Motor Input, E.H.P.
1	19,000	29.7	17.1	29.7	57.5	86.	66.8	82,000	1.46	15.4
2	18,000	24.1	13.1	27.9	47.0	82.	57.3	72,000	.89	14.8
3	10,300	31.0	9.67	19.3	50.1	82.	61.1	46,000	1.85	9.9

All of the above cranes hoisted the load by a two-part tackle, and the details of the gears were:

No. 1. Pinion 22 teeth, gear 70 teeth, 1½″ pitch, 4″ face.
Worm triple threaded, 32″ pitch, 9.6″ lead, 12⅓″ P.D.
Worm wheel 42 teeth, drum dia. 29¼″.
350 r.p.m. of motor = 30 ft. per min. hoist.

No. 2. Pinion 19 teeth, gear 87 teeth, 1½″ pitch, 4″ face.
Worm triple threaded, 3″ pitch, 9″ lead, 12½ P.D.
Worm wheel 33 teeth, drum dia. 24″.
400 r.p.m. of motor = 25 ft. per min. hoist.
This crane had also a pair of miter gears of 18 teeth, 2⅝″ pitch, 6″ face.

No. 3. Pinion 29 teeth, gear 63 teeth, 1½″ pitch, 4″ face.
Worm triple threaded, 2″ pitch, 6″ lead, 9″ P.D.
Worm wheel 57 teeth, drum dia. 26¼″.
360 r.p.m. of motor = 30 ft. per min. hoist.

DECK WINCHES.

The usual design of electric deck winch consists of a series motor geared by spur gearing to a shaft carrying a gypsy head, all being mounted on a suitable bed-plate. Part of the winches on a vessel usually have change gears giving two speeds, which are operated by clutches. The usual capacity is 2,200 pounds' pull at a speed of 300 feet per minute, and on winches having change gears the low speed is 13,000 pounds at 50 feet per minute. A friction band brake operated by a foot lever is used. Rheostatic control is used, with a reversible controller. Motor and controller are both entirely water-tight, and will stand a stream of water from the fire hose. The rheostats are mounted in the bed-plate, or else in a water-tight iron box.

The usual method of operation is to run the winch continuously at full speed in one direction, and then control the hoisting and lowering of the load by taking a suitable number of turns of the hoisting rope around the revolving winch head. Very good control of heavy loads can be obtained in this manner; but if much lowering of heavy loads is done, difficulty will be had with the winch heads becoming hot.

On single geared winches having but little friction in the gearing, the speed of a plain series motor at no load would be dangerously high, and to overcome this a small amount of shunt winding is added. On two-speed winches the initial friction is usually enough to prevent dangerous no-load speeds.

30 H.P. motors are used on both of the designs.

VENTILATION FANS.

Nearly all compartments of a ship have artificial ventilation by electrically-driven fans, usually operating on the pressure system, but in some cases exhaust fans are used. All of the hull ventilation fans are electric, but the forced draft fans for the boiler rooms are steam driven in most cases, although a few of the later vessels have electric drive.

Fans are driven by shunt motors, usually of the open type, but in some exposed locations entirely enclosed motors are used. Full speed of motors is that required to make the fan deliver air at 1½ ounces per square inch pressure, and speed variation down to the speed giving 1 ounce is required, which is a reduction of about 20 per cent. This speed variation is obtained by field resistance on motors above 1 H.P., and by armature resistance on smaller sizes. Controlling panels are used which have the necessary rheostats for the speed control, and also overload and no-voltage release.

Principal Requirements for Ventilating Fans.

The following may be considered as standard capacities for ventilating fans and will in general be specified:

600 cubic feet.	5,000 cubic feet.
1,000 cubic feet.	6,000 cubic feet.
1,600 cubic feet.	8,000 cubic feet.
2,500 cubic feet.	10,000 cubic feet.
4,000 cubic feet.	12,000 cubic feet.

All fans to be built up of steel plate with the exception of the 600, 1,000, and 1,600 cubic feet, which must be of cast shell construction. Fans to be practically noiseless and to be of the convertible type so constructed that they will be suitable for either right or left hand and for at least eight different angles of discharge. Cast shell fans to be so constructed that they may be installed on deck, on vertical bulkhead, or suspended from deck above. All fan wheels and the interior of steel-plate fan casings to be galvanized to prevent corrosion. Interior of casings of cast shell fans to be thoroughly coated with asphaltum. Fan wheels to be of steel, keyed on shaft with set screw in hub; hubs to be brass bushed; cast shell fans to be of heavy, soft, cast iron, free from all cracks, blowholes, or other defects, and suitably re-enforced at all points of strain. A hand hole to be provided in casing of all cast shell fans for access to set screw in hub of wheel; cover for this hole to be finished and made air-tight without the use of putty or similar substances. Scrolls of steel-plate fans to be in three removable sections. Each fan to be provided with a name plate giving the capacity in cubic feet per minute. Inlets and outlets of cast shell fans and inlets of steel-plate fans to be circular in shape, outlets of steel-plate fans to be rectangular. Area of fan inlets shall not exceed area of outlets, the inlet to be straight, and no temporary means shall be employed in any test to reduce the friction of the inlet. After installation on shipboard, the fans to be provided with suitable drip pans with cocks.

Each fan with its motor and controlling panel to be assembled and tested at the works of the maker in the presence of a government inspector, suitable means being provided for measuring all data.

In making shop tests the set shall be erected with free inlet to the fan. There shall be attached to the fan outlet a pipe of the area of the outlet, whose length shall be not less than 20 diameters of the outlet for fans with round outlets, or twenty times the average of the breadth and depth for fans with rectangular outlets. A double Pitot tube designed to indicate the pressure produced by the impact of the moving air, and the actual pressure in the moving air shall be inserted in the center of this pipe at about one-half its length, with the axis or the tube in the center line of the pipe. The Pitot tube to conform to dimensions shown on drawing, which may be obtained on application to the Bureau of Construction and Repair. An adjustable throttling device shall be fitted to the end of the pipe and adjusted with the fan running at its designed full speed, with motor fields hot, until head of water, in inches, shown by a manometer connected to the pressure side of the Pitot tube, is not less than 13.4 times the weight per cubic foot of the air in pounds. When this condition is obtained the head of water, in inches, shown by the manometer connected to the impact side of the Pitot tube, shall not be less than 17.4 times the weight of the air per cubic foot in pounds. The correct weight of the air in pounds per cubic foot shall be obtained from the tables of the Bureau of Construction and Repair, which are entered with the barometric pressure and wet and dry bulb temperatures. The wet and dry bulb thermometer shall be placed near the fan inlet but not so close to it as to appreciably obstruct the current of approaching air. It is the object of this test to make sure that the fan under test, when running at full speed, shall be capable of discharging air through a pipe the full size of the outlet against a pressure of five pounds per square foot, with a velocity of not less than 2,200 feet per minute at the center of the discharge pipe. A hook-draft water gauge or approved manometer apparatus shall be used in connection with the Pitot tube. For apparatus to record pressure direct a pressure of 5.2 pounds per square foot shall be taken as equivalent to one inch of water. No specific requirement as to air delivery with free outlet is made.

NOTE. — The above-mentioned tables of the weight of air under different atmospheric conditions will be furnished by the Bureau to fan manufacturers upon application.

Fans when tested under the above conditions must deliver their rated volumes at the required pressures and a static pressure in inches greater than 14.74 times the weight of air in pounds per cubic foot, or an impact pressure greater than 19.14 times the weight of air will not be allowed. The difference between the static and impact pressure must never be less than four times nor greater than 4.4 times the weight of the air. No means shall be employed to reduce the friction of the inlet during the tests.

In calculating results of tests the following approximate formulas will be used:

$$v = 997.\sqrt{\frac{h_3}{W}}.$$

This formula assumes that a velocity at the center of the pipe of 2,200 feet per minute corresponds to an average velocity over the whole area of the pipe of 2,000 feet per minute.

$$V = Av$$

$$\text{H.P.} = \frac{5.2 h_1 A v}{33000} = \frac{h_1 A v}{6345}$$

when V = volume in cubic feet per minute.
v = velocity in feet per minute.
h_1 = impact pressure in inches of water.
h_2 = static pressure in inches of water.
$h_3 = h_1 - h_2$ = velocity head in inches of water.
A = area of outlet in square feet.
H.P. = horse-power delivered by the fan.
W = weight of air in pounds per cubic foot.

NOTE. — Instead of a single Pitot tube a number of tubes, not less than nine or more than thirteen, distributed over the pipe section may be used if preferred, by the contractor. In this case the mean static pressure, in inches of water, must not be less than 13.4 times the weight per cubic foot of the air in pounds, and when this condition is obtained, the mean impact pressure in inches of water shall not be less than 16.72 times the weight of air in pounds per cubic foot. It is the object of this test to determine that the fan will deliver the required volume of air at a mean velocity of 2,000 feet per minute over the whole area of the pipe. Similar variation in pressures to that specified above will also be allowed under these conditions.

The heat run on each motor is to be of eight hours' duration, made when driving its fan with free outlet and inlet at the above required full speed, and under such conditions the temperature rises of all parts must not exceed those allowed for continuous-running motors. Also these temperature rises are not to be exceeded when the fan is run as above at full field strength of the motor.

Each set is also to be given an endurance test by running for forty-eight hours continuously at full speed with free inlet and outlet of fan (forty hours in addition to the above test of eight hours at full speed, the fan to be started up immediately after taking temperatures at end of eight-hour run), and during this run absolutely no attention or adjustment is to be given to the motor. At the end of the run the motor must be in operation in a satisfactory manner and without sparking, blackening, burning, or roughening of the commutator, or the development of high mica, copper sticking to the brushes, or any other latent defects. Any set which fails to pass this endurance test on the first trial will be allowed a second trial, after overhauling and adjusting, but if it fails on the second trial it will be rejected.

Results Obtained from above Shop Tests.

Rated Size.	r.p.m.	h_1.	h_2.	h_3.	W.	v.	A.	V.	H.P. from Motor.	H.P. in Air.	Fan Eff. Per cent.	Motor Eff. Per cent.
600	2200	1.350	1.041	.309	.0715	2072	.306	634	.298	.135	45.3	61.1
2500	1140	1.352	1.036	.316	.0726	2075	1.25	2595	1.415	.555	39.2	76.2
2500	1140	1.383	1.075	.308	.0734	2037	1.25	2546	1.25	.555	44.3	74.4
4000	875	1.318	1.014	.304	.0721	2052	2.00	4105	2.08	.854	41.	83.6
5000	810	1.377	1.062	.315	.0722	2084	2.50	5210	2.97	1.131	38.1	82.6
10,000	575	1.268	.971	.297	.0724	2016	5.00	10,080	5.00	2.014	40.3	84.1
12,000	525	1.275	.970	.305	.0725	2050	6.00	12,300	6.28	2.47	39.4	84.8

WATER-TIGHT DOORS.

Electrically-operated water-tight doors are now being installed on most large ships. The requirements of a successful system are that all doors can be simultaneously closed from the bridge, that during or after this closing any door can be opened by a person desiring to pass through from either side, and after such passage the door to automatically close itself.

The design in most general use is that of the Long-Arm System Co., of

Cleveland, O. The doors are moved by a 1 H.P. compound-wound motor geared to the door plate through spur gears and a worm and rack. Control at the door is obtained by a small hand-operated controller, having an operating handle on each side of the bulkhead. Control from a distance is obtained by an "emergency station" located on the bridge which closes the doors by means of a secondary circuit and solenoids. An indicator is also installed at the emergency station to show when each door closes.

The system is shown diagrammatically in Fig. 12. The controller connects the motor directly to the line, without the use of any starting resistance, and the motors are specially designed for this. When the door reaches either the top or bottom of its motion, it actuates the "upper limit switch," or the "lower limit switch," which opens the line circuit and stops the door. These limit switches are actuated through a series of cams, springs, and levers, attached to the driving gearing, so that a limit switch is opened whenever the door plate encounters any great resistance. In fact the operation of the limit switch, when the door opens or closes, is caused by the resistance to further motion, and not by the position of

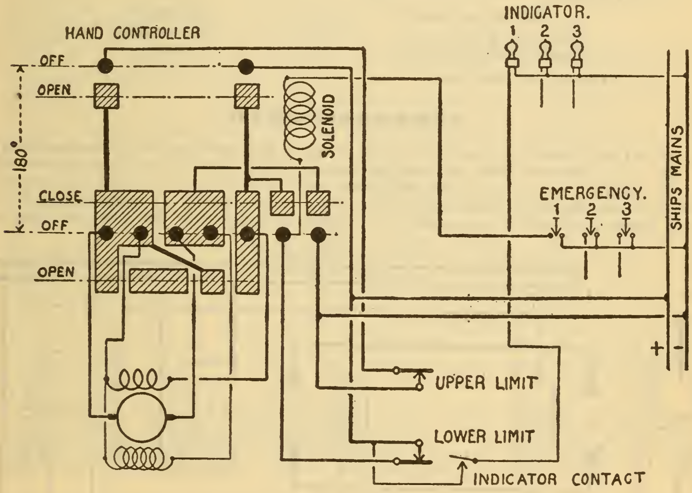


FIG. 12. Diagram of Connections for Electric Control of Water-tight Sliding Doors.

the door plate. This arrangement prevents any obstruction from burning out the motor, and at the same time, if the emergency station action is on, the door will continue its closing motion when the obstruction is removed.

The emergency station consists of a series of contacts, one for each door, which, when closed, excite solenoids located in the hand controllers. The two contact plates of the hand controller, which are located at the right-hand side of the diagram, are free to rotate on the controller shaft; and when the solenoid is excited it rotates them so that they make contact with their fingers, and thus produce the same result as moving the hand controller to the "close" position. The solenoid is so weak that it can be overpowered by the hand operation of the controller when it is moved to the "open" position, thus allowing a man at the door to make it open at any time when the emergency closing is in action. Upon releasing the handle of the hand controller it comes back by a spring to the "off" position, and if the emergency is still on, the door starts to close again. The mechanical construction of the emergency station is such that by moving a lever the contacts for the different doors are made one after the other with a slight interval of time between each, so that the sudden rush of starting current will not occur on all doors at the same instant.

The indicator consists of a case containing a small incandescent lamp for each door. When the door closes it operates an indicator contact which lights the corresponding lamp.

The door is powerful enough to cut through several inches of coal on the sill. In service the current required for operation of a vertical sliding door 2 ft. by 4 ft. 9 in. is about as follows:

Opening:	
Sudden throw, start	25 amp.
Running up	8 to 10 amp.
Sudden throw, stop	15 amp.
Closing:	
Sudden throw, start	20 amp.
Running down	6 to 9 amp.
Sudden throw, stop	11 amp.

Voltage is 125 volts.

STEERING-GEAR.

Electrical steering-gears are not at present used in the United States Navy, but are somewhat used in foreign navies. One method used is shown in the diagram of connections (Fig. 13), in which M is a shunt motor operated from the ship's mains and running continuously at constant speed; its shaft is directly coupled to G, a shunt generator, the two forming a

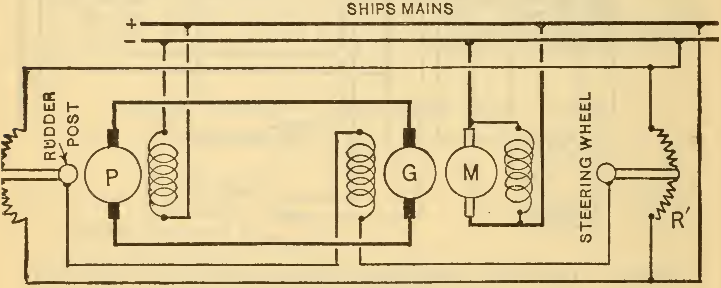


FIG. 13. Diagram of Steering-Gear.

motor generator set and located at any desired place, most conveniently in the dynamo room. P is a shunt motor geared by suitable gearing to the rudder post, and has its field constantly excited from the ship's mains, its brushes are directly connected to the brushes of the constantly running generator G. R and R′ are two equal and symmetrical rheostats, the contact arm of R being attached to the rudder post or any part of its gearing which has a similar rotation, and the contact arm R′ being attached by suitable gearing to the steering-wheel. The ends of the field of G are connected to these two contact arms, and the two rheostats are connected across the ship's mains.

It is now seen that the two rheostats and the field of G form a Wheatstone's bridge, the parts of the rheostat on each side of the contact arms being the four resistances, the field of G taking the place of the galvanometer and the line being the battery. This bridge is in balance, and no current will flow through the field of G whenever the two rheostant arms occupy similar positions on their respective rheostats; but if they do not occupy similar positions, then the bridge will be out of balance and current will flow through the field of G.

The operation is as follows: Starting with everything central as shown in the diagram, if the steering-wheel is turned, moving the arm of R′ a certain distance, the balance will be disturbed and current will flow through the field of G, causing it to generate an E.M.F. and start the motor P, which will continue to run until the arm of R has been moved a distance equal to the original movement made by the arm of R′, when the balance will be restored, no current will flow through the field of G, which will then develop no E.M.F., and the motor P will consequently stop. The gearing between P and the contact arm of R is so arranged that the movement of the arm will be in the proper direction to restore the balance. The direction of current flow in the field of G, and consequently the polarity of G and direction of rotation of P, will depend upon the direction of movement of the arm of R′. It is thus seen that the arm of R is given an exact copying motion of the arm of R′, both for distance moved and direction of rotation.

Instead of actually turning the rudder, the motor P can be made, if desired, to only operate the valve of a steam-steering engine; when this is done the device is called a "Telemotor."

Another method (which has only been applied for use as a telemotor) has the first movement of the steering-wheel connect the operating motor directly to the ship's mains, and the motion of the motor causes a step by step mechanism to disconnect it when it has moved the engine valve a distance proportional to the original movement of the steering-wheel. Both connection and disconnection of the operating motor are made by a switch at the steering-wheel, the interrupter of the step-by-step mechanism is at the operating motor and the mechanism itself at the steering-wheel. The mechanical arrangements are quite complicated.

Several ships of the Russian Navy have been fitted with direct acting steering-gears by the Electro-Dynamic Company, of Philadelphia, Pa., and work on the above first described bridge principle, with the addition of a small exciter for the generator mounted on the generator shaft, and the field of this exciter is connected with the bridge rheostats, instead of the main generator field itself. The motor of the motor-generator is rated at 70 H.P., the generator at 500 amperes and 100 volts, and the rudder motor at 50 H.P.; all being easily capable of standing 50% overloads for short periods of time. The motor-generator runs at 650 r.p.m. and weighs 11,000 pounds; the rudder motor runs at 400 r.p.m. and weighs 5,500 pounds; the accessory appliances weigh 1,500 pounds, making a total weight of 18,000 pounds.

Tests made on the Russian Cruiser "Variag" took 150 H.P. to move the rudder from hard-a-port to hard-a-starboard in 20 seconds, while going at a speed of 23 knots an hour. For ordinary steering at about 19 knots, readings taken every time the rudder was moved gave the following results:—

Amperes.	Volts.	K.W.
250	4	1.
250	10	2.5
150	14	2.1
180	30	5.4
200	40	8.
100	50	5.
100	55	5.5
50	5	.25
50	25	1.25
60	40	2.
100	22	2.2
100	25	2.5
50	15	.75
200	26	5.2
100	18	1.8
100	20	2.

Readings were taken for every movement occurring for a period of ½ hour, rudder was never moved more than 15 degrees.

INTERIOR COMMUNICATION SYSTEM.

The interior communication system of a ship consists of, as the name implies, the appliances for transmitting signals of all kinds from one part of the ship to another.

Order and Position Indicators.

Many devices have been tried for the electrical transmission of prearranged orders, or the position of a moving body, such as a rudder-head; but the most successful and the one generally installed consists at the receiving end of a number of small incandescent lamps, each mounted in a small, separate, light tight cell with a glass front, and the whole enclosed in a suitable case. On the glass front of each light cell is marked an order or number, or whatever particular information the particular device is to indicate. This receiver is connected to the transmitter by a cable having a separate wire for each lamp, and one wire for a common return. The transmitter consists of a switching device, by means of which any lamp or lamps in the receiver may be lighted, the current being taken from the lighting mains. As many receivers as desired can be operated from one transmitter, the receivers being connected in parallel.

Helm Angle Indicator.

When the above-described device is used to indicate in different parts of the ship the angle that the helm is turned; the transmitter switch consists of an arm, as shown in diagram (Fig. 14) fastened to the rudder stock, and moving over a series of contact pieces arranged in an arc in the same manner as an ordinary field rheostat. Each of the contact pieces is connected through one wire of an interior communication cable to one side of one of the receiver lamps, which lamp has marked on its front the number of degrees that the given contact is situated from the center line of the ship; the other side of the lamp is connected to the common return wire, which goes to the source of current and then to the contact arm. As the rudder turns, the contact arm makes connection with the different contact pieces, and as it touches each piece the corresponding lamp in the receiver lights up and indicates its position within the limits shown; when it is just midway between any two pieces it will touch both and light both corresponding lamps, which doubles the closeness with which the position is indicated.

As many receivers can be connected on as desired, all being operated in parallel.

Engine Telegraphs.

When used for engine order telegraphs the contact arm is mounted in a metal case and operated by a hand lever of the same construction as the hand lever of an ordinary mechanical ship's engine telegraph, as shown in Fig. 15. The case contains indicator lamps in parallel with the lamps of the receiver at the engine room, so that the operator on the bridge has visual evidence of the order sent. A small magneto is geared to the transmitter handle, and rings a bell at the receiver whenever the handle is moved, thus calling attention to the change of order.

Battle Order Indicators.

The receiving indicators are of the same construction as above described for the Helm indicators; but the transmitter consists of single-pole snap switches, connected up exactly like the lamps of the indicator, so that by turning the proper switches any desired number of lamps can be lighted,

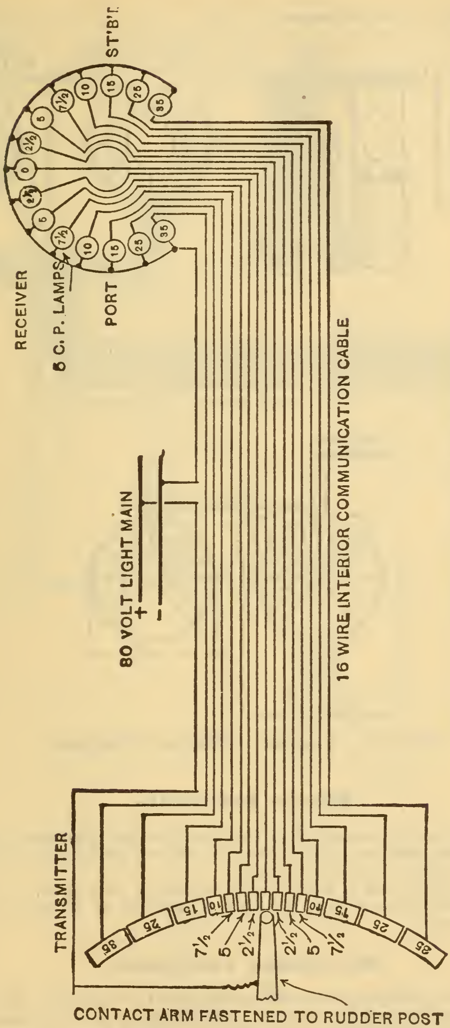


Fig. 14. Diagram of Helm Angle Indicator.

and of course any desired order can be marked in front of any lamp. Several indicators, located in different parts of the ship, are usually worked by each transmitter, all being connected in parallel.

The case which contains the transmitter switches also contains an indicator, thus always showing what orders are being indicated on the system.

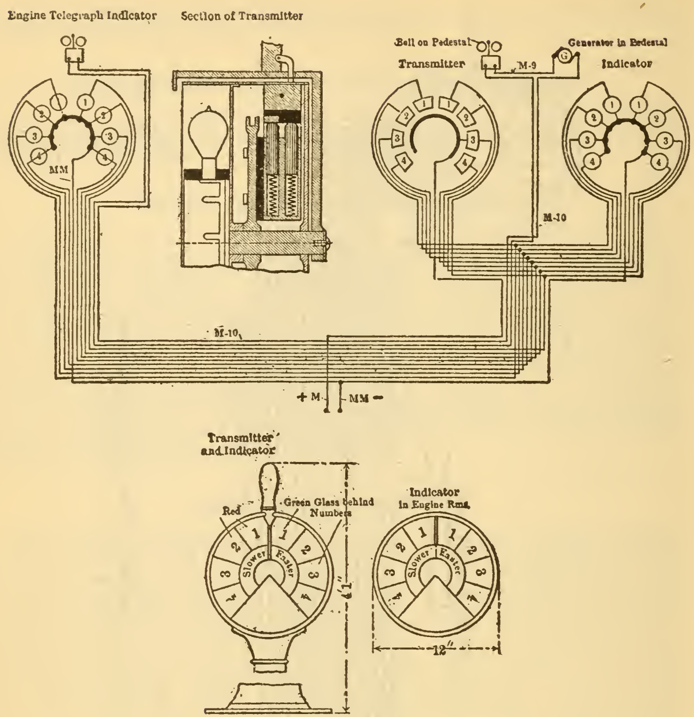


FIG. 15. Diagram of Engine Telegraph.

Range Indicators.

Range indicators are exactly like the battle order indicators, except that instead of having different orders marked before each lamp, a number representing the range in yards is marked.

A range indicator and a battle order indicator are usually mounted together at desired stations, thus showing what kind of firing is to be done and at what range.

Revolution Indicators.

To show on the bridge the direction and speed of rotation of the engines several appliances have been devised. The one most generally used is shown in Fig. 16, and consists at the transmitter of a small gear E, mounted eccentrically upon the propeller shaft S, and meshing with a pinion P, which is carried on the lower end of an arm A. The arm A is slotted and mounted on a pivot as shown, and when S is rotating, A will be turned to one side or the other, depending upon the direction of rotation of S, until it bits on the stop B, and will then remain against the stop and reciprocate up and down from the eccentric action of E; on each up movement it will make contact with clip C or C′, depending upon which side it is turned.

The receiver consists of two pivoted pointers, connected as shown to two electromagnets and marked "Astern" and "Ahead."

From the connections shown, it is seen that at each rotation of the propeller shaft the pointer corresponding to the direction of rotation will make a movement, and at the same time the magnet armature will make a plainly audible click, thus indicating both visually and audibly the rotation. The

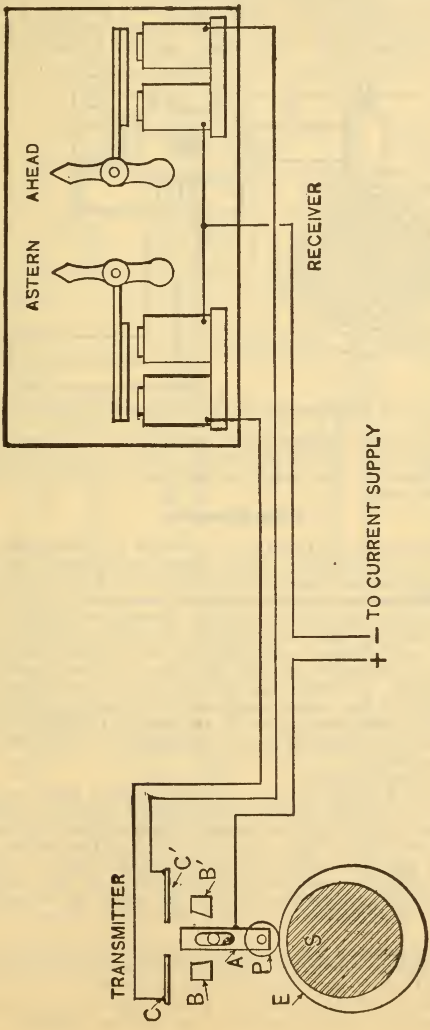


Fig. 16. Diagram of Connections for Revolution Indicator.

other pointer corresponding to the direction in the opposite rotation will remain still. For twin screws a separate transmitter and receiver is installed for each.

A later design of the transmitter is shown in Fig. 17, which eliminates reciprocating motion and prevents wear. E is a large multiple worm mounted on the propeller shaft S. D is a worm wheel on the small shaft F, on which is mounted the insulating drum B. A is a metallic contact strip set into B and makes contact across two of the leads as shown. C is a cam which moves B along its shaft, and holds B in the position shown for astern motion, so that the contact A connects the center and left hand leads at each revolution of F. For ahead rotation C shifts B to the right

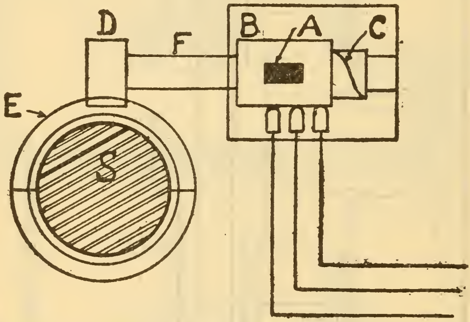


Fig. 17. Diagram of Connections of Transmitter for Revolution Indicator.

so that contact is made between the center and right-hand leads. For turbine vessels with fast running propellor shafts the gearing ratio of E and D is proportioned so that only one indicator is given for 3 and 4 revolutions of the main shaft.

Telephones.

On the latest vessels a central station is provided to which each set is directly connected. Fig. 18 is a diagram of the system as furnished by the Western Electric Co. The central board is known as the cordless and plugless type. Its main feature consists in having the connection circuits arranged in a series of horizontal bus-bars which are crossed vertically by the talking wires of each station, so that by putting an ordinary spring lever key at each intersection any desired combination of connections can be made. Usually the board is arranged for fifty stations and five connection circuits, so that five separate conversations between any five pairs of telephones may be carried on at the same time; also for issuing general orders any desired number of telephones may be connected together. The diagram shows only two connection circuits and two stations, but it can be extended as desired in either way.

The operation is as follows:

Three wires run to each station, two for talking and one for ringing. When the receiver is taken off the hook, current from the talking battery flows through the talking line wires and displays the line signal. When the operator throws one of the connection keys of the calling set the line signal is cut out and the talking wires connected direct to the horizontal connection bus which is permanently connected to the talking current supply. Throwing the connection key of the party to be called, which is on the same horizontal bus as the calling party, puts the pair in communication.

Ringing is accomplished by a separate ringing key for each set, taking current from a separate ringing battery and operating through the common ringing wire and the left-hand talking wire as shown.

Each horizontal connection bus has a clearing-out signal which is displayed when current is flowing from the talking supply. When both

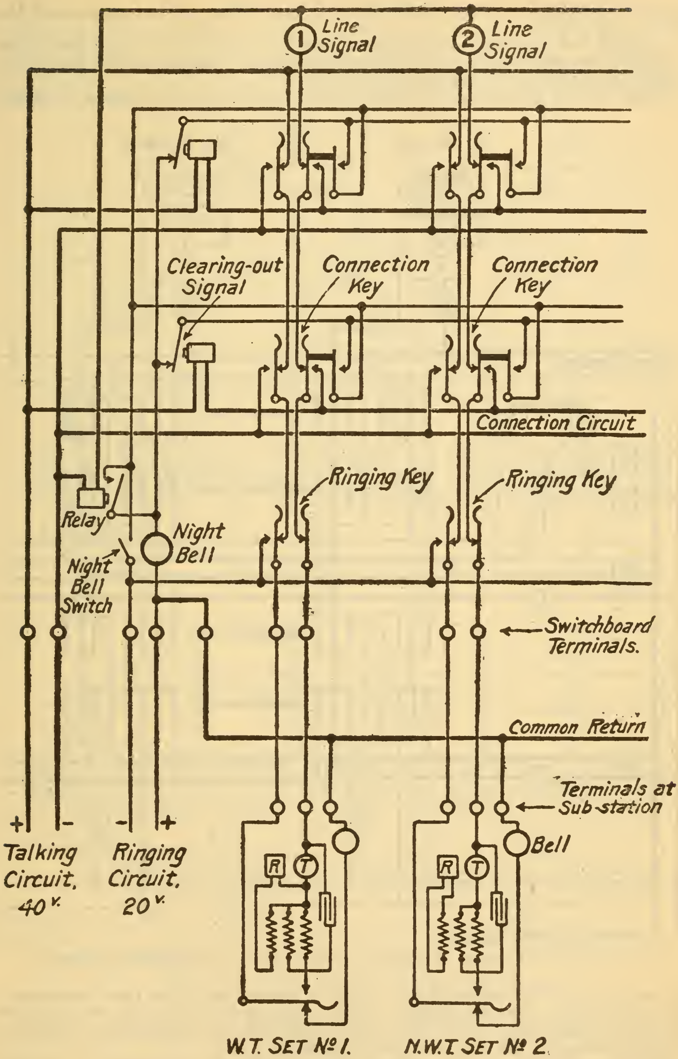


FIG. 18. Diagram of Western Electric General Telephone System.

parties hang up the receivers the flow of the talking current ceases and the signal falls back.

A night bell is provided which is operated by a relay when any line signal is displayed, also when any clearing-out signal falls back and the corresponding connection keys are not opened.

Cross-talk is prevented by choke coils (not shown on diagram) inserted

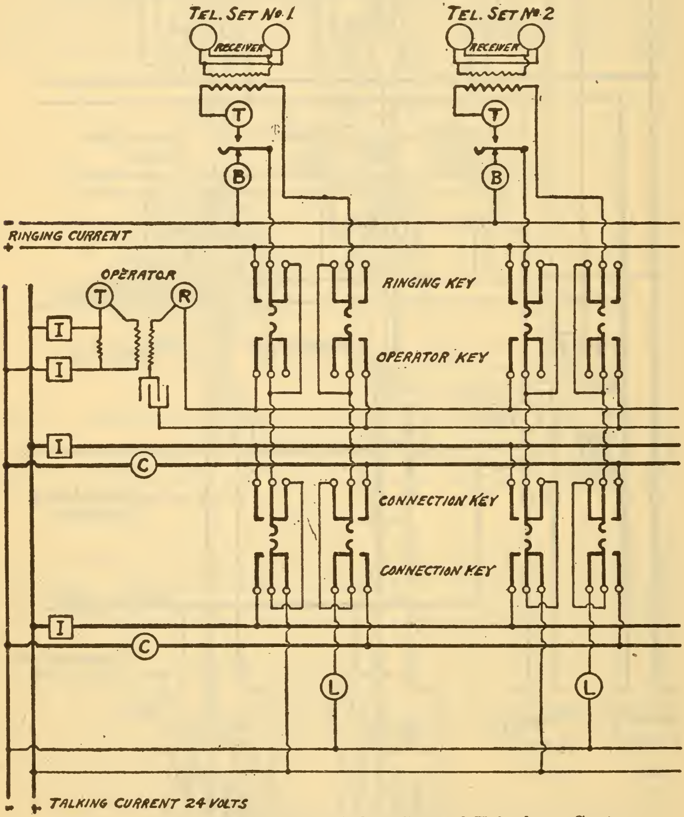


FIG. 19. Diagram of Holtzer-Cabot General Telephone System

in each side of the horizontal connection busses just after their connection to the talking current supply. Both talking and ringing currents are supplied either from batteries or motor generators taking power from the ship's generating plant, thus giving a reserve.

Both water-tight and non-water-tight telephones are used. The non-water-tight are of the ordinary wood case wall pattern, while the water-tight sets have the mechanism enclosed in a brass box with the cover having a rubber gasket and heavy clamps.

Figure 19 shows the design made by the Holtzer-Cabot Co. The general scheme of operation is the same as above described, the main difference being that the operator's set is handled by a separate additional row of keys instead of being treated simply as a station.

Figure 20 shows the design made by Charles Corey & Son. It is generally similar to the above systems, but uses a separate battery for each talking circuit instead of using talking current from a common bus supplied by dynamo current. Also each talking circuit consists of two sets of

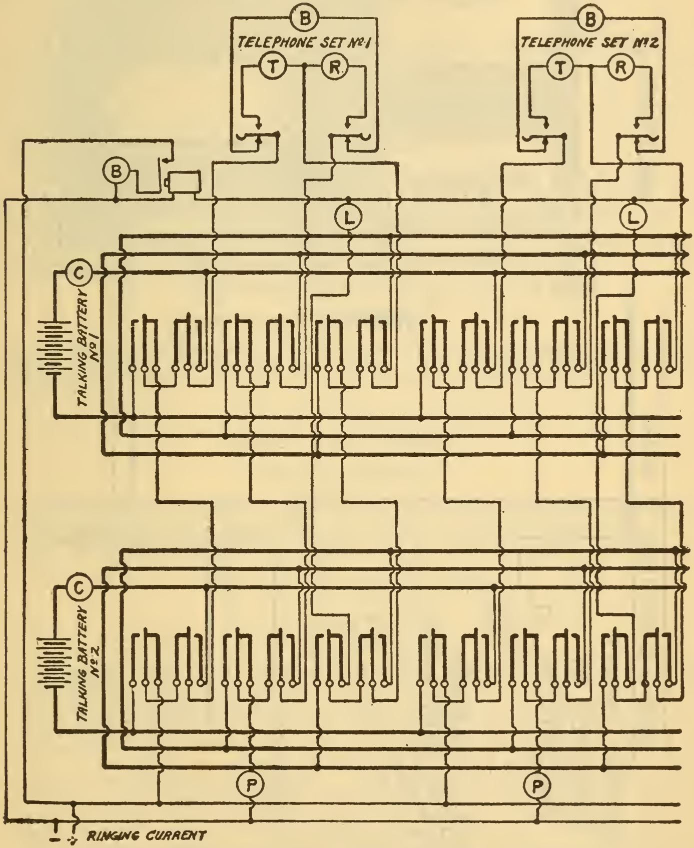


Fig. 20. Diagram of Corey General Telephone System.

horizontal busses, and the connection keys may be thrown either way to connect on the station, thus making it possible to reverse the direction of current flow through the contacts and instruments. Each set of connection keys is so grouped that one lever operates them all.

In the above telephone diagrams the following notation is used:

T. — Transmitter
R. — Receiver.
L. — Line signal.
C. — Clearing out signal.
I. — Choke coil.
P. — Push button.

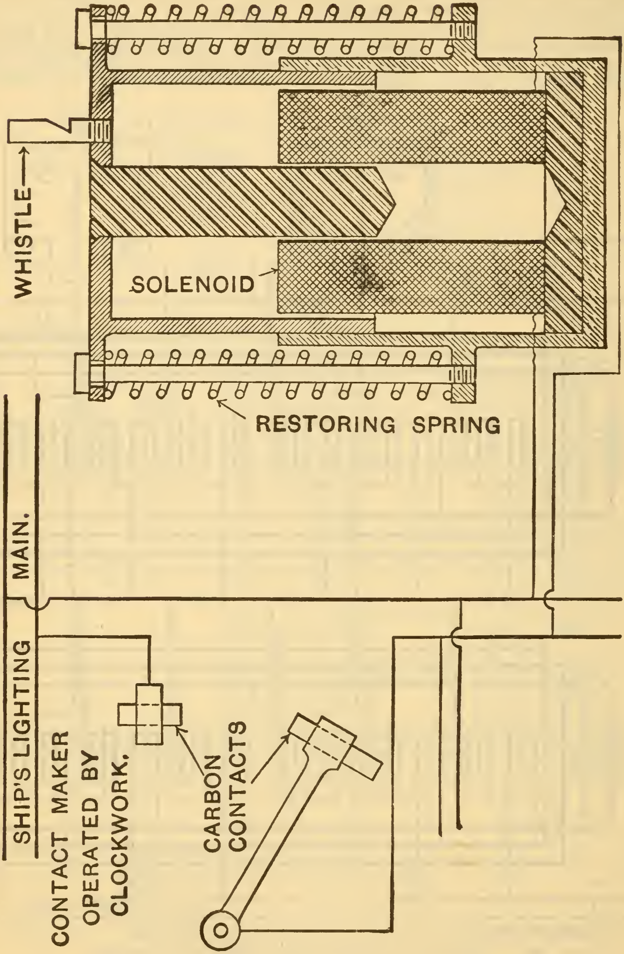


FIG. 21. Diagram of Connections of Electric Whistle.

Fire Alarms.

The fire alarm system consists of thermostats, located in all parts of the ship, and connected to an annunciator in the captain's office.

The thermostats consist of a helical metal coil, made of two strips of steel and brass, having a high temperature coefficient of expansion, mounted with one end free so that the tortional effect produced by a rise of temperature causes a slight displacement of the free end, thus closing the circuit and operating the corresponding annunciator drop. The working parts are enclosed in a heavy brass case.

Coal bunker and storeroom thermostats are set for 200 degrees Fahrenheit, and those in magazines at 100.

Water-tight Door Alarms.

To give a general signal for the closing of all water-tight doors, a system of alarm whistles is used. The whistle consists of a solenoid which pulls its core down into an air chamber, and thus forces the air out through a small shrill whistle. The core is restored by spiral springs. All whistles are connected in parallel, and are operated by a make and break mechanism, which by the pulling of a lever will interrupt the circuit continuously for about 30 seconds, each interruption giving a blast from each whistle. Current from the lightning mains is used.

The construction is shown in Fig. 21. The clockworks for operating the contact maker is constructed so that by rotating an operating lever it is wound up, and upon releasing the lever it vibrates the contact while running down, thus giving periodical signals.

In the latest design the whistle is inverted and pulled up against gravity, thus dispensing with the restoring springs.

Call Bells.

An elaborate system of call bells, annunciators, electro-mechanical signal gongs, etc., is installed on all large ships. The main difference from ordinary commercial work is that all appliances are made water-tight.

MISCELLANEOUS.

Range-Finder.

The following is a brief outline of the principles employed in the instrument designed by Lieutenant Bradley Fiske of the United States Navy.

In Fig. 22 let A represent the target and BC a known base. Then

$$AC : BC :: \sin ABC : \sin BAC.$$

$$AC = BC \times \frac{\sin ABC}{\sin BAC}.$$

The angle ABC can be readily measured. The angle $BAC = DBE$, the line BE being parallel to AC.

The Fiske range-finder measures the angle DBE by the use of the Wheatstone bridge, as follows:

Suppose the two semi-circles in Fig. 22 replaced by two metallic arcs (Fig. 23). At the center of each of these arcs is pivoted a telescope, the pivot of which is connected to a battery B. The telescopes are in electrical contact with the arcs. These metallic arcs are connected at their extremities with a galvanometer, c, the whole forming a Wheatstone bridge, whose arms are aa bb.

When the telescopes are pointed at the object A, it is evident that the arms of the bridge are unequal, and hence do not balance; and this fact is indicated by the deflection of the needle of the galvanometer. The arc FD is noted. By swinging the telescope at F around till the needle of the galvanometer indicates zero, the bridge balances, the telescope being parallel to the one at C, and the arc or angle $DF — FE$ is equal to the angle at A. From this the distance AC can be calculated, or read off directly on a properly constructed scale.

Generally, in using the instrument, the telescopes are mounted at a distance from the battery, where the view is uninterrupted, while the galvanometer is at the gun. The observers keep the telescopes constantly directed on the target, and the man at the gun balances the bridge by introducing a variable resistance into the circuit till the needle stands at

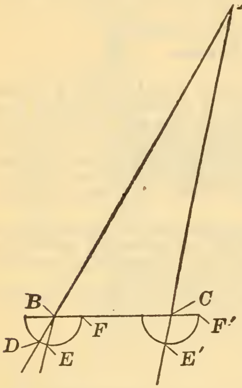


FIG. 22.

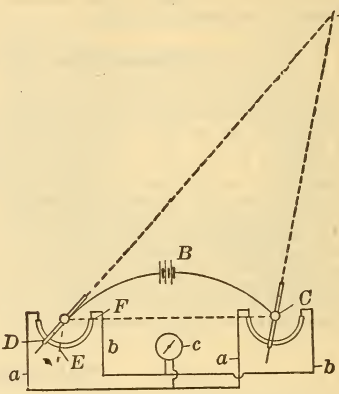


FIG. 23.

zero. This variable resistance is graduated so as to indicate the range corresponding to the resistance introduced. This instrument is not now used.

Firing Guns.

Large guns are arranged to use both percussion and electric primers for firing. The electric primer is of the same external shape as the percussion primers, and is exploded by a fine platinum wire, heated by current from the cells of a dry battery mounted near the gun. A ground return is used and a safety switch is fastened to the breech plug, so that the circuit cannot be completed until the breech plug is closed. A push-button is used to complete the circuit and fire the gun.

The same primer is also used for igniting the charge of powder to expel torpedoes from their directing tubes. Fig. 24 shows a section of the primer and diagram of connections for both torpedo and gun firing. In torpedo firing the opening of the sluice gate, which permits the torpedo to be discharged from the tube, closes the circuit and operates the signal lights at the tube and firing key. This also acts as a safety device by preventing the primer being fired before the gate is opened.

Speed Recorder.

An instrument called the "Weaver Speed Recorder" is somewhat used for measuring the speed of ships when run on the measured mile, and while being launched; also to measure the acceleration of turrets during test.

It consists essentially of a clockworks, which drives a paper tape over a set of five pens operated by electromagnets, so that when any magnet is excited it pulls its pen against the moving paper tape, and makes a dot thereon. The connecting levers between the magnet and pen are arranged something like a piano finger action, so that no matter how long the magnet is kept excited, the pen will only make a quick, short dot. All pens are located side by side in the same line, so that if they were all operated at the same instant, the result would be a line of dots across the tape.

When used for measuring mile runs, one pen is connected to a make and break chronometer, so that it makes a dot on the tape every second; another pen is connected to a hand push-button, so that a dot can be made at the start and finish of the run, and at as many intermediate points as desired; the other three pens are connected to contact makers on the shafts of the main engines, so that a dot is made for every revolution of the engine. (If the ship has twin screws, of course only two of the remaining pens are used and if single screw, only one.)

It is thus seen that by counting the number of second dots between the start and finish dots, the length of time to make the run is given, and by

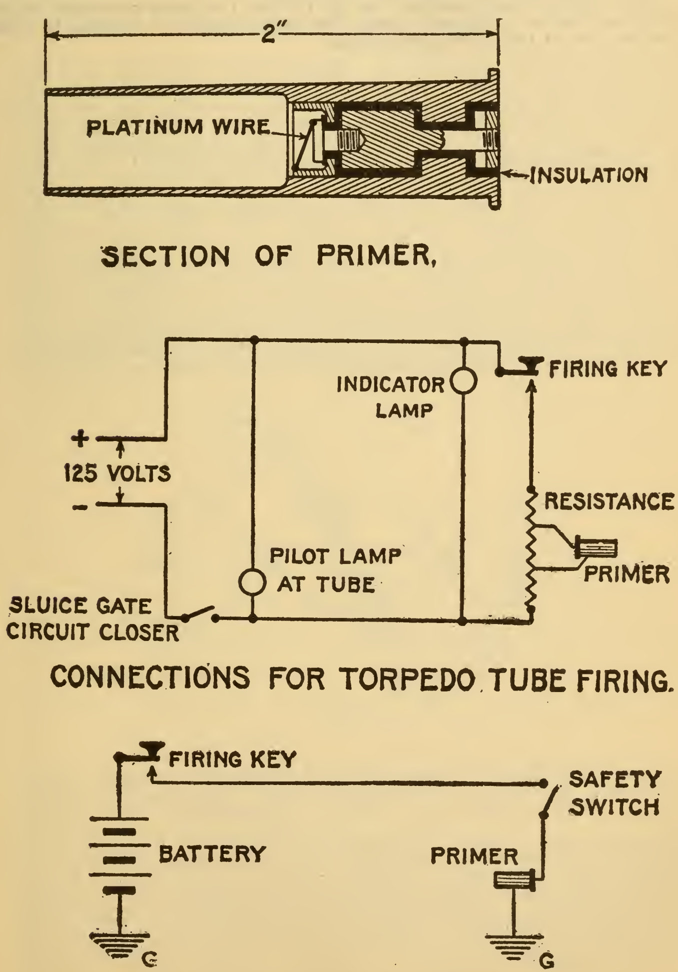


FIG. 24. Connections for Torpedo and Gun Firing.

counting the number of revolution dots in any desired space, the speed of the engine is given. Fractional seconds or revolutions can easily be scaled.

When used to obtain launching curves, a long steel wire wound on a drum has one end attached to the ship, and a contact maker is fastened to this drum. As the ship slides out the drum is revolved and dots made on the tape at each revolution; knowing the diameter of the drum, the speed at any instant is found by comparison of the revolution dots with the second dots. The hand-push is used to mark the start, finish, instant of pivoting, and any other desired matters.

When used for acceleration runs on turrets, the same procedure as for launching curves is followed, except the contact maker is attached to some rotating part of the turret mechanism.

RESONANCE.

REVISED BY LAMAR LYNDON.

IF in an alternating current circuit, an inductance be inserted, the self-induced E.M.F. will combine with the impressed E.M.F. and the resultant of the two will be the active E.M.F. which causes current flow. The current will always be exactly in phase with and proportional to the *resultant* E.M.F.

The inductive E.M.F. is 90 degrees, or one-fourth of a cycle, behind the current, and, therefore, behind the resultant E.M.F. which is in phase with the current. The algebraic sum of the instantaneous values of the resultant and inductive E.M.F.'s will give the corresponding values of the impressed E.M.F.

Fig. 1 shows this summation. *v,v,v,v,* is the resultant E.M.F. required to send current *i,i,i,i,* which is in phase therewith, through a given resistance. *L,L,L,L,* is the curve of E.M.F. necessary to overcome the counter E.M.F. of the inductance, the curve of the inductance E.M.F. being equal and opposite to the curve *L,L,L,L.* This curve of inductance E.M.F., which is indicated by the dotted curve *l,l,l,l,* is one-quarter period or 90 degrees behind the current and the resultant E.M.F. Combining the ordinates of *v,v,v,v,* and *L,L,L,L,* the curve *e,e,e,e* is produced. This represents in phase and magnitude the impressed E.M.F. required to send current *i,i,i,i,* through the resistance and overcome the counter E.M.F. of the inductance.

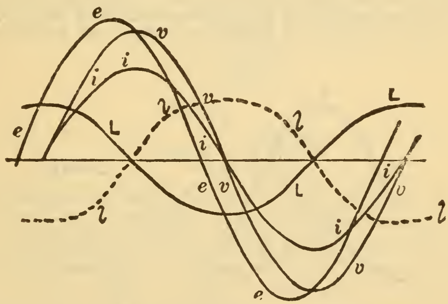


FIG. 1.

As may be seen, it is somewhat in advance of the resultant E.M.F. and, therefore, of the current. Also it is higher than the resultant E.M.F. by an amount which at each instant is equal to the counter E.M.E. of the inductance.

If a condenser or capacity be included in a circuit, and an alternating current be sent into it, flow will take place in the condenser, the current entering and charging it. As the amount of electricity stored increases, the E.M.F. of the condenser increases also until the impressed and condenser E.M.F.'s are equal. The condenser E.M.F. being a counter pressure, current flow ceases when the two E.M.F.'s balance. The current being zero at this point, and the condenser E.M.F. a maximum, it may be seen that the condenser E.M.F. is one-quarter period or 90 degrees in advance of the current, and, therefore, of the resultant E.M.F.

In Fig. 2, *V,V,V,V,* is the resultant E.M.F. made up of the two E.M.F.'s acting on the circuit. *i,i,i,i,* is the current, *C,C,C,C,* the condenser E.M.F., which is 90 degrees ahead of *i,i,i,i*. *c,c,c,c*, is the curve of F.M.F. necessary to overcome the condenser E.M.F., being equal and opposite to the condenser E.M.F. Combining *V,V,V,V*, and *c,c,c,c*, the impressed E.M.F. curve *e,e,e,e*, is produced, which is somewhat behind the current and resultant E.M.F., and behind the condenser E.M.F. Also, the impressed E.M.F. is greater than the resultant E.M.F.

From the foregoing it is evident that if either a capacity or inductance be inserted in an alternating current circuit, the phase of the current with

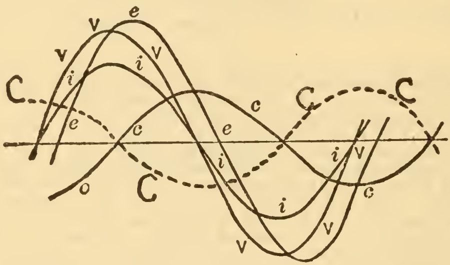


FIG. 2.

respect to the impressed E.M.F. will change, and the current flow be reduced. Since the one sets up an E.M.F. 90 degrees in advance of the current flow and the other a pressure 90 degrees behind it, the two effects tend to neutralize each other when connected in series, and when they are just equal, no E.M.F. other than the impressed is left to act on the circuit, the resultant and impressed E.M.F.'s are identical, and there is no phase displacement. This condition is called *resonance* and is shown in Fig. 3.

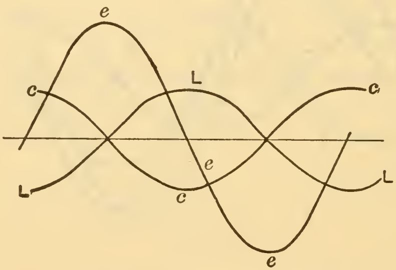


FIG. 3.

The curves *L,L,L,L*, and *c,c,c,c*, are equal and opposite at every instant and neutralize, leaving the impressed E.M.F. as the only one acting on the circuit.

The conditions for resonance then are, that with a given frequency and current the capacity and inductance be so related that the counter E.M.F.'s set up by them are equal, or it may be stated another way. If in an alternating current circuit an inductance and a capacity be connected in series, either of which, if inserted in the circuit alone, reduces the current flow the same amount, resonance occurs and the current flow is not changed by the presence of the *two in series*.

The formula for alternating current flow in a circuit containing resistance, inductance and capacity is

$$I = \frac{E}{\sqrt{R^2 + \left(L\omega - \frac{1}{\omega J}\right)^2}} \qquad (1)$$

in which

$E =$ E.M.F. (impressed volts),
$I =$ Current in amperes,
$R =$ Resistance in ohms,
$L =$ Inductance in henrys,
$J =$ Capacity in farads,
$\omega = 2\pi f = 6.28 \times$ frequency in cycles per second.

If the capacity and inductance effects neutralize,

$$L\omega = \frac{1}{\omega J}, \quad \text{and} \quad L\omega - \frac{1}{\omega J} = 0, \qquad (2)$$

and formula (1) becomes

$$I = \frac{E}{\sqrt{R^2}} = \frac{E}{R}, \qquad (3)$$

which is simply Ohm's law, showing that the current flow is opposed only by the resistance.

The farad is too large a unit for practical work, capacities seldom being more than a few micro-farads (or one millionth of a farad). If J be taken in micro-farads and called J_m, then for resonance

$$L\omega = \frac{1{,}000{,}000}{\omega J_m},$$

$$\omega = \sqrt{\frac{1{,}000{,}000}{LJ_m}}, \qquad (4)$$

also

$$\omega = 2\pi f.$$

Therefore,

$$f = \frac{1}{2\pi}\sqrt{\frac{1{,}000{,}000}{LJ_m}}, \qquad (5)$$

which is the frequency at which resonance will occur for a capacity J_m and an inductance L. Since the opposing E.M.F. of the inductance increases with increase of frequency, and that of the condenser decreases, with a given inductance and capacity there is only one frequency at which they will neutralize and resonance result, and if this frequency be changed, the E.M.F. of one will increase while that of the other will decrease, thus destroying the balance between the two.

As an example, assume a circuit having an inductance of 0.44 henry, and a capacity of 16 micro-farads. For resonance the frequency must be

$$f = \frac{1}{2\pi}\sqrt{\frac{1{,}000{,}000}{0.44 \times 16}} = 60 \text{ cycles, per second.}$$

The opposing inductance and capacity E.M.F.'s often set up local potentials very greatly in excess of the impressed.

Since the voltage required at the terminals of an inductance to force a given current through it $= E_l = \omega LI$, and for resonance, $I = \frac{E}{R}$, the voltage at the inductance

$$= E_l = \frac{E\omega L}{R}. \qquad (6)$$

Also the voltage required to send a given current through a condenser $= \frac{I}{\omega J}$, or

$$\frac{I \times 1{,}000{,}000}{\omega J m} = \frac{E \times 1{,}000{,}000}{R \omega J m}. \qquad (7)$$

Assume the circuit of 0.44 henry 16 micro-farads and 5 ohms.

$$f = 60 \text{ cycles,}$$
$$\text{Impressed E. M. F.} = 250 \text{ volts,}$$

the voltage at the terminals of the inductance,

$$E_l = \frac{250 \times 0.44 \times 2\pi \times 60}{5} = 8290 \text{ volts,}$$

while the volts at the condenser terminals

$$= E_c = \frac{250 \times 1{,}000{,}000}{5 \times 2\pi \times 60 \times 16} = 8290 \text{ volts,}$$

which is the same as the voltage at the terminals of the inductance.

Fig. 4 shows the diagram of such a circuit and indicates the potentials between the different terminals.

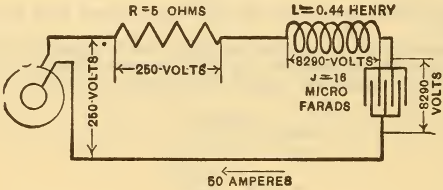


FIG. 4.

From the foregoing it is obvious that the smaller the resistance, the greater will be the local voltages set up by the capacity and inductance. For instance, if in the previous example the resistance were 2½ ohms instead of 5 ohms, the current flow would be 100 amperes and the potential at the terminals of the inductance and of the condenser would be 16,580 volts, the impressed E.M.F. being only 250 volts as before.

In practice the capacities and inductances are seldom so related as to allow complete resonance to occur at commercial frequencies, though whenever a capacity and inductance are in series the partial neutralization which takes place is liable to increase the E.M.F. locally to a higher value than that of the impressed.

All the foregoing is based on an impressed E.M.F., which is a pure sine function.

In practice, however, the E.M.F. wave differs more or less from this form, and may be considered as the resultant of several pure sine waves of varying amplitudes and frequencies. Those waves which have a higher frequency than the impressed E.M.F. wave, are termed higher or upper harmonics. Although the frequency of the impressed E.M.F. may not be sufficiently high to produce resonance, some one of the component waves or "upper harmonics" may have a frequency at which resonance will result. From equations (6) and (7) it is clear that, with a given resistance in circuit, the rise in E.M.F. due to resonance is proportional to the impressed E.M.F., and since the voltage of the upper harmonics is usually small, the rise in E.M.F. cannot be great.

When resonance occurs with one of the upper harmonics, the wave form of the current becomes greatly distorted, because while the other component waves must force the current against both the resistance and the reactance (i.e., inductance and capacity E.M.F.'s), this particular wave has only to overcome the ohmic resistance and, therefore, sends a greater current through the circuit in proportion to its voltage than do the other E.M.F. waves.

All these considerations apply only to circuits in which the inductance, resistance and capacity are in series. If the inductance and capacity be connected in parallel, as shown in Fig. 5, there can be no rise of voltage above the impressed even if the two be in resonance, but currents greater than those supplied by the source of impressed E.M.F. may surge back and forth through the local circuit, joining the condenser and the inductance, and, unless the resistance be high, the current sent through the main

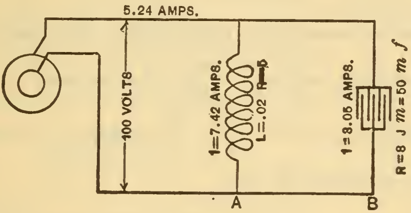


FIG. 5.

circuit will be greatly reduced: indeed, if the resistance were zero, the alternator could not send any current whatever through the circuit, for at every value of the impressed E.M.F. there would be an equal and opposite E.M.F. either from the condenser or inductance, and the resultant or active E.M.F. becomes zero. This condition is represented in Fig. 6 in which the curve *e* represents the impressed E.M.F. *c* is the curve of condenser *current*, and *L* of *current* in the inductance. The condenser current is 90° in advance of the impressed E.M.F. while the inductance current is 90° behind it,

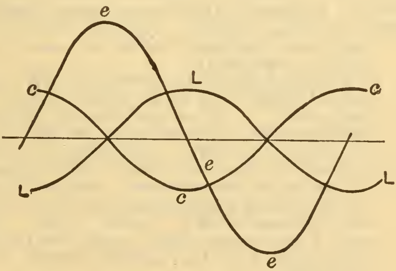


FIG. 6.

there being no resistance in the circuit. The sum of the two currents then is always equal to zero, as may be seen.

The physical conception of this condition is that of current flowing into the condenser, charging it, while the previous stored energy in the inductance discharges. This discharge sets up an E.M.F. opposing the impressed E.M.F., and also furnishes the current supply to charge the condenser. On reversal of the impressed E.M.F. the condenser discharges into the inductance, at the same time setting up a counter E.M.F. to oppose the flow of current from the line.

Thus, although there may be heavy currents flowing in the branch circuits, none will flow through the main circuit. In practice there is always a certain amount of resistance present in both of the branches, which will displace the phase relations of the two currents so that some current will flow in the main circuit, but this will often be less in amount than if one only of the two reactances were present when the resistances are very small.

As an actual case, consider the branch circuit shown in Fig. 5. Branch A has an inductance of .02 henry and 5 ohms resistance. Branch B has a capacity of 50 micro-farads, and a resistance of 8 ohms. Frequency = 100 cycles per second, and impressed E.M.F. = 100 volts.

$$\text{Impedance of branch } A = \sqrt{(5)^2 + (6.28 \times 100 \times .02)^2} = 13.5.$$

$$\text{Current through branch } A = \frac{100}{13.5} = 7.42 \text{ amperes.}$$

$$\text{Tan. angle of lag} = \frac{6.28 \times 100 \times .02}{5} = 2.512,$$

corresponding to an angle of 68° – 18′.

$$\text{Impedance of branch } B = \sqrt{(8)^2 + \left(\frac{1,000,000}{6.28 \times 100 \times 50}\right)^2} = 32.83.$$

$$\text{Current through branch } B = \frac{100}{32.83} = 3.05 \text{ amperes.}$$

$$\text{Tan. angle of lead} = \frac{\frac{1,000,000}{628 \times 50}}{8} = 3.98,$$

corresponding to an angle of 75° – 54′.

Combining these two currents in their proper phase relation, the sum is the current through the main circuit. This can best be done graphically after the usual manner of combining E.M.F.'s or currents vectorially.

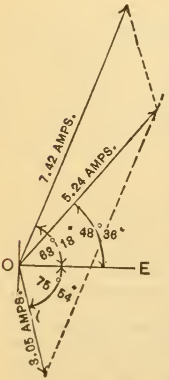


FIG. 7.

In Fig. 7 let the horizontal line OE represent the impressed E.M.F. and be the reference line. From O at an angle of 68° – 18″ upwards lay off 7.42 amperes to any suitable scale. At an angle of 75° – 54″ downward, lay off 3.05 amperes. Complete the parallelogram, as indicated by the dotted lines. The diagonal from O gives the value of the resultant current through the main circuit as 5.24 amperes, and shows also that it is behind the impressed E.M.F. by 48° – 36″. This, it will be seen, is less current than would flow through the circuit by branch A if the parallel branch B were entirely removed.

If the reactance E.M.F.'s have the same value, the capacity being .00005 farad (= 50 micro-farads), the inductance will be equal to .0506 henry. Assume that the resistance in branch B remains as before. If the resistance in branch A be 25 ohms the impedance will be = $\sqrt{(25)^2 + (31.83)^2} = 40.47$ and current = $\frac{100}{40.47} = 2.48$ amperes. Tan. of the angle of lag = $\frac{31.83}{25} = 1.271$, corresponding to 51° – 49″. Combining these values with the 3.05 amperes at an angle of lead of 75° – 54″ in Fig. 8, the resultant current is 2.49 amperes, and has an angle of lead = 4° − 24″. This current is less than that in branch B alone.

For the currents in two parallel branches to balance each other, so that the resultant current through the main circuit is brought in phase with the impressed E.M.F., the following condition must exist.

The amperes flow through one branch, multiplied by the sine of the angle of lead or lag of the current (referred to the impressed E.M.F.), must be equal to the amperes through the other branch multiplied by the sin of its angle of lag or lead. That is:

$I_1 \times \sin \phi = I_2 \times \sin \psi$, in which I_1 and I_2 are the currents through the two branches, ϕ is angle of lag of I_1 and ψ is angle of lead of I_2.

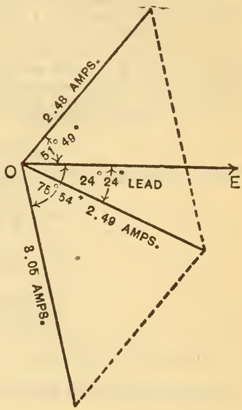


FIG. 8.

If in branch B of two parallel circuits the

$$\text{Impressed E.M.F.} = E,$$
$$\text{Capacity} = J,$$
and
$$\text{Resistance} = R,$$

$$\text{the impedance} = \sqrt{R^2 + \left(\frac{I}{\omega J}\right)^2},$$

ω being 6.28 × frequency.

$$\text{The current} = \frac{E}{\sqrt{R^2 + \left(\frac{1}{\omega J}\right)^2}}.$$

$$\text{Tan of the angle of lead} = \frac{\frac{1}{\omega J}}{R},$$

from which the angle and its sine are found. In branch A, either the resistance or reactance must be known. Calling I_2 the current and ψ the angle of lead in branch B, I_1 the current in branch A, and ϕ its angle of lag,

$$I_2 \sin \psi = I_1 \sin \phi,$$

$$\text{Tan } \phi = \frac{\sin \phi}{\sqrt{1 - \sin^2 \phi}} = \frac{L\omega}{R_1}, \tag{8}$$

where R_1 is the known or assumed resistance in branch A.

$$R_1^2 \times \sin^2 \phi = L^2\omega^2 (1 - \sin^2 \phi),$$

whence

$$\sin \phi = \sqrt{\frac{L^2\omega^2}{R_1^2 + L^2\omega^2}}; \tag{9}$$

$$I_1 = \frac{E}{\sqrt{R_1^2 + L^2\omega^2}},$$

$$I_1 \sin \phi = \frac{EL\omega}{R_1^2 + L^2\omega^2} = I_2 \sin \psi. \tag{10}$$

Calling $I_2 \sin \psi = \theta$, and solving,

$$L\omega = \frac{E}{2\,\theta} \pm \sqrt{\frac{E^2}{4\,\theta^2} - R_1^2}. \tag{11}$$

When R_1^2 is equal to or greater than $\frac{E^2}{4\,\theta^2}$, the quantity under the radical becomes zero or negative, and there is no reactance which will compensate for the effect of that in the other branch, the resistance being too high.

The sign before the radical being either plus or minus, there are *two* values of reactance with a given resistance which will compensate (if R_1 be not too great). The lesser reactance will, of course, permit the greater current flow, both through branch A and the main circuit.

As an example, assume a resistance of 8 ohms, a condenser capacity of 50 micro-farads in branch B; also a frequency of 100 cycles per second, impressed E.M.F. = 100 volts, and a resistance of 10 ohms in branch A. What inductance must be inserted in branch A to compensate for the reactance in branch B? Amperes through branch $B = I_2 = 3.05$. Angle of lead $= 75° \; 54'' = \psi$. Sin $\psi = .96987$.

$$I_2 \sin \psi = 3.05 \times .96987 = 2.9581 = \theta.$$

Substituting in formula (11)

$$L\omega = \frac{100}{2 \times 2.9581} \pm \sqrt{\frac{(100)^2}{4 \times (2.9581)^2} - (10)^2}$$

$$L\omega = 16.902 \pm 13.614 = \begin{cases} 3.288 \\ 30.516 \end{cases}.$$

$$\operatorname{Tan} \phi = \frac{L\omega}{R}.$$

Taking the first value, $\operatorname{Tan} \phi = \frac{3.288}{10} = .3288,$

corresponding to an angle of $18° - 12''$,

$$\sin \phi = .31233.$$

$$\text{Current through } A = \frac{100}{\sqrt{(10)^2 + (3.288)^2}} = 9.47 \text{ amperes.}$$

$$I \sin \phi = 9.47 \times .3123 = 2.9567,$$

which (within the limits of tabulated values of functions of angles) checks with the value of $I \sin \psi$.

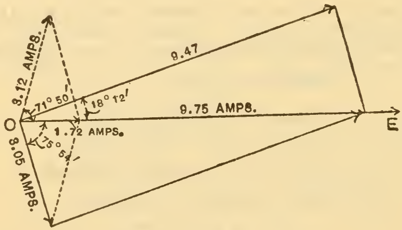


FIG. 9.

The resultant current in the main circuit is found graphically — shown by full lines in Fig. 9 — to be 9.75 amperes, and in phase with the impressed E.M.F.

If the greater value of $L\omega$ be taken,

$$\operatorname{Tan} \phi = \frac{30.516}{10} = 3.0516 = 71° - 50'',$$

$$\sin \phi = 0.95015.$$

$$\text{Current through branch } A = \frac{100}{\sqrt{(10)^2 + (30.516)^2}} = 3.12 \text{ amperes.}$$

$I_1 \sin \phi = 3.12 \times 0.95015 = 2.964$, which checks with $I_2 \sin \psi$ (within limits of tables of functions of angles).

Resultant current is found graphically, as shown by dotted lines in Fig. 9, to be 1.72 amperes, and is in phase with the impressed E.M.F.

From the foregoing equations it can be seen that if $L\omega$ be known and R_1 is the quantity to be determined,

$$R_1 = \sqrt{L\omega\left(\frac{E}{\theta} - L\omega\right)}. \tag{12}$$

If R_1 and L of branch A, and R_2 of branch B are known, the capacity required in branch B is found from the formula,

$$J_m = \frac{1{,}000{,}000}{\omega\left(\frac{E}{2B} \pm \sqrt{\frac{E^2}{4B^2} - R_2{}^2}\right)}, \tag{13}$$

in which $B = I_1 \sin\phi$.

If R_1, L, and J_m be known,

$$R_2 = \sqrt{\frac{1{,}000{,}000}{\omega J_m} \times \left(\frac{E}{B} - \frac{1{,}000{,}000}{\omega J_m}\right)}. \tag{14}$$

If J be taken in farads, formula 14 becomes,

$$R_2 = \sqrt{\frac{1}{\omega J} \times \left(\frac{E}{B} - \frac{1}{\omega J}\right)}. \tag{14a}$$

THE ELECTRIC AUTOMOBILE.

REVISED BY ALEXANDER CHURCHWARD.

THE Electric Automobile has proved itself successful for delivery service in cities and locations where the roads are good and the distance traveled per day is from fifteen to fifty miles, the distance being decreased in proportion to the loads carried. See *Motor World*, 1909.

Where the distance traveled per day under ordinary road conditions is less than ten miles and the speed low, the service can be performed at a lower cost with horse drawn vehicles.

Where the distance traveled per day is greater than fifty miles for the lighter vehicles and twenty-five for the heaviest type, the gasolene electric gives better results than those whose source of energy is a storage battery.

The above statements should be taken as applying to general conditions. Where the conditions are in any way special or severe, cost of operation by each of the three systems should be carefully computed.

Owing to the cost of a horse and wagon being less than a motor driven vehicle, a certain amount of work must be performed each day before the efficiency of the automobile becomes apparent.

The actual cost of gasolene is generally found to be greater per vehicle mile than the cost of charging storage batteries of automobiles for equal loads over the equal distances within the limits above given. Certain limits to daily travel will therefore be found when each type of transportation is cheapest.

(For a more detailed discussion, see *Motor World* on "Improvement of the Electric Vehicle," May 14, 1908. "Commercial Vehicle Problems," — *Motor World*, Oct. 1, 1908. "The Horsepower of the Horse," — *Motor World*, 1908.

Resistance Due to Gravity, and Power Required.

W. WORBY BEAUMONT.

The horse-power required to overcome weight, speed, road resistance, gravity resistance, and efficiency of transmission between armature shaft and road wheel, may be found as follows:

Let R = the resistance to traction of the vehicle on the road in pounds per ton.

G = the resistance due to gravity in pounds per ton.

W = total weight on the wheels in tons.

V = speed in feet per minute.

v = speed in miles per hour.

E = mechanical efficiency of transmission from armature shaft to road.

P = brake horse-power.

e = efficiency of motor.

p = watts supplied to motor.

$$P = \frac{(R+G)\,WV}{33{,}000\,E}, \quad (1)$$

$$P = \frac{(R+G)\,Wv}{375\,E}, \quad (2)$$

$$(R+G) = \frac{PE\,375}{Wv}, \quad (3)$$

$$E = \frac{(R+G)\,vW}{P\,375}, \quad (4)$$

$$v = \frac{PE\,375}{(R+G)\,W}, \quad (5)$$

$$W = \frac{PE\,375}{(R+G)\,v}, \quad (6)$$

$$p = 746\,\frac{P}{e}. \quad (7)$$

For a more detailed discussion of the mechanics of traction see *Electric Traction.*

Resistance to Traction on Common Roads.

W. WORBY BEAUMONT.

Road Surface Material.	Resistance in Lbs. per Ton. On Iron-tired Wheels.	On Solid Rubber Tires.
Asphalt	22 to 28	35 to 40
Wood, hard	22 " 26	40 " 45
" soft	30 " 38	
Macadam, very hard and smooth	40 " 45	35 " 40
" good	45 " 52	
" traffic rolled, wet	52 " 58	
" steam rolled, new and muddy	58 " 62	
" new, flat spread	95 " 105	
Gravel	100 " 140	
Granite tramway	12.5 " 15	
Iron plate tramway	10 " 12	

In most cases these resistances increase slowly at higher speeds, and it must also be noted that the resistance on bad, soft, and gravel roads will probably be greater with propelling wheels than with most hauled wheels. Most of the figures relate to road resistance at walking or slow trotting pace.

Tires.

Solid rubber tires have a higher resistance than steel tires on asphalt roads and have less resistance on macadam and other roads. The perfectly smooth surface of the asphalt produces a drag on the rubber tires, thus increasing their resistance. Pneumatic tires are best adapted to roads with slight inequalities, and for pleasure cars run at high speeds. For both solid and pneumatic tires, the draw-bar pull required to overcome the rolling resistance depends on the speed. This subject has been investigated by Mr. Alex Churchward, and the results of his tests* are reprinted below:

Material of Road.	Grade.	Draw-Bar Pull in Lbs.	Miles per Hour.	Type of Tire.
Asphalt	Level	24	12	Solid
		37	12	Pneumatic
Macadam	1.1%	48	11	Solid
		66	10.6	Pneumatic
Macadam	Level	29	12	Solid
		44	12	Pneumatic
Belgium block	9.5%	250	5	Solid
		270	5	Pneumatic
Asphalt	4.7%	132	7	Solid
		150	7	Pneumatic
Macadam	3.75%	114	8	Solid
		128	8	Pneumatic
Asphalt and brick	3.125%	95	8.5	Solid
		119	8.5	Pneumatic
Asphalt	2.25%	85	8.8	Solid
		103	8.8	Pneumatic

* See *The Commercial Vehicle*, April, 1906.

The above figures are averages of readings taken for a great many vehicles.

The difference in the consumption of power when running on wet and dry pavements was discovered to be so small that the additional tractive effort required when the pavements are wet may be neglected.

The temperature of the asphalt greatly affects the consumption of energy. In one case a difference of 40 per cent was found in the power required for operating a car on cold and on warm asphalt.

Tractive efforts of 119 pounds per ton for two inches of sand and 138 pounds per ton for muddy roads were obtained.

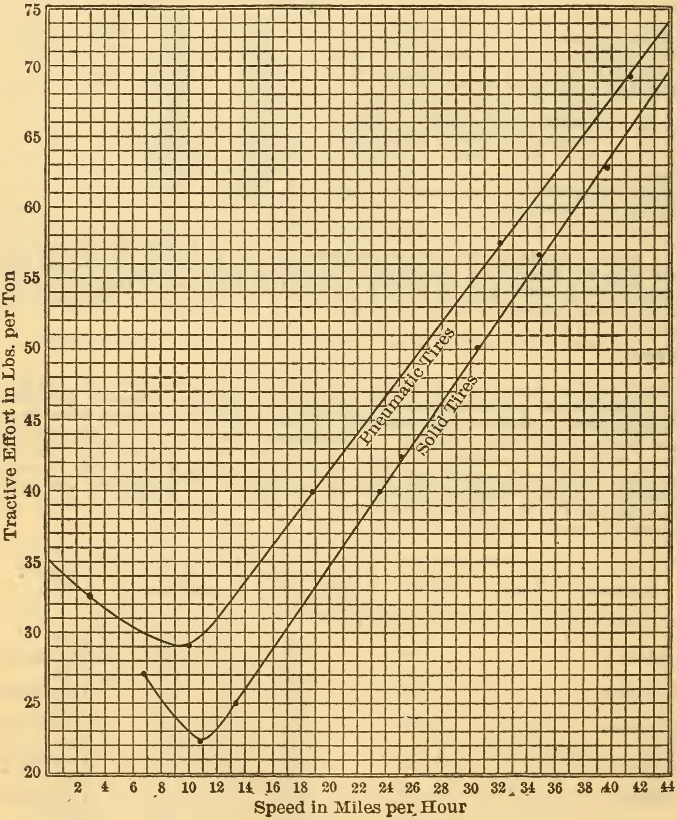


FIG. 1.

Results of tests for the tractive effort at several speeds are shown by the curves in Fig. 1. It will be noticed that the draw-bar pull diminishes as the speed is reduced, to a minimum, and increases as the speed is still further reduced. The speed in miles per hour at which the minimum point occurs varies with different weights of vehicles, diameter of wheels and types of tires used.

Motors.

The present general practice is to install one series-wound motor on all except the very largest trucks. However, under certain conditions of road bed and the type of tires used, it may be advantageous to use even a four-motor four-wheel drive. Usually, however, under fair road conditions, one large motor has proved more efficient than a number of smaller ones.

A normal voltage has been adopted at 80–85 volts to correspond with the minimum discharge voltage of batteries adapted to 110–115 volt charging circuit. Some of the motors are designed for operation at increased speeds by shunting the fields with a resistance, especially on the higher speed pleasure vehicles. This practice is considered preferable to commutating the batteries.

Controllers.

In the past few years, the number of speed points has been almost doubled, combining this with the latest type of control by the continuous torque system; the handling of a vehicle is now smooth and more efficient. There is no perceptible jar or shock when going from one speed point to another and the result is that the maintenance of the entire vehicle has been considerably reduced.

Batteries.

The standard equipment for the wagons and trucks is 44 cells of the lead type of storage battery or 60 cells of the Edison type and of a suitable ampere capacity. These numbers permit of charging from the lighting companies' feeders at 110–115 volts with a minimum loss in the charging rheostat. Runabouts and other very small vehicles are equipped with 24 or 30 cells of moderate ampere capacity, as a saving in weight is thereby obtained over 44 cells of smaller ampere capacity that more than offsets the loss in the charging resistance. A battery can be supplied to meet almost any requirement of travel in miles per day, but it is generally found that the weight of battery required for distances above 50 miles per day for light commercial vehicles and 25 miles per day for the heaviest so reduces the efficiency of the automobile as a whole that the gain over other methods of transportation is not so marked as it is with the battery of standard size.

The following lists of batteries may be used as a guide in selecting those for any equipment:

The Electric Storage Battery Company.

	Type MV "Exide."								Type PV "Exide."			
Number of plates	7	9	11	13	15	17	19	21	5	7	9	11
Discharge in amperes for 4 hours	21	28	35	42	49	56	63	70	12	18	24	30
Size of plates:												
Width	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	4 13/16	4 13/16	4 13/16	4 13/16
Height	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8	8 5/8
Outside measurements of rubber jars, in inches:												
Length	2 3/4	3 1/2	4 1/4	5	5 3/4	6 1/2	7 1/4	8	2	2 3/4	3 1/2	4 1/4
Width	6 1/8	6 1/8	6 1/8	6 1/8	6 1/8	6 1/8	6 1/8	6 1/8	5 5/16	5 5/16	5 5/16	5 5/16
Height	12 3/8	12 3/8	12 3/8	12 3/8	12 3/8	12 3/8	12 3/8	12 3/8	11 7/8	11 7/8	11 7/8	11 7/8
Allow 3/4 inch above the top of jars for straps.												
Weight in pounds:												
Element	18 1/2	23 1/2	28 3/4	34	39	44	49 1/4	54 1/4	10	14	18	22
Electrolyte	2 1/2	3 1/4	3 3/4	4 1/2	5	5 3/4	6 1/4	7	1	2	3 1/2	5
Complete cell	22	28 3/4	35 1/4	41	46 3/4	53 1/2	60 1/4	66 3/4	14 1/4	19 1/4	24 1/4	29 3/4

Gould Storage Battery Company.

	Type EP. Plates $5\frac{3}{4} \times 8\frac{3}{4}$					Type TP. Plates $5\frac{3}{4} \times 8\frac{3}{4}$				Type NP. Plates $4\frac{3}{4} \times 8\frac{3}{4}$.			
Number of plates . .	11	13	15	17	19	7	9	11	13	5	7	9	11
Discharge in amperes at four-hour rate .	42	$49\frac{1}{2}$	57	$64\frac{1}{2}$	72	21	28	35	42	12	18	24	30
Capacity at four-hour rate of discharge .	168	198	228	258	288	84	112	140	168	48	72	96	120
Outside dimensions of rubber jar in inches:													
Length	5	$5\frac{3}{4}$	$6\frac{1}{2}$	$7\frac{1}{4}$	8	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$	5	2	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$
Width	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$6\frac{1}{8}$	$5\frac{5}{16}$	$5\frac{5}{16}$	$5\frac{5}{16}$	$5\frac{5}{16}$
Height	12	12	12	12	12	12	12	12	12	12	12	12	12
Weight of cell complete: Pounds	45	53	61	69	77	$24\frac{1}{2}$	$31\frac{1}{2}$	$38\frac{1}{2}$	$45\frac{1}{2}$	$14\frac{1}{4}$	$19\frac{1}{4}$	$24\frac{1}{4}$	$29\frac{3}{4}$

To height of jar add $\frac{1}{2}$ inch for straps, and 1 inch for bottom of tray.

Rules for the Proper Care of Batteries.

A battery must always be charged with direct current and in the right direction.

Be careful to charge at the proper rates and to give the right amount of charge; do not undercharge or overcharge to an excessive degree.

Do not bring a naked flame near the battery while charging or immediately afterwards.

Do not overdischarge.

Do not allow the battery to stand completely discharged.

Voltage readings should be taken only when the battery is charging or discharging; if taken when the battery is standing idle they are of little or no value.

Do not allow the battery temperature to exceed 100° F.

Keep the electrolyte at the proper height above the top of the plates and at the proper specific gravity. Use only pure water to replace evaporation. *Never add acid* except under conditions as explained in the instructions.

Keep the cells free from dirt and all foreign substances, both solid and liquid.

Keep the battery and all connections clean; keep all bolted connections tight.

If there is lack of capacity in a battery, due to low cells, do not delay in locating and bringing them back to condition.

Do not allow sediment to accumulate to the level of the plates.

ELECTROCHEMISTRY.—ELECTRO-METALLURGY.

REVISED BY PROFESSORS F. B. CROCKER AND M. ARENDT, OF COLUMBIA UNIVERSITY.

ELECTROCHEMISTRY.

Electrolysis: The separation of a chemical compound into its constituents by means of an electric current. Faraday gave the nomenclature relating to electrolysis. He called the compound to be decomposed the Electrolyte, and the process Electrolysis. The plates or poles of the battery he called Electrodes. The plate where the greatest potential exists he called the Anode, and the other pole the Cathode. The products of decomposition he called Ions.

Lord Rayleigh found that a current of one ampere will deposit 0.017253 grain, or 0.001118 gramme, of silver per second on one of the plates of a silver voltameter, the liquid employed being a solution of silver nitrate containing from 15 per cent to 20 per cent of the salt.

The weight of hydrogen similarly set free by a current of one ampere is .00001044 gramme per second.

Knowing the amount of hydrogen thus set free, and the chemical equivalents of the constituents of other substances, we can calculate what weight of their elements will be set free or deposited in a given time by a given current.

Thus the current that liberates 1 gramme of hydrogen will liberate 7.94 grammes of oxygen, or 107.11 grammes of silver, these numbers being the chemical equivalents for oxygen and silver respectively; the chemical equivalent being the atomic weight divided by the effective valency.

To find the weight of metal deposited by a given current in a given time, find the weight of hydrogen liberated by the given current in the given time, and multiply by the chemical equivalent of the metal.

Thus: Weight of silver deposited in 10 seconds by a current of 10 amperes = weight of hydrogen liberated per second $\times$ number seconds $\times$ current strength $\times$ 107.11 = .00001044 $\times$ 10 $\times$ 10 $\times$ 107.11 = .1118 gramme.

Weight of copper deposited in 1 hour by a current of 10 amperes =
.00001044 $\times$ 3600 $\times$ 10 $\times$ 31.55 = 11.86 grammes.

Since 1 ampere per second liberates .00001044 gramme of hydrogen, strength of current in amperes

$$= \frac{\text{weight in grammes of } H. \text{ liberated per second}}{.00001044}$$

$$= \frac{\text{weight of element liberated per second}}{.00001044 \times \text{chemical equivalent of element}}$$

Resistances of Dilute Sulphuric Acid.

(Jamin and Bouty.)

Density.	Ohms per c.c. at				Ohms per Cu. In. at			
	0° C. or 32° F.	8° C. or 46.4° F.	16° C. or 60.8° F.	24° C. or 73.2° F.	0° C. or 32° F.	8° C. or 46.4° F.	16° C. or 60.8° F.	24° C. or 73.2° F.
1.1	1.37	1.04	.845	.737	.540	.409	.333	.290
1.2	1.33	.926	.666	.486	.524	.364	.262	.191
1.25	1.31	.896	.624	.434	.516	.353	.246	.171
1.3	1.36	.940	.662	.472	.535	.370	.260	.186
1.4	1.69	1.30	1.05	.896	.666	.512	.413	.353
1.5	2.74	2.13	1.72	1.52	1.16	.838	.677	.598
1.6	4.82	3.62	2.75	2.21	1.90	1.43	1.08	.870
1.7	9.41	6.25	4.23	3.07	3.71	2.46	1.67	1.21

Elements.	Symbols and Valencies.	Atomic Masses.*	Chemical Equivalents.	Electro-Chemical Equivalents. Grammes per Coulomb.	Grammes per Ampere-hour.	Ampere-hours per Gramme.	Pounds per Ampere-hour.	Ampere-hours per Pound.
Aluminium† . . .	Al III	26.9	8.965	.0000936	0.3370	2.9674	.000743	1346.0
Antimony	Sb III	119.5	39.83	.0004157	1.4965	0.6682	.003299	303.1
Bromine	Br I	79.34	79.34	.0008281	2.9812	0.3354	.006572	152.1
Calcium	Ca II	39.8	19.90	.0002077	0.7477	1.3374	.001648	606.6
Carbon	C IV	11.9	2.975	.0000310	0.1116	8.9606	.000246	4064.5
Chlorine	Cl I	35.18	35.18	.0003672	1.3219	0.7565	.002914	343.1
Copper (cupric) . .	Cu II	63.1	31.55	.0003293	1.1855	0.8435	.002614	382.6
Copper (cuprous) . .	Cu I	63.1	63.10	.0006586	2.3710	0.4218	.005228	191.3
Gold	Au III	195.7	65.23	.0006809	2.4512	0.4080	.005404	185.1
Hydrogen	H I	1.000	1.000	.00001044	0.0376	26.5957	.000083	12063.6
Iodine	I I	125.89	125.89	.0013140	4.7304	0.2114	.010429	95.9
Iron (ferric)† . . .	Fe III	55.6	18.53	.0001934	0.6962	1.4364	.001535	651.5
Iron (ferrous) . . .	Fe II	55.6	27.80	.0002902	1.0447	0.9576	.002302	434.4
Lead	Pb II	205.36	102.68	.0010718	3.8585	0.2592	.008506	117.6
Magnesium	Mg II	24.1	12.05	.0001258	0.4529	2.2080	.000998	1001.5
Manganese	Mn II	54.6	27.30	.0002850	1.0260	0.9747	.002262	442.1
Mercury (mercuric) .	Hg II	198.5	99.25	.0010360	3.7296	0.2681	.008222	121.6
Mercury (mercurous)	Hg I	198.5	198.50	.0020719	7.4588	0.1340	.016444	60.8
Nickel	Ni II	58.25	29.125	.0003040	1.0944	0.9137	.002413	414.4
Nitrogen	N III	13.93	4.64	.0000484	0.1742	5.7405	.000384	2603.8
Oxygen	O II	15.88	7.94	.0000829	0.2984	3.3512	.000658	1520.1
Platinum (platinic) .	Pt IV	193.4	48.35	.0005047	1.8169	0.5504	.004006	249.7
Platinum (platinous)	Pt II	193.4	96.70	.0010094	3.6338	0.2752	.008012	124.8
Potassium	K I	38.82	38.82	.0004052	1.4587	0.6855	.003216	310.9
Silver	Ag I	107.11	107.11	.0011180	4.0248	0.2485	.008873	112.7
Sodium	Na I	22.88	22.88	.0002388	0.8597	1.1632	.001895	527.6
Tin (stannic) . . .	Sn IV	118.1	29.525	.0003082	1.1095	0.9013	.002446	408.8
Tin (stannous) . . .	Sn II	118.1	59.05	.0006164	2.2190	0.4506	.004892	204.4
Zinc	Zn II	64.9	32.45	.0003387	1.2193	0.8201	.002688	372.0

* From the report of the Committee on Atomic Weights to the American Chemical Society, published in the Journal of the American Chemical Society, February, Nineteen Hundred.

† Effective Valency, or number of Hydrogen atoms it will replace.

(Compiled and Calculated by R. S. Woodward, Jr., and G. A. Miller, Jr.)

Resistances of Sulphate of Copper at 10° C. or 50° F.

(Ewing and MacGregor.)

Density.	Ohms per		Density.	Ohms per	
	c.c.	Cu. In.		c.c.	Cu. In.
1.0167	164.4	64.8	1.1386	35.0	13.8
1.0216	134.8	53.1	1.1432	34.1	13.4
1.0318	98.7	38.8	1.1679	31.7	12.5
1.0622	59.0	23.2	1.1829	30.6	12.0
1.0858	47.3	18.6	1.2051 Saturated	29.3	11.5
1.1174	38.1	15.0			

Resistances of Sulphate of Zinc at 10° C. or 50° F.

Density.	Ohms per		Density.	Ohms per	
	c.c.	Cu. In.		c.c.	Cu. In.
1.0140	182.9	72.0	1.2709	28.5	11.2
1.0187	140.5	55.3	1.2891	28.3	11.1
1.0278	111.1	43.7	1.2895	28.5	11.2
1.0540	63.8	25.1	1.2987	28.7	11.3
1.0760	50.8	20.0	1.3288	29.2	11.5
1.1019	42.1	16.6	1.3530	31.0	12.2
1.1582	33.7	13.3	1.4053	32.1	12.6
1.1845	32.1	12.6	1.4174	33.4	13.2
1.2186	30.3	11.9	1.4220 Saturated	33.7	13.3
1.2562	29.2	11.5			

Specific resistance of fused sodium chloride (common salt) at various temperatures.

Temperature Cent.	720°	740°	750°	770°	780°
Ohms per cu. cm.	.348	.310	.294	.265	.247

Applications of Electrochemistry.

The word electrochemistry is here used to include electrometallurgy, as there is no generic term for the two subjects. Electrochemistry may be defined as that branch of science relating to the electrical production of chemical substances and chemical action or to the generation of electrical energy by chemical action. On the other hand electrometallurgy is the branch of science that relates to the electrical production and treatment of metals. The two subjects are based upon the same principles, the theory, laws and data of one being applicable to the other. Hence it is proper and now customary to combine them under the head of electrochemistry.

Electrochemistry may be subdivided as follows:

A. **Electrolytic Chemistry,** which consists in separating or producing other action upon chemical substance by the decomposing effect of an electric current or vice versa. Since the electrolyte is usually in the liquid state, there are:

"Wet methods" with solution.

"Dry methods" with fused materials.

In the latter case the materials are maintained in a state of fusion by the heat due to the electrolytic current or by external heat.

Electrolytic chemistry is applied to the following purposes:

1. *Primary batteries*, including various forms of voltaic cell in which electrical energy is generated by chemical action.

2. *Secondary or storage batteries* are similar to the foregoing, but the chemical action must be reversible, so that after periods of working the cell may be charged or brought back to an active condition by sending through it a current opposite in direction to that which it generates.

3. *Electrotyping* is the art of reproducing the form of type and other objects by electrodepositing metal on the object itself or on a mold obtained from it.

4. *Electroplating* is the art of coating articles with an adherent layer of metal by electrodeposition, as in nickel plating.

5. *Electrolytic refining of metals and chemicals* by the elimination of impurities, as in the conversion of crude copper into pure metal.

6. *Electrolytic production of metals and chemicals*, as in the Hall process for extracting aluminum from alumina dissolved in fused cryolite, and in the Castner process for making caustic soda and chlorine from a solution of common salt.

7. *Electrolytic chemical effects*, such as bleaching, tanning, etc.

8. *Electrolytic chemical analysis*, as in copper determination.

B. **Electrothermal Chemistry** includes those methods in which electric current raises the temperature of materials, usually to a high degree, in order to produce fusion, chemical action or other effects. Since electrolysis is not desired an alternating current is generally employed.

9. *Chemical action with electrical heating*, as in the production of calcium carbide from lime and carbon in an electric furnace.

10. *Electrical smelting* consists in reducing metallic compounds at a high temperature produced by an electric current, as in the reduction of iron ore in an electric furnace, or in the Cowles process for making aluminum bronze from a mixture of alumina, carbon and granulated copper.

11. *Electric fusion of chemicals*, usually those that are very refractory, such as silica and alumina. It has been proposed to make bricks by melting instead of baking clay; electric heat has been used in furnaces for melting glass.

12. *Electrical heating and working of metals* consists in treating metals mechanically with the aid of heat generated by electric currents, as in electrical welding, forging, rolling, casting, tempering, etc.

Strictly speaking, the last two applications are not chemical, but some chemical actions usually occur and they are similar to the others in methods and results, so that it is customary to consider them under the head of electrochemistry.

C. **Chemical Action Due to Electrical Discharges.**

13. *Chemical effects of electrical arcs* to produce combinations of nitrogen and oxygen, for example.

14. *Chemical effects of electric sparks.*

15. *Chemical effects of silent electrical discharge*, as in the production of ozone.

Historical Notes. — The first electrochemical apparatus was the primary battery invented by Volta in 1799. The next year Nicholson and Carlisle discovered the chemical action of the electric current in decomposing water. In 1807 Sir Humphrey Davy gave his famous lecture "On Some Chemical Agencies of Electricity," he having, the same year, discovered the metals sodium and potassium by reducing their compounds electrolytically. In 1834 Faraday established definite laws and nomenclature for electrochemistry. From 1836 to 1839 Jacobi, Spencer, Jordan and Elkington applied these principles to practical use in the making of electrotypes. Planté began the development of the storage battery in 1859. Since that time, but mostly after 1886, the theory and applications of electrochemistry have made great progress, so that now it is one of the most important branches of science as well as of industry.

Primary and Secondary Batteries. — The various forms of these batteries may be regarded as applications of electrochemistry, but they are treated as special subjects in other parts of this book.

Electrotyping. — To reproduce an engraving, typographical composition, or other object, a mold of gutta percha, wax, plaster or fusible alloy is made from the object. If it is not a conductor it is coated with graphite to start the action, connection being made to it by a wire or clamp put around it. It is used as the cathode in a bath consisting of a 20 per cent solution of copper sulphate acidulated with 2–8 per cent sulphuric acid, while the best results are obtained with a current density of .2–.25 amperes per square inch of cathode surface. The anode is a plate of copper. The ordinary thickness of deposit is .01 to .03 inch. The "shell" thus formed is separated from the mold and backed by a filling of type metal.

Electroplating an article with an adherent coating of metal requires the article to be thoroughly *cleaned* mechanically and chemically.

Cleaning.—Solutions for cleaning *Gold, Silver, Copper, Brass* and *Zinc* are prepared as follows:

	Water.	Nitric Acid.	Sulphuric.	Hydrochloric.
For copper and brass . .	100	50	100	2
Silver	100	10	—	–
Zinc	100	—	10	–
Iron, wrought	100	2	8	2
Iron, cast	100	3	12	3

Lead, Tin, Pewter, are cleaned in a solution of caustic soda.

Objects to be plated with gold or silver must be carefully and thoroughly freed from acids before transfer to the solutions. Objects cleaned in soda or those cleaned in acid for transfer to acid coppering solutions may be rinsed in clean water, after which they should be transferred immediately to the depositing solution.

Baths for plating.—The reader is referred to the various books on *electroplating* for particulars, as but few, and those the most used solutions can be referred to here.

Solutions should be adapted to the particular object to be plated, and must have little if any action upon it. Cyanide of gold and silver act chemically upon copper to a slight extent and the objects should be connected to the electrical circuit before being immersed.

Solutions are best made chemically, but can be made by passing a current through a plate of the required metal into the solvent.

Copper.—A good solution for plating objects with copper is made by dissolving in a gallon of water 10 ounces potassium cyanide, 5 ounces copper carbonate, and 2 ounces potassium carbonate.

The rate of deposit should be varied to suit the nature and form of the surface of the object, large smooth surfaces taking the greatest rate of deposit. Electrotype plates must be worked at a slow rate, owing to the rough and irregular surface.

Non-metallic Surfaces may be plated by first providing a conducting surface of the best black lead or finely ground gas coke. Care is required in starting objects of this sort, to obtain an even distribution of the metal, and hollow places may be temporarily connected by the use of fine copper wire.

Copper on iron or on any metal that is attacked by copper sulphate is effected by an alkaline solution. One which can be worked cold is made up of ½ ounce of copper sulphate to a pint of water. Dissolve the copper sulphate in a half pint of water, add ammonia until all the first formed precipitate re-dissolves, forming a deep blue solution, then add cyanide of potassium until the blue color disappears. A heavy current is required with this solution, enough to give off gas from the surface. This solution will deposit at a high rate but ordinarily leaves a rough and crystalline surface, and will not do good work on steel.

A cyanide solution is the most used, takes well on steel or brass, as well as on iron, and permits of many variations.

For each gallon of water use:

Copper carbonate	5 ozs.
Potassium carbonate	2 ozs.
Potassium cyanide, chem. pure.	10 ozs.

Dissolve about nine-tenths of the potassium cyanide in a portion of the water then add nearly all the copper carbonate, which has also been dissolved in a part of the water: dissolve the carbonate of potash in water and add slowly to the above solution stirring slowly until thoroughly mixed. Test the solution with a small object, adding copper or cyanide until the deposit is uniform and strong. For coppering before nickel plating, the coating of copper must be made thick enough to stand hard buffing, and for this reason the coppering solution must be rich in cyanide and have just enough copper to give a free deposit. Use electrolytically deposited copper for anodes, as it gives off copper more freely. Regulate the current for the work in the tanks, and it should be rather weak for working this solution.

Brass Solutions of any color may be made by adding carbonate of zinc in various quantities to the copper solution. The zinc should be dissolved in water with two parts, by weight, of potassium cyanide, and the mixture should then be added to the copper bath. A piece of work in the tank at the time will indicate the change in color of the deposit. Two parts copper to one zinc gives a yellow brass color. For the color of light brass add a little carbonate of ammonia to the brass solution. To darken the color add copper carbonate. Varying the amount of current will also change the color, a strong current depositing a greater amount of zinc, thus producing a lighter color.

Silver. — The standard solution for silver plating is chloride of silver dissolved in potassium cyanide. This solution consists of 3 ounces silver chloride with 9 to 12 ounces of 98 per cent potassium cyanide per gallon of water. Rub the silver chloride to a thin paste with water. dissolve 9 ounces potassium cyanide in a gallon of water and add the paste, stirring until dissolved. Add more cyanide until the solution works freely. The bath should be cleaned by filtering. Great care should be taken to keep the proper proportions between current, silver and cyanide. A weak current requires more free cyanide than a strong one, and too much cyanide prevents the work plating readily, and gives it a yellowish or brownish color. If there is not enough cyanide in the solution the resistance to the current is increased and the plating becomes irregular.

The most suitable current for silver plating seems to be about one ampere for each sixty (60) inches of surface coated.

Gold. — Cyanide of gold and potassium cyanide make the best solution for plating with gold. The solution is prepared in the same manner as the silver solution just described, using chloride of gold in place of chloride of silver. The electrical resistance of the bath is controlled by the quantity of cyanide, the more cyanide the less the resistance, but an excess of cyanide produces a pale color. Hot baths for hot gilding require from 11 to 20 grains of gold per quart of solution and a considerable excess of cyanide. Baths for cold gilding and for plating should have not less than 60 grains per quart and may have as much as 320 grains, this quantity being used with a dynamo current for quick dipping.

Nickel. — The solution now almost universally used for nickel plating is made up from the double sulphate of nickel and ammonia, with the addition of a little boracic acid.

The double salt is dissolved by boiling, using 12 to 14 ounces of the salts to a gallon of water; the bath is then diluted with water until a hydrometer shows a density of 6.5° to 7° Baumé.

Cast anodes are to be preferred as they give up the metal to the solution more freely. Anodes should be long enough to reach to the bottom of the work and should have a surface greater than that of the objects being plated.

Current strength should be moderate, for if excessive the work is apt to be rough, soft or crystalline. Voltage may vary from 3.5 to 6 volts and the most suitable current is from .4 to .8 ampere per 15 square inches surface of the object. Zinc is the only metal requiring more current than this, and takes about double the amount named.

A nickel bath should be slightly acid in order that the work may have a suitable color. An excess of alkali darkens the work, while too much acid causes "peeling."

Iron. — A hard white film of iron can be deposited from the double chloride of iron and ammonia which can be prepared by the current process. It is somewhat used for coating copper plates to make them wear a long time, the covering being renewed occasionally.

The Electromotive Forces suited to the different metals are:

Copper in sulphate	Volt, 1.5–2.5
" cyanide	4. –6.
Silver in "	1. –2.
Gold in "	.5–3.
Nickel in sulphate	2.5–5.5

The Resistance will depend on the nature of the surface. Work is best effected with about equal surface of anode and objects, and the coating will be more even, the greater the distance between them, especially where there are projecting points or rough surfaces.

Copper and *silver* should never show any sign of hydrogen being given off at the objects; gold may show a few bubbles if deep color is wanted. Nickel is always accompanied with evolution of hydrogen, but the bath should not be allowed to froth.

The Rate of Deposit is proportional to current, as described under the head of "Electrolysis," in the proportions given in the table of electrochemical equivalents except in the case of gold, the equivalent of which in combination with cyanogen is 195.7, but subject to modifications dependent upon the hydrogen action just described; there is also a partial solution of the metal, so that there is always a deduction to be made from the theoretical value. Thus: —

Gold gives about		80 to 90	per cent.
Nickel	"	80 to 95	"
Silver	"	90 to 95	"
Copper	"	98	"

An ampere of current maintained for one hour, which serves as a unit of quantity called the "ampere-hour," represents

Gramme	.0376	Grain	.58
Ounce Troy . . .	.00121	Ounce Avoir. . .	.00132

which multiplied by the chemical equivalent will furnish the weight of any substance deposited.

The Electrolytic Refining of Copper.

The largest and most important of electrochemical industries is copper refining, conducted at many places in this country and abroad. The process of refining copper electrolytically consists in the transfer of copper from the anode to the cathode, by the selective action of the electric current, and in leaving the impurities behind in the anode, electrolyte or sediment.

Theoretically the mere transference of copper should require no expenditure of energy, the energy needed to precipitate it from its solution being balanced by the energy set free upon its change to copper sulphate, but practically some is needed on account of the resistance of the electrolyte, and differences in mechanical structure as well as in chemical purity of the anode and cathode.

The material at present subjected to profitable electrolytic refining is crude copper containing from 96 to 98 per cent pure copper and varying amounts of other elements according to the character of the ore and method of dry refining adopted. The composition of the crude material varies greatly, typical samples being given in the following table:

	No. I. Per Cent.	No. II. Per Cent.	No. III.* Per Cent.
Copper	96.35	97.19	98.60
Arsenic	0.08	2.68	0.80
Antimony . . .	0.10	0.01	0.10
Lead	1.19	. . . .	0.10
Tin	0.22	. . . .	. . . .
Bismuth . . .	0.05	0.08	0.05
Iron	0.61	0.02	0.10
Nickel	. . . .	0.02	0.10
Sulphur . . .	0.69	. . . .	0.10
Silver	. . . .	. . . .	0.05
Oxygen and loss	0.71	. . . .	. . . .
	100.00	100.00	100.00

* Chili bar.

Besides these, the crude copper frequently contains small quantities of gold (about one-tenth to one-fifth ounce per ton).

The crude material is cast in iron molds into anode plates, about three feet long, two feet wide, and one inch thick, weighing approximately 250 pounds. The cathode plates are of electrolytically refined copper practically the same in length and width as the anodes but only one-twentieth inch thick. The electrolyte or bath in which the plates are suspended is a solution of 12 to 20 per cent copper sulphate, and 4 to 10 per cent sulphuric acid, the latter being added to decrease the resistance of the solution. This resistance is further reduced by keeping the electrolyte warm at about 40° C.

The containing tanks are of wood, usually lined with sheet lead or carefully coated with a pitch compound, and of such dimensions that a distance of about one inch exists between the faces of the plates.

In some cases the plates are arranged in series, and in others in parallel or multiple, as illustrated. The former has the advantage of requiring electrical connections to be made at the first and last plates only, whereas

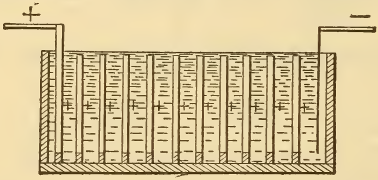


FIG. 1. Series Arrangement of Plates.

the parallel system requires a connection at every plate; but in the series system the leakage of current due to the short-circulating action of the sediment and sides of the tank is from 10 to 20 per cent, so that the parallel is more generally used.

The connections between the various plates and the circuit in the parallel systems are made by copper rods, which are run at two different levels along the edges of the tanks, one bar for anodes and one for cathodes. In some instances these rods are of the inverted V shape, so that the edges will

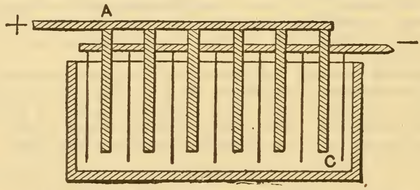


FIG. 2. Parallel Arrangement of Plates.

cut through any corrosion that may happen to form at the points of contact. The drop in pressure at these points is not more than .01 volt. The vats are arranged so that each is accessible from all sides, and the circulation of the electrolyte is possible. This circulation may be obtained by blowing a stream of air through the electrolyte, but more frequently by arranging the vats in steps and connecting them by pipes so that the electrolyte may pass from the top of one vat to the bottom of the next, as shown in Figs. 3 and 4. This maintains a uniform density of the electrolyte which is necessary for the proper formation of the deposit.

The electrical pressure required is from .2 to .4 volt per tank, with a current density of 10 to 15 amperes per square foot of cathode plate surface. The question of current density is very important, because upon this depends the rapidity and quality of the deposit. The rate of deposit, however, is limited and varies with different grades of the crude metal, depending upon the impurities present. For example, antimony, bismuth and arsenic if present would prevent the use of a current density of more than 10 amperes per square foot, as they would be carried over and deposited, especially if present in a soluble form. The maximum current density employed in ordinary copper refineries is as above stated, 10 to 15 amperes per square foot. If the current density is too great the following difficulties will occur:

a. Liberation of hydrogen at the cathode, and thus a resultant waste of energy.

b. Poor character of deposit.

If the current density is too low, the copper is in the tanks too long, and this results in excessive interest charges.

The individual vats are connected in series with each other, so that the total voltage required may be approximately equal to that of the gener-

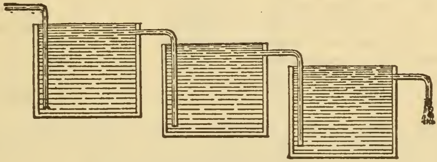


FIG. 3. Circulating System.

ator, allowing the usual drop of about 10 per cent. Standard generators are built to give 125 volts so that a working pressure of about 110 volts is obtained, which is a standard value for lighting and other purposes.

In practice from 400 to 450 ampere-hours are required per pound of copper deposited, the theoretical amount according to Faraday's law being

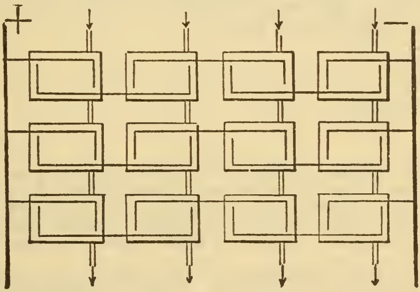


FIG. 4. General Arrangement of Plant.

only 386.2 ampere-hours. The loss varies from 4 to 20 per cent, according to the system employed.

Anode Impurities and their Effect upon the Electrolyte.—The electrolyte when first added consists of 12 to 20 per cent copper sulphate and 4 to 10 per cent sulphuric acid. The impurities likely to exist in the crude metal anodes have been given in the sample analyses preceding, and the following reactions generally occur in an acidulated solution:

1. Silver and gold remain undissolved in the anode or fall to the bottom of the vat.
2. Lead is converted to lead sulphate and precipitates.
3. Antimony, bismuth and tin are partly dissolved as sulphates, or form unstable sulphates which precipitate as basic sulphates or oxides; they partly also remain in the anode sludge.
4. Arsenic, nickel, cobalt and iron dissolve, but are not under ordinary conditions redeposited, hence they merely contaminate the electrolyte.

5. Alkaline earth metals except barium and calcium dissolve readily, the latter precipitating as sulphates.

In addition to contaminating the electrolyte and thus interfering with the purity of the deposit the presence of these impurities, except gold, silver and lead, is objectionable, due to the fact that the anode is consumed unevenly. The more electropositive metals such as tin, zinc, etc., being more rapidly attacked, the anode surface does not remain smooth, and frequently pieces break off and fall to the bottom of the tank. Arsenic, if present, often forms arsenates on the anodes, which results in a non-conducting film, decreasing the current and thus the output.

Effect of the Electrolyte Impurities on the Deposit. — The electrolyte does not accumulate all the impurities of the anode because many of them never go into solution but simply fall to the bottom of the vat as mud. In addition to the proper constituents of the electrolyte there may be present in the dissolved state the sulphates of iron, zinc, cadmium, aluminum, sodium, etc., besides basic sulphates of arsenic, bismuth and antimony. The largest part of the impurities present consists of iron, but the most objectionable are compounds of arsenic and antimony, as these yield their metals at the cathode, with serious results, since as little as .01 per cent of either will reduce the electrical conductivity of copper from 4 to 5 per cent.

Cuprous oxide and copper sulphide remain partly in the sludge and partly dissolve according to the acidity of the electrolyte. Their only evil effect is to neutralize some of the free sulphuric acid.

The composition of the anode sludge (residue) will evidently vary according to the composition of the anode employed, and in practice various amounts of gold, silver and lead are obtained therefrom by subsequent treatment.

The cost of refining copper by the electrolytic method is from ¼ to ¾ cent per pound. The following products of refining are marketed: commercial cathodes, which are sometimes shipped to consumers but more frequently cast into wire bars, ingots, cakes or slabs of standard dimensions and weight. They usually assay from 99.86 to 99.94 per cent of pure copper, a sample analysis being as follows:

	PER CENT.
Copper *	99.938
Antimony	.002
Iron	.004
Oxygen and loss	.056
	100.00

The yield in commercial cathodes is from 97 to 99 per cent of the anodes treated, excluding the anode scrap which varies from 7 to 15 per cent of the original anode in parallel operated plants; but this scrap is not a loss, as it is collected and recast into anode plates. Besides electrolytic copper, most plants recover gold, silver and nickel from the slime as previously stated.

The electrolytic copper refineries in the world are now producing copper at the rate of 322,295 tons annually, valued at $96,688.500 with copper selling at $300 per ton. In addition the by-product in recovered gold and silver is valued at $20,000,000 per annum. There are now in active operation 33 electrolytic copper refineries, with a total generator capacity of 20,000 kilowatts; 10 of these are located in the United States, and supply about 86 per cent of the world's output; 6 plants are in England and Wales producing about 9 per cent, while the remaining plants are on the continent of Europe.

Silver is refined from copper bullion by taking anodes of the bullion ½ inch thick and 14 inches square, and cathodes of sheet silver slightly oiled. The electrolyte consists of water with 1 per cent of nitric acid. When the current is started the copper and silver form nitrates of copper and silver and free nitric acid from which the silver is deposited, leaving the copper in solution. Trays are placed under the cathode for catching the deposited silver, and if there is any copper deposited owing to the solution contain-

* This sample was obtained by refining the crude copper given in column III of the preceding table of crude copper anodes.

ing too little silver or a superabundance of copper, the copper falls into the trays and is redissolved.

In the Moebius process the deposit is continually removed from the cathode by means of a mechanical arrangement of brushes, and falls into the trays above mentioned.

Aluminum. — Practically the output of this metal for the entire world is now produced electrolytically. The only process used on a large scale is that invented independently in 1886 by Mr. Charles M. Hall in the United States, and by Paul L. V. Héroult in France. This process consists in electrolyzing alumina dissolved in a fused bath of cryolite. The alumina is obtained from the mineral bauxite which occurs abundantly in Georgia, Alabama and other regions. The natural material, being a hydrated alumina containing silica, iron oxide and titanic oxide in the following proportions:

Al_2O_3	.56
Fe_2O_3	.03
SiO_2	.12
TiO	.03
H_2O	.26

must be treated in order to drive off the water and eliminate the impurities. This may be accomplished by a chemical process, but it is effected more simply by heating the material mixed with a little carbon as a reducing agent in an electric furnace. The impurities are thus reduced and collect as a metallic regulus in the bottom of the mass. This leaves the alumina nearly pure and it may be tapped off while fused or easily separated by breaking it up after cooling. In practice it requires two pounds of alumina for each pound of aluminum produced. The flux or bath in which the alumina is dissolved consists of cryolite, a natural double fluoride of aluminum and sodium ($Al_2F_6.6NaF$) found in Greenland. This is melted in a large carbon-lined, rectangular, sheet-iron tank, which constitutes the negative electrode, a group of 40 carbon cylinders, each 3 inches diameter and 18 inches long, which are suspended in the tank, forming the positive electrode. A direct current of about 65 horse-power at 5 to 6 volts is used. Only a portion of this voltage is required to decompose the alumina, the balance, amounting to about two or three volts, represents the heat produced which keeps the bath at the proper temperature and fluidity necessary for electrolysis — 850 to 900° C. The passage of the current causes the aluminum to deposit on the bottom of the tank as a fused metal, being drawn off periodically. The oxygen set free combines with the carbon of the positive electrodes and passes off as carbonic oxide. The reaction is $Al_2O_3 + 3C = 2Al + 3CO$. About one pound of carbon is consumed for one pound of aluminum produced. When the alumina becomes exhausted from the bath, the voltage rises and lights a lamp shunted across the electrodes, thus giving notice that more material is needed. Each electrical horse-power produces about one pound of aluminum per day of 24 hours. According to Faraday's law the weight of aluminum deposited by 1,000 amperes is .743 pound per hour. The actual yield of metal by the Hall process is about 85 per cent of this theoretical amount.

The aluminum obtained averages 0.1 per cent iron, 0.3 per cent silicon, with traces of copper, titanium and carbon, but is guaranteed over 99 per cent pure.

The metal when drawn from the tanks is cast into rough ingots which are afterwards remelted and converted into commercial shapes such as sheets, rods, wires, etc.

PRODUCTION OF CAUSTIC SODA.

Caustic soda or sodium hydrate ($NaOH$) is used in the manufacture of hard soaps, in the rendering of wood pulp for paper manufacture, in the purification of petroleum and petroleum residues, and also for the production of metallic sodium.

Many attempts, extending over nearly a century, have been made to manufacture caustic soda ($NaOH$) and chlorine (Cl_2) from ordinary salt ($NaCl$), by means of electrolytic action. The fundamental reaction:

$$2NaCl + 2H_2O + \text{Elect.} = 2NaOH + H_2 + Cl_2$$

is readily obtained experimentally, but is difficult to accomplish on a commercial basis. Salt, or sodium chloride, when electrolyzed in the presence of water will form caustic soda, but secondary reactions take place and the result is a mixture of salt, caustic and hypochlorite of soda. This difficulty can be avoided by separating the caustic soda solution that is formed by a porous diaphragm, or by drawing it off as soon as formed; and in some cases the metallic sodium is absorbed in mercury or molten lead.

The following conditions have been found necessary for the success of this process:

1. Cost of power must be very low — not in excess of $30 per horsepower per annum (24 hours per day).
2. The process must be continuous.
3. The electrodes must be as nearly indestructible as possible.
4. The products of electrolysis must be capable of removal from the vessel or electrolyte as the process proceeds.
5. The maintenance costs must be small.
6. The plant must operate on a large scale.

It is only lately that a few processes have been commercially successful. The two most prominent systems for the electrolytic production of caustic soda and chlorine from common salt are the Castner-Kellner and the Acker processes, one operating at moderate temperatures (40° C.) and the other at high temperatures (850° C.).

The Castner process employed in this country at Niagara Falls is as follows: The electrolytic tank consists of a slate box 4 feet long, 4 feet

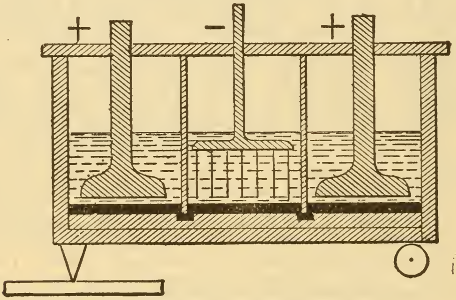


FIG. 5. Castner Cell.

wide and 6 inches deep, the joints being made by means of a rubber cement. Two slate partitions reaching within $\frac{1}{16}$ inch of the bottom (under which are grooves) divide the cell into three compartments, each 15 inches by 4 feet, sealed from each other by a layer of mercury covering the bottom of the tank to a considerable depth. The two end compartments through which the brine is passed are provided with carbon anodes, shaped like a rail section, the broader flange being placed about a half inch above the mercury. These compartments are provided with tight covers and exhaust pipes of rubber and lead to convey the chlorine away. The central compartment has an iron cathode composed of twenty upright strips and is supplied with pure water, which is drawn off whenever its specific gravity increases to 1.27, due to the presence of the maufactured caustic, while the liberated hydrogen is led from this chamber by means of pipes and used as a fuel for the concentration of the caustic. The tank is pivoted at one end on a knife-blade and rests at the other on an eccentric, which raises and lowers that end of the tank about a half an inch once a minute and causes a circulation of the mercury between the outer and middle compartments. The current enters the outer chambers, splits up the sodium chloride (common salt, NaCl) into sodium and chlorine (Na and Cl), the latter is liberated at the carbon anodes and passes through the exhaust pipe to the absorption chambers, where it combines with slacked lime to form bleaching powder ($CaCl_2O_2.CaCl_2$). The sodium combines with the mercury, forming an amalgam containing about 2 per cent of sodium, which by the tilting of the tank passes to the central chamber. where it serves as the anode, and combines with the water to form caustic soda ($NaOH$) and hydrogen (H), the latter appearing at the iron cathode.

Each of these tanks uses 630 amperes at 4.3 volts; 10 per cent of this current is shunted around the inner cell, because otherwise the amalgam would fail to deliver enough sodium, and the mercury would oxidize, thus producing mercury salts and contaminating the caustic. The theoretical voltage required is but 2.3, the remainder being utilized in overcoming the ohmic resistance of the electrolyte and in keeping it warm, the limit of temperature being 40° C., as above this point chlorate is formed. The output of this process per horse-power per day is 12 pounds of caustic and 80 pounds of bleaching powder for each cell. The product contains from 97 to 99 per cent caustic, ½ per cent sodium carbonate, .3 to .8 per cent of sodium chloride and traces of sodium sulphate and silicate.

The Acker process, formerly used at Niagara, for obtaining caustic soda and chlorine from salt is similar to the Castner-Kellner process just described, but differs in that it employs molten lead in place of mercury as a seal, fused salt instead of brine as the electrolyte and operates at a temperature of 850° C. which is required to maintain the fused condition of the electrolyte. The containing vessel is a cast-iron tank five feet long, two feet wide and one foot deep, the sides above the molten lead being covered with magnesia so that the current must pass from the carbon anodes to the lead which acts as the cathode, the lower faces of the anode blocks being three-fourths inch above the lead. At one end of the tank is a small compartment separated from the remainder of the vessel by a partition dipping into the lead to such a depth that nothing but this fused lead can pass from one compartment to the other. The chambers are loosely closed by fire-clay slabs and the escaping chlorine drawn away through side flues by powerful exhausts. In the smaller compartment the lead is subjected to a stream of steam, which, acting upon the lead sodium alloy, forms caustic soda and liberates hydrogen. The steam jet is introduced below the surface, but points vertically upwards, and the resulting spray strikes a curved hood which deflects it into a third chamber in which the lead and caustic separate, the latter flowing out of the furnace over a cast-iron lip, the lead sinking and passing back to the main chamber, while the evolved hydrogen is conducted away. The fused caustic is collected in an iron pan where it solidifies and is removed every hour. The output is 25 pounds of solid caustic per hour. This process avoids the evaporation of the water required in the Castner-Kellner process, but higher maintenance costs offset this advantage. The current employed per vessel in the Acker process is 2100 amperes at from 6 to 7 volts, of which energy 54 per cent is used in chemical action and the remainder in maintaining the temperature.

The same methods that have been commercially successful for the production of caustic soda and chlorine from salt are used to produce caustic potash and chlorine. Caustic potash is of value for the manufacture of soft soaps, the preparation of oxalic acid from sawdust, and for the extraction of metallic potassium. The raw material, potassium chloride (KCl), is more expensive than sodium chloride, costing approximately four times as much,* so it is an advantage to employ the electrochemical process which is more economical in raw material than an ordinary chemical method would be.

Production of Metallic Sodium. — This metal was formerly obtained by the reduction of its carbonate or hydrate mixed with carbon, but at the present time all the metallic sodium employed in commerce is obtained by means of the Castner electrolytic process. The raw material is solid caustic which fuses readily at a low red heat and is obtained by the Castner caustic process already described. A diagrammatic view of the apparatus is shown in Fig. 6. The containing vessel is of steel, the electrodes are usually of cast iron. The electrical pressure employed is about 4.4 volts direct current, the action being as follows: The vessel is placed in an ordinary furnace flue, in which the gases are at a temperature high enough to maintain the caustic soda in a fused state. The current enters at the posi-

* $NaCl$ costs $9.00 per ton; KCl costs $37.05 per ton.

tive electrode, which is a hollow cylinder provided with vertical slits, so as to allow free circulation of the electrolyte. The negative electrode is placed at the bottom of the vessel, and terminates in the space in the center of the anode. A cylinder of iron wire gauze is placed between the electrodes, its function being to prevent the separated sodium from spreading over the entire surface and coming in contact with the oxygen liberated at the anode. The extreme fluidity of the fused caustic, however, allows it to pass readily through the gauze openings, while the greater surface tension of the liberated sodium will not allow it to pass through the same. The metallic sodium in its fused state has a lower specific gravity than the fused caustic, hence it remains at the surface, and is bailed out from time to time. The liberation of hydrogen at the cathode serves to protect the metal from the possible action of the oxygen.

Potassium Chlorate is produced in considerable quantities both here and abroad. The Gibbs process used at Niagara Falls consists in the elec-

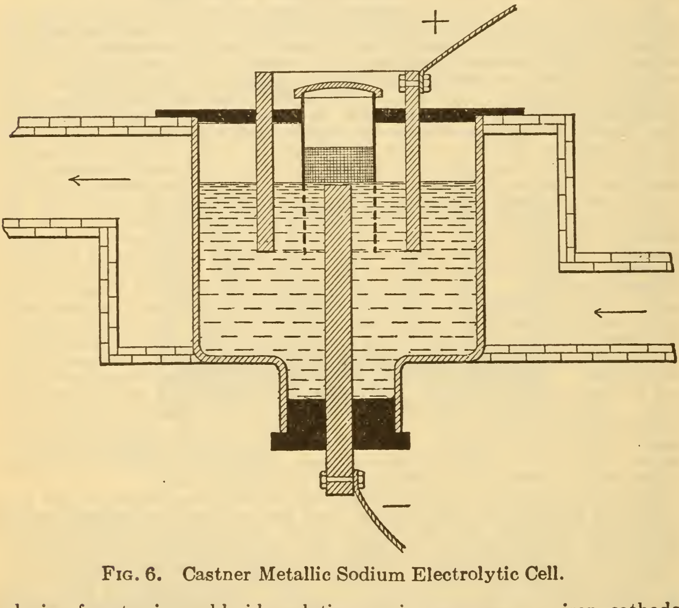


FIG. 6. Castner Metallic Sodium Electrolytic Cell.

trolysis of potassium chloride solutions, using a copper or iron cathode and a platinum anode. The cells are composed of a wooden frame, *A*, covered with some metal, *B*, such as lead, not attacked by the electrolyte. The latest form of cathode consists of a grid of vertical copper wires, *C*, kept in position by crossbars, *D*, of some insulating material, as shown in Fig. 6. The grid is placed in a vertical position against one side of the cell frame, and kept in place by the anode of the adjoining cell, from which it is insulated by the strips, *F*, and bars, *D*.

The opposite side of the cell from that occupied by the cathode is partially closed by the anode (see dotted lines of Fig. 7). This consists of a thick lead plate, *L*, covered with platinum foil on the outer side, *E* (Fig. 8). This anode is held in position by the cathode and framework of the following cell. *G* is a pipe, reaching to the bottom of the cell, by which the potassium chloride is continuously supplied, and *H* is the overflow pipe to convey the mixed solution of the chloride and chlorate, as well as the liberated hydrogen gas away from the cell. *S*, *S*, *S*, *S* are lugs projecting from the framework, by means of which any number of cells can be bolted together to form a series of cells. Fig. 8 shows a group of three cells, the heavy plates (*X* and *Y*) being used to close the ends of the wooden framework, and form a fully closed series of cells with the only openings at the various supply and overflow points. The current connections are made at the points (*m* +) and (*n* —). In normal working the cell is continuously fed by each of the supply pipes *G*, with a solution of potassium chloride, the rate of supply being so regulated as to maintain the temperature of the cell at 50° C., and the amount of chlorate in the discharged solution slightly under 3 per cent.

Since the plates *C* and *L* of each cell are in metallic contact, due to the lead lining, the electrolysis occurs between the anode of one cell and the cathode of the following cell (see narrow space between cells), this space

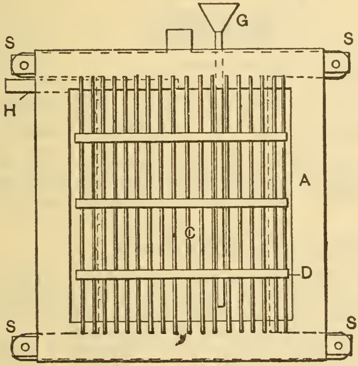


Fig. 7. Gibbs Cell.

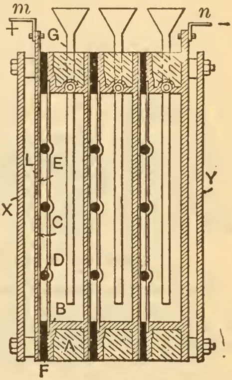


Fig. 8. Gibbs Cell.

being not more than one-eighth inch wide. The fact that the cathode is a grid allows the electrolyte to circulate around it, and all the solution thus passes upwards and out of the cells at *H*.

The percentage of chlorate in the overflow solution is low, thus refrigeration is necessary to recover it, and Fig. 9 is a representation of an electrolytic chlorate plant using this form of apparatus. *S* is the supply tank, *V* the electrolytic cell, *R* the refrigerators, and *P* the pump by means of which the exhausted electrolyte is returned to the supply tank, while the chlorate precipitates out as crystals. The reason for using the refrigerator is that in solutions containing only 3 per cent of chlorate, the latter will not crystallize out upon natural cooling, as it would if present in large quantities. This low percentage of chlorate present is necessary to obtain quick recovery, as otherwise the presence of the hydrogen will cause secondary reactions, and cut down the efficiency of the conversion. The pressure employed is about four volts per cell, of which 1.4 is required to convert the chloride into chlorate

$$6KCl + 6H_2O + Elect. = 6KOH + \overbrace{3H_2} + \overbrace{3Cl_2}$$

$$6KOH + \overbrace{3H_2} + \overbrace{3Cl_2} = 2KClO_3 + 4KCl + \overbrace{3H_2}$$

and the remainder produces the heat that maintains the electrolyte at 50° C. which is necessary for the proper reaction. The current density is high, about 500 amperes per square foot of anode surface. At Niagara the plant consists of fifty such cells, connected up into two sets of 25 cells in series. A direct current of 10,000 amperes is supplied at 175 volts, which, allowing for line drop and losses at cell contacts, gives the proper pressure.

Electrolytic chemical effects such as bleaching have been produced through the action of chlorine or other matter set free by an electric current. It is possible in this way to cause substances to act while in the nascent state and therefore more powerful. Disinfecting and deodorizing of sewage has also been accomplished in a similar manner, as in the Woolf process by

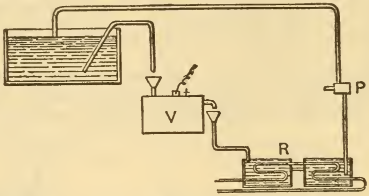


FIG. 9. Arrangement of Gibbs Process.

the electrolysis of a salt solution mixed with the sewage. The passage of the current liberates (Cl_2) chlorine and sodium hypochlorite $(NaClO)$, which act upon the refuse matter.

Electrolytic chemical analysis is a special subject, the discussion of which is usually confined to books and journals relating particularly to chemical analysis; it is not ordinarily considered in connection with the general subject of electrochemistry.

ELECTROTHERMAL CHEMISTRY.

Electrothermal Chemistry includes those methods in which an electric current raises the temperature of materials, usually to a high degree, in order to produce fusion, chemical action or other effects. Since electrolysis is not desired an alternating current is generally employed.

The effect on the materials and the amount of product obtained is more or less proportional to the heat energy developed in the furnace. While the heat necessary to produce a certain change in a given amount of material is perfectly definite, the heat lost by radiation, conduction, etc., is variable, so that the efficiency must always be less than 100 per cent.

The proportion existing between the heat energy employed in an electric furnace to produce a desired physical or chemical change and the total heat supplied is termed the efficiency of the furnace.

The degree of efficiency attainable depends upon many factors:

1. The size of the furnace.
2. Necessary temperature for the desired reaction.
3. Protection from radiation.
4. Arrangement of terminals.
5. Method of recharging, continuous operation being most economical as the heat of the furnace walls is retained.
6. Method of removing the charge, it being undesirable to destroy a furnace to get at the charge.

The most important of all these considerations is undoubtedly the size of the furnace, since the radiating surface of a small capacity is relatively greater than that of a large furnace. Consider two cubical furnaces: one of 1000 units' volume, the other of one unit's volume, the radiating surfaces would be 600 square units for the former, and 6 for the latter; hence the radiating surface for the smaller would be ten times larger per unit capacity and the losses would be in the same ratio.

Electric furnaces are divided into three general classes as follows:

a. Resistance Types.	The material may be heated by passing current directly through it. The material may be heated by the heat generated in a conducting core.
b. Arc Types.	The material may be acted upon by heat radiated from an electric arc. The material may be fed through an arc stream.
c. Induction Type.	Where the charge is conductive and is heated by currents induced in it.

The phenomena occurring in a furnace may be subdivided as follows:
a. Heating alone without fusion, as in the manufacture of graphite.
b. Heating and fusion, as in the treatment of bauxite.
c. Heating and chemical change without fusion, as in the manufacture of carborundum.
d. Heating, fusion and chemical change, as in the manufacture of calcium carbide.

Calcium Carbide. — This compound is produced by an electrothermal process invented by Willson in 1891, the total output throughout the world being about 300,000 tons in 1902. Its value lies in the fact that 1 pound of this substance mixed with water produces theoretically 5.5 and actually about 5 cubic feet of acetylene, equivalent in illuminating power to about 70 cubic feet of ordinary gas. The reaction yielding acetylene is $CaC_2 + H_2O = CaO + C_2H_2$. Various forms of electric furnace have been employed in the production of calcium carbide. One type invented by King and represented in Fig. 10 consists of an iron car, *A*, which holds the materials and carbide, at the same time acting as one electrode. It is run into place or removed as desired, and being provided with trunnions its contents may be tipped out. The other electrode consists of a bundle of carbon plates carried by a heavy rod, *C*, composed of a copper strip strengthened by iron side bars. The material fed through the channels *G*, *F*, consists of a mixture of 1 ton of burnt lime and ¾ ton of ground coke to produce 1 ton of carbide, the reaction being $CaO + 3C = CaC_2 + CO$. An arc is first formed between the electrode, *C*, and the floor of the truck. The resulting high temperature converts the mixture into carbide, the electrode being gradually raised and more material added until the car is nearly filled with the product, when it is run out and replaced by another. At Niagara Falls a rotary form of furnace invented by C. S. Bradley is used, being operated continuously and producing about two tons in 24 hours when supplied with 3,500 amperes at 110 volts, or about 500 horse-power. Since no electrolytic action is required, an alternating current is employed.

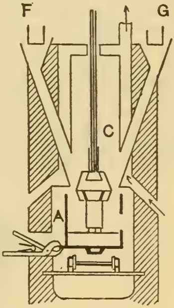


Fig. 10. King Carbide Furnace.

Carborundum is a commercial name for carbon silicide (CSi) produced in large quantities according to the inventions of A. G. Acheson and his assistants. It is used as an abrasive, being hard enough to scratch ruby. It is formed by intensely heating in an electric furnace a mixture of 3½ tons of ground coke, 6 tons of sand and about 1½ tons of sawdust and salt, the yield being 3 or 4 tons of crystalline carborundum and about as much more of the amorphous material. The furnaces used at Niagara Falls consist of fire-brick hearths 16 feet long and 5 feet wide, loosely set together so that the liberated CO can readily escape, with solid brick walls at each end about 2 feet thick and 6 or 8 feet high as illustrated. In the middle of each of these walls there are iron frames through which the current is led to a core composed of carbon, weighing about 1000 pounds and extending the entire length of the furnace. This core is raised to a very high temperature (about 3000° C.) by passing through it for 36 hours an alternating current of about 1000 electrical horse-power at 190 decreasing to 125 volts. The heat from the core permeates the mass and converts it into carbon silicide, which is broken up after the furnace has cooled and used to make hones, wheels for grinding, etc.

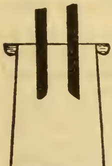


Fig. 11. Alundum Furnace.

Manufacture of Graphite. — This application of the electric furnace depends only upon heat and was suggested to Acheson by the fact that when the temperature limit of the carborundum furnace was exceeded even slightly (250° C.) a large amount of graphite was formed around the conducting core. In fact, it has been stated that a variation of 3 per cent in the size of the carbon core one way or the other would seriously interfere with the working efficiency of the carborundum process — when the core is too small the heat becomes excessive and it is reduced to graphite — the silicon volatilizing. Acheson's experiments indicate that all metallic carbides are decomposed by the application of intense heat, the metal constituent volatilizing, the carbon remaining behind as practically pure graphite, and his patents are based upon this theory.

The commercial work of the Acheson Company is in two lines:

A. Graphitizing formed carbon objects.

B. Graphitizing anthracite coal *en masse.*

The product in every case is pure graphite.

In case *A*, the material to be graphitized, is stacked up in a furnace between the electrodes as a partial core 2 feet square and about 30 feet long, being thickly covered and the spaces between the pieces filled with a finely ground mixture of carbon and carborundum, alternating current of 3000 amperes at 220 volts is applied, and changed to 9000 amperes at 80 volts before the end of the run of about 20 hours.

In case *B* it is found that the best results are obtained if the core consists of a rather impure form of carbon, one which when burned at ordinary temperatures would leave a large percentage of ash (10 to 15 per cent). This is ground to the size of rice grains and used as the furnace charge, with a conducting core of partially graphitized carbon, about **1000 H.P.** of alternating current being applied for 20 hours.

Alundum, the trade name for artificial corundum, is an abrasive made by a process due to C. B. Jacobs and others. Bauxite, a natural hydrated alumina, the same material as used in the Hall aluminum process, is calcined to drive off the water and then fed into an electric furnace, the construction of which is shown in the illustration. It consists of a conical

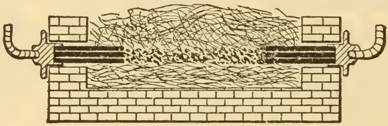


FIG. 12. Carborundum Furnace.

sheet-iron shell mounted on a hydraulically operated plunger that raises and lowers it, to maintain a constant current of 2,000 amperes at 80 volts. The electrodes consist of two carbon rods that project into the shell, which is cooled by water, from the U-shaped trough, trickling down its outer surface.

The time consumed for fusion is about 12 hours. The mass is allowed to cool and is then removed from the furnace by holding the sheet-iron shell in position and lowering the plunger, the product being broken up and sorted. It consists of four parts; namely, a red and blue mass in the interior, crystals that form in the blow holes, a porous outer portion and a by-product consisting of a metallic regulus of ferro-silicon which is used for the treatment of iron in the Bessemer and open-hearth furnaces. The porous outer part is used as a recharge, and the mass as well as the crystals, which are of the general nature of rubies and sapphires, in fact chemically identical with these gems, are ground up and used to make grinding wheels and other abrasives.

Cyanides of Potassium and Sodium are produced electrochemically by the process of C. S. Bradley, C. B. Jacobs and others. A mixture of barium oxide or carbonate with carbon is heated in an electric furnace to produce barium carbide (BaC^2). While the mass is still hot, nitrogen (air cannot be used, as the oxygen present would oxidize the barium and carbon) is passed through it and barium cyanide forms, the complete reaction being:

$$BaO + 3C + N_2 = BaC,N, + CO.$$

The barium cyanide thus produced is treated with sodium carbonate, the result being a mixture of sodium cyanide and barium carbonate. The former is separated by dissolving it in water, the insoluble barium carbonate being used over again. Potassium cyanide is made in a similar manner and either salt is suitable for gold extraction and other purposes for which cyanides are employed.

Electric Smelting.— One of the earliest commercial processes in electrochemistry was that devised by E. H. and A. H. Cowles in 1884. A mixture of about 2 parts of alumina, 1 or 2 parts of granulated copper and 1 or 2 parts of carbon was introduced in a brickwork chamber. Bundles of carbon rods inserted at the ends formed the electrodes between which a current of 3000 amperes at 50 volts was maintained. At a very high temperature the alumina was reduced ($Al_2O_3 + 3C = Al_2 + 3CO$) and the resulting aluminum combined with the copper to form aluminum bronze. This process is no longer of commercial importance, since pure aluminum can be readily purchased; and when smelted with pure copper gives a better grade of aluminum bronze at a lower cost than is possible with the above method.

Iron and steel can be produced by reducing iron ore with carbon in an electric furnace. For example, a mixture of magnetite and carbon can be heated by passing a current through it as in the Cowles aluminum bronze process; through a carbon core in contact with the material as in the carborundum process; or by the action of an arc as in the carbide process. The reaction is $Fe_3O_4 + 4C = 3Fe + 4CO$. Pure (i.e., wrought) iron, cast iron or steel may be produced, depending upon the proportion of carbon. The chief advantages are the directness of the process and the fact that the impurities in the fuel (sulphur, silicon, etc.) are not introduced. On the other hand, it is a question whether the electric furnace can compete in economy with the blast furnace and Bessemer converter.

The field which is at present being developed is the conversion of scrap iron and pig iron into crucible steel by means of the electric furnace. This method offers reasonable chance of success, since the cost of crucible steel is high and therefore the method employed may be relatively costly.

There are several distinctive types of furnaces employed, some being of the arc type, some of the resistance type, and another of the induction type. This latter method seems to be the most promising, since the possibility of introducing anode impurities into the charge is absolutely done away with.

X-RAYS.

REVISED BY EDWARD LYNDON.

The ultimate nature of X-rays is as much a matter of doubt at the present day as when Professor Roentgen presented his original papers in 1895. It is generally conceded that they are the product of cathode rays, these latter having their origin in electrical discharges through high vacua.

X-rays are produced whenever cathode rays strike some solid substance, and the method employed for their production consists in exciting a vacuum tube, having electrodes sealed in its ends, by means of a static machine or from the secondary of a high potential induction coil.

Under the influence of a high potential dark or cathode rays emanate from the negative terminal or cathode; these rays are repelled from the surface of the cathode, and where they impinge on a solid substance X-rays are emitted.

X-rays and cathode rays are fundamentally different in that the cathode rays are subject to magnetic deflection, while X-rays are not. This fact is explained on the assumption that the cathode stream consists of particles moving at high velocity and carrying a negative charge. Such a stream is capable of being deflected by a magnetic field. When, however, the cathode stream strikes the solid substance, called the anti-cathode, the particles yield up their electric charge, and in passing from this point as X-rays show no magnetic deflection.

The discharge of the cathode stream does not necessarily take place within the tube from terminal to terminal, but may be made to travel in any desired direction by altering the position and configuration of the cathode.

The generally accepted idea is that these rays travel in lines normal to the surface from which they originate, and for this reason the cathode may be so shaped that the rays can be focused on the anti-cathode; that cathode rays can be focused is well known, but William Rollins holds that it is doubtful if the rays actually travel in lines normal to the cathode surface, reasoning that since the cathode stream is made up of moving particles carrying a negative charge there must exist a repelling force between all such particles; if this repelling force did not exist, the path of travel would be normal to the cathode surface, and the focus point would be found at the center of curvature of the cathode. Rollins states that the focus point lies *beyond* the center of curvature of the cathode and that this distance between the actual focus and the center of curvature increases with increasing potential across the tube terminals, due to an increased charge and consequent increased repelling force between the particles constituting the cathode stream.

Where cathode rays strike upon glass or a like substance, the phenomenone of fluorescence appears. These rays are similar in many respects to X-rays, both are able to excite fluorescence, to affect sensitive films, and are subject to selective absorption in passing through solid substances.

The fact that reflection and refraction have not been conclusively shown by experiment to be properties of X-rays would indicate that these rays are not in the order of transverse vibrations.

Quite recently, however, experiments have been made in which it was shown that X-rays are subject to polarization, and while reflection and refraction have not been absolutely proven to be properties of the rays, the generally accepted idea is that X-rays are ether vibrations of enormous frequency and short wave length. These rays, like ultra violet light, will discharge electrified bodies. This fact may be accounted for on the material theory of X-rays, on the assumption that when the charged particles making up the cathode stream strike the anti-cathode they yield up their electric charge and pass from this point as X-rays, to all purposes a stream of moving particles divested of their electric charge; these particles would then tend to become charged again in the presence of an electrified body. It is more probable, however, that X-rays are ether vibrations, and that discharge of electrified bodies under their influence is due to ionization of the air, being similar in this respect to ultra violet light.

Tubes. — Tubes for the production of X-rays are made of glass, the electrodes are sealed in the tube and the air exhausted, and upon the degree of vacuum depends the penetration of the X-rays emitted.

It is desirable, and the general practice, to provide some metallic body in the tube upon which to focus the cathode rays, this being the anti-cathode, and it is from this body that X-rays are emitted. In Fig. 1, *A* is the anode, *B* the anti-cathode, and *C* the cathode. The relative positions of these terminals may vary considerably with the different types, but in all cases the functions are the same.

A separate electrode in the tube acting as the anti-cathode is not essential in the production of X-rays; as they are emitted whenever the cathode rays strike any solid substance, they would appear if the cathode rays were focused on the glass tube itself, or the cathode rays may be focused so as to fall on the anode, making this single electrode both anode and anti-cathode.

The anode and cathode are usually made of aluminum, as this metal undergoes very little disintegration under the action of discharge. Owing

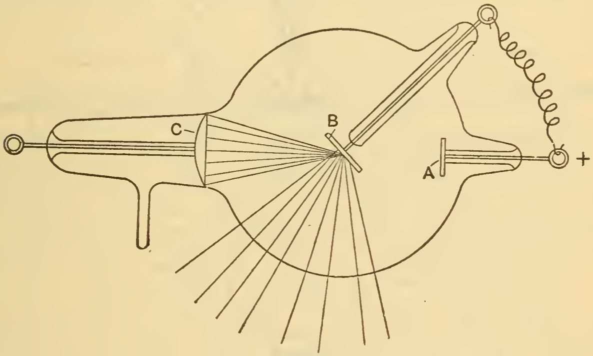


FIG. 1.

to the difference in the expansion coefficients of glass and aluminum it is necessary to join the anode and cathode to platinum wires, sealing the platinum into the glass in order to make the external connections.

Where the cathode rays strike upon a comparatively small area on the anti-cathode considerable heat is developed, consequently some metal, such as platinum, which is capable of withstanding high temperature, must be used for the anti-cathode.

Under normal operating conditions the anode and the anti-cathode are connected to the positive of the source of supply, while the cathode is, of course, connected to the negative. Considerable care should be exercised in keeping the direction of current flow through the tube in the right direction, for if the direction of current be reversed and continued for a length of time, blackening of the tube will result because of the disintegration of the platinum anti-cathode, and the tube becomes inoperative. The direction of the current flow, *per se*, through the tube has nothing to do with the production of X-rays, but it is essential that the cathode stream should travel in such a direction at all times so as to strike the anti-cathode.

The tube shown in Fig. 1 would emit X-rays if the exciting source were an alternating current of sufficiently high potential, but X-rays available for use, i.e., those sent out from the anti-cathode, would be emitted only half the time, or during that time in which the current would be normal in direction, while the tube would be subject to a certain amount of damage during those portions of time in which the current flowed in the wrong direction.

Tubes have been made for use with alternating currents, one form of which is shown in Fig. 2. In the tube shown both terminals are so shaped as to focus the cathode rays from each terminal during the half cycle in which it is a cathode, upon a common anti-cathode.

The penetration of X-rays is dependent upon the vacuum in which they originate, while the emissivity of the anti-cathode increases as the atomic weight of the substance forming it increases.

Since the penetrative power of the rays is in a measure proportional to the degree of vacuum, several tubes of various degrees of exhaustion are necessary where the class of work is varied, and in all cases tubes should be selected for the particular use for which they are intended; but one having a vacuum, the resistance of which is equivalent to a six or eight-inch spark gap, will give fairly good results for a variety of work.

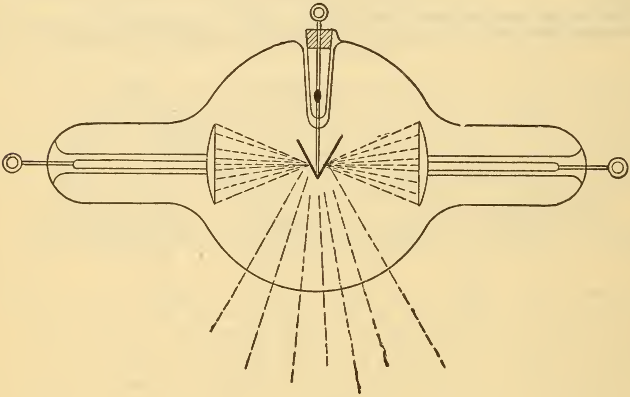


FIG. 2.

A. W. Isenthal and H. Snowden Ward state that "there exists a condition, the causes for which have not yet been sufficiently studied, when the tube emits rays of great penetration and withal yields a vigorous image, both on the fluorescent screen and on the plate. The characteristics of this stage of maximum efficiency are an incandescent anti-cathode with some traces of blue anode light in the tube. Unfortunately this state of affairs is more or less transient, and the tube soon becomes perforated."

The vacuum gradually increases with the amount of use of tubes, this being ascribed to the fact that the anti-cathode and other platinum parts within the tube are subject to slow disintegration under the action of discharge, and the particles so separated, on cooling, occlude some of the residual gas in the tube.

If the increased vacuum is due to the occlusion of the residual gas, obviously the original vacuum may be partially restored by the application of heat, the occluded gas being given up under the action of heat.

This heat may be supplied by some external source or by sending through the tube a current of sufficient strength to appreciably warm it, the former method being preferable.

In all cases it is advisable to include a spark gap in the circuit to the tube. It lessens the liability of the tube to puncture in case one of the electrodes becomes detached, and it acts as a gauge on the vacuum, discharge taking place across the gap if the vacuum and the consequent resistance of the tubes increase appreciably.

Regenerative Tubes. — It is impossible to prevent gradual changes in vacuum, and resulting changes in resistance and penetrative power of the rays with continued use of a tube, but these changes from the original state may be minimized by the use of Regenerative Tubes, many types of which are on the market.

There are certain substances, such as palladium, etc., which occlude gas at ordinary temperatures and yield up this occluded gas on being heated; advantage is taken of this property for maintaining the vacuum. One type of regenerative tube is shown in Fig. 3.

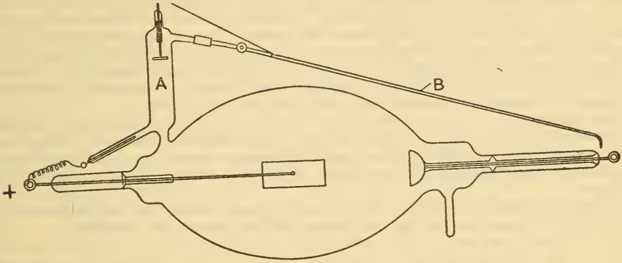


FIG. 3.

The absorbent is placed in a branch of the tube, shown at *A*; an auxiliary path for the current is provided through this branch, but under normal conditions no current passes via this auxiliary path. If, however, the vacuum increases beyond a predetermined spark length for which the adjustable arm *B* is set, the current will then travel by way of the auxiliary path in preference to the path through the tube, with the result that the cathode rays from the auxiliary cathode in the absorbent chamber will heat the absorbent, causing it to give up its gas which lowers the vacuum in the tube. This gas, however, is reabsorbed when the tube cools.

Another method of regeneration depends upon the fact that at high temperatures platinum is permeable to hydrogen. Fig. 4 shows a tube in which a platinum wire is sealed into the side neck of the tube at *A* and is protected by a glass cap. When the resistance of the tube increases appreciably the glass cap protecting the wire is removed, and as the latter is heated by means of a Bunsen Burner or a spirit lamp, hydrogen is introduced into the tube, lowering the vacuum.

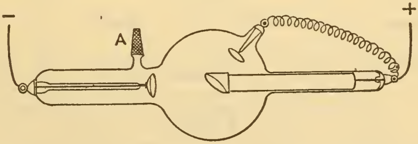


FIG. 4.

The tube shown in Fig. 4 has an anti-cathode designed to obviate high temperatures at this point. This anti-cathode consists of a heavy metallic head with an oblique reflecting surface, the head forming part of a metallic tube which extends back into the comparatively cool side neck, this metallic tube being connected to the outside terminal by means of a wire. Due to the fact that the head and metallic tube have considerable mass and are good conductors of heat, exposing a large surface for radiation, the heating of the reflecting surface is not excessive.

Various forms of anti-cathodes have been devised to obviate high temperatures, generally taking the form of water cooling (not in direct contact), or by so disposing metallic bodies that the heat generated at the reflecting surface will be rapidly conducted away.

Exciting Source. — The minimum potential across the terminals of a vacuum tube for the production of X-rays has been variously estimated from 7000 to 100,000 volts. The appearance of X-rays, however, under a pressure of 7000 volts was due to special conditions, and, ordinarily, pressures much higher must be employed.

High potentials could, of course, be obtained from specially designed transformers working on alternating current circuits, but since double focus tubes, adapted for alternating current, present difficulties in actual operation, their use has not become general, and other sources of high potential giving a uni-directional current are almost universally used.

Static machines give very good results, their current being uni-directional and the potential practically constant, and therefore a steady discharge is produced through tubes excited from these machines.

They are simple, and since they dispense with batteries and induction coils have much to recommend them; unfortunately, however, they behave in the most erratic fashion, the polarity being subject to reversal whenever rotation of the disks is discontinued, this, of course, being a serious disadvantage.

The most general method employed for excitation is by induction coils, giving high potentials at the terminals of the secondary winding.

The induced current in the secondary winding is not, however, uni-directional, but alternating in character. The wave form of the secondary current, while alternating, is not uniform, i.e., the induced E.M.F. due to rupturing the current in the primary circuit greatly exceeds the induced E.M.F. produced by closing the primary circuit, or, in other words, the induced E.M.F. at break is greater than E.M.F. of make.

Fig. 5 shows the manner in which the current in the primary circuit varies.

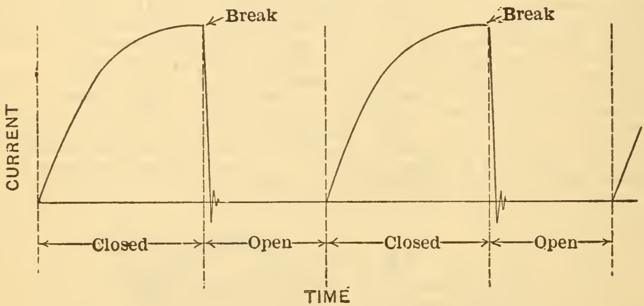


Fig. 5.

Because of the inductance of the coil, the current does not immediately reach its maximum value, but increases logarithmically as indicated by that portion of the curve marked "closed."

The inclination of the curve, or the rapidity with which it reaches its maximum, will vary with the constants of the circuit for each particular coil, but Fig. 5 shows the general form of the current curve. The rapidity with which the current changes in a circuit is proportional to the time constant of the circuit or L/R, in which L is the self-induction and R the resistance of the circuit.

When the circuit is ruptured, however, the time within which the current falls to zero, depending upon the ratio of the inductance (L) and resistance

(R) of the circuit, is greatly diminished because R is increased enormously, due to opening the circuit. The ratio L/R, and consequently the time in which the current falls to zero, is very small as compared with the corresponding values on closing the circuit.

Since the induced E.M.F. in the secondary circuit is proportional to the *rate* of *change* of magnetic lines through the turns of the secondary coil, it is evident that the induced E.M.F. of break will greatly exceed that of make, as the current of the primary circuit changes very much more rapidly in the former case than in the latter.

Usually the E.M.F. due to closing the primary circuit is not of sufficient intensity to excite the tube, so, for this purpose, the current from the secondary of an induction coil may be considered as uni-directional.

Interrupters. — Interrupters for opening and closing the primary circuit should have the following characteristics: (1) Uniformity of interruption, (2) high frequency, and (3) completeness of interruption. With respect to frequency of interruption there are limitations imposed by the properties of the iron core, and the disposition and number of turns of wire composing the coil.

Since the primary current does not instantly reach its maximum value when the circuit is closed, a certain time must be allowed for this increase. If the speed of interrupter be such that the circuit is opened before the current has reached its maximum value, the full capabilities of the coil are not used. This condition is shown in Fig. 6, and the curves shown therein are for current in the primary with respect to time.

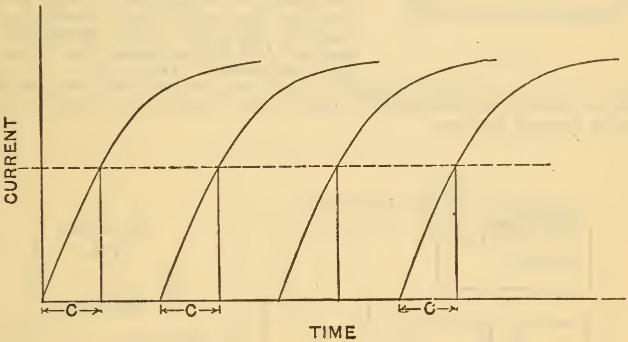


FIG. 6.

In the figure, the frequency of the interrupter is such that the circuit remains closed only through the time interval indicated by the letter C, during which time the primary current has reached only a value shown by the height of the ordinate at the instant of interruption.

A coil operating with an interrupter having too high a frequency may have its effectiveness increased if the E.M.F. impressed on the primary circuit be increased, thereby forcing the primary current to a higher value in the same time interval; on the other hand, the effectiveness may be increased under certain conditions by increasing the time of make and reducing the time of break, the frequency of the interrupter and the applied E.M.F. remaining the same.

There are two general types of interrupters, viz., mechanical and electrolytic. Many forms of mechanical interrupters have been devised and various designs are on the market in which provisions have been made for varying the frequency of interruption and the ratio of time of make and break.

It is essential in all cases that the actual breaking of the current should be as nearly instantaneous as possible, and to this end the spark forming between the breaking surfaces or points must be extinguished. In some instances sparking across contacts is obviated by connecting a condenser across the interrupter, while in other designs the spark is blown out by a jet of air.

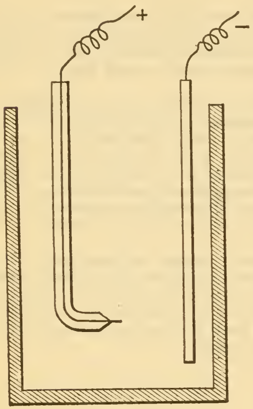


FIG. 7.

The electrolytic or Wehnelt interrupter is shown in its simplest form in Fig. 7, and consists of two electrodes of widely dissimilar proportions, such as a platinum needle point and a large sheet of lead, immersed in a solution of dilute sulphuric acid. The platinum needle point is introduced into the electrolyte through a glass tube, the platinum being sealed into the glass, so that a very small area — practically a point — is in direct contact with the electrolyte. If these two electrodes be connected through an inductance to a source of supply, the current in the circuit will be subject to regular and rapid interruptions. The platinum point electrode should be connected to the positive of the supply source.

The speed of this type of interrupter is decreased by increasing the area of the positive electrode, other conditions remaining the same, while increasing the applied E.M.F. increases the frequency and the current in the circuit.

Fig. 8, shows complete diagram of connections for an X-ray outfit in which an electrolytic interrupter is made use of, the source of current supply being a storage battery.

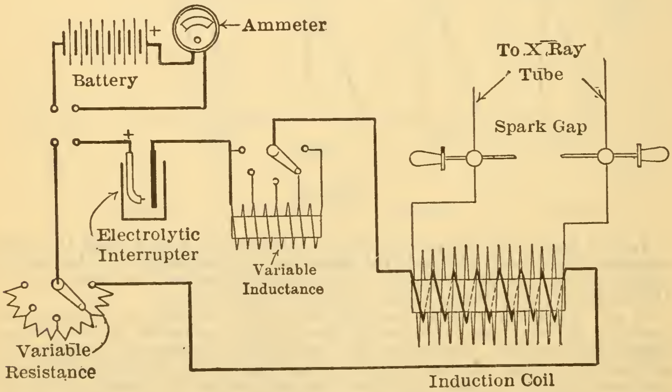


FIG. 8.

As shown in the figure, a variable inductance is included in the circuit. This inductance is unnecessary if there is sufficient self-induction in the winding of the induction coil to properly operate the interrupter.

A variable resistance is also included in circuit in order to vary the applied E.M.F.

FLUORESCOPES.

The phenomenon of fluorescence is the emission of visible light when X-rays or cathode rays strike certain substances.

In transforming the energy of X-rays into light for the examination of radioscopic images some substance must be used which fluoresces under the action of the rays. Roentgen originally used barium platino-cyanide, and this is very largely used now, although various other substances, such as potassium platino-cyanide and calcium tungstate, are in use.

Since the amount of light given out by a fluorescent screen is small, it is necessary to exclude all other forms of light either by carrying out the observations in a dark room or by enclosing the screen in some suitable observation chamber having an opening for the eyes.

The chemicals used in preparing the fluorescent screen are applied to some support, this support in turn being fastened in the observation chamber. Various supports for the chemicals, such as cardboard, vellum, blackened on one side, and rubber, have all been more or less used.

ELECTRIC HEATING, COOKING AND WELDING.

REVISED BY MAX LOEWENTHAL, E. E.

For definitions of Heat, Units, Joule's Law, etc., etc., see pages 3 and 4, "Electrical Engineering Units."

Various Methods of Utilizing the Heat Generated by the Electric Current.

I. **Metallic Conductors** (Uninterrupted Circuit).

1. Exposed coils of wire or strips.
   (*a*) Entirely surrounded by air.
   (*b*) Wound around insulating material.

2. Wire or strips of metal imbedded in enamel.
   (*a*) In the form of coils. } Leonard, Simplex, General Electric,
   (*b*) In flat layers. } Crompton, and others.

3. Wire or strips of metal imbedded in asbestos and other insulating materials.
   (*a*) In the form of coils.
   (*b*) In flat layers.

4. Wire imbedded in various insulating compounds.
   (*a*) Crystallized acetate of sodium, etc. Tommasi.

5. A Film of metal.
   (*a*) Rare metal fired on enamel. } Prometheus.
   (*b*) Rare metal fired on mica. }
   (*c*) Silver deposited on glass. Reed.

6. Sticks of metal.
   (*a*) Crystallized silicon in tubes of glass. Le Roy.
   (*b*) Metallic powder mixed with clay and compressed. Parvillé.

7. Metal in the form of powder or granules.
   (*a*) Kryptol.

8. Incandescent filaments in vacuum.
   (*a*) High wattage, low efficiency lamps. Dowsing, General Electric.

II. **Heat of the Electric Arc** (Interrupted Circuit).

1. The electric furnace. Siemens, Cowles, Parker, and others.
2. Heat of arc acting upon material, producing local fusion. Meritens, Werdemann, Bernardos, Howells, and others.
3. Welding by bringing metals in contact. Thomson.
4. Deflecting arc by magnet. Zerener.

III. **Hydro-electrothermic System, or Water-Pail Forge.** Burton, Hoho and Lagrange.

Referring to the above classification, Section I, the methods referred to under subheads 1 and 3 require no further explanation. The method under subhead 2 consists in imbedding the resistance wire in some fireproof insulation such as enamel or glass. This insulation is of comparatively poor quality as a conductor of heat, and so thin that it affords the least possible resistance to the flow of heat from the heated resistance.

The **Simplex System** (*Carpenter Patents*, subhead 2), employs high resistance wire imbedded in an enamel, consisting of two parts, the ground mass and the surface. The former consists of silica, crystallized borax (for fluxing), fluorspar and magnesium carbonate, mixed in various proportions, powdered and fused. To this is added aluminum silicate and pure powdered quartz. The enamel proper consists of flint meal, also tin oxide, saltpetre, ammonia carbonate, lead sulphate, magnesium sulphate, potassium carbonate, borax, and sometimes gypsum and arsenic. These are carefully mixed, as too much of any ingredient will make the enamel crack off, or will make the fusion point too high or too low. The insulation resistance varies from 40 megohms when cold to 1000 ohms at 400° C. Most enamels melt at about 900° C.

The **General Electric** quartz enamel type unit (subhead 2), consists of spirals of "Climax" resistance wire electrically insulated from the surface to be heated by quartz enamel. The quartz grains are used as an excellent binder for the enamel.

The **General Electric** cartridge type unit (subhead 3), consists of a German silver wire flattened into a ribbon and wound edgewise in a spiral. To insulate between the turns of this spiral it is dipped in a bath of insulating cement. The mass is then squeezed together, so that a thickness of insulating material of .003 inch remains between the turns. The spiral, forming a solid cartridge, is slipped into a brass or German silver shell, with only .01 inch of mica between the edges of the ribbon and the shell. The heat, passing through the thin thickness of mica is conducted to the outer shell and thence by direct contact to the surface to be heated.

The **Prometheus System** (subhead 5) employs units composed of strips of mica about .004 inch thick, on which is painted a thin film of gold or platinum, sometimes only .001 mm. thick. The metals, in the form of powders, are mixed with a flux and then painted on the mica, after which the whole is subjected to a high temperature, the finished films sometimes having a resistance of 100,000 ohms, each being made to consume not more than 70 watts, this giving a temperature of about 450° C. To prevent injury to the film it is covered with another strip of mica, and then together are partly enclosed in a thin metal frame. The insulation resistance of these strips varies from 50 to 300 megohms, and the increase in the resistance of the foil varies from 10 to 20 per cent during a period varying from 1 to 8 minutes.

The **Reed** method of depositing a layer of silver on glass was described in the *Electrical World*, June 5, 1895.

The method employed by **LeRoy** (subhead 6) consists of enclosing sticks of crystallized carbon, having a specific resistance 1333 as high as that of ordinary arc light carbon, in glass tubes. For 110 volts, rods are 100 mm. long, 10 mm. wide, and 3 mm. thick. This takes about 150 watts; and having a surface of 26 sq. cm., the dissipation of heat is at the rate of about 5 kg. calories per sq. cm. of surface, or an absorption of electrical energy of 6 watts per sq. cm. of surface.

Parvillé (*L'Eclairage Elec.*, Jan. 28, 1899) uses rods of metallic powder, mixed with fusible clay (quartz, kaolin), compressed under a pressure of 2000 kg. per sq. cm., and baked at a temperature of 1350° C. A rod 5 cm. long, 1 cm. wide, 0.3 cm. thick, has a resistance of 100 ohms, and absorbs 16500 watts per kg. One quart of water boils in 5 minutes with 15 amp. and 110 volts.

Kryptol (subhead 7) is a patented German substance, consisting of a mixture of graphite, carborundum, silicate and clay in a granular form. A bed of this refractory material has an electrode of carbon at each end. The size of Kryptol granules varies according to the voltage. The current is determined by the thickness of the bed. Temperatures up to 3600° F. may be obtained. During a test made by H. Allen, a cube of copper weighing 8.45 grains was melted in one minute, the pressure being 240 volts and the current 15 amperes.

The above methods are utilized in the construction of electric cooking and heating apparatus, while those enumerated under Sections II and III are employed for purposes of welding, smelting, and forging.

Equivalent Values of Electrical and Mechanical Units.

(H. W. Leonard in "The Electrical Engineer," Feb. 25, 1895, Modified.)

Unit.	Equivalent Value in other Units.
1 K. W. Hour =	1,000 watt hours. 1.34 H.-P. hours. 2,654,200 ft.-lbs. 3,600,000 joules. 3,412 heat-units. 367,000 kilogram meters. .235 lb. carbon oxidized with perfect efficiency. 3.53 lbs. water evap. from and at 212° F. 22.75 lbs. of water raised from 62° to 212° F.
1 H.-P. Hour =	.746 K.W. hours. 1,980,000 ft.-lbs. 2,545 heat-units. 273,740 kg. m. .175 lb. carbon oxidized with perfect efficiency. 2.64 lbs. water evap. from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 Kilo-watt =	1,000 watts. 1.34 horse-power. 2,654,200 ft.-lbs. per hour. 44,240 ft.-lbs. per minute. 737.3 ft.-lbs. per second. 3,412 heat-units per hour. 56.9 heat-units per minute. .948 heat-unit per second. .2275 lb. carbon oxidized per hr. 3.53 lbs. water evap. per hour from and at 212° F.
1 H.-P. =	746 watts. .746 K. W. 33,000 ft.-lbs. per minute. 550 ft.-lbs. per second. 2,545 heat-units per hour. 42.4 heat units per minute. .707 heat units per second. .175 lb. carbon oxidized per hour. 2.64 lbs. of water evap. per hour from and at 212° F.
1 Joule =	1 watt second. .000000278 K.W. hour. .102 kg. m. .0009477 heat-units. .7373 ft.-lb.
1 Ft.-lb. =	1.356 joules. .1383 kg. m. .000000377 K.W. hours. .001285 heat-units. .0000005 H.-P. hour.
1 Watt =	1 joule per second. .00134 H.-P. 3.412 heat units per hour. .7373 ft.-lb. per second. .0035 lb. water evap. per hour. 44.24 ft.-lbs. per minute.
1 Watt per sq. in. =	8.19 heat-units per sq. ft. per minute. 6371 ft.-lbs. per sq. ft. per minute. .193 H.-P. per sq. ft.
1 Heat. unit =	1055 watt seconds. 778 ft. lbs. 107.6 kilogram meters. .000293 K.W. hour. .000393 H.-P. hour. .0000688 lb. carbon oxidized. .001036 lb. water evap. from and at 212° F.
1 Heat-unit per Sq. Ft. per min. =	.122 watts per sq. in. .0176 K.W. per sq. ft. .0236 H.-P. per sq. ft.
1 Kilo-gram meter =	7.233 ft.-lbs. .00000365 H.-P. hour. .00000272 K.W. hour. .0093 heat-unit.
1 lb. carbon oxidized with perfect efficiency =	14,544 heat units. 1.11 lb. anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 21 cu. ft. illuminating gas. 4.26 K.W. hours. 5.71 H.-P. hours. 11,315,000 ft.-lbs. 15 lbs. of water evap. from and at 212° F.
1 lb. water evap. from and at 212° F. =	.283 K.W. hour. .379 H.-P. hour. 965.7 heat units. 103,900 kg. m. 1,019,000 joules. 751,300 ft.-lbs. .0664 lb. of carbon oxidized.

ELECTRIC COOKING.

Cost of Operating Electric Cooking Utensils.

On account of the number of variables which enter into the determination of the cost of electric heating and cooking, it is impossible to present any general data. These variables may be classified as follows:

1. Cost of current. 2. The skill of the operator from the cooking standpoint. 3. The skill of the operator from the standpoint of using the electrical apparatus economically. 4. The type of apparatus employed.

It is possible, however, by assuming an arbitrary cost for current, to calculate the cost of heating a given quantity of water. Let it be required to heat one gallon of water at a temperature of 50° F. (10° C.), without actually boiling it, to the boiling-point, or 100° C.; it would then be elevated 90° C. Hence 3786 cubic centimeters would be raised 90° C. or 3786 × 90 = 340,740 water-gramme-degrees-centigrade of heat are produced. The unit corresponding to a water-gramme-degree-centigrade is the calorie, which requires an expenditure of 4.18 joules, so that the work required to be done in raising a gallon of water to the temperature of 100° C. is equal to 340,740 × 4.18 = 1,424,293 joules. Assuming the cost of electric current, in large quantities, to be 5 cents per kilowatt-hour (which is equal to 3,600,000 joules, as 1 joule = 1 watt per second), the cost of raising one gallon of water to the boiling-point is approximately 2 cents. If we assume the current to cost 15 cents per kilowatt-hour, then the cost would be 6 cents.

This calculation, however, is strictly theoretical, as the assumption is made that all the heat generated is utilized in raising the temperature of the water. This, of course, is not the case, as a certain amount of the heat is transmitted to the metal vessel and the air during the time of the operation (about 15 minutes). Assuming the efficiency of the vessel to be 70 per cent, which represents the ratio between the useful and the total developed heat, then the actual cost of heating a gallon of water from 10° to 100° C. at a cost for current of 5 cents per kilowatt-hour would be $2 \times \frac{100}{70} = 2.86$ cents, or at 10 cents per kilowatt-hour would be 2 × 2.86 = 5.72 cents.

An approximate rule (according to Roger Williams) for estimating the amount of energy required to raise the temperature of a quantity of water in a given time, by means of an electrically heated pot is:

One-third watt will raise one pint of water 1° F. in one hour, or 300 watts will raise one pint of water from 70° F to 212° F in ten minutes.

Cost of Heating Water to Different Temperatures at Various Rates for Electric Energy.

James I. Ayer.

Initial temperature of water, 60° F. Efficiency of apparatus, 85%.

Total Temp. Deg. F.	One Pint Watts Used for				Cost in Cents with Current at			
	5 m.	10 m.	20 m.	1 Hour	3 c.	5 c.	10 c.	20 c.
100	164	82	41.04	13.68	.041	.068	.136	.272
150	372	186	93	31	.093	.155	.31	.62
175	468	234	117	39	.117	.195	.39	.78
200	576	288	144	48	.144	.24	.48	.96
212	624	312	156	52	.156	.26	.52	1.04
		One Quart.						
100	324	162	81	27	.08	.136	.272	.544
150	744	372	186	62	.186	.31	.62	1.24
175	936	468	234	78	.234	.39	.78	1.56
200	1,152	576	288	96	.288	.48	.96	1.92
212	1,248	624	312	104	.312	.52	1.04	2.08
		One Gallon.						
100	1,296	648	324	108	.32	.544	1.088	2.17
150	2,976	1,488	744	248	.74	1.24	2.48	4.96
175	3,744	1,872	936	312	.94	1.56	3.12	6.24
200	4,608	2,304	1,152	384	1.15	1.92	3.84	7.68
212	4,992	2,492	1,248	416	1.25	2.08	4.16	8.32

Efficiency of Electric Cooking Apparatus.

According to Mr. Crompton, the efficiency of an ordinary cooking-stove using solid fuel is only about 2 per cent, 12 per cent being wasted in obtaining a glowing fire, 70 per cent going up the chimney, and 16 per cent being radiated into the room.

In a gas-stove, considering that the number of heat units obtainable from the gas at a certain price is but small compared with solid fuel, the ventilating current required for the operation alone consumes at least 80 per cent of the heat units obtained by burning the gas.

In the case of an electrical oven, more than 90 per cent of the heat energy can be utilized; and thus, although possibly 5 to 6 per cent only of the heat energy of the fuel is present in the electrical energy, 90 per cent of this, or 4½ per cent of the whole energy, actually goes into the food, and thus the electrical oven is practically twice as economical as any other oven, whether heated by solid fuel or by gas.

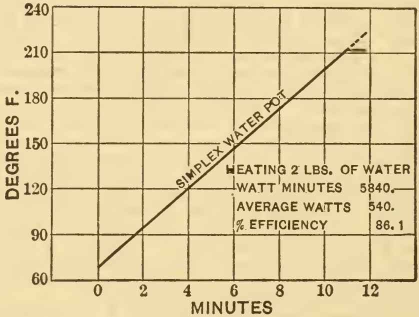


Fig. 1.

Comparative Operating Costs of Gas and Electric Cooking.

Report of Heating Committee, Association of Edison Illuminating Companies, September, 1905.

The comparative operating cost of electric and gas cooking depends upon two questions, — the relative rates for gas and electric heat units, and the relative heat efficiencies of gas and electric apparatus. A third quantity — the effect produced by the different rates and modes of heat applications in the two classes of utensils — may effect the efficiency slightly, but the existence of this effect is not yet verified.

Starting with the heat of coal, which may be fairly estimated as 12,000 B.T.U. per pound, we compute the relative efficiency of the heat conversion as follows:

Gas.

1 pound coal produces 5 cubic feet gas.
5 cubic feet gas contain 3000 B.T.U.
Efficiency heat conversion is

$$\frac{3000}{12000} = 25 \text{ per cent.}$$

Electricity.

1 pound coal produces 0.25 K.W.
0.25 K.W. contains 853 B.T.U.
Efficiency heat conversion is

$$\frac{853}{12000} = 7.1 \text{ per cent.}$$

$$\frac{\text{Efficiency Electrical Heat Conversion}}{\text{Efficiency Gas Heat Conversion}} = 28.4 \text{ per cent.}$$

With manufacturing processes of equal cost per pound of coal converted, it is apparent, then, that an electric heat unit must cost nearly four times as much as a gas heat unit, but with present processes the relative rates are:

Gas.	Electricity.
\$1.00 per 1,000 cubic feet.	\$0.10 per K.W.H.
1 B.T.U. .000167 cents.	1 B.T.U. 0.00293 cents.

$$\frac{\text{Electric B.T.U. } 0.00293}{\text{Gas B.T.U. } 0.000167} = 17.5.$$

It is known that the efficiency of electrical apparatus is about four times that of gas, and, consequently, as the gas utensil requires four times as many B.T.U., the above figure of 17.5 is reduced to 4.4. If, then, the rate for electricity is reduced to one-quarter of that assumed, or 2.5 cents per K.W.H. this figure of 4.4 is changed to 1.1, and we have practically identical operating costs.

Comparison between Gas and Electric Rates.

According to James I. Ayer (report for National Electric Light Association, May, 1904) electric heat at an average efficiency of seventy per cent equals .4197 K.W.H. per 1,000 effective heat units, and for 105,000 effective heat units there would be required 44.065 K.W.H. to give the same results. To compete with gas at equal rates, electricity will have to be sold

at 5.67 cents per K.W.H. where gas is at \$2.50 per 1,000 cubic feet.
at 4.54 cents per K.W.H. where gas is at 2.00 per 1,000 cubic feet.
at 3.40 cents per K.W.H. where gas is at 1.50 per 1,000 cubic feet.
at 2.83 cents per K.W.H. where gas is at 1.25 per 1,000 cubic feet.
at 2.27 cents per K.W.H. where gas is at 1.00 per 1,000 cubic feet.

The above is as fair a comparison as can be made where exact figures cannot well be secured. The results above quoted have been checked by records made in the same family alternately using gas and electricity each week for considerable periods in a number of cases, and from a variety of records obtained otherwise. It is assumed that suitable equipments both of electric and gas appliances are used.

Cost of Operating Electrically Heated Utensils.

Article.	Average Watt Hour Consumption.	Period of Operation.	Cost During that Period at 10 cts. per K.W.H.
		Minutes.	Cents.
Chafing dish	400	20	1⅓
Pint baby milk warmer and food heater	250	6	¼
Quart food heater	500	6	½
Coffee percolator	300	20	1
Stove, 6 inches	500	15	1¼
Stove, 8 inches	800	15	2
Broiler 9 × 12 inch	1,200	15	3
Curling iron heater	60	15	$\frac{3}{20}$
Iron 3½ lbs.	250	30	1¼
Iron 6 lbs.	500	30	2½
Frying pan (7 inches diameter) . . .	500	30	2½
Waffle iron	500	12	1
Tea kettle	300	20	1
Glue pot, 1 quart	300	20	1
Soldering iron, 2 lbs.	200	30	1
Doctor's sterilizer	1,000	30	5
Bath room radiator	1,000	30	5
Heating pad	50	per hour	½

Daily Electric Cooking Record for One Week.

(Report of Heating Committee, Edison Electric Illuminating Companies, June, 1907.)

	Break-fast.	Persons Served.	Food.	Lunch.	Persons Served.	Food.	Dinner.	Persons Served.	Food.	Special Baking.	Ironing.
	KW.H			KW.H.			KW.H.				
Mon.	1.9	5	Cereal, toast, coffee, boiled eggs.	1 9	4	Warmed over dishes — tea, toast.	1.4	3	Broiled steak, tea, boiled potatoes.		
Tues.	2.8	5	Cereal, coffee, poached eggs, toast.	1.5	4	Omelette, tea.	3.5	5	Roast mutton, asparagus, potatoes, beets.		2.9
Wed.	2.8	5	Cereal, coffee, griddle cakes.	.6	4	Stew, tea.	4.9	3	Chops, peas, tea, potatoes, custard.		
Thurs.	1.5	5	Cereal, coffee, toast, boiled eggs.	1.6	3	Eggs, tea, toast.	6.1	5	Roast veal, corn, spinach, potatoes.		
Fri.	2.5	5	Cereal, coffee, griddle cakes.	2.0	4	Stew, tea, poached eggs.	3.7	5	Soup, fried fish, tomatoes, spinach, potatoes, pudding.		
Sat.	2.6	5	Cereal, coffee, stew, toast.	.5	4	Warmed over soup, tea.	3.5	4	Steak, potatoes, corn, baked apples.	4.2	
Sun.	3.1	5	Cereal, coffee, toast, eggs.	5.0	4	Roast beef, potatoes, string beans, soup, ice cream.	.5	5	Cake (baked Saturday), salad, tea.		
	17.2	35		13.1	27		23.6	30		4.2	2.9

Equipment Used.

Simplex Range No. 7 consisting of:

2–8 in. stove consuming	1,625 Watts
1–6 in. stove consuming	440 Watts
1–9 × 12 in. broiler consuming	1,300 Watts
1 oven consuming	1,500 Watts
Also 1 plate warmer (12 × 14 × 20) consuming	300 Watts
Total	5,165 Watts

Consumption Data.

Total cooking consumption	51.8	K.W.H.
Watts per person per meal	631.	Watts
Number of meals served	92	
Average number of persons per meal	4.4	
Lighting consumption	5.63	K.W.H.
Milk warmer	1.63	K.W.H.
Ironing	2.9	K.W.H.

Electric Irons for Domestic and Industrial Purposes.

The advantages of electric irons over irons heated by gas, coal, or other fuel are as follows: Cleanliness, continuous operation, saving time and energy by eliminating the travel between iron and source of heat, concentration of heat, so that the iron only and not the room is being heated, improved sanitary conditions and practically uniform temperature of iron face. In view of a number of these advantages, it has been found in actual practice that an average family of five persons, where the collars and cuffs are sent out to be ironed, consumes about 13.2 kilowatt hours per month for ironing, which at the 10 cent rate per K.W.H. amounts to $1.32 per month, which is about the same as if gas were used, costing $1.00 per 1,000 cubic feet. The cost of operation varies with size of iron. For ordinary domestic requirements, without a current regulator, the iron most commonly used is one weighing about six pounds and consuming about 500 watts per hour. The regulators, whether of the switch in the handle or resistance in the stand type, effect a saving of from 15 to 20 per cent. The power consumption of the various types of irons is as follows:

	Watts
4 pounds Troy Polishing, diamond face	330
3½ pounds Small Seaming (can be connected to lamp socket)	200
4 pounds Gentleman's Small Hat Iron	200
5½ pounds Light Domestic	500
5½ pounds Light Domestic, round nose	500
7 pounds Domestic	600
5½ pounds Morocco Bottom	500
Morocco Bottom, round nose	500

Commercial Electric Laundry Equipment.

(At Eshleman & Craig Company, Philadelphia, Pa.)

				Watts
7–5 pounds Sad Irons	each	3.25 Amp.	at 110 V.	2502
2–7 pounds Sad Irons	each	3.80 Amp.	at 110 V.	836
2 Body Ironers	each	41.50 Amp.	at 110 V.	9130
2–12 inch Sleeve Ironers	each	12.40 Amp.	at 110 V.	2728
1 Collar and Cuff Ironer	each	6.50 Amp.	at 110 V.	715
3 Bosom Ironers	each	16.80 Amp.	at 110 V.	5544
1 Rotary Collar Edger	each	2.50 Amp.	at 110 V.	275
1–7 pound Sad Iron	each	23.00 Amp.	at 24 V.	552
2–7 pound Sad Iron	each	24.00 Amp.	at 24 V.	1152
1 Collar Edging Machine	each	6.25 Amp.	at 20 V.	125
1 Heim Collar Shaper	each	5.50 Amp.	at 20 V.	121
	Total Equipment			23.68 K.W.

A full description of "A Model Electrically Operated Laundry," by H. S. Knowlton may be found in the July, 1905, issue of *The Electrical Age*, New York.

ELECTRIC HEATING.

Unless electricity is produced at a very low cost, it is not commercially practicable to heat residences or large buildings. While this is true, the electric heater still has a field of application, in heating small offices, bathrooms, cold corners of rooms, street railway waiting rooms, the summer villa on cool evenings, and in mild climates a still wider range. It has the peculiar advantage of being instantly available, and the amount of heat is regulated at will. The heaters are perfectly clean, do not vitiate the atmosphere, and are portable.

Radiators and Convectors.

(Prometheus Electric Company of England.)

The heating of rooms and buildings can be accomplished either by radiant or convected heat. With the former method heating is effected by the agency of glow lamps, and with the latter by resistances working at comparatively low temperatures.

In the glow lamp type the filaments of the lamps are raised to an exceedingly high temperature, and the electric energy is transformed mainly into radiant heat, only a small portion being given off by conduction and convection — hence the name "radiator."

In the non-luminous type the resistances are either bare or embedded in enamel and raised to a comparatively low temperature, which heats the air in contact with them, thereby setting up convection currents in the air. They are generally designated as radiators, though the term is a misnomer. They should rather be named "convectors or air warmers." The difference between these two methods of heating is a very wide one. The best method to employ depends entirely on the nature of the work for which the heaters are required, as explained below.

Heating by Radiation. — The heat from glow lamp radiators has been likened to sunshine. The analogy is excellent and has no doubt induced many non-technical people to universally employ this type of heating in preference to any other, regardless of the nature of the work which they desire it to perform.

It is very necessary in deciding which type of heater will give the most satisfactory results, to know the purpose for which it is to be used, and the conditions under which it will work.

Radiant heat only raises the temperature of a body which is opaque to heat waves; it passes through the air without heating it in the slightest, and only causes a rise of temperature in the air by heating any objects that offer opposition to its passage through them, these in turn heating the air in contact with them by conduction.

Heat waves are unaffected by air currents and the glow lamp radiator is, therefore, suitable for warming oneself by out of doors, in balconies, etc., or for quickly warming any portion of one's body. The light emitted is also considered by some people to add greatly to the attractiveness of the heater.

The heat rays are reflected forward by means of highly polished reflectors placed at the back of the lamps, and strike against any objects in their path. The zone of action is dependent on the shape of the reflectors, which for constructional reasons are made in simple shapes, confining the heating field to a small area.

The temperature to which the glow lamp radiators will raise any opaque body when placed in any definite position relative to the lamps is dependent on the density of the heat rays on the surface on which they fall, from which no doubt has arisen the popular fallacy that a radiator, in front of which it is uncomfortable to hold one's hands, must be emitting more heat than a convector, in front of which they may be kept for any length of time without any sense of discomfort. The only true measure of the rate at which heat is being developed by two different heaters working under exactly similar conditions is the amount of air heated per unit of time multiplied by the temperature through which it is raised. Thus a heater constructed to work at a very low temperature may be giving out far more heat than one working at a high temperature, though the former would appear to be the more powerful of the two if gauged merely by the sensation produced on putting one's hands close to the flames.

Air warming by radiant heat is an indirect method by which uniformity of temperature throughout a room or building can never be attained. It is of the utmost importance that the temperature be uniform, as freedom from draughts and consequent comfort and healthy conditions cannot otherwise be secured.

Heating by Convection. — The heat generated in the resistance warms the body of the convector, and the air is heated by direct contact with the hot surfaces. Convection currents are consequently set up in the neighboring air, which quickly equalizes the temperature throughout the room in which the convector is placed. This method of heating dwelling rooms is, therefore, under normal conditions, far more efficient than that of radiation, provided the temperature of the resistance material is not high enough to materially affect the humidity of the air. Convectors are not, however, in virtue of the comparatively low temperature at which they work, so efficient as radiators for quickly warming one's hands or any portion of one's body, neither can they compete with radiators when very strong air currents are present, or for open air work such as balconies, band stands, etc.

It has been asserted that convectors do not, like radiators, accomplish useful work as soon as they are switched in. Such broad statements are not based on facts as the relative rate of air heating by a radiator or convector, absorbing the same power, depends entirely on their capacity for heat. Naturally a convector with a heavy cast iron frame will absorb a large quantity of heat before it can work at its maximum efficiency, but all the heat that is stored in the frame is, of course, taken up by the air after the convector is switched off; such convectors, therefore, are suitable only for continuous work over long periods.

Energy Consumption of Electric Heaters.

According to Houston and Kennelly, one joule of work expended in producing heat will raise the temperature of a cubic foot of air about $\frac{1}{18}$° F.

The amount of power required for electrically heating a room depends greatly upon the amount of glass surface in the room, as well as upon the draughts and admission of cold air.

An empirical rule, commonly employed, is to figure from 1½ to 2 watts per cubic foot of space to be heated.

According to an European authority if a sitting-room with a content of 100 cubic meters is to be heated to 17° C., while the temperature of the outside is 3° C., he estimates that 3,500 kilogram calories are required per hour; with electric heating this means a consumption of 4 kilowatt-hours for every hour, while with coal fuel, about 3 kilograms of coal are required per hour. Experience has shown, says the same authority, that for every degree Centigrade difference between the lowest outside temperature and the desired inside temperature and for every cubic meter of space to be heated 1 to 1.5 watts of electric power are required; as an approximate average 1.2 watts may be assumed. For instance, if the outside temperature is 10° C. below, and a sitting-room of 50 cubic meters is to be heated to 18° C., the difference of temperature is 28° C. Hence, 1,680 to 1,800 watts are required, while the time in which the desired temperature is obtained varies from one to three hours, varying of course, according to whether the neighboring rooms are heated or not.

Comparison between Electric and Coal Heating.

A kilowatt-hour in heat is about 3,600 B.T.U., and costs a consumer in our large cities from 5 to 20 cents according to the conditions, or from 72,000 to 18,000 thermal units per dollar. On the other hand a short ton of ordinary good steam coal will contain 28,000,000 of B.T.U. and allowing a loss of 25 per cent in a boiler wall and flue, some 21,000,000 of heat units can be looked for in boiler water, such coal costing from one to three dollars per ton according to circumstances, and representing a yield of 21,000,000 to 7,000,000 of thermal units per dollar, or in the neighborhood of three hundred times more heat than the electric method would furnish. The comparison is in a certain sense unjust, seeing that the retail price of electric energy on a small scale is compared with manufacturing cost of fuel alone for heating water on a large scale, and a far better relative showing could be made where both methods were compared from either the manufacturer's or the purchaser's standpoint, whatever the scale of production might be. (*Editorial Electrical World and Engineer.*)

ELECTRIC CAR HEATING.

At the Montreal meeting of the American Street Railway Association in 1895, Mr. J. F. McElroy read an exhaustive paper on the subject of car-heating, from which the following abstracts are taken:

In practice it is found that 20,000 B.T.U. are necessary to heat an 18 to 20 foot car in zero weather. When the outside temperature is 12½° F. only 16,000 B.T.U. are required, etc., which shows the necessity of having electric heaters adjustable.

The amount of heat necessary in a car to maintain a given inside temperature depends on: 1. The amount of artificial heat which is given to it. 2. The number of passengers carried. The average person is capable of giving out an amount of heat in 24 hours which is equal to 191 B.T.U.

This is evidently an error, as Kent says that a person gives out about 400 heat units per hour; and tests by the Bureau of Standards show the same (413) for a person at rest, and about twice that for a man at hard labor (835).

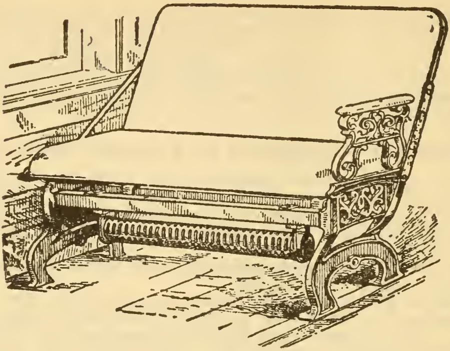


FIG. 2.

Cost of Car Heating.

The following table was compiled by Mr. McElroy from the reply received from the Albany Railway Company:

Average fuel cost on Albany Railway, per amp. hour = .241 cent.

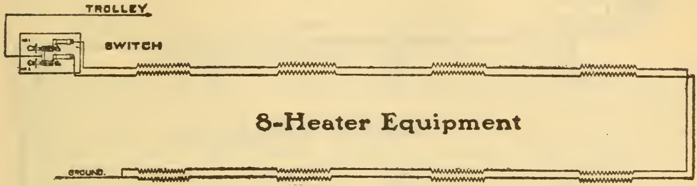
Average total cost for fuel, labor, oils, waste, and packings per amp. hour = .423 cent.

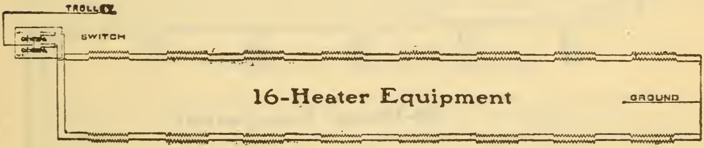
	Cost of fuel per hour for heating a car with electric heaters with coal at $2.00 per 2000 lbs.				
	Position of Switch.				
	1st	2d.	3d.	4th.	5th.
	Amperes equal.				
	2.14	2.88	6.88	8.09	12.0
	cts.	cts.	cts.	cts.	cts.
Simple high speed condensing . .	.43	.58	1.40	1.62	2.41
Simple low speed condensing . .	.40	.54	1.30	1.51	2.24
Compound high speed condensing	.39	.52	1.27	1.47	2.20
Compound low speed condensing	.36	.48	1.17	1.36	2.03

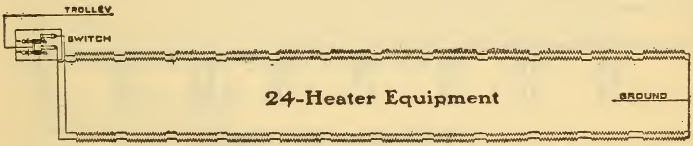
Average Cost Per Day for Stoves.

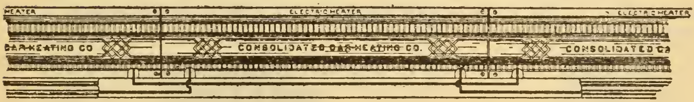
33 lbs. of coal at $4.55 per ton	$.075
Repairs	.005
Dumping and removing coal and ashes, coaling up and kindling fire, including cost of kindling, and part of cleaning car	.100
Removing stoves for summer, installing for winter, repairing head linings, repainting, etc., average per day	.0125
Total	$.1925

Diagrams of Wiring for "Consolidated" Heaters for Use Along Truss Plank.





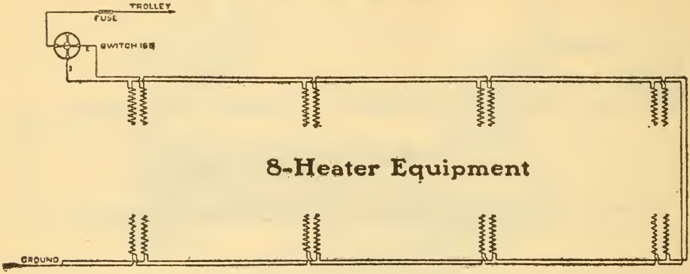


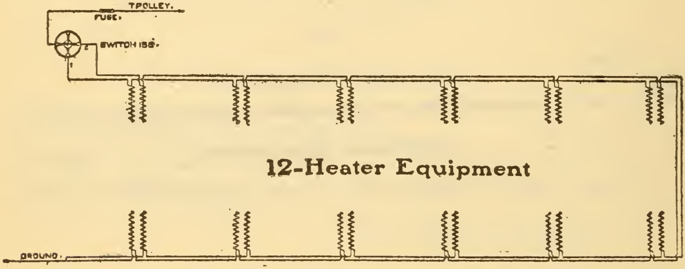


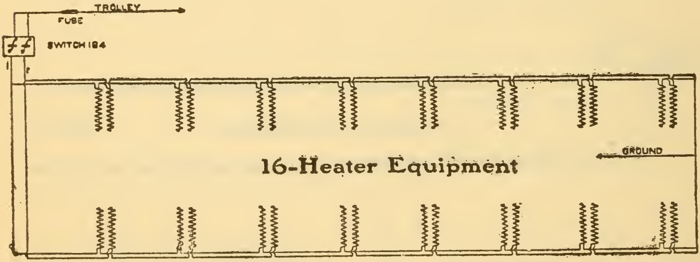
Truss Plank Heater in position, showing wiring in moulding.

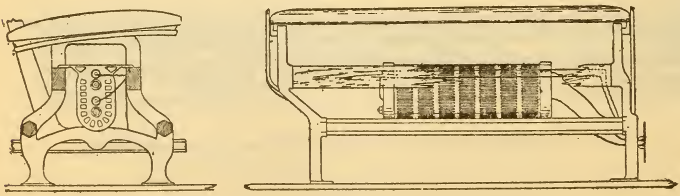
FIG. 3.

Diagrams of Wiring for "Consolidated" Heaters for Cross Seats.









Cross Seat "Consolidated" Heater in position.

FIG. 4.

According to a paper read by J. T. McElroy before the Street Railway Association of New York, on car heating, about 10 to 20 per cent of the energy required for running is spent in the heaters, and the average of tests taken upon American cars with coal and electric heaters for 15-hour runs gave the price per day of 15 hours for coal as $2.33, and for electricity $2.20.

Pointers to Purchasers of Electric Car Heaters.

(*Street Railway Journal, November* 5, 1904.)

We think it only fair to the electric heater to call attention to a very common fault on the part of companies purchasing electric car heating equipments, which fault usually results in the end in a condemnation of electric heaters. This fault lies in trying to get along with a few heaters worked at a high temperature rather than a large number worked at a lower temperature. The reason why companies attempt to do this is, of course, to reduce the first cost of heater equipment. If a car is to be heated as comfortably by electric heaters as by hot water, the nearer you can come to distributing the heat evenly throughout the length of the car and avoiding excessively hot points, the better will be the results. It is coming to be more and more established, that heating of any kind can be done more efficiently by a large radiating surface worked at low temperature than by a small radiating surface worked at high temperature. Furthermore, working electric heaters at low temperatures is conducive to a long life, while working at high temperature is not.

Industrial Electric Heating.

Among the industries to which electrically heated apparatus has been successfully applied may be mentioned: Book binderies, printing shops, hat factories, candy and chocolate manufactories, laundries, wood-working establishments, shoe, paper box, glove, corset, dental goods factories, as well as hotels, hospitals, restaurants, laboratories, bakeries, etc. In fact, wherever gas or steam is being employed for the localized application of heat, electricity has been found, in most cases, a more sanitary, flexible, safer, cleaner, as well as equally economical source of heat.

Electric Heat in Printing Establishments. — The most extensive, as well as most economical, heating equipment in a printing office, is, no doubt, that at the Government Printing Office at Washington, D. C., designed and installed by the Hadaway Electric Heating Company.

The following pieces of apparatus are being electrically operated successfully at the present time (1907) in this office:

Matrix Drying Tables.
Wax Stripping Tables.
Wax Melting Kettles.
Case Warming Cabinet.
Case Warming Table.
Wax Knife, Cutting down Machine.
Building up Tool Heaters.
Sweating-on Machines.
Soldering Iron Heaters.
Embossing and Stamping Press Heads.
Glue Heater Equipments.
Glue Cookers.
Case Making Machines.
Book Cover Shaping Machines.
Finishers' Tool Heaters.
Pamphlet Covering Machines.
Sealing Wax Melters.

Further details of this equipment have been published in the Washington Electrical Handbook, issued in September, 1904, by the American Institute of Electrical Engineers, and a series of articles in the *Electrical World and Engineer*, Vol. 43, pages 9–14, and succeeding issues.

The claims made by the government representatives in favor of electrically heated apparatus as compared with steam and gas, are as follows:

The absence of excess of heat that would be found in forms other than electrical.

The ability to reduce the amount of time necessary to make impressions.

The ability to bring the apparatus to a working condition in less time.

The fact that in eight years of operation they have not had an instance of a burnt-out coil.

Electrically Heated Devices in the Printing Shop of P. F. Collier & Son, New York.

The following list of apparatus is given here in order to show some of the details of this class of apparatus as well as the developments of this class of industry.

Apparatus.	Type and Size.	Max. Amp.	Min. Amp.	Volts.	Watts
2 glue pots . .	Simplex 20 gal.	100	22	110	22,000
23 glue pots .	Hadaway 1 qt.	2	.5	110	5,060
1 glue pot . .	Simplex 1 qt.	2.5	...	110	275
8 glue pots .	Hadaway 2 qt.	10	2.5	110	8,800
2 glue pots . .	2 gal	22.8	...	220	12,672
2 wax heaters		100	40	110	22,000
5 press heads .	22 in. × 24 in. × 3⅞ in.	35	2.8	110	19,250
1 press head .	22 in. × 24 in. × 3⅞ in.	36	4	110	3,960
1 press head .	22 in. × 24 in. × 3⅞ in.	36	3.6	110	3,960
1 press head .	22 in. × 24 in. × 3⅞ in.	36	3.5	110	3,960
1 press head .	22 in. × 24 in. × 3⅞ in.	36	4.5	110	3,960
1 press head .	19 in. × 12 in. × 3⅞ in.	30	2.5	110	3,300
1 press head .	12 in. × 12 in. × 3⅞ in.	25	2.5	110	2,750
					111,947

Forty-nine articles, consuming 112 Kilowatts.

Summary { 11 Press Heads.
36 Glue Pots.
2 Wax Heaters.

Laboratory Use. — The milk supply of New York City is governed by tests made in the Laboratory of the *Board of Health*, by means of electric stoves. Twenty-five 4-inch disc stoves, of 60 watts capacity, are used to boil the ether used in the tests. Fourteen times per hour these little stoves cause the ether to vaporize. The germ producer, measuring 22×22×22 inches, is heated to 130° C., by means of electricity, a maximum current of 16 amperes being employed for 15 minutes every hour, while 3 amperes keep up the desired temperature.

Coffee and Cocoa Dryers. — The cocoa and coffee trade has applied electric heat to its small desiccating or drying cabinets. A dryer 3½ feet by 5 feet, requiring a temperature of 150 degrees, requires about 74 watts per cubic foot when properly jacketed. The beans are particularly susceptible to the odors arising from combustion, hence the advantage of electric heat. For drying kilns 40 watts per cubic foot are recommended.

Candy Manufacture. — Warming tables and chocolate dipping-pots have proved successful. Fifty watts produce sufficient heat to keep the chocolate in working condition. A 30-gallon tank holding caramel paste is supplied with 10 kilowatt hours to keep the paste at 285° C., and each melting costs about 65 cents. The service is intermittent, hence the adaptability of electric heat.

Soldering and Branding Irons. — The canning industry, as well as the makers of switchboards, and others, find the electric soldering iron a useful and economical tool. It has been found more economical to operate electric soldering irons heated by current costing 5 cents per kilowatt hour than irons heated in gas furnaces, with gas at $1.00 per 1000 cubic feet. Heaters of 110-watt capacity are made, into which a soldering iron is thrust, thereby doing away with the connecting handle cord. One thousand hogs per hour are stamped, "Inspected," by the government meat inspectors in Chicago, by means of a 400-watt branding tool, which is an electric soldering iron with a die inserted in place of the copper tip.

Thawing Water Pipes.

The following figures show the details of operation of a 44-cell storage battery outfit, mounted on an automobile truck, in comparison with those obtained by the use of a rheostat in series with a direct-current 3-wire Edison system with the neutral wire grounded. The figures represent the average amounts in each case.

	Amperes.	K.W. Hours.	Time, Min.	Pipe, Inch.	Voltage.	Cost per Case.	Revenue per Case.
Storage battery .	513	1.39	5.44	5/8	31.5	$10.85	$16.40
Street supply . .	275	10.4	19.0	5/8	120.0	14.43	16.93

The street supply is used until the season has so far advanced that the number of cases will warrant the exclusive service of an automobile truck.

ELECTRIC WELDING AND FORGING.

The current employed in electric welding may be theoretically either continuous or alternating, but on account of the difficulty of producing low tension continuous currents, it is only practicable to employ alternating current. All electric welding machines are fitted with an alternating current transformer as an integral part of the machine.

Thomson Electric Welding Process.

The principle involved in the system of electric welding, invented by Prof. Elihu Thomson, is that of causing currents of electricity to pass through the abutting ends of the pieces of metal which are to be welded, thereby generating heat at the point of contact, which also becomes the point of greatest resistance, while at the same time mechanical pressure is applied to force the parts together. The passage of the current through the metal at the point of junction, gradually but quickly brings the temperature of the metal to a welding point. Pressure follows up simultaneously, a weld being effected at once.

Horse-Power Used in Electric Welding.

The power required for the different sizes varies nearly as the cross sectional area of the material at the joint where the weld is to be made.

Within certain limits, the greater the power, the shorter the time; and vice versa.

The following tables are based upon actual experience in various works, and from very careful electrical and mechanical tests made by reliable experts. The time given is that required for the application of the current only, and may be shortened with a corresponding increase in the amount of power applied.

Round Iron or Steel.

Diameter.	Area.	H.-P. Applied to Dynamo.	Time in Seconds.
1/4 in.	.05	2.0	10
1/3 in.	.10	4.2	15
1/2 in.	.22	6.5	20
5/8 in.	.30	9.0	25
3/4 in.	.45	13.3	30

Extra Heavy Iron Pipe.

Inside Diameter.	Area.	H.-P. applied to Dynamo.	Time in Seconds.
½ in.	.30	8.9	33
¾ in.	.40	10.5	40
1 in.	.60	16.4	47
1¼ in.	.79	22.0	53
1½ in.	1.10	32.3	70
2 in.	1.65	42.0	84
2½ in.	2.25	63.7	93
3 in.	3.00	96.2	106

General Table.

Iron and Steel.			Copper.		
Area in sq. in.	Time in Seconds.	H.-P. applied to Dynamos.	Area in sq. in.	Time in Seconds.	H.-P. applied Dynamos.
0.5	33	14.4	.125	8	10.0
1.0	45	28.0	.25	11	23.4
1.5	55	39.4	.375	13	31.8
2.0	65	48.6	.5	16	42.0
2.5	70	57.0	.625	18	51.9
3.0	78	65.4	.75	21	61.2
3.5	85	73.7	.875	22	72.9
4.0	90	83.8	1.0	23	82.1

Axle Welding.

1″ round axle requires 25 Horse-power for 45 seconds.
1″ square " " 30 " " " 48 "
1¼″ round " " 35 " " " 60 "
1¼″ square " " 40 " " " 70 "
2″ round " " 75 " " " 95 "
2″ square " " 90 " " " 100 "

The slightly increased time and power required for welding the square axle is not only due to the extra metal in it, but in part to the care which it is best to use to secure a perfect alignment.

Tire Welding.

1″ x 3/16 tire requires 11 Horse-power for 15 seconds.
1¼″ x ⅜″ " " 23 " " " 25 "
1½″ x ⅜″ " " 23 " " " 30 "
1½″ x ½″ " " 23 " " " 40 "
2″ x ½″ " " 29 " " " 55 "
2″ x ¾″ " " 42 " " " 62 "

The time above given for welding is of course that required for the actual application of the current only, and does not include that consumed by placing the axles or tires in the machine, the removal of the upset, and other finishing processes.

From the data thus submitted, the cost of welding can be readily figured for any locality where the price of fuel and cost of labor are known.

A test on the electric welding equipment of the American Steel Frame and Band Iron Company of New York, made by the New York Edison Company, to determine the amount of energy used per weld, gave the following result. The equipment consists of a 50 horse-power 220 volt, direct current motor, belted to a 50 kilowatt 220 volt, 2 phase, 60 cycle, separately excited alternator, and three 7.5 kilowatt step-down transformers, with an approximate ratio of 45 to 1.

When welding iron frames .0352 square inch in cross section, it takes 1 kilowatt hour, supplied to the transformer, to make 500 welds, the time required being 53 minutes. This averages 2 watt hours per weld, and taking the time the current is applied as 0.7 seconds per weld, the welding current figures out about 2000 amperes at 4.75 volts. A meter installed in the motor circuit showed 4.2 kilowatt hours direct-current input for 390 welds, making an average of 10.77 watt hours per weld.

Electric Rail Welding.

The "Electric" joint, applied by the Lorain Steel Co., is made by welding plates on both sides of the web of the rail. The plates shown in Fig. 6 are 1 inch by 3 inches, by 18 inches, and have three bosses, three welds

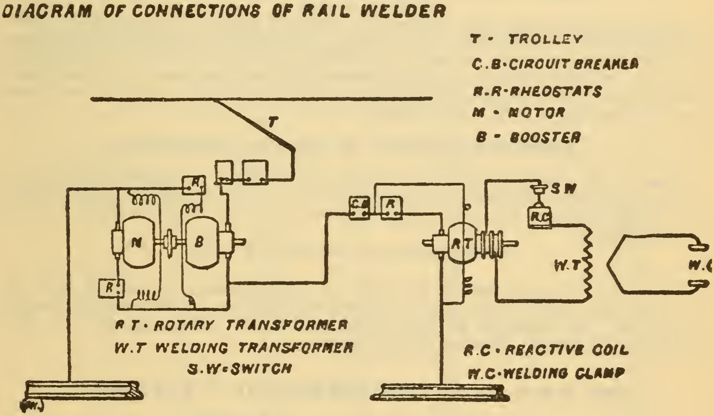
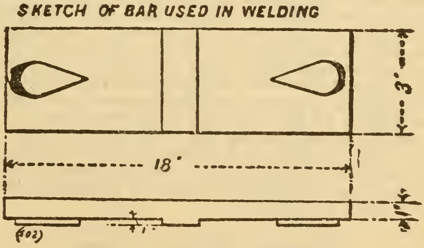


FIG. 5.



Web Plates

FIG. 6.

being made at each joint. Great pressure up to 35 tons is maintained on the joint whilst making and cooling. The welding current runs as high as 25,000 amperes. The connections are shown in Fig. 5.

Zerener System.

In this system an arc is used in combination with a magnet which deflects the arc, making a flame similar to that of a blow-pipe, but having the temperature of the arc. The apparatus contains a self-regulating device which is driven by a small electric motor ; for welding iron a current of 40 to 50 amperes at 40 volts will suffice for strips of metal three mm. thick.

Bernardos System.

In this system the article to be operated upon is made to constitute one pole of the electric circuit, while a carbon pencil attached to a portable insulated holder, and held by the workman, constitutes the other pole, the electric arc — which is the heating agent of the process — being struck between the two poles thus formed. This system has been used extensively in England for the repair of machinery. The Barrbeat-Strange Patent Barrel Syndicate use this system for the welding of the seams of sheet-steel barrels.

Voltex Process for Welding and Brazing

Consists in the use of an electric arc formed between two special carbon rods inclined to each other at an angle of about 90°. The whole apparatus can generally be held in one hand. With gas and coke, gas costing only 70 cents per 1000 cubic feet, it is claimed the complete cost of brazing and filling up a bicycle frame is $1.43, while with the Voltex process, at 6 cents per kilowatt hour, it is only 46 cents.

Stassano Process of Electric Smelting

Consists of heating, in an arc furnace, briquettes composed of iron ore, carbon, and lime made into a paste with tar. The smelting process occurs in a blast furnace, the iron being reduced, and the siliceous matter of the ore slagged off.

Annealing of Armor Plate.

The spot to be treated is brought to a temperature of about 1000 ° F. The current used is equivalent to 40,000 amperes per square inch, a density which is only possible by the use of cooling by water circulation. The operation generally takes seven minutes.

HYDRO-ELECTROTHERMIC SYSTEMS.

Hoho and Lagrange System.

In this system an electrolytic bath is employed, into which an electric current of considerable E.M.F. is led, passing from the positive pole which forms the boundaries of the bath and presents a large surface to the electrolyte and thence to the negative pole, consisting of the metal or other material to be treated, and which is of relatively small dimensions.

Through the electrolytic action hydrogen is rapidly evolved at the negative pole and forms a gaseous envelope around the pole ; as the gas is a very poor conductor of electricity, a large resistance is thus introduced in the circuit, entirely surrounding the object to be treated. The current in passing through this resistance develops thermal energy, and this is communicated to the metal or other object which forms the negative pole.

This system has been extensively used in England, and is described in *The Electrical World*, Dec. 7, 1895.

Burton Electric Forge.

In a patent granted to George D. Burton on an electrolytic forge, the portion to be heated is placed in a bath consisting of a solution of sal soda, or water, carbonate of soda, and borax. The tank is preferably made of porcelain or fire-clay. The anode plate has a contact surface with the liquid much greater than the area of contact of the article to be heated. This plate is composed of lead, copper, carbon, or other suitable conducting material.

FUSE DATA.

In a lecture on "The Rating and Behavior of Fuse Wires," before the A. I. E. E., in October, 1895, Messrs. Stine, Gaytes, and Freeman arrived at the following conclusions:

1. Covered fuses are more sensitive than open ones.
2. Fuse wire should be rated for its carrying capacity for the ordinary lengths employed.

2(*a*). When fusing a circuit, the distance between the terminals should be considered.

3. On important circuits, fuses should be frequently renewed.
4. The inertia of a fuse for high currents must be considered when protecting special devices.
5. Fuses should be operated under normal conditions to ensure certainty of results.
6. Fuses up to five amperes should be at least 1½ inches long, one-half inch to be added for each increment of five amperes capacity.
7. Round fuse wire should not be employed in excess of 30 amperes capacity. For higher currents flat ribbons exceeding four inches in length should be employed.

Fuse Wire.

The following table shows the sizes of fuse wire and the approximate current-carrying capacity of each size:

Tested Fuse Wire.

(*Chase-Shawmut Company, Boston.*)

Carrying Capacity in Amperes.	Standard Length in Inches.	Diameter in Mils.	Feet per Pound.
¼	1½	10	2,700
½	1½	17	950
1	1½	20	670
1½	1½	23	510
2	1½	25	430
3	1½	27	370
4	1½	30	300
5	2	35	220
6	2	38	185
7	2	44	140
8	2	47	120
9	2	54	93
10	2	58	80
12	3	62	70
14	3	68	60
15	3	70	52
16	3	73	49
18	3	78	43
20	4	86	86
25	4	90	82
30	4	100	26
35	4	110	22
40	4	122	18
45	4	126	13
50	4	147	12.5
60	5	160	10.3
70	5	172	9.0
75	5	178	8.3
80	5	190	7.5
90	5	198	6.7
100	5	220	5.5

Installation of Fuses.

(*H. C. Cushing, Jr.*)

Enclosed fuses of standard sizes are now on the market and are preferable to link fuses. Where the link fuses are used they should have contact surfaces or tips of harder metal, having perfect electrical connection with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps, or other devices provided for holding the fuse.

They should be stamped with about 80 per cent of the maximum current they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

The following table shows the maximum break distance and the separation of the nearest metal parts of opposite polarity for plain open link fuses, when mounted on slate or marble bases for different voltages, and for different currents:

125 VOLTS OR LESS.

	Separation of Nearest Metal. Parts of Opposite Polarity.	Minimum Break. Distance.
10 amperes or less	¾ inch	¾ inch
11–100 amperes	1 inch	¾ inch
101–300 amperes	1 inch	1 inch

125 TO 250 VOLTS.

10 amperes or less	1½ inch	1¼ inch
11–100 amperes	1¾ inch	1¼ inch
101–300 amperes	2 inch	1½ inch

Fuse terminals should be stamped with the maker's name, initials, or some known trade-mark.

The lengths of fuses and distances between terminals are important points to be considered in the proper installation of these electrical "safety valves." No fuse block should have its terminal screws nearer together than one inch on 50 or 100 volt circuit, and one inch additional space should always be allowed between terminals for every 100 volts in excess of this allowance. For example:

200 volt circuits should have their fuse terminals 2 inches apart, 300 volts 3 inches, and 500 volts 5 inches. This rule will prevent the burning of the terminals on all occasions of rupture from maximum current, and this current means a "short circuit."

Enclosed Fuses. — The "Enclosed Fuse" or "Cartridge Fuse," consists of a fusible strip or wire placed inside of a tubular holding jacket, which is filled with porous or powdered insulating material through which the fuse wire is suspended from end to end. The wire, tube and filling are made into one complete self-contained device with brass or copper terminals or ferrules at each end, the fuse wire being soldered to the inside of the ferrules. When an enclosed fuse "blows" by excess current, the gases resulting are taken up by the filling, the explosive tendency is reduced and flashing and arcing are eliminated. "D. & W.," "G. E.," "Noark" and "Shawmut," enclosed fuses are approved by the National Electric Code.

LIGHTNING CONDUCTORS.

Views concerning the proper function and value of lightning rods, conductors, arresters and all protective devices have undergone considerable modification during the past ten years. There may be said to be four periods in the history of the development of the lightning protector. The first embraces the discovery of the identity of lightning with the disruptive discharge of electrical machines and Franklin's clear conception of the dual function of the rod as a conductor and the point as a discharger. The second begins with the experimental researches of Faraday and the miniature house some twelve feet high, which he built and lived in while testing the effects of external discharges. Maxwell's suggestion to the British Association, in 1876, embodies a plan based upon Faraday's experiments, for protecting a building from the effects of lightning by surrounding it with a cage of rods or stout wires. The third period begins with the experiments of Hertz upon the propagation of electro-magnetic waves, and finds its most brilliant expositor in Dr. Oliver J. Lodge, of University College, Liverpool, whose experiments made plain the important part which the momentum of an electric current plays, especially in discharges like those of the lightning flash, and all discharges that are of very high potential and oscillatory in character. The fourth period is that of the present time, when individual flashes are studied; and protection entirely adequate for the particular exposure is devised, based upon some knowledge of the electrical energy of the flash, and the impedance offered by appropriate choke coils or other devices. For example, under actual working conditions, with ordinary commercial voltages, effective protection to electrical machinery connected to external conductors may be had with a few choke coils in series with intervening arresters.

A good idea of the growth of our knowledge of the nature and behavior of the lightning flash may be obtained from the following publications:

Franklin's letters.

Experimental Researches. . . . Faraday.

Report of the Lightning Rod Conference, 1882.

Lodge's "Lightning Conductors and Lightning Guards," 1892.

"Lightning and the Electricity of the Air." . . . McAdie and Henry, 1899.

FIG. 1 EFFECT OF THE ACTION OF LIGHTNING UPON A ROD.

That a lightning rod is called upon to carry safely to earth the discharge from a cloud was made plain by Franklin, and the effect of the passage of the current very prettily shown in the melting of the rod and the point (aigrette).

Here indeed was a clew to the measurement of the energy of the lightning flash. W. Kohlrausch in 1890 estimated that a normal lightning discharge would melt a copper conductor 5 mm square, with a mean resistance of 0.01 ohm in from .03 to .001 second. Koppe in 1895 from measurements of two nails 4 mm in diameter fused by lightning, determined the current to be about 200 amperes and the voltage about 20,000 volts. The energy of the flash, if the time be considered as 0.1 second, would be about 70,000 horse power, or about 52,240 kilowatts.

Statistics show plainly that buildings with conductors when struck by lightning suffer comparatively little damage compared with those not provided with conductors. The same rod, however, cannot be expected to serve equally well for every flash of lightning. There is great need of a classification of discharges based less upon the appearance of the flash than upon its electrical energy. Dr. Oliver J. Lodge has made a beginning with his study of *steady strain* and *impulsive rush* discharges. "The energy of an ordinary flash," says Lodge, "can be accounted for by the discharge of a very small portion of a charged cloud for an area of ten yards square at the height of a mile would give a discharge of over 2,000 foot-tons energy."

We must get clearly in our minds then the idea that the cloud, the air, and the earth constitute together a large air condenser, and that when the strain in the dielectric exceeds a tension of ½ gramme weight per square centimeter, there will be a discharge probably of an oscillatory character. And as the electric strain varies, the character of the discharge will vary. Remember too that the air is constantly varying in density, humidity and purity. We should therefore expect to find, and in fact do, every type of discharge from the feeble brush to the sudden and terrific break. Recent experiments indicate that after the breaking-down of the air and the passage of the first spark or flash, subsequent discharges are more easily accomplished; and this is why a very brilliant flash of lightning is often followed almost immediately by a number of similar flashes of diminishing brightness. The heated or incandescent air we call lightning, and the lines of fracture of the dielectric can be photographed; but the electrical waves or oscillations in the ether are extremely rapid, and are beyond the limits of the most rapid shutter and most rapid plate. Dr. Lodge has calculated the rapidity of these oscillations to be several hundred thousand per second. Lodge has also demonstrated experimentally that the secondary or induced electrical surgings in any metallic train cannot be disregarded; and, as in the case of the Hotel de Ville at Brussels which was most elaborately protected by a network, these surgings may spark at points, and ignite inflammable material close by.

While therefore it cannot be said that any known system of rods, wires, or points affords complete and absolute protection, it can be said with confidence that we now understand why "spitting-off" and "side" discharges occur; and furthermore, to quote the words of Lord Kelvin, that "there is a very comfortable degree of security . . . when lightning conductors are made according to the present and orthodox rules."

Selection and Installation of Rods.—The old belief that a copper rod an inch in diameter could carry safely any flash of lightning is perhaps true, but we now know that the core of such a rod would have little to do in carrying such a current as a lightning flash, or, for that matter, any high frequency currents. Therefore, since it is a matter of surface area rather than of cubic contents, and a problem of inductance rather than of simple conductivity, tape or cable made of twisted small wires can be used to advantage and at a diminished expense.

All barns and exposed buildings should have lightning rods with the necessary points and earth connections. Ordinary dwelling-houses in city blocks well built up have less need for lightning conductors. Scattered or isolated houses in the country, and especially if on hillsides, should have rods. All protective trains, including terminals, rods, and earth connections, should be tested occasionally by an experienced electrician, and the total resistance of every hundred feet of conductor should not greatly exceed one ohm. Use a good iron or copper conductor. If copper, the conductor should weigh about six ounces per linear foot; if iron, the weight should be about two pounds per foot. A sheet of copper, a sheet of iron, or a tin roof, if without breaks, and fully connected by well soldered joints, can be utilized to advantage.

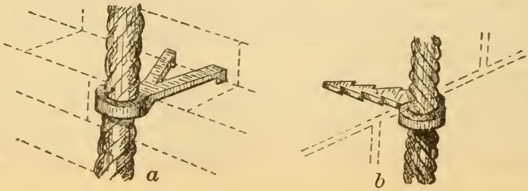


FIG. 2 AND 3 APPROVED CONDUCTORS AND FASTENINGS.

In a recently published* set of Rules for the Protection of Buildings from Lightning, issued by the Electro-Technical Society of Berlin, Dr. Slaby gives the results of the work of various committees for the past sixteen years studying this question. The lightning conductor is divided into three parts, — the terminal points or collectors, the rod or conductor proper attached to the building, and the earth plates or ground. All projecting metallic surfaces should be connected with the conductors, which, if made of iron, should have a cross section of not less than 50 mm square (1.9 sq. inches); copper, about half of these dimensions, zinc about one and a half, and lead about three times these dimensions. All fastenings must be secure and lasting. The best ground which can be had is none too good for the lightning conductor. For many flashes an ordinary ground will suffice, but there will come occasional flashes when even the small resistance of $\frac{1}{10}$ ohm may count. Bury the earth plates in damp earth or running water. The plates should be of metal at least three feet square.

"If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another, connect them metallically. The neighborhood of small bore fusible gas pipes, and indoor gas pipes in general, should be avoided." — Dr. Lodge.

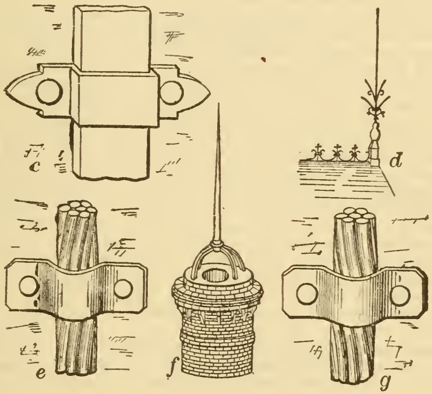


FIG. 4 CONDUCTORS AND FASTENINGS.
(FROM ANDERSON, AND LIGHTNING ROD CONFERENCE.)

The top of the rod and all projecting terminal points should be plated, or otherwise protected from corrosion and rust.

Independent grounds are preferable to water and gas mains. Clusters of points or groups of two or three along the ridge rod are good. Chain or linked conductors should not be used.

It is not true that the area protected by any one rod has a radius equal to twice the height of the conductor. Buildings are sometimes, for reasons which we understand, damaged within this area. All connections should be of clean well-scraped surfaces properly soldered. A few wrappings of wire around a dirty water or gas pipe does not make a good ground. It is not necessary to insulate the conductor from the building.

H. W. Spang gives the following estimate of increase of property destruction by lightning from the "Chronicle Fire Tables."

During five years ending	No. of fires.	Property loss.
1892	2,505	$ 8,879,745
1897	5,637	11,315,414
1902	15,755	21,767,185

* *Electrotechnische Zeitschrift*, 1901, May 29.

Much of this increase in property loss is said to be due to the great increase in the use of wire fences in the suburban districts, also to the vastly increased use of metal work inside of houses, such as metal lath, steam and water pipes, and all metal trimmings now used so much in exterior trimmings. Electric wires and their containing tubes also attract lightning; in fact, all the metal work now used in modern building construction serves to attract lightning and convey it to the ground or store it up as in a condenser, which, upon being released, is liable to cause a spark and thus set fire to adjacent inflammable material.

It is said that grounded arresters as now employed in power stations in connection with outdoor overhead electrical conductors also invite lightning discharges, which, if they take place in the interior of buildings, are liable to cause fire loss; and therefore, it is inadvisable to locate such lightning arresters adjacent to wood-work or other inflammable material. Large electric signs on the roofs of buildings also serve to attract lightning, and being connected with the interior electrical wires, sometimes jeopardize the safety of the buildings. Electrical wires in the upper stories of our tall buildings are said to become highly electrified during a thunder storm, and lightning from these is liable to impair any underground electrical conductor connected therewith.

Overhead network wires such as those used for electric light, telephone, telegraph and fire alarm, also attract lightning, and the discharges upon these wires seem to increase in proportion to the number of grounded lightning arresters connected therewith — so much so, that it is now common to dispense with the lightning arresters in fire alarm boxes. Where lead sheathings of underground circuits or conductors of all kinds are metallically connected with the track rails and return circuit of street railways, lightning is also liable to be attracted, and discharges from it in some cases cause considerable damage. It is also said that the grounding of secondary transformer distributing systems at their neutral points has also resulted in lightning discharges to the impairment of lighting transformers.

Mr. Spang suggests that rather than connect overhead circuits directly with grounded lightning arresters or to connect return circuits of railways with other metallic networks that are grounded, there should be employed an overhead parallel wire, which shall be thoroughly connected to earth at intervals, and which should preferably be located at the side of any overhead electrical circuit and parallel thereto; but experienced engineers who have made a thorough study of protection from lightning, show that this parallel conductor does not materially benefit the conditions.

From the Underwriters' standpoint, therefore, the following rules are suggested as necessary for protection of buildings from lightning:

1. The employment of suitable metallic conductors about the ridges, chimneys or other ordinary elevations above the roof, in connection with all metal work about the roof and also with all exterior and interior metal work, pipes, etc., all metallically connected together so as to provide numerous vertical metallic paths from the roof to the cellar and thereby constitute with the underground water, gas and other metal pipes, a diffusive system of metallic conductors about the roof and building and over the earth.

2. The shunting of the gas meters by suitable wires or other metal conductors.

3. The employment of two vertical iron or copper conductors along opposite sides of a church spire or a high chimney between a metal cross, weather vane or other suitable air terminal conductor upon the top thereof and the metallic conductors upon the roof, which are metallically connected with the underground water, gas and other metal pipes or other suitable ground connection.

4. A system of wires or conductors with suitable air terminals above the roof of a barn, ice-house or storage warehouse and connected by at least four vertical conductors with ground connections distributed over a suitable area of adjacent earth, so that the atmospheric electricity will be diffused over a greater and better conducting area than that offered by the compactly stored hay, ice, etc.

5. The placing of lightning arresters or other grounded protection devices employed with electrical circuits about buildings in iron or non-combustible boxes, attached to brick, stone or other non-combustible material or buildings and preferably upon the outside thereof.

CHIMNEY PROTECTION.

The builders of chimneys have made an exhaustive study of lightning action and have developed a number of standard fittings for lightning rods. One form of lightning-rod point is shown in Fig. 5.

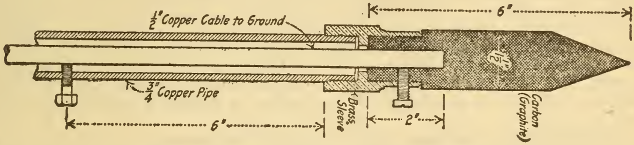


FIG. 5. Detail of Lightning-rod Point.

Usually four of these points are installed at the chimney top, connected together by a band, and having two or more conductors to the earth.

The United States Government has investigated thoroughly the requirements for chimney protection as summarized in the following paragraphs:

1. **Chimney Protection for Power Plants.** — Lightning conductors shall be laid up in the form of a seven-strand cable and each strand laid up with seven copper wires of No. 10 B. and S. gauge. For chimneys of 50 feet and less in height two lightning conductors shall be used. For chimneys over 50 feet up to and including 100 feet, three conductors shall be installed. For chimneys higher than 100 feet, four conductors shall be installed. All heights to be considered from ground level. All conductors or cables shall be symmetrically arranged about the chimney with one cable on the prevailing weather side of the chimney. Said lightning conductors or cables to be securely attached both mechanically and electrically to independent pure copper earth plates or bars. In cases where the chimney foundations have already been filled in, instead of earth plates, earth terminals may be used, composed of pure copper bars 3 by ½ inches by 3 feet. In all cases the lightning conductor terminals shall extend to the ground water level, and in no case shall they extend to less than 15 feet from the ground surface. Earth plates shall consist of pure copper 3 by 3 feet by ⅛ inch.

2. **Application of Conductors to Chimney.** — Each lightning conductor shall be secured to the exterior of the chimney by means of bronze or brass anchors, without the intervention of any insulators or insulating material whatever. The brackets for attaching ring or conductors to chimneys to be of high grade bronze or brass, composition of same to be submitted for approval, and to be fitted with approved clamps for securely gripping said conductors and making a good electrical connection therewith. The tongues or shanks of the anchors or brackets shall enter the masonry of the chimney a distance of at least 6 inches, and shall be at least ⅛ inch in thickness by 1 inch wide, terminating in a suitable head or angle to prevent the anchor from being pulled out of the masonry. Anchors to be attached to conductors at intervals of not over 10 feet, and "sweated" to the conductors with solder at intervals of 50 feet. Conductors to terminate within 5 feet of the top of the chimney, and to be connected through the agency of a suitable brass or bronze fitting and be soldered to a 1½ by ½ inch ring of copper attached to the periphery of the chimney by brackets spaced not over 2 feet apart. Said brackets to enter the brick work a distance of at least 6 inches and to be of approved design with a tongue at least 1½ inches in width and ¼ inch in thickness, with a suitable angle or head to prevent pulling out. All joints in the continuity of said copper ring, as well as between the continuity of the ring and conductor or conductors running down to the ground bars or plates and including the latter, to be scraped bright and after making a secure mechanical joint to be "sweated with solder." Said solder shall consist of one-half lead and one-half tin. All joints when finished shall be thoroughly washed off with water to remove every trace of soldering salts, acids, or other compounds

used. All joints secured by bolts or screws to be lock-nutted. In applying conductors where the chimney is already constructed, holes shall be drilled in the brick and said anchor brackets and anchors grouted in, the best Portland cement being used.

3. **Terminal Rods for Lightning Conductors.** — Copper ring shall be connected through the agency of clamps, insuring a good mechanical and electrical joint, with vertically arranged copper rods at least ¾ inch in diameter and 10 feet in length. The joints to be "sweated with solder" as before described. Copper rods to be placed equidistant around this ring, and supported in a rigid position vertically through the agency of additional anchors set in the masonry and a copper spider resting on chimney top as shown in the drawings. Rods to be arranged with a uniform spacing of practically 4 feet. This is taken to mean, for example, that ten such vertical rods shall be provided for a chimney of 12 feet outside diameter of masonry at top.

4. **Discharge Points.** — Each rod shall terminate in a two-point brass aigrette, each spur or point of this aigrette to be at least 3¾ inches long, the bases of which spurs shall be at least ⅝ inch in diameter, tapering to a sharp and well finished point; said aigrette to be provided with approved means to secure a strong mechanical and electrical joint with the vertical rods heretofore described and to which it is attached. The joints shall be "sweated with solder" as heretofore described.

5. **Chimney Base Protection.** — All lightning conductors shall be enclosed at bottom with a heavy galvanized-iron pipe of 1½ inch diameter, and extending 3 feet into the soil and 10 feet above. Said iron pipe to be provided with approved brackets to securely hold it to the chimney; brackets to be not over 3 feet apart.

TESTS OF LIGHTNING RODS.

All lightning rods should be tested for continuity and for resistance of ground plate each year, and the total resistance of the whole conductor and ground plate should never exceed an ohm.

TESTS OF LIGHTNING RODS.

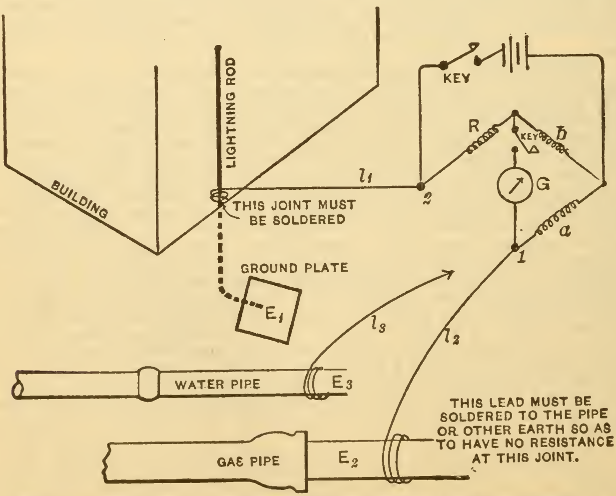


FIG. 6. Diagram of Connections for Test of Lightning Rods.

The continuity and resistance of the lightning rods above ground can be measured with a Wheatstone bridge. The resistance of the ground plate to earth can be determined from three resistance measurements; from ground plate to each of two other grounds and from one to the other of these arbitrarily chosen grounds, as follows:

To make the test, first determine the resistance of the lead wire l_1 and call it l_1. Then connect E_1 and E_2 as shown in the diagram, call the result R_1; then connect E_1 and E_3, call the result R_2; connect E_2 and E_3 and call the result R_3.

Now, $R_1 = l_1 + E_1 + E_2$ and $E_2 = R_1 - l_1 - E_1$

$R_2 = l_1 + E_1 + E_3$ and $E_3 = R_2 - l_1 - E_1$

$R_3 = E_2 + E_3$

solving, we have

$$E_1 = \frac{R_1 + R_2 - R_3}{2} - l_1.$$

The resistance of the ground plate to earth is E_1 as calculated from the above formula.

DIRECTIONS FOR PERSONAL SAFETY DURING THUNDER STORMS.

Do not stand under trees or near wire fences; neither in the doorways of barns, close to cattle, near chimneys or fireplaces. Lightning does not, as a rule, kill. If a person has been struck do not give him up as beyond recovery, even if seemingly dead. Stimulate respiration and circulation as best you can. Keep the body warm; rub the limbs energetically, give water, wine, or warm coffee. Send for a physician.

THE ECONOMY OF ISOLATED ELECTRIC PLANTS.

(By Isaac D. Parsons.)

The following investigation was undertaken by the writer and Mr. Arnold von Schrenk in an attempt to ascertain which of the two methods is the more economical in six classes of buildings in New York, and to determine as nearly as possible those conditions, either inherent in a class of buildings or due to peculiarities of installation or management which materially influence the economy. The six classes referred to are:— Office buildings, loft buildings, department stores, apartment houses, hotels, and clubs, and over two hundred and fifty buildings were visited in the effort to obtain reliable figures and to ascertain the various conditions of operation. Of this number seventeen only were found where information could be obtained which was reliable in every particular, and only these will be considered in detail, as the great variation in conditions even among similar buildings of the same class renders incomplete statistics of very doubtful value.

The figures as to electrical output of each of these plants were obtained from wattmeter readings or from hourly ammeter readings, and were verified by personal observation of the instruments from which they were obtained, and were also checked by comparison with other buildings where similar conditions exist. In some cases, tests were made of the instruments to determine their accuracy. The figures recorded as the output of a plant are in every case the total number of kilowatt hours supplied at the switchboard and used as light or power, and where a storage battery was installed its output only was considered. The expenses of the plants were divided into those of labor, gas, central-station auxiliary or breakdown service, coal, water, ash cartage, oil and waste, repairs incandescent lamps and arc-lamp carbons, interest, depreciation, and sundry supplies not included in the foregoing. Figures concerning these items were obtained in most cases directly from the books of the chief engineer or owner, and may be considered within very small limits absolutely accurate. Under the item labor are included the wages of all the engineers, firemen, oilers and coal passers employed in the plant, excepting in a few cases where extra employees were required by a large refrigerating machine or similar apparatus. In these cases the wages of the extra men were deducted from the total. If it were determined what employees could be dispensed with were the plant not installed, and the wages of these men only were taken, it would give the true cost of labor chargeable against the plant. To decide this, however, was in most instances a rather uncertain and difficult problem, and it was thought fairer to include in the expenses the wages of all the employees, which, with the other items, give the total cost of running the building with a plant. Then, by adding to the expenses of the central-station service the cost of the labor necessary for heating, elevator supervision, etc., the total cost of running under the conditions of central-station supply can be found. The difference between the two results is the true amount gained or lost by the installation of the plant.

The item coal includes that which is burned to generate the steam used for the engines driving the generators, for the feed pumps, and in most cases that used for the house pump and whatever live steam is used in heating the building. In many buildings, refrigerating machines, steam laundries, steam cooking apparatus, or pumps, received steam from the same boilers as the engines driving the dynamos; but in such instances figures from recent tests were available by which the amount of coal used for these purposes could be determined.

With the central-station supply either a boiler or a connection with the street mains is required to obtain the steam necessary for heating the building, as well as for the hot-water supply and for running the house pump, unless it is operated electrically. To determine what extra sum must be added to the actual cost of current in order to find the total expense of running the building from the central station, figures were obtained from two large loft buildings, an office building, and six apartment houses and hotels using steam for heating and for house pumps only, from which the cost of coal, labor, and water required for these purposes could be calculated. The expenses for coal were reduced to dollars per 1,000 cubic feet heated, and showed practically constant factors, irrespective of the shape or size of the building, of $1.10 per 1,000 cubic feet for apartment houses, 90 cents per 1,000 cubic feet for office buildings, and 40 cents per 1,000 cubic feet for loft buildings. The cost of labor, which includes the wages of the firemen and the expense of elevator supervision, has to be determined in each particular case, but usually amounts to a sum about equal to the cost of coal.

Interest was calculated in all cases at 5 per cent on the principal invested in the plant. Depreciation on dynamos, engines, and switchboards of 5 per cent, and on boilers, pumps, and steam piping of 8 per cent, was considered liberal; and since, as a rule, the cost of the dynamos, engines, and switchboards approximates two-thirds of the total cost of installation, and that of the boilers, pumps, and steam piping one-third, a uniform rate of $10/3+8/3$, or 6, per cent was charged against the whole plant. If 5 per cent of the original capital invested in the engines is set aside each year as a sinking fund, this sum will accumulate interest at 5 per cent, and at the end of fourteen and one half years the total of the amounts reserved, with compound interest, will equal the original cost of the engines; so that 5 per cent depreciation assumes a life of but fourteen and one-half years. Similarly 8 per cent depreciation on boilers assumes a life of ten years. As a matter of fact, both of these periods are much exceeded in first class modern installations. On storage batteries where depreciation is a somewhat doubtful quantity, it was taken as 10 per cent, which assumes a life of but seven years. The load factor in every case was calculated for the hours the plant was in actual operation.

As regards load and other conditions of operation, all the buildings can be divided into two classes — those used for business purposes, such as office and loft buildings and stores, and those which are used for residential purposes — such as hotels, apartment houses, and clubs. In the former class a small uniform lighting load during most of the day is succeeded at about 3 P.M. by a heavy load lasting but a few hours, which after 7 P.M. again becomes very small. In the latter class the heavy load, instead of falling off in the evening, continues to 1 or 2 A.M., giving a more uniform load and a higher load factor. We will consider the business buildings first.

TABLE I. — DATA OF ISOLATED PLANTS.

All buildings heated by steam. All engines non-condensing and direct-connected to the generators.

Building number	1	2	3	4	5	6	7	8
Type of building	Office	Office	Office	Office	Office	Loft	Loft	Loft
Number of floors	11	over 20	13	15	12	12	12	10
Ground plan	50×120	70×100	60×150	75×100	40×100	200×176	100×100	40×200
Number of electric elevators	4.25 H.P.	10.25 H.P.	6.27 H.P.	8.30 H.P.	3.20 H.P.	15.20 H.P.	4.20 H.P.	4.25 H.P.
Part of building lighted	All	All	All	All	6 floors	All	All	All
Type of engine	Simple	Comp'd	Comp'd	Simple	Simple	Simple	Simple	Simple
Number of generators	4	4	5	3	1	3	3	3
Total capacity of generators, kilow.	260	575	475	300	40	300	260	90
Average load on generators	.55	.75	.75	.90	.65	.90	.75	.60
Voltage	220 & 240	120	115 & 240	116	240	240	240	240
Type of boiler	H. Tub.	W. Tube	W. Tube	H. Tub.	H. Tub.	H. Tub.	W. Tube	H. Tub.
Boiler pressure	90	125	115	100	95	90	100	100
Back pressure	0	0	1 to 3	4	1 to 5	3 to 9	2 to 5	7 to 10
Kind of coal	Pea	Buck.	Buck.	Pea	Buck.	Rice	Buck.	Buck.
Capacity storage battery, amp. hrs.	....	3500	....	3000	300	....	....	....
Load factor of lighting load	.24	.43	.72	....	.87	.70	.45	....

Cost of Light, Heat and Power, with Plant Installed.

Time covered by figures	1 year	1 year	9 mos.	1 year	1 year	1 year	1 year	1 year	1 year
Labor	$2,460	$7,228	$6,750	$9,000	$6,318	$1,484	$4,628	$4,776	$1,662
Coal and removal of ashes	2,758	10,070	7,663	10,238	9,174	1,012	4,192	2,736	2,129
Water	254	776	756	1,004	900	97	446	204	270
Oil and waste	181	287	171	215	128	103	193	108	80
Lamps	120	600	338	450	420	44	233	33	57
Repairs and sundries	183	50	429	568	65	295	100	108	478
Interest and depreciation	1,340	10,420	3,630	4,840	5,365	1,274	2,200	2,730	908
Central station service	1,370	....	....	....	....	225	....	300	579
Total	$8,666	$29,431	$19,737	$26,315	$22,370	$4,534	$11,992	$10,995	$6,163

Cost of Light, Heat and Power, with Plant Installed. — *Continued.*

Output — light K.W. hours .	91,804	409,233	395,949	550,000	....	18,123	....	....	....
Output — power K.W. hours	59,760	266,344	160,963	225,000	....	48,437	....	....	....
Output — total K.W. hours .	151,564	677,577	556,912	775,000	721,301	66,560	379,939	143,320	130,000
Cost per K.W. hour.	$0.057	$0.044	$0.034	$0.034	$0.031	$0.068	$0.032	$0.077	$0.047
Tons of coal consumed . . .	919	3,007	2,250	3,012	2,619	337	1,873	863	835
Lbs. coal per K.W. hour . .	15.5	10.0	9.1	....	8.2	11.4	11	13.5	14.4

Probable Cost of Light, Heat and Power for same Period without Plant Installed.

Central station bill	$12,374	$28,000	$22,300	$31,000	$29,500	$5,307	....	....	$6,500
Labor	1,000	3,600	2,700	3,650	3,600	1,136	$1,840	$1,740 }	1,600
Coal	660	1,800	700	1,070	1,080	877	920	765 }	
Total	$14,034	$33,400	$25,700	$35,720	$34,180	$7,320			$8,100

TABLE II.—POWER EXPENSES AND OUTPUT FOR ONE YEAR OF EIGHT RESIDENTIAL BUILDINGS.

All buildings heated by steam. All engines simple non-condensing and all direct connected to generators except in building No. 17, where they are belted.

Building number	10	11	12	13	14	15	16	17
Type of building	Ap't H'se	Ap't H'se	Ap't H'se	Hotel	Hotel	Club	Club	Club
Number of floors	7	10	11	6	9	5	3	4
Ground plan	90×65	44×81	50×200	100×200	25×60	35×100	75×200	110×100
Number of electric elevators	1.15 H.P.	2.20 H.P.	3.25 H.P.	....	2.15 H.P.	....	1.20 H.P.	....
Floors of building lighted	All	All	All	1st & 2d	All	All	All	All
Number of generators	2	2	3	2	2	1	3	2
Total capacity of generators, kilow.	45	60	175	66	80	20	130	50
Average load on generators	.48	.20	.60	.50	.67	.40	.40	.75
Voltage	115	240	115	118	115	116	118	118
Type of boiler	Hor. Tub.	Marine	W. Tube	Hor. Tub.	Hor. Tub.	Hor. Tub.	Hor. Tub.	Hor. Tub.
Boiler pressure	90	100	125	90	100	80	90	80
Back pressure	5	2 to 5	3 to 5	4	3 to 6	6	3 to 5	3 to 5
Kind of coal	Pea	Buck.	Buck.	Pea	Bitum.	Buck.	Buck.	Buck.
Load factor of lighting load	.43	.40	.40	.60	.67	.50	.44	.85

Cost of Light, Heat and Power, with Plant Installed.

Time covered by figures	1 year	6 mos.	1 year	*10 mos.	1 year	†	‡	1 year	1 year
Labor	$2,280	$1,320	$3,840	$480	$3,690	$325	$325	$2,700	$2,400
Coal and removal of ashes	1,995	936	5,563	620	5,530	263	389	1,355	1,551
Water	164	64	303	60	486	22	30	117	196
Oil and waste	136	72	240	92	339	6	6	56	90
Lamps	28	8	136	40	354	5	6	24	93
Repairs and sundries	45	46	200	50	500	16	16	112	90
Interest and depreciation	572	495	2,376	880	1,045	115	115	1,100	770
Central station service	.....	300	......	......	......	....	....	.....	584
Total	$5,220	$3,241	$12,658	$2,222	$11,944	$752	$887	$5,464	$5,774

Cost of Light, Heat and Power, with Plant Installed. — *Continued.*

Output — light K.W. hours	55,730	.....	182,360	115,000	......	6,306	9,407	.....	68,513
Output — power K.W. hours	26,400	.....	50,000	......	......	....	....	.....	....
Output — total K.W. hours	82,130	26,605	232,960	115,000	329,500	6,306	9,407	93,800	68,513
Cost per K.W. hour	$0.064	$0.120	$0.055	$0.019	$0.037	$0.12	$0.09	$0.057	$0.084
Tons of coal consumed	570	312	1,919	1,007	1,826	75	111	466	486
Pounds coal per K.W. hour	15.5	25.1	18.4	13.5	12.4	26.7	26.4	11.1	16.6

Probable Cost of Light, Heat and Power for Same Period without Plant Installed.

Central station bill	$7,351	$2,199	$11,330	$5,750	$15,650	$753	$908	$7,770	$5,841
Labor	600	300	1,600	......	1,300	125	125	720	720
Coal	650	672	1,400	......	150	240	240	910	600
Total	$8,601	$3,171	$14,330	$5,750	$17,050	$1,118	$1,273	$9,400	$7,161

* These figures are the cost of generating electricity only, and do not include the cost of heating.
† 5 months, 1900. ‡ 5 months, 1901.

FOUNDATIONS AND STRUCTURAL MATERIALS.

REVISED BY W. W. CHRISTIE.

POWER STATION CONSTRUCTION.

Chart.

BY E. P. ROBERTS & CO.

- STATION
  - Steam Plant
    - Boilers
      - Foundation
      - Setting
      - Stack
      - Water. .
        - Source
        - Pumps and injectors, valves and gauges
        - Heaters
        - Sediment
          - Blow off
          - Mud drum
        - Steam
          - Steam pipe and valve to heater
          - Entrained water, separator
      - Fuel . .
        - Placing in building
        - Placing in boiler
        - Removal of coke and ashes
        - Removal of soot
      - Air . . . . Supply to surface
    - Link
      - Piping and valves
      - Coverings
      - Drains and drips
      - Supports
    - Engines
      - Foundation
      - Steam to cylinder
      - Oil to cylinder
      - Steam from cylinder
      - Water from cylinder
      - Oil to engine
      - Oil from engine
      - Engine indicator
      - Steam to condenser
      - Water to condenser
      - Water from condenser
  - Connecting links . . .
    - Belts
    - Shafts
    - Pulleys
      - . Foundations
      - Lubrication
  - Electrical plant
    - Dynamos . .
      - Foundation
      - Lubrication
      - Insulation
      - Governing devices
      - Measuring devices
      - Safety devices
    - Wire . . . . .
      - Dynamos to switchboard
      - Switchboards to line
      - Track to dynamo
    - Switchboard
      - Distribution devices
      - Dynamo governing devices
      - Dynamo measuring devices
      - Feeder to measuring devices
      - Safety devices
      - Cut-out and lightning arrester
  - Building
    - Weatherproof
    - Fireproof
    - Ventilated
    - Light
    - Provisions for cranes or other strains foreign to its functions as a shelter.

FOUNDATIONS.

The term *foundation* designates the portion of a structure used as a base on which to erect the superstructure, and must be so solid that no movement of the superstructure can take place after its erection.

As all foundations or structures of coarse masonry, whether of brick or stone, will settle to some extent, and as nearly all soils are compressible under heavy weight, care must be taken that the settlement be even all over the structure in order to avoid cracks or other flaws. Although it is quite general to make the excavation for all the sub-foundation without predetermining in more than a general way the nature of the subsoil, and then adapting the base of the foundation to the nature of soil found; yet in large undertakings, where there may be question as to the bearing, borings are made and samples brought up in order to determine the different strata and distance of rock below the surface. Where foundations are not to be deep, or the soil is of good quality, a trench or pit is often sunk alongside the location of the proposed foundation. and the quality of the soil determined in that way.

Foundations on Rock.

The surface of rock should be cleaned and dressed, all decayed portions removed, crevices filled with *grouting* or *concrete*, and where the surface is inclined, it should be cut into a series of level steps before commencing the structure. In such cases of irregular levels, all mortar joints must be kept as close as possible, in order to prevent unequal settlement. A still better way is to bring all such uneven surfaces to a common level with a good thick bed of concrete, which, if properly made, will become as incompressible as stone or brick.

The load on rock foundation should never exceed one-eighth its crushing-load. Baker says "the safe bearing power of rock is certainly *not less* than one-tenth of the ultimate crushing strength of *cubes*. That is to say, the safe bearing power of solid rock is *not less* than 18 tons per square foot for the softest rock, and 180 for the strongest. It is safe to say that almost any rock, from the hardness of granite to that of a soft crumbling stone easily worn by exposure to the weather or to running water, when well bedded will bear the heaviest load that can be brought upon it by any masonry construction." Rankine gives the average of ordinary cases as 20,000 pounds per square foot on rock foundations. Later in this chapter (page 1322) will be found a table that gives the crushing load in pounds per square inch for most of the substances used in foundations and building-walls.

Foundations on Sand or Gravel.

Strong gravel makes one of the best bottoms to build on; it is easily leveled, is almost incompressible, and is not affected by exposure to the atmosphere.

Sand confined so that it cannot escape forms an excellent foundation, and is nearly incompressible. It has no cohesion, and great care must be used in preparing it for a foundation. Surface water must be kept from running into earth foundation beds, and the beds themselves must be well-drained and below frost-line. Baker says that a rather thick bed of sand or gravel, well protected from running water, will safely bear a load of 8 to 10 tons per square foot. Of course the area of the surface must be proportioned to the weight of the superstructure, and to the bearing resistance of the material, and for this reason it is common practice to spread the subfoundation to give it the proper area. Rankine gives 2,500 to 3,500 lbs. per square foot as the greatest allowable pressure on firm earths.

Foundation on Clay.

A good stiff clay makes a very good foundation bed, and will support great weight if care is taken in its preparation. Water must be kept away from it, and the foundation level must be below the frost-line. The less clay is exposed to the atmosphere the better will be the result. Baker gives as safe bearing power for clay 3,000 or 4,000 pounds per square foot. Gaudard says a stiff clay will support in safety 5,500 to 11,000 pounds per square foot.

Foundation on Soft Earth.

Where the earth is too soft to support the superstructure, the trench is excavated to a considerable width, and to a considerable depth below the frost-line; then a bed is prepared of stones, sand, or concrete, the latter being most in use to-day. In fact, it is a common thing to cover the whole area of the basement of large power stations with a heavy layer of concrete, of a thickness sufficient to sustain not only the building-walls, but all machine foundations.

Sand makes a good foundation bed over soft earth, if the earth is of a quality that will retain the sand in position. Sand may be rammed in 9-inch layers in a soft earth trench, or it can be used as *piles* instead of wooden ones, by boring holes 6 or 8 inches in diameter and say six feet deep, and ramming the sand in wet. It is necessary to cover the surface with planking or concrete to prevent the earth pressing upward. Alluvial soils are considered by Baker safe under a load of one-half to one ton per square foot.

Foundation on Piles.

When the earth is unsuitable in nature to support foundations, it is common to drive piles, on the tops of which the foundation is then built. When possible the piles are driven to bed rock, otherwise they are made of such length and used in such number as to support the superstructure by reason of the friction of their surfaces in the soil. Where the soil is quite soft it is also common to drive piles in large number all over the basement area in order to consolidate the earth, and make all parts of a better bearing quality.

Piles must be driven and cut off below the water level, and a grillage of heavy timbers or a layer of broken stone and a capping of concrete must be placed on top of them for supporting the foundation.

The woods most used for piles are spruce and hemlock in soft or medium-soft soils, or when they are to be always under water, hard pine, elm, and beech in firmer soils, and oak in compact soils. When piles are liable to be alternately wet and dry, white oak or yellow pine should be employed.

Piles should not be less than 10 inches in diameter at the small end, nor more than 14 inches at the large end. They should be straight-grained, and have the bark removed. The point is frequently shod with an iron shoe, to prevent the pile from splitting, and the head is hooped with an iron band to prevent splitting or brooming.

Safe Load on Piles.

Rankine gives as safe loads on piles 1,000 pounds per square inch of head, if driven to firm ground; 200 pounds, if in soft earth, and supported by friction.

Major Sanders, U. S. Engineers, gives the following rule for finding the safe load for a wooden pile driven until each blow drives it short and nearly equal distances:

$$\text{Safe load in pounds} = \frac{\text{Weight of hammer in pounds} \times \text{fall in inches}}{8 \times \text{inches driven by last blow}}.$$

Trautwine's rule is as follows:

$$\text{Extreme load in gross tons} = \frac{\sqrt[3]{\text{Fall in feet}} \times \text{Lbs. wgt. of hammer} \times .023}{\text{inches driven by last blow} + 1}.$$

He recommends as safe load one-half the extreme load where driven in firm soils, and one-sixth when driven in soft earths or mud. The last blow should be delivered on solid wood, and not on the "broomed" head.

Piles under Trinity Church, Boston, support two tons each.

Piles under the bridge over the Missouri River at Bismarck, Dakota, were driven into sand to a depth of 32 feet, and each sustained a load of 20 tons.

A pile under an elevator at Buffalo, N. Y., driven into the soil to a depth of 18 feet, sustained a load of 35 tons.

Arrangement of Piles.

Under walls of a building piles are arranged in rows of two or three, spaced 24 inches or 30 inches on centers. Under piers or machine foundations they are arranged in groups, the distance apart being determined by the weight to be supported, but usually, as above, from two to three feet apart on centers.

Concrete Sub-Foundation.

As mentioned in a previous paragraph, concrete is now used to a very great extent for foundation beds, not only in soft earths, but to level up all kinds of foundation beds.

Good proportions are by measure, using Portland cement:

Cement, 1 part; coarse sand, 2 parts; broken stone, 5 parts.

Only hard and sharp broken stone that will pass through a 1½- or 2-inch ring should be used; and the ingredients should be thoroughly mixed dry, and after mixing, add just as little water as will fully wet the material.

Concrete should be placed carefully. It is never at its best when dropped any distance into place. It should be thoroughly rammed in six- or nine-inch layers, and after setting the top of each layer should be cleaned, wet, and roughened before depositing another layer over it. It is common practice to place side-boards in trenches and foundation excavations in order to save concrete. This is economical, but not good practice, if the earth is even moderately firm, as filling out the inequalities makes the foundation much firmer and steady in place. Weight of good concrete per cubic foot is 130 to 160 lbs. dry.

Foundations of Engines.

John Young, Ayr, Scotland, says that brick is more resilient than concrete.

Foundations should weigh 2½ to 4 times that of its engine, depending on whether horizontal or vertical type, also on the outside forces, belt pull, direction, etc.

He also advises a concrete bed 2 to 3 feet deep of Portland cement concrete, and for large work, coating the earth under the concrete with asphalt before concrete is laid.

This helps preventing rise of moisture in foundation masonry.

Permissible Loads on Foundation Beds.

Piles, in firm soil, each pile,	30,000 to 140,000 lbs.
Piles in made ground, each pile,	4,000 "
Clay,	4,000 "
Coarse gravel and sand,	2,500 to 3,500 "
Rock foundations, average,	20,000 "
Concrete,	8,000 "
New York City laws, no pile to be weighted with a load exceeding,	40,000 "
New York City rule for solid natural earth per superficial foot,	8,000 "

Concrete Foundations.

One of the best foundations for engines or other heavy machinery is constructed wholly of concrete, rammed in a mold of planking. The mold can be made of any desired shape; the holding-down bolts placed by template, and the material rammed in layers not exceeding 12 inches thick.

Re-inforced Concrete.

Re-inforced concrete, or Concrete and Steel Construction, is being used quite extensively at the present time for bridges, foundations, retaining walls, floors, and even entire buildings.

When made of the very best Portland cement and good sharp sand and *hard* broken stone all properly incorporated, and when the imbedding of the steel bars is carefully and conscientiously done, the results will prove satisfactory in that class of work for which it is adapted.

Brick Foundations.

Only the best hard-burned brick should be used for foundations, and they should be thoroughly wet before laying. To insure a thorough wetting, the bricks should be deposited in a tub of water. Bricks should be *push placed* in a good rich cement mortar. Grouting should never be used, as it takes too long to dry. Joints should be very small. A well-constructed brick foundation will break as easily in the brick as at the joints after it has been built for some time.

Stone Foundations.

Rubble stone foundations should start with large flat stones on the bottom. Care must be taken that all are well bedded in mortar, and that the work is well tied together by headers.

Dimension stone foundations are always laid out with the heavy and thick stones at the bottom, and gradually decreasing in height, layer by layer, to the top. A large cap-stone, or several if the size is too great for one, is often placed on top of the foundation. Care must be taken to bed each stone in cement mortar, so that the joints will be thin and yet leave all the spaces between the stones completely filled with mortar to prevent any unequal trains on the stone. In all large foundations use plenty of headers; and if the backing or center is of rubble, see that all stones are well bedded, and the crevices filled with spawls and cement.

I-Beam Foundations.

One of the best and now most common methods of constructing foundations for piers, walls, columns, etc., is the use of steel I-beams set in concrete. Knowing the weight to be supported and the bearing value of the soil, excavation is made of the right dimensions to get the proper area of bearing, then I-beams of predetermined dimensions are laid parallel along the bottom, and held in place with bolts from one beam to the next. Concrete is rammed in all the spaces to a level with the tops of the beams. Another similar layer of beams is then laid on top of the first, and at right angles thereto, and the spaces also filled with concrete. The column base, or footing course, is then set on the structure ready to receive the column.

For method of calculation of dimensions of I-beams for use in foundations for piers and walls, the reader can consult the hand-book of the Carnegie Steel Company, and those of other Steel Companies.

MORTARS.

Lime Mortar.

Good proportions are: 1 measure or part quicklime, 3 measures of sand, well mixed, or tempered with clean water.

Quantity required.— Trautwine. 20 cu. ft. sand and 4 cu. ft. of lime, making about 22½ cu. ft. mortar, will lay 1,000 bricks with average coarse joints.

Weight. — 1 bbl. weighs 230 lbs. net, or 250 lbs. gross; 1 heaped bushel of lump lime weighs about 75 lbs.; 1 struck bushel ground quicklime, loose, weighs about 70 lbs. Average hardened mortar weighs about 105 to 115 lbs. per cu. ft.

Tenacity. — Ordinary good lime mortar 6 months old has cohesive strength of from 15 to 30 lbs. per sq. inch.

Adhesion to common bricks or rubble. — At 6 months old, 12 to 24 lbs. per sq. inch.

Cement Mortar.

Good proportions are: 1 measure cement, 2 measures sand, ½ measure water. The above is rich and strong, and for ordinary work will allow increase of sand to 3 or 4 measures.

Quantity required. — Trautwine. 1 bbl. cement, 2 bbls. sand, will lay 1 cu. yd. of bricks with ⅝ inch joints or 1 cu. yard rubble masonry.

Weight. —

American Rosendale, ground, loose, average,		56 lbs. per cu. ft.
" "	U. S. struck bushel,	70 " " " "
English Portland,		81 to 102 " " " "
" "	per struck bushel,	100 to 128 " " " "
" "	per bbl.	400 to 430 " " " "

Average Strength of Neat Cement after 6 Days in Water.

	Tensile, Lbs. per sq. in.	Compress, Lbs. per sq. in.	Compress, Tons per sq. ft.
Portland, artificial . . .	200 to 350	1400 to 2400	90 to 154
" Saylor's natural	170 to 370	1100 to 1700	71 to 109
U. S. common hydraulic .	40 to 70	250 to 450	16 to 29

Cements are weakened by the addition of sand somewhat as shown in the following table: calling neat cement 1.

Sand.	0	$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3	4	5	6
Strength.	1	$\frac{2}{3}$	$\frac{1}{2}$	.4	$\frac{1}{3}$	.3	$\frac{1}{4}$	$\frac{1}{6}$	$\frac{1}{8}$

Adhesion to Bricks or Rubble.

Adhesion of cement, either neat or mixed with sand, will average about three-fourths the tensile strength of the mortar at the same age.

SAND AND CEMENT.

Recommendations of Am. Soc. Civil Engineers.

Sand.—To be crushed quartz only. To pass,
1st sieve, 400 meshes per square inch.
2d " 900 " " " "

Sand to pass the 400 mesh, but be caught by the 900 mesh, all finer particles to be rejected.

Portland Cement.—For fineness, to pass,
1st sieve, 2500 meshes per square inch.
2d " 5476 " " " "
3d " 10000 " " " "

Should be stored in bulk for at least 21 days to air-slake and free it from lime, as lime swells the bulk, and if not removed is apt to crack the work.

IRON AND STEEL.

Iron, weight of:	**cu. in.**	**cu. ft.**
Cast,	.2604 Lbs.	450 Lbs.
Wrought,	.2777 "	480 "

a = sectional area wrought-iron bar.
x = weight per foot " " "

$$a = \frac{3x}{10} \qquad x = \frac{10a}{3}.$$

Steel, weight of:	**cu. in.**	**cu. ft.**
	.2831 Lbs.	489.3 Lbs.

Cast Iron. Test.

Bar an inch square, supported on edges 1 foot apart, must sustain 1 ton at center.

WEIGHT OF FLAT ROLLED IRON IN POUNDS PER LINEAL FOOT.

Widths from 1 in. to 12 in.

Iron weighing 480 lbs. per cubic foot. For steel add 2 per cent.

Thickness in Inches.	Widths.															
	1 in.	1¼ in.	1½ in.	1¾ in.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.	3¼ in.	3½ in.	3¾ in.	4 in.	4¼ in.	4½ in.	4¾ in
1/16	.208	.260	.313	.365	.417	.469	.521	.573	.625	.677	.729	.781	.833	.885	.938	.990
1/8	.417	.521	.625	.729	.833	.938	1.04	1.15	1.25	1.35	1.46	1.56	1.67	1.77	1.88	1.98
3/16	.625	.781	.938	1.09	1.25	1.41	1.56	1.72	1.88	2.03	2.19	2.34	2.50	2.66	2.81	2.97
1/4	.833	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50	2.71	2.92	3.13	3.33	3.54	3.75	3.96
5/16	1.04	1.30	1.56	1.82	2.08	2.34	2.60	2.86	3.13	3.39	3.65	3.91	4.17	4.43	4.69	4.95
3/8	1.25	1.56	1.88	2.19	2.50	2.81	3.13	3.44	3.75	4.06	4.38	4.69	5.00	5.31	5.63	5.94
7/16	1.46	1.82	2.19	2.55	2.92	3.28	3.65	4.01	4.38	4.74	5.10	5.47	5.83	6.20	6.56	6.93
1/2	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	5.00	5.42	5.83	6.25	6.67	7.08	7.50	7.92
9/16	1.88	2.34	2.81	3.28	3.75	4.22	4.69	5.16	5.63	6.09	6.56	7.03	7.50	7.97	8.44	8.91
5/8	2.08	2.60	3.13	3.65	4.17	4.69	5.21	5.73	6.25	6.77	7.29	7.81	8.33	8.85	9.38	9.90
11/16	2.29	2.86	3.44	4.01	4.58	5.16	5.73	6.30	6.88	7.45	8.02	8.59	9.17	9.74	10.31	10.89
3/4	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75	9.38	10.00	10.63	11.25	11.88
13/16	2.71	3.39	4.06	4.74	5.42	6.09	6.77	7.45	8.13	8.80	9.48	10.16	10.83	11.51	12.19	12.86
7/8	2.92	3.65	4.38	5.10	5.83	6.56	7.29	8.02	8.75	9.48	10.21	10.94	11.67	12.40	13.13	13.85
15/16	3.13	3.91	4.69	5.47	6.25	7.03	7.81	8.59	9.38	10.16	10.94	11.72	12.50	13.28	14.06	14.84
1	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	10.00	10.83	11.67	12.50	13.33	14.17	15.00	15.83
1 1/16	3.54	4.43	5.31	6.20	7.08	7.97	8.85	9.74	10.63	11.51	12.40	13.28	14.17	15.05	15.94	16.82
1 1/8	3.75	4.69	5.63	6.56	7.50	8.44	9.38	10.31	11.25	12.19	13.13	14.06	15.00	15.94	16.88	17.81
1 3/16	3.96	4.95	5.94	6.93	7.92	8.91	9.90	10.89	11.88	12.86	13.85	14.84	15.83	16.82	17.81	18.80
1 1/4	4.17	5.21	6.25	7.29	8.33	9.38	10.42	11.46	12.50	13.54	14.58	15.63	16.67	17.71	18.75	19.79
1 5/16	4.37	5.47	6.56	7.66	8.75	9.84	10.94	12.03	13.13	14.22	15.31	16.41	17.50	18.59	19.69	20.78
1 3/8	4.58	5.73	6.88	8.02	9.17	10.31	11.46	12.60	13.75	14.90	16.04	17.19	18.33	19.48	20.63	21.77
1 7/16	4.79	5.99	7.19	8.39	9.58	10.78	11.98	13.18	14.38	15.57	16.77	17.97	19.17	20.36	21.56	22.76
1 1/2	5.00	6.25	7.50	8.75	10.00	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75
1 9/16	5.21	6.51	7.81	9.11	10.42	11.72	13.02	14.32	15.63	16.93	18.23	19.53	20.83	22.14	23.44	24.74
1 5/8	5.42	6.77	8.13	9.48	10.83	12.19	13.54	14.90	16.25	17.60	18.96	20.31	21.67	23.02	24.38	25.73
1 11/16	5.63	7.03	8.44	9.84	11.25	12.66	14.06	15.47	16.88	18.28	19.69	21.09	22.50	23.91	25.31	26.72
1 3/4	5.83	7.29	8.75	10.21	11.67	13.13	14.58	16.04	17.50	18.96	20.42	21.88	23.33	24.79	26.25	27.71
1 13/16	6.04	7.55	9.06	10.57	12.08	13.59	15.10	16.61	18.13	19.64	21.15	22.66	24.17	25.68	27.19	28.70
1 7/8	6.25	7.81	9.38	10.94	12.50	14.06	15.63	17.19	18.75	20.31	21.88	23.44	25.00	26.56	28.13	29.69
1 15/16	6.46	8.07	9.69	11.30	12.92	14.53	16.15	17.76	19.38	20.99	22.60	24.22	25.83	27.45	29.06	30.68
2	6.67	8.33	10.00	11.67	13.33	15.00	16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67

WEIGHT OF FLAT ROLLED IRON IN POUNDS PER LINEAL FOOT. Continued.

Thickness in Inches.	Widths.															
	5 in.	$5\frac{1}{4}$ in.	$5\frac{1}{2}$ in.	$5\frac{3}{4}$ in.	6 in.	$6\frac{1}{4}$ in.	$6\frac{1}{2}$ in.	$6\frac{3}{4}$ in.	7 in.	$7\frac{1}{2}$ in.	8 in.	$8\frac{1}{2}$ in.	9 in.	10 in.	11 in.	12 in.
$\frac{1}{16}$	1.04	1.09	1.15	1.20	1.25	1.30	1.35	1.41	1.46	1.56	1.67	1.77	1.88	2.08	2.29	2.50
$\frac{1}{8}$	2.08	2.19	2.29	2.40	2.50	2.60	2.71	2.81	2.92	3.13	3.33	3.54	3.75	4.17	4.58	5.00
$\frac{3}{16}$	3.13	3.28	3.44	3.59	3.75	3.91	4.06	4.22	4.38	4.69	5.00	5.31	5.63	6.25	6.88	7.50
$\frac{1}{4}$	4.17	4.38	4.58	4.79	5.00	5.21	5.42	5.63	5.83	6.25	6.67	7.08	7.50	8.33	9.17	10.00
$\frac{5}{16}$	5.21	5.47	5.73	5.99	6.25	6.51	6.77	7.03	7.29	7.81	8.33	8.85	9.38	10.42	11.46	12.50
$\frac{3}{8}$	6.25	6.56	6.88	7.19	7.50	7.81	8.13	8.44	8.75	9.38	10.00	10.63	11.25	12.50	13.75	15.00
$\frac{7}{16}$	7.29	7.66	8.02	8.39	8.75	9.11	9.48	9.84	10.21	10.94	11.67	12.40	13.13	14.58	16.04	17.50
$\frac{1}{2}$	8.33	8.75	9.17	9.58	10.00	10.42	10.83	11.25	11.67	12.50	13.33	14.17	15.00	16.67	18.33	20.00
$\frac{9}{16}$	9.38	9.84	10.31	10.78	11.25	11.72	12.19	12.66	13.13	14.06	15.00	15.94	16.88	18.75	20.63	22.50
$\frac{5}{8}$	10.42	10.94	11.46	11.98	12.50	13.02	13.54	14.06	14.58	15.63	16.67	17.71	18.75	20.83	22.92	25.00
$\frac{11}{16}$	11.46	12.03	12.60	13.18	13.75	14.32	14.90	15.47	16.04	17.19	18.33	19.48	20.63	22.92	25.21	27.50
$\frac{3}{4}$	12.50	13.13	13.75	14.38	15.00	15.63	16.25	16.88	17.50	18.75	20.00	21.25	22.50	25.00	27.50	30.00
$\frac{13}{16}$	13.54	14.22	14.90	15.57	16.25	16.93	17.60	18.28	18.96	20.31	21.67	23.02	24.38	27.08	29.79	32.50
$\frac{7}{8}$	14.58	15.31	16.04	16.77	17.50	18.23	18.96	19.69	20.42	21.88	23.33	24.79	26.25	29.17	32.08	35.00
$\frac{15}{16}$	15.63	16.41	17.19	17.97	18.75	19.53	20.31	21.09	21.88	23.44	25.00	26.56	28.13	31.25	34.38	37.50
1	16.67	17.50	18.33	19.17	20.00	20.83	21.67	22.50	23.33	25.00	26.67	28.33	30.00	33.33	36.67	40.00
$1\frac{1}{8}$	18.75	19.69	20.63	21.56	22.50	23.44	24.38	25.31	26.25	28.13	30.00	31.88	33.75	37.50	41.25	45.00
$1\frac{1}{4}$	20.83	21.88	22.92	23.96	25.00	26.04	27.08	28.13	29.17	31.25	33.33	35.42	37.50	41.67	45.83	50.00
$1\frac{3}{8}$	22.92	24.06	25.21	26.35	27.50	28.65	29.79	30.94	32.08	34.38	36.67	38.96	41.25	45.83	50.42	55.00
$1\frac{1}{2}$	25.00	26.25	27.50	28.75	30.00.	31.25	32.50	33.75	35.00	37.50	40.00	42.50	45.00	50.00	55.00	60.00
$1\frac{5}{8}$	27.08	28.44	29.79	31.15	32.50	33.85	35.21	36.56	37.92	40.63	43.33	46.04	48.75	54.17	59.58	65.00
$1\frac{3}{4}$	29.17	30.63	32.08	33.54	35.00	36.46	37.92	39.38	40.83	43.75	46.67	49.58	52.50	58.33	64.17	70.00
$1\frac{7}{8}$	31.25	32.81	34.38	35.94	37.50	39.06	40.63	42.19	43.75	46.88	50.00	53.13	56.25	62.50	68.75	75.00
2	33.33	35.00	36.67	38.33	40.00	41.67	43.33	45.00	46.67	50.00	53.33	56.67	60.00	66.67	73.33	80.00

Other Sizes.—Weight of other sizes can easily be obtained from the above table by means of combinations or divisions. Thus, for example,

Weight of 12 × $1\frac{1}{4}$ equals weight of 12 × 1 plus weight of 12 × $\frac{1}{4}$ 50.00
Or, twice weight of 12 × $\frac{5}{8}$, as it is twice as thick 50.00
Weight of 6 × $1\frac{15}{16}$ equals midway weight between 6 × $1\frac{7}{8}$ and 6 × 2 . . . . . 38.75
Weight of 24 × $\frac{15}{16}$, being twice as wide as 12 × $\frac{15}{16}$, weighs 75.00

WEIGHTS OF SQUARE AND ROUND BARS OF WROUGHT IRON IN POUNDS PER LINEAL FOOT.

Iron weighing 480 lbs. per cubic foot. For steel add 2 per cent.

Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.	Thickness or Diameter in Inches.	Weight of Square Bar One Foot Long.	Weight of Round Bar One Foot Long.
0			11/16	24.08	18.91	3/8	96.30	75.64
1/16	.013	.010	3/4	25.21	19.80	7/16	98.55	77.40
1/8	.052	.041	13/16	26.37	20.71	1/2	100.8	79.19
3/16	.117	.092	7/8	27.55	21.64	9/16	103.1	81.00
1/4	.208	.164	15/16	28.76	22.59	5/8	105.5	82.83
5/16	.326	.256	3	30.00	23.56	11/16	107.8	84.69
3/8	.469	.368	1/16	31.26	24.55	3/4	110.2	86.56
7/16	.638	.501	1/8	32.55	25.57	13/16	112.6	88.45
1/2	.833	.654	3/16	33.87	26.60	7/8	115.1	90.36
9/16	1.055	.828	1/4	35.21	27.65	15/16	117.5	92.29
5/8	1.302	1.023	5/16	36.58	28.73	6	120.0	94.25
11/16	1.576	1.237	3/8	37.97	29.82	1/8	125.1	98.22
3/4	1.875	1.473	7/16	39.39	30.94	1/4	130.2	102.3
13/16	2.201	1.728	1/2	40.83	32.07	3/8	135.5	106.4
7/8	2.552	2.004	9/16	42.30	33.23	1/2	140.8	110.6
15/16	2.930	2.301	5/8	43.80	34.40	5/8	146.3	114.9
1	3.333	2.618	11/16	45.33	35.60	3/4	151.9	119.3
1/16	3.763	2.955	3/4	46.88	36.82	7/8	157.6	123.7
1/8	4.219	3.313	13/16	48.45	38.05	7	163.3	128.3
3/16	4.701	3.692	7/8	50.05	39.31	1/8	169.2	132.9
1/4	5.208	4.091	15/16	51.68	40.59	1/4	175.2	137.6
5/16	5.742	4.510	4	53.33	41.89	3/8	181.3	142.4
3/8	6.302	4.950	1/16	55.01	43.21	1/2	187.5	147.3
7/16	6.888	5.410	1/8	56.72	44.55	5/8	193.8	152.2
1/2	7.500	5.890	3/16	58.45	45.91	3/4	200.2	157.2
9/16	8.138	6.392	1/4	60.21	47.29	7/8	206.7	162.4
5/8	8.802	6.913	5/16	61.99	48.69	8	213.3	167.6
11/16	9.492	7.455	3/8	63.80	50.11	1/4	226.9	178.2
3/4	10.21	8.018	7/16	65.64	51.55	1/2	240.8	189.2
13/16	10.95	8.601	1/2	67.50	53.01	3/4	255.2	200.4
7/8	11.72	9.204	9/16	69.39	54.50	9	270.0	212.1
15/16	12.51	9.828	5/8	71.30	56.00	1/4	285.2	224.0
2	13.33	10.47	11/16	73.24	57.52	1/2	300.8	236.3
1/16	14.18	11.14	3/4	75.21	59.07	3/4	316.9	248.9
1/8	15.05	11.82	13/16	77.20	60.63	10	333.3	261.8
3/16	15.95	12.53	7/8	79.22	62.22	1/4	350.2	275.1
1/4	16.88	13.25	15/16	81.26	63.82	1/2	367.5	288.6
5/16	17.83	14.00	5	83.33	65.45	3/4	385.2	302.5
3/8	18.80	14.77	1/16	85.43	67.10	11	403.3	316.8
7/16	19.80	15.55	1/8	87.55	68.76	1/4	421.9	331.3
1/2	20.83	16.36	3/16	89.70	70.45	1/2	440.8	346.2
9/16	21.89	17.19	1/4	91.88	72.16	3/4	460.2	361.4
5/8	22.97	18.04	5/16	94.08	73.89	12	480.	377.

WEIGHT OF PLATE IRON, PER LINEAL FOOT, IN POUNDS.

(Based on 480 lbs. per Cubic Foot. For Steel add 2 per cent.)

Width in Inches.	Thickness in Inches.															
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
12	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00
13	2.71	5.42	8.13	10.83	13.54	16.25	18.96	21.67	24.38	27.08	29.79	32.50	35.21	37.92	40.63	43.33
14	2.92	5.83	8.75	11.67	14.58	17.50	20.42	23.33	26.25	29.17	32.08	35.00	37.92	40.83	43.75	46.67
15	3.13	6.25	9.38	12.50	15.63	18.75	21.88	25.00	28.13	31.25	34.38	37.50	40.63	43.75	46.88	50.00
16	3.33	6.67	10.00	13.33	16.67	20.00	23.33	26.67	30.00	33.33	36.67	40.00	43.33	46.67	50.00	53.33
17	3.54	7.08	10.63	14.17	17.71	21.25	24.79	28.33	31.88	35.42	38.96	42.50	46.05	49.59	53.13	56.67
18	3.75	7.50	11.25	15.00	18.75	22.50	26.25	30.00	33.75	37.50	41.25	45.00	48.75	52.50	56.25	60.00
19	3.96	7.92	11.87	15.83	19.79	23.75	27.71	31.67	35.67	39.58	43.54	47.50	51.45	55.41	59.37	63.33
20	4.17	8.33	12.50	16.67	20.83	25.00	29.17	33.33	37.50	41.67	45.83	50.00	54.17	58.33	62.50	66.67
21	4.38	8.75	13.13	17.50	21.88	26.25	30.63	35.00	39.38	43.75	48.13	52.50	56.88	61.25	65.63	70.00
22	4.58	9.17	13.75	18.33	22.92	27.50	32.08	36.67	41.25	45.83	50.42	55.00	59.58	64.17	68.75	73.33
23	4.79	9.58	14.38	19.17	23.96	28.75	33.54	38.33	43.13	47.92	52.71	57.50	62.30	67.09	71.88	76.67
24	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00	75.00	80.00
25	5.21	10.42	15.62	20.83	26.04	31.25	36.46	41.67	46.88	52.08	57.29	62.50	67.70	72.91	78.13	83.33
26	5.42	10.83	16.25	21.67	27.08	32.50	37.92	43.33	48.75	54.17	59.58	65.00	70.42	75.83	81.25	86.67
27	5.63	11.25	16.88	22.50	28.13	33.75	39.38	45.00	50.63	56.25	61.88	67.50	73.13	78.75	84.38	90.00
28	5.83	11.67	17.50	23.33	29.17	35.00	40.83	46.67	52.50	58.33	64.17	70.00	75.84	81.67	87.50	93.33
29	6.04	12.08	18.13	24.17	30.21	36.25	42.29	48.33	54.38	60.42	66.46	72.50	78.55	84.59	90.63	96.67
30	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	68.75	75.00	81.25	87.50	93.75	100.0
32	6.67	13.33	20.00	26.67	33.33	40.00	46.67	53.33	60.00	66.67	73.33	80.00	86.67	93.33	100.0	106.7
34	7.08	14.17	21.25	28.33	35.42	42.50	49.58	56.67	63.75	70.83	77.91	85.00	92.08	99.17	106.3	113.3
36	7.50	15.00	22.50	30.00	37.50	45.00	52.50	60.00	67.50	75.00	82.50	90.00	97.50	105.0	112.5	120.0
38	7.92	15.83	23.75	31.67	39.59	47.50	55.42	63.33	71.25	79.17	87.09	95.00	102.9	110.8	118.8	126.7
40	8.33	16.67	25.00	33.33	41.67	50.00	58.33	66.67	75.00	83.33	91.67	100.0	108.3	116.7	125.0	133.3
42	8.75	17.50	26.25	35.00	43.75	52.50	61.25	70.00	78.75	87.50	96.25	105.0	113.7	122.5	131.3	140.0
44	9.17	18.33	27.50	36.67	45.84	55.00	64.17	73.33	82.50	91.67	100.8	110.0	119.2	128.3	137.5	146.7
46	9.58	19.17	28.75	38.33	47.92	57.50	67.08	76.67	86.25	95.83	105.4	115.0	124.6	134.2	143.8	153.3
48	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.0	110.0	120.0	130.0	140.0	150.0	160.0
50	10.42	20.83	31.25	41.67	52.08	62.50	72.91	83.33	93.75	104.2	114.6	125.0	135.4	145.8	156.3	166.7
52	10.83	21.67	32.50	43.33	54.17	65.00	75.83	86.67	97.50	108.3	119.2	130.0	140.8	151.7	162.5	173.3
54	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00	101.3	112.5	123.8	135.0	146.3	157.5	168.8	180.0
56	11.67	23.33	35.00	46.67	58.33	70.00	81.66	93.33	105.0	116.7	128.3	140.0	151.7	163.3	175.0	186.7
58	12.08	24.17	36.25	48.33	60.42	72.50	84.58	96.67	108.8	120.8	132.9	145.0	157.1	169.2	181.3	193.3
60	12.50	25.00	37.50	50.00	62.50	75.00	87.50	100.00	112.5	125.0	137.5	150.0	162.5	175.0	187.5	200.0

U. S. STANDARD GAUGE FOR SHEET AND PLATE IRON AND STEEL. 1893.

Number of Gauge.	Approximate Thickness in Fractions of an Inch.	Approximate Thickness in Decimal Parts of an Inch.	Approximate Thickness in Millimeters.	Weight per Sq. Ft. in Ounces Avoirdupois.	Weight per Sq. Ft. in Pounds Avoirdupois.	Weight per Sq. Ft. in Kilograms.	Weight per Square Meter in Kilograms.	Weight per Square Meter in Pounds Avoirdupois.
0000000	1–2	0.5	12.7	320	20.	9.072	97.65	215.28
000000	15–32	0.46875	11.90625	300	18.75	8.505	91.55	201.82
00000	7–16	0.4375	11.1125	280	17.50	7.938	85.44	188.37
0000	13–32	0.40625	10.31875	260	16.25	7.371	79.33	174.91
000	3–8	0.375	9.525	240	15.	6.804	73.24	161.46
00	11–32	0.34375	8.73125	220	13.75	6.237	67.13	148.00
0	5–16	0.3125	7.9375	200	12.50	5.67	61.03	134.55
1	9–32	0.28125	7.14375	180	11.25	5.103	54.93	121.09
2	17–64	0.265625	6.746875	170	10.625	4.819	51.88	114.37
3	1–4	0.25	6.35	160	10.	4.536	48.82	107.64
4	15–64	0.234375	5.953125	150	9.375	4.252	45.77	100.91
5	7–32	0.21875	5.55625	140	8.75	3.969	42.72	94.18
6	12–64	0.203125	5.159375	130	8.125	3.685	39.67	87.45
7	3–16	0.1875	4.7625	120	7.5	3.402	36.62	80.72
8	11–64	0.171875	4.365625	110	6.875	3.118	33.57	74.00
9	5–32	0.15625	3.96875	100	6.25	2.835	30.52	67.27
10	9-64	0.140625	3.571875	90	5.625	2.552	27.46	60.55
11	1–8	0.125	3.175	80	5.	2.268	24.41	53.82
12	7–64	0.109375	2.778125	70	4.375	1.984	21.36	47.09
13	3–32	0.09375	2.38125	60	3.75	1.701	18.31	40.36
14	5–64	0.078125	1.984375	50	3.125	1.417	15.26	33.64
15	9–128	0.0703125	1.7859375	45	2.8125	1.276	13.73	30.27
16	1–16	0.0625	1.5875	40	2.5	1.134	12.21	26.91
17	9–160	0.05625	1.42875	36	2.25	1.021	10.99	24.22
18	1–20	0.05	1.27	32	2.	0.9072	9.765	21.53
19	7–160	0.04375	1.11125	28	1.75	0.7938	8.544	18.84
20	3–80	0.0375	0.9525	24	1.50	0.6804	7.324	16.15
21	11–320	0.034375	0.873125	22	1.375	0.6237	6.713	14.80
22	1–32	0.03125	0.793750	20	1.25	0.567	6.103	13.46
23	9–320	0.028125	0.714375	18	1.125	0.5103	5.493	12.11
24	1–40	0.025	0.635	16	1.	0.4536	4.882	10.76
25	7–320	0.021875	0.555625	14	0.875	0.3969	4.272	9.42
26	3–160	0.01875	0.47625	12	0.75	0.3402	3.662	8.07
27	11–640	0.0171875	0.4365625	11	0.6875	0.3119	3.357	7.40
28	1–64	0.015625	0.396875	10	0.625	0.2835	3.052	6.73
29	9–640	0.0140625	0.3571875	9	0.5625	0.2551	2.746	6.05
30	1–80	0.0125	0.3175	8	0.5	0.2268	2.441	5.38
31	7–640	0.0109375	0.2778125	7	0.4375	0.1984	2.136	4.71
32	13–1280	0.01015625	0.25796875	6½	0.40625	0.1843	1.983	4.37
33	3–320	0.009375	0.238125	6	0.375	0.1701	1.831	4.04
34	11–1280	0.00859375	0.21828125	5½	0.34375	0.1559	1.678	3.70
35	5–640	0.0078125	0.1984375	5	0.3125	0.1417	1.526	3.36
36	9–1280	0.00703125	0.17859375	4½	0.28125	0.1276	1.373	3.03
37	17–2560	0.006640625	0.168671875	4¼	0.265625	0.1205	1.297	2.87
38	1–160	0.00625	0.15875	4	0.25	0.1134	1.221	2.69

COLUMNS, PILLARS, OR STRUTS.

Hodgkinson's Formula for Columns.

P = crushing weight in pounds ; d = exterior diameter in inches ; d_1 = interior diameter in inches ; L = length in feet.

Kind of Columns.	Both ends rounded, the length of the column exceeding 15 times its diameter.	Both ends flat, the length of the column exceeding 30 times its diameter.
Solid cylindrical columns of cast iron .	$P = 33{,}380 \frac{d^{3.76}}{L^{1.7}}$	$P = 98{,}920 \frac{d^{3.55}}{L^{1.7}}$
Hollow cylindrical columns of cast iron	$P = 29{,}120 \frac{d^{3.76} - d_1^{3.76}}{L^{1.7}}$	$P = 99{,}320 \frac{d^{3.55} - d_1^{3.55}}{L^{1.7}}$
Solid cylindrical columns of wrought iron	$P = 95{,}850 \frac{d^{3.76}}{L^2}$	$P = 299{,}600 \frac{d^{3.55}}{L^2}$
Solid square pillar of Dantzic oak (dry) .	. . . .	$P = 24{,}540 \frac{d^4}{L^2}$

These formulæ apply only to cases of breakage caused by bending rather than mere crushing. Where the column is short, or say five times its diameter in length, then the following formula applies.

Let

P = value given in preceding formulæ,
K = transverse section of column in square inches,
C = ultimate compressive resistance of the material,
W = crushing strength of the column.

Then

$$W = \frac{P\,C\,K}{P + \frac{3}{4}\,C\,K}.$$

Hodgkinson's experiments were made upon columns the longest of which for cast iron was 60½ inches, and for wrought iron 90¾ inches.

The following are some of his conclusions :

1. In all long pillars of the same dimensions, when the force is applied in the direction of the axis, the strength of one which has flat ends is about three times as great as one with rounded ends.

2. The strength of a pillar with one end rounded and the other flat is an arithmetical mean between the two given in the preceding case of the same dimensions.

3. The strength of a pillar having both ends firmly fixed is the same as one of half the length with both ends rounded.

4. The strength of a pillar is not increased more than one-seventh by enlarging it at the middle.

Gordon's formulæ, deduced from Hodgkinson's experiments, are more generally used than Hodgkinson's own. They are :

Columns with both ends fixed or flat $P = \dfrac{fS}{1 + a\dfrac{l^2}{r^2}}$;

Columns with one end flat, the other end round, $P = \dfrac{fS}{1 + 1.8a\dfrac{l^2}{r^2}}$

Columns with both ends round or hinged, $P = \dfrac{fS}{1 + 4a\dfrac{l^2}{r^2}}$;

$S =$ area of cross section in inches ;
$P =$ ultimate resistance of column in pounds ;
$f =$ crushing strength of the material in pounds per square inch ;
$r =$ least radius of gyration, in inches, $r^2 = \frac{\text{Moment of inertia}}{\text{area of section}}$;
$l =$ length of column in inches ;
$a =$ a coefficient depending upon the material ;

f and a are usually taken as constants ; they are really empirical variables, dependent upon the dimensions and character of the column as well as upon the material. (Burr.)

For solid wrought-iron columns, values commonly taken are : $f = 36,000$ to $40,000$; $a = \frac{1}{36,000}$ to $\frac{1}{40,000}$.

New York City Building Laws 1897–1898 give the following values for f :

Cast iron	$f = 80,000$ lbs.
Rolled steel	$f = 48,000$ lbs.
Wrought or rolled iron	$f = 40,000$ lbs.
American oak . . .	$f = 6,000$ lbs.
Pitch or Georgia pine .	$f = 5,000$ lbs.
White pine and spruce	$f = 3,500$ lbs.

For solid cast-iron columns, $f = 80,000$, $a = \frac{1}{6400}$.

For hollow cast-iron columns, fixed ends, $p = \frac{80,000}{1 + 800\frac{l^2}{d^2}}$, $l =$ length and $d =$ diameter in the same unit, and $p =$ strength in lbs. per square inch.

Sir Benjamin Baker gives,

For mild steel $f = 67,000$ lbs., $a = \frac{1}{22,400}$.

For strong steel $f = 114,000$ lbs., $a = \frac{1}{14,400}$.

STRENGTH OF MATERIALS.

The terms *stress* and *strain* are generally used synonymously, authorities differing as to which is the proper use. Merriman defines *stress* as a force which acts in the interior of a body, and resists the external forces which tend to change its shape. A *deformation* is the amount of change of shape of a body caused by the stress. The word *strain* is often used as synonymous with *stress*, and sometimes it is also used to designate the deformation. Merriman gives the following general laws for simple tension or compression, as having been established by experiment.

a. When a small stress is applied to a body, a small deformation is produced, and on the removal of the stress the body springs back to its original form. For small stresses, then, materials may be regarded as perfectly elastic.

b. Under small stresses the deformations are approximately proportional to the forces or stresses which produce them, and also approximately proportional to the length of the bar or body.

c. When the stress is great enough, a deformation is produced which is partly permanent; that is, the body does not spring back entirely to its original form on removal of the stress. This permanent part is termed a set. In such cases the deformations are not proportional to the stress.

d. When the stress is greater still, the deformation rapidly increases, and the body finally ruptures.

e. A sudden shock or stress is more injurious than a steady stress, or than a stress gradually applied.

ELASTIC LIMIT.

The *elastic limit* of a material under test for tensile strength is defined as the point where the rate of stretch begins to increase, or where the deformations cease to be proportional to the stresses, and the body loses its power to return completely to its former dimensions when the stress is removed.

Modulus of Elasticity.

The *modulus* or *coefficient* of *elasticity* is the term expressing the relation of the amount of extension or compression of a material under stress to the load producing that stress or deformation. It is the load per unit of section divided by the extension per unit of length.

If $P =$ applied load,
$k =$ sectional area of piece,
$l =$ length of the part extended,
$\lambda =$ amount of extension,
$M =$ modulus of elasticity,

$$M = \frac{P}{k} \div \frac{\lambda}{l} = \frac{Pl}{k\lambda}.$$

Following are the *Moduli* of elasticity for various materials.

Brass, cast	9,170,000			
" wire	14,230,000			
Copper	15,000,000	to	18,000,000.	
Lead	1,000,000			
Tin, cast	4,600,000			
Iron, cast	12,000,000	to	27,000,000 (?)	
Iron, wrought	22,000,000	to	29,000,000	
Steel	26,000,000	to	32,000,000	
Marble	25,000,000			
Slate	14,500,000			
Glass	8,000,000			
Ash	1,600,000			
Beech	1,300,000			
Birch	1,250,000	to	1,500,000	
Fir	869,000	to	2,191,000	
Oak	974,000	to	2,283,000	
Teak	2,414,000			
Walnut	306,000			
Pine, long-leaf (butt-logs)	1,119,200	to	3,117,000	Average, 1,926,00

Factor of Safety.

This may be defined as the factor by which the breaking strength of a material is divided to obtain a safe working-stress. The factor of safety is sometimes a rather indefinite quantity, owing to lack of information as to the strength of materials, and it is now becoming common to name a definite stress which is substantially the result of dividing the average strengths by a factor.

The following factors are found in the "Laws Relating to Building in New York City," 1897–1898.

For beams, girders, and pieces subject to transverse strains, factor of safety = 4.

For wrought-iron or rolled-steel posts, columns, or other vertical supports, 4.

For other materials subject to a compressive strain, 5.

For tie-rods, tie-beams, and other pieces subject to tensile strain, 6.

MOMENT OF INERTIA.

The moment of inertia of a body about any axis, is the sum of the products of the mass of each particle of the body, into the square of its (least) distance from the axis.

RADIUS OF GYRATION.

The radius of gyration of a section is the square root of the quotient of the *moment of inertia*, divided by the area of the section, or

$$\text{Radius of gyration} = \sqrt{\frac{\text{Moment of inertia}}{\text{Area of section.}}}$$

The radius of gyration of a solid about an axis is equal to the

$$\sqrt{\frac{\text{Moment of Inertia}}{\text{Mass of the Solid}}}$$

Use in the Formulæ for Strength of Girders and Columns.

The strength of sections to resist strains, either as girders or as columns, depends on the form of the section and its area, and the property of the section which forms the basis of the constants used in the formulæ for strength of girders and columns to express the effect of the form, is its moment of inertia about its neutral axis. Thus the moment of resistance of any section to transverse bending is its moment of inertia divided by the distance from the neutral axis to the fibers farthest removed from the axis; or

$$\text{Moment of resistance} = \frac{\text{Moment of inertia}}{\text{Distance of extreme fiber from axis}}. \quad M = \frac{I}{e}.$$

Moment of Inertia of Compound Shapes.

(Pencoyd Iron Works.)

The moment of inertia of any section about any axis is equal to the I about a parallel axis passing through its center of gravity + (the area of the section × the square of the distance between the axes).

By this rule, the moments of inertia or radii of gyration of any single sections being known, corresponding values may be obtained for any combination of these sections.

Radius of Gyration of Compound Shapes.

In the case of a pair of any shape without a web the value of R can always be found without considering the moment of inertia.

The radius of gyration for any section round an axis parallel to another axis passing through its center of gravity is found as follows:

Let r = radius of gyration around axis through center of gravity; R = radius of gyration around another axis parallel to above; d = distance between axes:

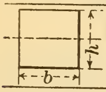
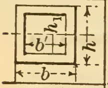
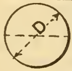
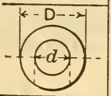
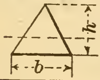
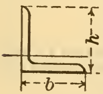
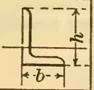
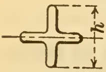
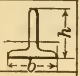
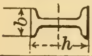
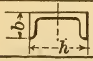
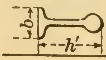
$$R = \sqrt{d^2 + r^2}$$

When r is small, R may be taken as equal to d without material error.

ELEMENTS OF USUAL SECTIONS.

Moments refer to horizontal axis through center of gravity. This table is intended for convenient application where extreme accuracy is not important. Some of the terms are only approximate; those marked * are correct. Values for radius of gyration in flanged beams apply to standard minimum sections only.

A = area of section;
b = breadth;
h = depth;
D = diameter.

Shape of Section.		Moment of Inertia.	Moment of Resistance.	Square of Least Radius of Gyration.	Least Radius of Gyration.
	Solid Rectangle.	$\frac{bh^3}{12}$*	$\frac{bh^2}{6}$*	$\frac{(\text{Least Side})^2}{12}$*	$\frac{\text{Least side}}{3.46}$*
	Hollow Rectangle.	$\frac{bh^3-b_1h_1^3}{12}$*	$\frac{bh^3-b_1h_1^3}{6h}$*	$\frac{h^2+h_1^2}{12}$*	$\frac{h+h_1}{4.89}$
	Solid Circle.	$\frac{AD^2}{16}$*	$\frac{AD}{8}$*	$\frac{D^2}{16}$*	$\frac{D}{4}$*
	Hollow Circle A, area of large section; a, area of small section.	$\frac{AD^2-ad^2}{16}$	$\frac{AD^2-ad^2}{8D}$	$\frac{D^2+d^2}{16}$*	$\frac{D+d}{5.64}$
	Solid Triangle.	$\frac{bh^3}{36}$	$\frac{bh^2}{24}$	The least of the two: $\frac{h^2}{18}$ or $\frac{b^2}{24}$	The least of the two: $\frac{h}{4.24}$ or $\frac{b}{4.9}$
	Even Angle.	$\frac{Ah^2}{10.2}$	$\frac{Ah}{7.2}$	$\frac{b^3}{25}$	$\frac{b}{5}$
	Uneven Angle	$\frac{Ah^2}{9.5}$	$\frac{Ah}{6.5}$	$\frac{(hb)^2}{13(h^2+b^2)}$	$\frac{hb}{2.6(h+b)}$
	Even Cross.	$\frac{Ah^2}{19}$	$\frac{Ah}{9.5}$	$\frac{h^2}{22.5}$	$\frac{h}{4.74}$
	Even Tee.	$\frac{Ah^2}{11.1}$	$\frac{Ah}{8}$	$\frac{b^2}{22.5}$	$\frac{b}{4.74}$
	I-Beam.	$\frac{Ah^2}{6.66}$	$\frac{Ah}{3.2}$	$\frac{b^2}{21}$	$\frac{b}{4.58}$
	Channel.	$\frac{Ah^2}{7.34}$	$\frac{Ah}{3.67}$	$\frac{b^2}{12.5}$	$\frac{b}{3.54}$
	Deck Beam.	$\frac{Ah^2}{6.9}$	$\frac{Ah}{4}$	$\frac{b^2}{36.5}$	$\frac{b}{6}$

Distance of base from center of gravity, solid triangle, $\frac{h}{3}$; even angle, $\frac{h}{3.3}$; uneven angle, $\frac{h}{3.5}$; even tee, $\frac{h}{3.3}$; deck beam, $\frac{h}{2.3}$; all other shapes given in the table, $\frac{h}{2}$ or $\frac{D}{2}$.

Solid Cast-iron Columns.

Table, based on Hodgkinson's formula (gross tons).

The figures are one-tenth of the breaking weight in tons, for solid columns, ends flat and fixed.

Diam. in Inches.	Length of Column in Feet.								
	6.	8.	10.	12.	14.	16.	18.	20.	25.
1½	.82	.50	.34	.25	.19	.15	.13	.11	.07
1¾	1.43	.87	.60	.44	.34	.27	.22	.18	.13
2	2.31	1.41	.97	.71	.55	.44	.36	.30	.20
2¼	3.52	2.16	1.48	1.08	.83	.67	.54	.46	.31
2½	5.15	3.16	2.16	1.58	1.22	.97	.80	.66	.56
2¾	7.26	4.45	3.05	2.23	1.72	1.37	1.12	.94	.64
3	9.93	6.09	4.17	3.06	2.35	1.87	1.53	1.28	.88
3½	17.29	10.60	7.26	5.32	4.10	3.26	2.67	2.23	1.53
4	27.96	17.15	11.73	8.61	6.62	5.28	4.32	3.61	2.47
4½	42.73	26.20	17.93	13.15	10.12	8.07	6.60	5.52	3.78
5	62.44	38.29	26.20	19.22	14.79	11.79	9.65	8.06	5.52
5½	88.00	53.97	36.93	27.09	20.84	16.61	13.60	11.37	7.78
6	120.4	73.82	50.51	37.05	28.51	22.72	18.60	15.55	10.64
6½	160.6	98.47	67.38	49.43	38.03	30.31	24.81	20.74	14.19
7	209.7	128.6	87.98	64.53	49.66	39.57	32.30	27.08	18.53
7½	268.8	164.8	112.8	82.73	63.66	50.73	41.53	34.72	23.76
8	339.1	207.9	142.3	104.4	80.31	64.00	52.39	43.80	29.97
8½	421.8	258.6	177.0	129.8	99.90	79.61	65.16	54.48	37.28
9	518.2	317.7	217.4	159.5	122.7	97.80	80.05	66.92	45.80
9½	629.5	386.0	264.2	193.8	149.1	118.8	97.25	81.70	55.64
10	757.2	464.3	317.7	233.1	179.3	142.9	117.0	97.79	66.92
10½	902.6	553.5	378.7	277.8	213.8	170.3	139.4	116.6	79.77
11	1067.1	654.4	447.8	328.5	252.7	201.4	164.9	137.8	94.31
11½	1252.3	767.9	525.5	385.4	296.6	236.4	193.5	161.7	110.7
12	1459.6	895.1	612.5	449.3	345.7	275.5	225.5	188.5	129.0

Where the length is less than 30 diameters,

$$\text{Strength in tons of short columns} = \frac{SC}{10S + \frac{3}{4}C},$$

S being the strength given in the above table, and $C = 49$ times the sectional area of the metal in inches.

Hollow Columns.

The strength nearly equals the difference between that of two solid columns, the diameters of which are equal to the external and internal diameters of the hollow one.

More recent experiments carried out by the Building Department of New York City on full-size cast-iron columns, and other tests made at the Watertown Arsenal on cast-iron mill columns, show Gordon's formula, based on Hodgkinson's experiments, to give altogether too high results.

The following table, from results of the New York Building Department tests, as published in the *Engineering News*, January 13–20, 1898, show actual results on columns such as are constantly used in buildings. Applying Gordon's formula to the same columns gives the following as the breaking load per square inch. For 15-inch columns, 57,000 lbs.; for 8-inch and 6-inch columns, 40,000 lbs., all of which are much too high, as shown by the table.

Prof. Lanza gives the average of 11 columns in the Watertown tests as 29,600 pounds per square inch, and recommends that 5,000 pounds per square inch be used as the maximum safe load for crushing strength.

Tests of Cast-iron Columns.

Number.	Diam. Inches.	Thickness.			Breaking Load.	
		Max.	Min.	Average.	Pounds.	Pounds per sq. in.
1	15	1	1	1	1,356,000	30,830
2	15	$1\frac{5}{16}$	1	$1\frac{1}{8}$	1,330,000	27,700
3	15	$1\frac{1}{4}$	1	$1\frac{1}{8}$	1,198,000	24,900
4	$15\frac{1}{8}$	$1\frac{7}{32}$	1	$1\frac{1}{8}$	1,246,000	25,200
5	15	$1\frac{11}{16}$	1	$1\frac{11}{64}$	1,632,000	32,100
6	15	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{3}{16}$	2,082,000+	40,400+
7	$7\frac{3}{4}$ to $8\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	1	651,00	31,900
8	8	$1\frac{3}{32}$	1	$1\frac{3}{64}$	612,800	26,800
9	$6\frac{1}{16}$	$1\frac{5}{32}$	$1\frac{1}{8}$	$1\frac{9}{64}$	400,000	22,700
10	$6\frac{3}{32}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{1}{64}$	455,200	26,300

Ultimate Strength of Hollow, Cylindrical Wrought and Cast-iron Columns, when Fixed at the Ends.

(Pottsville Iron and Steel Co.)

Computed by Gordon's formula, $p = \dfrac{f}{1 + C\left(\dfrac{l}{d}\right)^2}$

$p =$ Ultimate strength in lbs. per square inch;
$l =$ Length of column, } both in same units;
$h =$ Diameter of column, }
$f = \begin{cases} 40{,}000 \text{ lbs. for wrought iron;} \\ 80{,}000 \text{ lbs. for cast iron;} \end{cases}$
$C = 1/3000$ for wrought iron, and $1/800$ for cast iron.

For cast iron, $$p = \frac{80{,}000}{1 + \frac{1}{800}\left(\frac{l}{h}\right)^2}.$$

For wrought iron, $$p = \frac{40{,}000}{1 + \frac{1}{3{,}000}\left(\frac{l}{h}\right)^2}.$$

Hollow Cylindrical Columns.

Ratio of Length to Diameter. $\frac{l}{h}$	Maximum Load per sq. in.		Safe Load per Square Inch.	
	Cast Iron.	Wrought Iron.	Cast Iron, Factor of 6.	Wrought Iron, Factor of 4.
8	74075	39164	12346	9791
10	71110	38710	11851	9677
12	67796	38168	11299	9542
14	64256	37546	10709	9386
16	60606	36854	10101	9213
18	56938	36100	9489	9025
20	53332	35294	8889	8823
22	49845	34442	8307	8610
24	46510	33556	7751	8389
26	43360	32642	7226	8161
28	40404	31712	6734	7928
30	37646	30768	6274	7692

Hollow Cylindrical Columns.—*Continued.*

Ratio of Length to Diameter. $\frac{l}{h}$	Maximum Load per Sq. In.		Safe Load per Square Inch.	
	Cast Iron.	Wrought Iron.	Cast Iron, Factor of 6.	Wrought Iron, Factor of 4.
32	35088	29820	5848	7455
34	32718	28874	5453	7218
36	30584	27932	5097	6983
38	28520	27002	4753	6750
40	26666	26086	4444	6522
42	24962	25188	4160	6297
44	23396	24310	3899	6077
46	21946	23454	3658	5863
48	20618	22620	3436	5655
50	19392	21818	3262	5454
52	18282	21036	3047	5259
54	17222	20284	2870	5071
56	16260	19556	2710	4889
58	15368	18856	2561	4714
60	14544	18180	2424	4545

Ultimate Strength of Wrought-iron Columns.

$p =$ ultimate strength per square inch;
$l =$ length of column in inches;
$r =$ least radius of gyration in inches.

For square end-bearings, $$p = \frac{40000}{1 + \frac{1}{40000}\left(\frac{l}{r}\right)^2}.$$

For one pin and one square bearing, $$p = \frac{40000}{1 + \frac{1}{30000}\left(\frac{l}{r}\right)^2}$$

For two pin bearings, $$p = \frac{40000}{1 + \frac{1}{20000}\left(\frac{l}{r}\right)^2}.$$

For safe working-load on these columns use a factor of 4 when used in buildings, or when subjected to dead load only; but when used in bridges the factor should be 5.

Wrought-Iron Columns.

$\frac{l}{r}$	Ultimate Strength in Lbs. per Square Inch.			$\frac{l}{r}$	Safe Strength in Lbs. per Square Inch—Factor of 5.		
	Square Ends.	Pin and Sq. End.	Pin Ends.		Square Ends.	Pin and Sq. End.	Pin Ends.
10	39944	39866	39800	10	7989	7973	7960
15	39776	39702	39554	15	7955	7940	7911
20	39604	39472	39214	20	7921	7894	7843
25	39384	39182	38788	25	7877	7836	7758
30	39118	38834	38278	30	7821	7767	7656
35	38810	38430	37690	35	7762	7686	7538
40	38460	37974	37036	40	7692	7595	7407
45	38072	37470	36322	45	7614	7494	7264
50	37646	36928	35525	50	7529	7386	7105
55	37186	36336	34744	55	7437	7267	6949
60	36697	35714	33898	60	7339	7148	6780
65	36182	34478	33024	65	7236	6896	6605
70	35634	34384	32128	70	7127	6877	6426
75	35076	33682	31218	75	7015	6736	6244
80	34482	32966	30288	80	6896	6593	6058
85	33883	32236	29384	85	6777	6447	5877
90	33264	31496	28470	90	6653	6299	5694
95	32636	30750	27562	95	6527	6150	5512
100	32000	30000	26666	100	6400	6000	5333
105	31357	29250	25786	105	6271	5850	5157

TRANSVERSE STRENGTH.

Transverse strength of bars of rectangular section is found to vary directly as the breadth of the specimen tested, as the square of its depth, and inversely as its length. The deflection under load varies as the cube of the length, and inversely as the breadth and as the cube of the depth. Algebraically, if $S =$ the strength and D the deflection, l the length, b the breadth, and d the depth,

$$S \text{ varies as } \frac{bd^2}{l} \text{ and } D \text{ varies as } \frac{l^3}{bd^3}.$$

To reduce the strength of pieces of various sizes to a common standard, the term *modulus of rupture* (R) is used. Its value is obtained by experiment on a bar of rectangular section supported at the ends and loaded in the middle, and substituting numerical values in the following formula:

$$R = \frac{3}{2}\frac{Pl}{bd^2},$$

in which $P =$ the breaking load in pounds, $l =$ the length in inches, b the breadth, and d the depth.

Fundamental Formulæ for Flexure of Beams.

(Merriman.)

Resisting shear = vertical shear;
Resisting moment = bending moment;
Sum of tensile stresses = sum of compressive stresses;
Resisting shear = algebraic sum of all the vertical components of the internal stresses at any section of the beam.

If A be the area of the section and S_s the shearing unit stress, then resisting shear $= AS_s$; and if the vertical shear $= V$, then $V = AS_s$.

The vertical shear is the algebraic sum of all the external vertical forces on one side of the section considered. It is equal to the reaction of one support, considered as a force acting upward, minus the sum of all the vertical downward forces acting between the support and the section.

The resisting moment = algebraic sum of all the moments of the internal horizontal stresses at any section with reference to a point in that section, $= \frac{SI}{c}$, in which $S =$ the horizontal unit stress, tensile or compressive as the case may be, upon the fiber most remote from the neutral axis, $c =$ the shortest distance from that fiber to said axis, and $I =$ the moment of inertia of the cross-section with reference to that axis.

The bending moment M is the algebraic sum of the moment of the external forces on one side of the section with reference to a point in that section = moment of the reaction of one support minus sum of moments of loads between the support and the section considered.

$$M = \frac{SI}{c}.$$

The bending moment is a compound quantity = product of a force by the distance of its point of application from the section considered, the distance being measured on a line drawn from the section perpendicular to the direction of the action of the force.

Concerning the above formula, Prof. Merriman, *Eng. News*, July 21, 1894, says: The formula just quoted is true when the unit-stress S on the part of the beam farthest from the neutral axis is within the elastic limit of the material. It is not true when this limit is exceeded, because then the neutral axis does not pass through the center of gravity of the cross section, and because also the different longitudinal stresses are not proportional to their distances from that axis, these two requirements being involved in the deduction of the formula. But in all cases of design the permissible unit-stresses should not exceed the elastic limit, and hence the formula applies rationally, without regarding the ultimate strength of the material or any of the circumstances regarding rupture. Indeed, so great reliance is placed upon this formula that the practice of testing beams by rupture has been almost entirely abandoned, and the allowable unit-stresses are mainly derived from tensile and compressive tests.

General Formulæ for Transverse Strength of Beams of Uniform Cross-Section.

Beam.	Rectangular Beam.		Beam of any Section.		
	Breaking Load.	Deflection for Load P or W.	Maximum Moment of Stress.	Moment of Rupture.	Deflection Δ
Fixed at one end, load at the other	$P=\frac{1}{6}\frac{Rbd^2}{l}$	$\frac{4Pl^3}{Ebd^3}$	$Pl =$	$\frac{RI}{c}$	$\frac{1}{3}\frac{Pl^3}{EI}$
Same with load distributed uniformly	$W=\frac{1}{3}\frac{Rbd^2}{l}$	$\frac{3}{2}\frac{Wl^3}{Ebd^3}$	$\frac{1}{2}Wl =$	$\frac{RI}{c}$	$\frac{1}{8}\frac{Wl^3}{EI}$
Supported at ends, loaded in middle	$P=\frac{2}{3}\frac{Rbd^2}{l}$	$\frac{Pl^3}{4Ebd^3}$	$\frac{1}{4}Pl =$	$\frac{RI}{c}$	$\frac{1}{48}\frac{Pl^3}{EI}$
Same loaded uniformly	$W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{5}{32}\frac{Wl^3}{Ebd^3}$	$\frac{1}{8}Wl =$	$\frac{RI}{c}$	$\frac{5}{384}\frac{Wl^3}{EI}$
Same, loaded at middle, and also with uniform load	$2P+W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{1}{4}\left(P+\frac{1}{8}W\right)\frac{l^3}{Ebd^3}$	$\left(\frac{1}{4}P+\frac{1}{8}W\right)l =$	$\frac{RI}{c}$	$\frac{1}{48}\left(P+\frac{5}{8}W\right)\frac{l^3}{EI}$
Fixed at both ends, loaded in middle	$P=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{1}{16}\frac{Pl^3}{Ebd^3}$	$\frac{1}{8}Pl =$	$\frac{RI}{c}$	$\frac{P}{192}\frac{l^3}{EI}$
Same, Barlow's Experiments	$P=\frac{Rbd^2}{l}$		$\frac{1}{6}Pl =$	$\frac{RI}{c}$	
Same, uniformly loaded	$W=\frac{2Rbd^2}{l}$	$\frac{1}{32}\frac{Wl^3}{Ebd^3}$	$\frac{1}{12}Wl =$	$\frac{RI}{c}$	$\frac{W}{384}\frac{l^3}{EI}$
Fixed at one end, supported at the other, loaded at .634l from fixed end		$\frac{.1148Pl^3}{Ebd^3}$	$\frac{3}{8}\left(2\sqrt{3}-3\right)Pl =$	$\frac{RI}{c}$	$\frac{P}{105}\frac{l^3}{EI}$ (nearly).
Same, uniformly loaded	$W=\frac{4}{3}\frac{Rbd^2}{l}$	$\frac{.0648Wl^3}{Ebd^3}$	$\frac{1}{8}Wl =$	$\frac{RI}{c}$	$\frac{W}{185}\frac{l^3}{EI}$ (nearly).

Formulæ for Transverse Strength of Beams.

(Referring to table on preceding page.)

$P =$ load at middle;
$W =$ total load, distributed uniformly;
$l =$ length; $b =$ breadth; $d =$ depth, in inches;
$E =$ modulus of elasticity;
$R =$ modulus of rupture, or stress per square inch of extreme fiber;
$I =$ moment of inertia;
$c =$ distance between neutral axis and extreme fiber.

For breaking-load of circular section, replace bd^2 by $0.59d^3$.

For good wrought iron the value of R is about 80,000, for steel about 120,000, the percentage of carbon apparently having no influence. (Thurston, "Iron and Steel," p. 491.)

For cast iron the value of R varies greatly according to quality. Thurston found 45,740 and 67,980 in No. 2 and No. 4 cast iron, respectively.

For beams fixed at both ends and loaded in the middle, Barlow, by experiment, found the maximum moment of stress $= \frac{1}{6}Pl$ instead of $\frac{1}{8}Pl$, the result given by theory. Prof. Wood ("Resistance Materials," p. 155) says of this case, "The phenomena are of too complex a character to admit of a thorough and exact analysis, and it is probably safer to accept the results of Mr. Barlow in practice than to depend upon theoretical results."

APPROXIMATE GREATEST SAFE LOAD IN LBS. ON STEEL BEAMS.

(Pencoyd Iron Works.)

Based on fiber strains of 16,800 lbs. for steel. (For iron the loads should be one-sixth less, corresponding to a fiber strain of 14,000 lbs. per square inch.)

$L =$ length in feet between supports;
$A =$ sectional area of beam in square inches;
$D =$ depth of beam in inches;
$a =$ interior area in square inches;
$d =$ interior depth in inches;
$w =$ working-load in net tons.

Shape of Section.	Greatest Safe Load in Lbs.		Deflection in Inches.	
	Load in Middle.	Load Distributed.	Load in Middle.	Load Distributed.
Solid Rectangle.	$\frac{940AD}{L}$	$\frac{1880AD}{L}$	$\frac{wL^3}{32AD^2}$	$\frac{wL^3}{52AD^2}$
Hollow Rectangle.	$\frac{940(AD-ad)}{L}$	$\frac{1880(AD-ad)}{L}$	$\frac{wL^3}{32(AD^2-ad^2)}$	$\frac{wL^3}{52(AD^2-ad^2)}$
Solid Cylinder.	$\frac{700AD}{L}$	$\frac{1400AD}{L}$	$\frac{wL^3}{24AD^2}$	$\frac{wL^3}{38AD^2}$
Hollow Cylinder.	$\frac{700(AD-ad)}{L}$	$\frac{1400(AD-ad)}{L}$	$\frac{wL^3}{24(AD^2-ad^2)}$	$\frac{wL^3}{38(AD^2-ad^2)}$

Shape of Section.	Greatest Safe Load in Lbs.		Deflection in Inches.	
	Load in Middle.	Load Distributed.	Load in Middle.	Load Distributed.
Even-legged Angle or Tee.	$\frac{930AD}{L}$	$\frac{1860AD}{L}$	$\frac{wL^3}{32AD^2}$	$\frac{wL^3}{52AD^2}$
Channel or Z Bar.	$\frac{1600AD}{L}$	$\frac{3200AD}{L}$	$\frac{wL^3}{53AD^2}$	$\frac{wL^3}{85AD^2}$
Deck Beam.	$\frac{1450AD}{L}$	$\frac{2900AD}{L}$	$\frac{wL^3}{50AD^2}$	$\frac{wL^3}{80AD^2}$
I-Beam.	$\frac{1780AD}{L}$	$\frac{3560AD}{L}$	$\frac{wL^3}{58AD^2}$	$\frac{wL^3}{93AD^2}$
I	II	III	IV	V

The rules for rectangular and circular sections are correct, while those for the flanged sections are approximate, and limited in their application to the standard shapes as given in the Pencoyd tables.

The calculated safe loads will be approximately one-half of loads that would injure the elasticity of the materials.

The rules for deflection apply to any load below the elastic limit, or less than double the greatest safe load by the rules.

If the beams are long, without lateral support, reduce the loads for the ratios of width to span as follows :

Length of Beam.	Proportion of Calculated Load forming Greatest Safe Load.
20 times flange width.	Whole calculated load.
30 " " "	9–10 " "
40 " " "	8–10 " "
50 " " "	7–10 " "
60 " " "	6–10 " "
70 " " "	5–10 " "

These rules apply to beams supported at each end. For beams supported otherwise, alter the coefficients of the table as described below, referring to the respective columns indicated by number.

Changes of Coefficients for Special Forms of Beams.

Kind of Beam.	Coefficient for Safe Load.	Coefficient for Deflection.
Fixed at one end, loaded at the other.	One-fourth of the coefficient of col. II.	One-sixteenth of the coefficient of col. IV.

Changes of Coefficients — *Continued.*

Kind of Beam.	Coefficient for Safe Load.	Coefficient of Deflection.
Fixed at one end, load evenly distributed.	One-fourth of the coefficient of col. III.	Five forty-eighths of the coefficient of col. V.
Both ends rigidly fixed, or a continuous beam, with a load in middle.	Twice the coefficient of col. II.	Four times the coefficient of col. IV.
Both ends rigidly fixed, or a continuous beam, with load evenly distributed.	One and a half times the coefficient of col. III.	Five times the coefficient of col. V.

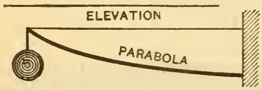
Modulus of Elasticity and Elastic Resilience.

Let $P =$ tensile stress in pounds per square inch at the elastic limit;
$e =$ elongation per unit of length at the elastic unit;
$E =$ modulus of elasticity $= P \div e$; $e = P \div E$.
Then elasticity resilience per cubic inch $= \frac{1}{2}Pe = \frac{1}{2}\frac{P^2}{E}$.

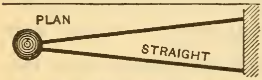
BEAMS OF UNIFORM STRENGTH THROUGHOUT THEIR LENGTH.

The section is supposed in all cases to be rectangular throughout. The beams shown in plan are of uniform depth throughout. Those shown in elevation are of uniform breadth throughout.

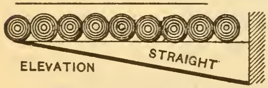
$B =$ breadth of beam. $D =$ depth of beam.



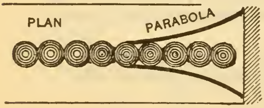
Fixed at one end, loaded at the other; curve parabola, vertex at loaded end; BD^2 proportional to distance from loaded end. The beam may be reversed so that the upper edge is parabolic, or both edges may be parabolic.



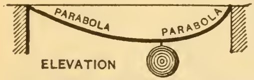
Fixed at one end, loaded at the other; triangle, apex at loaded end; BD^2 proportional to the distance from the loaded end.



Fixed at one end; load distributed; triangle, apex at unsupported end; BD^2 proportional to square of distance from unsupported end.



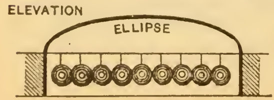
Fixed at one end; load distributed; curves two parabolas, vertices touching each other, at unsupported end; BD^2 proportional to distance from unsupported end.



Supported at both ends; load at any one point; two parabolas, vertices at the points of support, bases at point loaded; BD^2 proportional to distance from nearest point of support. The upper edge or both edges may also be parabolic.

Supported at both ends; load at any one point; two triangles, apices at points of support, bases at point loaded; BD^2 proportional to distance from the nearest point of support.

Supported at both ends; load distributed; curves two parabolas, vertices at the middle of the beam; bases center line of beam; BD^2 proportional to product of distances from points of support.



Supported at both ends; load distributed; curve semi-ellipse; BD^2 proportional to the product of the distances from the points of support.

TRENTON BEAMS AND CHANNELS.

(Trenton Iron Works.)

To find which beam, supported at both ends, will be required to support with safety a given *uniformly distributed* load:

Multiply the load in pounds by the span in feet, and take the beam whose "Coefficient for Strength" is nearest to and exceeds the number so found. The weight of the beam itself should be included in the load.

The deflection in inches for such distributed load will be found by dividing the square of the span taken in feet, by seventy (70) times the depth of the beam taken in inches for iron beams, and by 52.5 times the depth for steel.

EXAMPLE. — Which beam will be required to support a uniformly distributed load of 12 tons (= 24,000 lbs.) on a span of 15 feet?

24,000 × 15 = 360,000, which is less than the coefficient of the $12\frac{1}{4}$-inch 125-lb. iron beam. The weight of the beam itself would be 625 lbs., which, added to the load and multiplied by the span, would still give a product less than the coefficient; thus,

$$24,625 \times 15 = 369,375.$$

The deflection will be:

$$\frac{15 \times 15}{70 \times 12\frac{1}{4}} = 0.26 \text{ inch.}$$

The safe distributed load for each beam can be found by dividing the coefficient by the span in feet, and subtracting the weight of the beam.

When the load is concentrated entirely at the center of the span, one-half of this amount must be taken.

The beams must be secured against yielding sideways, or the safe loads will be much less.

TRENTON ROLLED STEEL BEAMS.

Designation of Beam.	Weight per Yard in Lbs.		Width of Flanges in Inches.	Thickness of Stem.	Coefficient for Strength in Lbs., Minimum Weight.
	Min.	Max.			
15 inch	150	190	5.75	.45	753,000
15 "	123	160	5.5	.40	603,000
12 "	120	150	5.5	.39	500,000
12 "	96	125	5.25	.32	407,000
10 "	135	160	5.25	.45	461,000
10 "	99	125	5.0	.37	344,000
10 "	76	100	4.75	.32	264,000
9 "	81	105	4.75	.31	262,000
9 "	63	85	4.5	.27	200,000
8 "	66	85	4.5	.27	192,000
8 "	54	75	4.25	.25	154,000
7 "	60	80	4.25	.27	151,000
7 "	46.5	65	4.0	.23	118,000
6 "	50	65	3.5	.30	104,000
6 "	40	55	3.0	.25	83,300
5 "	39	52	3.13	.26	67,000
5 "	30	42	3.0	.22	52,900
4 "	30	40	2.75	.24	41,200
4 "	22.5	32	2.62	.20	31,400
2 "	$4\frac{1}{2}$		.75	$\frac{1}{8}$	2,660
$1\frac{1}{4}$ "	$5\frac{1}{4}$		1.50	$\frac{1}{8}$	2,300

TRENTON IRON BEAMS AND CHANNELS.

I-Beams.

Height in In.	Least Weight per Yd. in Lbs.	Width of Flange in Inches.	Thickness of Web in Inches.	Coefficient in Lbs. for Transverse Strength.
20	272	$6\frac{3}{4}$	$\frac{11}{16}$	1,320,000
20	200	6	$\frac{1}{2}$	990,000
$15\frac{1}{8}$	200	$5\frac{3}{4}$	.6	748,000
$15\frac{3}{16}$	150	5	$\frac{1}{2}$	551,000
$15\frac{1}{8}$	125	5	.42	460,000
$12\frac{5}{16}$	170	$5\frac{1}{2}$	.6	511,000
$12\frac{1}{4}$	125	4.8	.47	377,000
12	120	$5\frac{1}{2}$	.39	375,000
12	96	$5\frac{1}{4}$	.32	306,000
$10\frac{1}{2}$	135	5	.47	360,000
$10\frac{1}{2}$	105	$4\frac{1}{2}$	$\frac{3}{8}$	286,000
$10\frac{1}{2}$	90	$4\frac{1}{2}$	$\frac{5}{16}$	250,000
9	125	$4\frac{1}{2}$	.57	268,000
9	85	$4\frac{1}{2}$	$\frac{3}{8}$	199,000
9	70	4	.3	167,000
8	80	$4\frac{1}{2}$	$\frac{3}{8}$	168,000
8	65	4	.3	135,000
7	55	$3\frac{3}{4}$	.3	101,000
6	120	$5\frac{1}{4}$	$\frac{5}{8}$	172,000
6	90	5	$\frac{1}{2}$	132,000
6	50	$3\frac{1}{2}$	.3	76,800
6	40	3	$\frac{1}{4}$	62,600
5	40	3	$\frac{5}{16}$	49,100
5	30	$2\frac{3}{4}$	$\frac{1}{4}$	38,700
4	37	3	$\frac{5}{16}$	36,800
4	30	$2\frac{3}{4}$	$\frac{1}{4}$	30,100
4	18	2	$\frac{3}{16}$	18,000

Height in In.	Least Weight per Yard in Lbs.	Width of Flange in Inches.	Thickness of Web in Inches.	Coefficient in Lbs. for Transverse Strength.
Channels.				
15	190	$4\frac{3}{4}$	$\frac{3}{4}$	625,000
15	120	4	$\frac{1}{2}$	401,000
$12\frac{1}{4}$	140	4	$\frac{11}{16}$	381,000
$12\frac{1}{4}$	70	3	.33	200,100
$10\frac{1}{2}$	60	$2\frac{3}{4}$	$\frac{3}{8}$	134,750
10	48	$2\frac{1}{2}$	$\frac{5}{16}$	102,000
9	70	$3\frac{1}{8}$	$\frac{7}{16}$	146,000
9	50	$2\frac{1}{2}$	.33	104,000
8	45	$2\frac{1}{2}$	.26	88,950
8	33	2.2	.20	65,800
7	36	$2\frac{1}{2}$	$\frac{1}{4}$	62,000
7	$25\frac{1}{2}$	2	.20	39,500
6	45	$2\frac{1}{2}$	.40	58,300
6	33	$2\frac{1}{4}$	.28	45,700
6	$22\frac{1}{2}$	$1\frac{7}{8}$	.18	33,680
5	19	$1\frac{5}{8}$	.20	22,800
4	$16\frac{1}{2}$	$1\frac{1}{2}$	.20	15,700
3	15	$1\frac{1}{2}$	.20	10,500
Deck Beams.				
8	65	$4\frac{1}{2}$	$\frac{3}{8}$	91,800
7	55	$4\frac{1}{2}$	$\frac{5}{16}$	63,500
Strut Bars.				
5	22	$1\frac{7}{16}$	$\frac{5}{16}$	11,900
5	16	$1\frac{5}{16}$	$\frac{1}{4}$	9,100

TABLE GIVING THE SIZE OF BEAMS AND THEIR DISTANCE APART, SUITABLE FOR FLOORS HAVING LOADS PER SQUARE FOOT FROM 100 LBS. TO 300 LBS.

Clear Span in Feet.	Load per Square Foot. 100 Lbs.			Load per Square Foot. 150 Lbs.			Load per Square Foot. 200 Lbs.			Load per Square Foot. 250 Lbs.			Load per Square Foot. 300 Lbs.		
	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.	Size and Weight per Yard.		Distance from Center to Center.
	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB.	FEET.	IN.	LB.	FEET.
8	4	30	4.6	4	30	3.1	5	30	3.0	6	40	3.9	6	40	3.2
	5	30	5.9	5	30	4.0	6	40	4.8	6	50	4.7	5	50	3.9
10	5	30	3.8	6	40	4.1	6	40	3.0	6	50	3.0	7	55	3.3
	5	40	4.8	6	50	5.0	6	50	3.7	7	55	4.0	8	65	4.4
12	6	40	4.2	6	50	3.4	7	55	3.4	8	65	3.6	8	65	3.0
	6	50	5.2	7	55	4.6	8	65	4.5	9	70	4.5	9	70	3.8
14	7	55	5.0	7	55	3.3	8	65	3.3	9	70	3.3	9	85	3.3
	8	65	6.7	8	65	4.5	9	70	4.1	10½	90	5.0	10½	90	4.2
16	8	65	5.0	8	65	3.3	9	85	3.7	10½	90	3.8	10½	105	3.6
	9	70	6.3	9	70	4.2	10½	90	4.7	10½	105	4.3	12¼	125	4.8
18	9	70	4.9	9	85	3.9	10½	105	4.2	10½	105	3.4	10½	135	3.6
	9	85	5.9	10½	90	4.9	12	96	4.6	12¼	125	4.5	12¼	125	3.7
20	10½	90	6.0	10½	105	4.5	10½	105	3.4	12¼	125	3.6	12¼	125	3.0
	. . .	. . .	. .	12¼	125	6.0	12¼	125	4.5	12¼	170	4.9	15	150	4.4
22	10½	90	4.9	12	96	4.0	12¼	125	3.7	12¼	125	3.0	12¼	170	3.3
	10½	105	5.6	12¼	125	4.9	15	125	4.5	15	125	3.6	15	150	3.6
24	12	96	5.0	12¼	125	4.1	12¼	125	3.0	12¼	170	3.3	15	150	3.0
	12¼	125	6.1	15	125	5.0	15	150	4.5	15	150	3.6	15	200	4.1
26	12¼	125	5.1	15	125	4.3	15	150	3.8	15	150	3.0	15	200	3.5
	. . .	. . .	. . .	15	150	5.1	15	200	5.2	15	200	4.2	20	200	4.7
28	15	125	5.5	15	150	4.3	15	200	4.4	15	200	3.5	20	200	3.9
	. . .	. . .	. . .	15	200	5.9	20	200	6.0	20	200	4.8	20	272	5.3
30	15	150	5.6	15	150	3.7	15	200	3.8	20	200	4.1	20	200	3.4
	. . .	. . .	. . .	15	200	5.1	20	200	5.2	20	272	5.5	20	272	4.6

WOOD.

Properties of Timber.

Description.	Weight per cubic foot in lbs.	Weight per ft. B. M. in lbs. average	Tensile strength per sq. in., in lbs.	Crushing strength per sq. in., in lbs.	Relative strength for cross breaking White Pine = 100.	Shearing strength with the grain, lbs. per sq. in.	Pressure in lbs. per sq. in. to indent $\frac{1}{20}''$.
Ash	43 to 55.8	4.1	11000 to 17207	4400 to 9363	130 to 180	458 to 700	1800 to 1850
Beech	43 to 53.4	3.9	11500 to 18000	5800 to 9363	100 to 144	. . . .	. . . . .
Cedar	50 to 56.8	4.5	10300 to 11400	5600 to 6000	55 to 63	. . . .	. . . . .
Cherry	. . . . .	. . . . .	. . . . . .	. . . . . .	130	. . . .	. . . . .
Chestnut	33	2.75	10500	5350 to 5600	96 to 123	. . . .	. . . . .
Elm	34 to 36.7	2.9	13400 to 13489	6831 to 10331	96	. . . .	. . . . .
Hemlock	. . . . .	. . . . .	8700	5700	88 to 95	. . . .	. . . . .
Hickory	. . . . .	. . . . .	12800 to 18000	8925	150 to 210	. . . .	. . . . .
Locust	44	3.7	20500 to 24800	9113 to 11700	132 to 227	. . . .	. . . . .
Maple	49	4.1	10500 to 10584	8150	122 to 220	367 to 647	1700 to 1900
Oak, White	45 to 54.5	4.1	10253 to 19500	4684 to 9509	130 to 177	752 to 966	2300 to 3550
Oak, Live	70	5.8	. . . . . .	6850	155 to 189	. . . .	. . . . .
Pine, White	30	2.5	10000 to 12000	5000 to 6650	100	225 to 423	875 to 1160
Pine, Yellow	28.8 to 33	2.6	12600 to 19200	5400 to 9500	98 to 170	286 to 415	1900
Spruce	. . . . .	. . . . .	10000 to 19500	5050 to 7850	86 to 110	253 to 374	875 to 1025
Walnut, Black . . .	42	3.5	9286 to 16000	7500	. . . .	. . . .	2200 to 2600

Tests of American Woods.

In all cases a large number of tests were made of each wood. Minimum and maximum results only are given. All of the test specimens had a sectional area of 1.575 × 1.575 inches. The transverse test specimens were 39.37 inches between supports, and the compressive test specimens were 12.60 inches long. Modulus of rupture calculated from formula $R = \frac{3}{2} \frac{Pl}{bd^2}$; $P =$ load in pounds at the middle, $l =$ length in inches, $b =$ breadth, $d =$ depth:

Name of Wood.	Transverse Tests, Modulus of Rupture.		Compression Parallel to Grain, pounds per sq. in.	
	Min.	Max.	Min.	Max.
Cucumber tree	7440	12050	4560	7410
Yellow poplar, white wood	6560	11756	4150	5790
White wood, Basswood	6720	11530	3810	6480
Sugar maple, Rock maple	9680	20130	7460	9940
Red maple	8610	13450	6010	7500
Locust	12200	21730	8330	11940
Wild cherry	8310	16800	5830	9120
Sweet gum	7470	11130	5630	7620
Dogwood	10190	14560	6250	9400
Sour gum, pepperidge	9830	14300	6240	7480
Persimmon	18500	10290	6650	8080
White ash	5950	15800	4520	8830
Sassafras	5180	10150	4050	5970
Slippery elm	10220	13952	6980	8790
White elm	8250	15070	4960	8040
Sycamore, Buttonwood	6720	11360	4960	7340
Butternut, white walnut	4700	11740	5480	6810
Black walnut	8400	16320	6940	8850
Shellbark hickory	14870	20710	7650	10280
Pignut	11560	19430	7460	8470
White oak	7010	18360	5810	9070
Red oak	9760	18370	4960	8970
Black oak	7900	18420	4540	8550
Chestnut	5950	12870	3680	6650
Beech	13850	18840	5770	7840
Canoe birch, paper birch	11710	17610	5770	8590
Cottonwood	8390	13430	3790	6510
White cedar	6310	9530	2660	5810
Red cedar	5640	15100	4400	7040
Cypress	9530	10030	5060	7140
White pine	5610	11530	3750	5600
Spruce pine	3780	10980	2580	4680
Long-leaved pine, Southern pine	9220	21060	4010	10600
White spruce	9900	11650	4150	5300
Hemlock	7590	14680	4500	7420
Red fir, yellow fir	8220	17920	4880	9800
Tamarack	10080	16770	6810	10700

Wooden Beams.

Safe Uniformly Distributed Load in Tons of 2000 Pounds for Rectangular Spruce or White Pine Beams one Inch in Thickness.

Span in feet.	Depth in Inches.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.069	0.278	0.625	1.111	1.736	2.500	3.403	4.444	5.625	6.944	8.403	10.000	11.737	13.611	15.625
2	0.035	0.139	0.312	0.556	0.868	1.250	1.701	2.222	2.812	3.472	4.201	5.000	5.868	6.806	7.812
3	0.023	0.093	0.208	0.370	0.579	0.833	1.134	1.481	1.875	2.315	2.801	3.333	3.912	4.537	5.208
4	0.017	0.069	0.156	0.278	0.434	0.625	0.851	1.111	1.406	1.738	2.101	2.500	2.934	3.403	3.906
5	0.014	0.056	0.125	0.222	0.347	0.500	0.681	0.888	1.125	1.389	1.681	2.000	2.347	2.722	3.125
6	0.012	0.046	0.104	0.185	0.289	0.417	0.567	0.741	0.938	1.157	1.400	1.667	1.956	2.269	2.604
7	0.010	0.040	0.089	0.159	0.248	0.357	0.486	0.635	0.804	0.992	1.200	1.429	1.677	1.944	2.232
8	0.009	0.035	0.078	0.139	0.217	0.312	0.425	0.555	0.703	0.868	1.050	1.250	1.467	1.701	1.953
9	0.008	0.031	0.069	0.123	0.193	0.278	0.378	0.494	0.625	0.772	0.934	1.111	1.304	1.512	1.736
10	0.007	0.028	0.062	0.111	0.174	0.250	0.340	0.444	0.562	0.694	0.840	1.000	1.174	1.361	1.562
11	0.006	0.025	0.057	0.101	0.158	0.227	0.309	0.404	0.511	0.631	0.764	0.909	1.067	1.237	1.420
12	0.006	0.023	0.052	0.093	0.145	0.208	0.284	0.370	0.469	0.579	0.700	0.833	0.978	1.134	1.302
13	0.005	0.021	0.048	0.085	0.134	0.192	0.261	0.342	0.433	0.534	0.646	0.769	0.903	1.047	1.202
14	0.005	0.020	0.045	0.079	0.124	0.179	0.243	0.317	0.402	0.496	0.600	0.714	0.838	0.972	1.116
15	0.005	0.019	0.042	0.074	0.116	0.167	0.227	0.296	0.375	0.463	0.560	0.667	0.782	0.907	1 042
16	0.004	0.017	0.039	0.069	0.109	0.156	0.213	0.278	0.352	0.434	0.525	0.625	0.734	0.851	0.977
17	0.004	0 016	0.037	0.065	0.102	0.147	0.200	0.261	0.331	0.408	0.494	0.588	0.690	0.801	0.919
18	0.004	0.015	0.035	0.062	0.096	0.139	0.189	0.247	0.312	0.386	0.467	0.556	0.652	0.756	0.868
19	0.004	0.015	0.033	0.058	0.091	0.132	0.179	0.234	0.296	0.365	0.442	0.526	0.617	0.716	0.822
20	0.003	0.014	0.031	0.056	0.087	0.125	0.170	0.222	0.281	0.347	0.420	0.500	0.587	0.681	0.781
21	...	0.013	0.030	0.053	0.083	0.119	0.162	0.212	0.268	0.331	0.400	0.476	0.559	0.648	0.744
22	...	0.013	0.028	0.051	0.079	0.114	0.155	0.202	0.256	0.311	0.382	0.455	0.533	0.619	0.710
23	...	...	0.027	0.048	0.075	0.109	0.148	0.193	0.245	0.302	0.365	0.435	0.510	0.592	0.679
24	...	...	...	0.046	0.072	0.104	0.142	0.185	0.234	0.289	0.350	0.417	0.489	0.567	0.651
25	...	...	...	...	0.069	0.100	0.136	0.178	0.225	0.278	0.336	0.400	0.469	0.544	0.625
26	...	...	...	...	...	0.096	0.131	0.171	0.216	0.267	0.323	0.385	0.451	0.524	0.601
27	...	...	...	...	...	...	0.126	0.165	0.208	0.257	0.311	0.370	0.435	0.504	0.579
28	...	...	...	...	...	...	...	0.159	0.201	0.248	0.300	0.357	0.419	0.486	0.558
29	...	...	...	...	...	...	...	...	0.196	0.239	0.290	0.345	0.405	0.469	0.539
30	...	...	...	...	...	...	...	...	...	0.231	0.280	0.333	0.391	0.454	0.521

These loads are about one-eighth the breaking-load.

RULE. — *To find the safe uniformly distributed load* in tons for white pine or spruce beams, multiply the number given in the above table by the thickness of the beam in inches. For beams of other wood, multiply also by the following numbers:

White Oak.	Hemlock.	White Cedar.	Yellow Pine.	Chestnut.
1.45	.99	.60	1.50	1.08

Formulæ for White Pine Beams.

Subject to vibration from *live* loads.

$w =$ safe load in pounds, less weight of beam.
$l =$ length of beam in inches.
$d =$ depth of beam in inches.
$b =$ breadth of beam in inches.

For a beam fixed at one end and loaded at the other:

$$w = \frac{1000\,bd^2}{6l}.$$

For a beam fixed at one end and uniformly loaded:

$$w = \frac{1000\,bd^2}{3l}.$$

For a beam supported at both ends and loaded at the middle:

$$w = \frac{2000\,bd^2}{3l}.$$

For a beam supported at both ends and uniformly loaded:

$$w = \frac{4000\,bd^2}{3l}$$

NOTE. — In placing very heavy loads upon short, but deep and strong beams, care should be taken that the beams rest for a sufficient distance on their supports to prevent all danger from *crushing* or *shearing* at the ends. Ordinary timbers crush under 6,000 lbs. per square inch. To assure a safety of beam against crushing at the end, divide half of the load by 1000; the quotient will be the least number of square inches of base that should be allowed for each end to rest on.

Table of Safe Load for Moderately Seasoned White Pine Struts or Pillars.

The following table, exhibiting the approximate strength of white pine struts or pillars, with flat ends, is outlined and interpolated from the rule of Rondolet, that the safe load upon a cube of the material being regarded as unity, the safe load upon a post whose height is,

12 times the side will be	$\frac{5}{6}$
24 " " "	$\frac{1}{2}$
36 " " "	$\frac{1}{3}$
48 " " "	$\frac{1}{6}$
60 " " "	$\frac{1}{12}$
72 " " "	$\frac{1}{24}$

700 pounds per square inch is assumed as the safe load upon a cube of white pine.

The strength of each strut is considered with reference to the first-named dimension of its cross section, so that if the second dimension is less than the first, the strut must be supported in that direction, to fulfill the conditions of the computation.

The strength of pillars, as well as of beams of timber, depends much on their *degree of seasoning.* Hodgkinson found that perfectly seasoned blocks 2 diameters long, required in many cases twice as great a load to crush them as when only moderately dry. This should be borne in mind when building with green timber.

I. Safe Distributed Loads upon Southern Pine Beams One Inch in Width.

(C. J. H. Woodbury.)

(If the load is concentrated at the center of the span, the beams will sustain half the amount as given in the table.)

Span, Feet.	Depth of Beam in Inches.														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Load in Pounds per Foot of Span.														
5	38	86	154	240	346	470	614	778	960						
6	27	60	107	167	240	327	427	540	667	807					
7	20	44	78	122	176	240	314	397	490	593	705	828			
8	15	34	60	94	135	184	240	304	375	454	540	634	735		
9	..	27	47	74	107	145	190	240	296	359	427	501	581	667	759
10	..	22	38	60	86	118	154	194	240	290	346	406	470	540	614
11	..	..	32	50	71	97	127	161	198	240	286	335	389	446	508
12	..	..	27	42	60	82	107	135	167	202	240	282	327	375	474
13	..	..	..	36	51	70	90	115	142	172	205	240	278	320	364
14	..	..	..	31	44	60	78	99	123	148	176	207	240	276	314
15	..	..	..	27	38	52	68	86	107	129	154	180	209	240	273
16	..	..	..	..	34	46	60	76	94	113	135	158	184	211	240
17	..	..	..	..	30	41	53	67	83	101	120	140	163	187	217
18	..	..	..	..	..	36	47	60	74	90	107	125	145	167	190
19	..	..	..	..	..	..	43	54	66	80	96	112	130	150	170
20	..	..	..	..	..	..	38	49	60	73	86	101	118	135	154
21	..	..	..	..	..	..	..	44	54	66	78	92	107	122	139
22	..	..	..	..	..	..	..	..	50	60	71	84	97	112	127
23	..	..	..	..	..	..	..	..	45	55	65	77	89	102	116
24	..	..	..	..	..	..	..	..	..	50	60	70	82	94	107
25	..	..	..	..	..	..	..	..	..	46	55	65	75	86	98

II. Distributed Loads upon Southern Pine Beams Sufficient to Produce Standard Limit of Deflection.

(C. J. H. Woodbury.)

Span, Feet.	Depth of Beam in Inches.															Deflection, Inches.
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	Load in Pounds per Foot of Span.															
5	3	10	23	44	77	122	182	259								.0300
6	2	7	16	31	53	85	126	180	247							.0432
7	..	5	12	23	39	62	93	132	181	241						.0588
8	..	4	9	17	30	48	71	101	139	185	240	305				.0768
9	..	..	7	14	24	38	56	80	110	146	190	241	301			.0972
10	..	..	6	11	19	30	46	65	89	118	154	195	244	300		.1200
11	..	..	..	9	16	25	38	54	73	98	127	161	202	248	301	.1452
12	..	..	..	..	13	21	32	45	62	82	107	136	169	208	253	.1728
13	..	..	..	..	11	18	27	38	53	70	91	116	144	178	215	.2028
14	..	..	..	..	..	16	23	33	45	60	78	100	124	153	186	.2352
15	..	..	..	..	..	14	20	29	40	53	68	87	108	133	162	.2700
16	..	..	..	..	..	..	18	25	35	46	60	76	95	117	147	.3072
17	..	..	..	..	..	..	16	22	31	41	53	68	84	104	126	.3468
18	..	..	..	..	..	..	..	20	27	37	47	60	75	93	112	.3888
19	..	..	..	..	..	..	..	18	25	33	43	54	68	83	101	.4332
20	..	..	..	..	..	..	..	..	22	30	38	49	61	75	91	.4800
21	..	..	..	..	..	..	..	..	20	27	35	44	55	68	83	.5292
22	..	..	..	..	..	..	..	..	..	24	32	40	50	62	75	.5808
23	..	..	..	..	..	..	..	..	..	22	29	37	46	57	69	.6348
24	..	..	..	..	..	..	..	..	..	..	27	34	42	52	63	.6912
25	..	..	..	..	..	..	..	..	..	..	25	31	39	48	58	.7500

MASONRY.

Brick-Work.

Brick work is generally measured by 1000 bricks laid in the wall. In consequence of variations in size of bricks, no rule for volume of laid brick can be exact. The following scale is, however, a fair average.

7	common	bricks	to	a super. ft.	4-inch	wall.
14	"	"	"	"	9-inch	"
21	"	"	"	"	13-inch	"
28	"	"	"	"	18-inch	"
35	"	"	"	"	22-inch	"

Corners are not measured twice, as in stone-work. Openings over 2 feet square are deducted. Arches are counted from the spring. Fancy work counted 1½ bricks for 1. Pillars are measured on their face only.

One thousand bricks, closely stacked, occupy about 56 cubic feet.

One thousand old bricks, cleaned and loosely stacked, occupy about 72 cubic feet.

One cubic foot of foundation, with one-fourth inch joints, contains 21 bricks. In some localities 24 bricks are counted as equal to a cubic foot.

One superficial foot of gauged arches requires 10 bricks.

Stock bricks commonly measure 8¾ inches by 4¼ inches by 2¾ inches, and weigh from 5 to 6 lbs. each.

Paving bricks should measure 9 inches by 4½ inches by 1¾ inches, and weigh about 4½ lbs. each.

One yard of paving requires 36 stock bricks, of above dimensions, laid flat, or 52 on edge; and 35 paving bricks, laid flat, or 82 on edge.

The following table gives the usual dimensions of the bricks of some of the principal makers.

Description.	Inches.	Description.	Inches.
Baltimore front	} 8¼ × 4⅛ × 2⅜	Maine	7½ × 3⅜ × 2⅜
Philadelphia front		Milwaukee	8½ × 4⅛ × 2⅜
Wilmington front		North River	8 × 3½ × 2¼
Trenton front		Trenton	8 × 4 × 2¼
Croton	8½ × 4 × 2¼	Ordinary	{ 7¾ × 3⅝ × 2¼
Colabaugh	8¼ × 3⅝ × 2⅜		8 × 4⅛ × 2½

Fire Brick — { Valentine's (Woodbridge, N. J.) . . 8⅞ × 4⅜ × 2½ inches
Downing's (Allentown, Pa.) . . . . 9 × 4½ × 2½ inches

To compute the number of bricks in a square foot of wall.—To the face dimensions of the bricks used, add the thickness of one joint of mortar, and multiply these together to obtain the area. Divide 144 square inches by this area, and multiply by the number of times which the dimension of the brick, at right angles to its face, is contained in the thickness of the wall.

EXAMPLE.—How many Trenton bricks in a square foot of 12-inch wall, the joints being ¼ inch thick?

$\overline{8 + \frac{1}{4}} \times \overline{2\frac{1}{4} + \frac{1}{4}} = 20.62$; $144 \div 20.62 = 7$; $7 \times 3 = 21$ bricks per square ft.

Weight and Bulk of Bricks.

Gross Tons.	Pounds.	Cu. ft.	Number of Bricks, by itself. C. Brick.	F. Brick.	in wall with cement. C. Brick.	F. Brick.
1	2240	22.4	448	416.6	381	347
0.04464	100	1	20	18.6	17	15½
2.23	5000	50.00	**1000**	930	850	772
2.4	5376	53.76	1075	**1000**	914	834
2.62	5872	58.72	1130	1100	**1000**	913
2.88	6451	64.51	1240	1200	1100	**1000**

One perch of stone is 24.75 cubic feet.

In New York City laws a cubic foot of brick-work is deemed to weigh 115 lbs.

Building-stone is deemed to weigh 160 lbs. per cubic foot.

The safe load for brick-work according to the New York City Laws is as follows: —

In tons per superficial foot,

For good lime mortar . . . . 8 tons.
For good lime and cement mortar mixed . 11½ tons.
For good cement mortar . . . . 15 tons.

Average Ultimate Crushing-Load in Pounds per Square Inch for Bricks, Stones, Mortars, and Cements.

	Lbs. per Sq. In.
Brick, common (Eastern)	10000
Brick, best pressed	12000
Brick (Trautwine)	770 to 4660
Brick, paving, average of 10 varieties (Western)	7150
Brick-work, ordinary	300 to 500
Brick-work, in good cement	450 to 1000
Brick-work, first-class, in cement	930
Concrete (1 part lime, 3 parts gravel, 3 weeks old)	620
Lime mortar, common	770
Portland cement, best English,	
Pure, three months old	3760
Pure, nine months old	5960
1 part sand, 1 part cement,	
Three months old	2480
Nine months old	4520
Granites, 7750 to 22,750	12000
Blue granite, Fox Island, Me.	14875
Blue granite, Staten Island, N. Y.	22250
Gray granite, Stony Creek, Conn.	15750
North River (N. Y.) flagging	13425
Limestones, 11,000 to 25,000	12000
Limestone from Glen's Falls, N. Y.	11475
Lake limestone, Lake Champlain, N. Y.	25000
White limestone, Marblehead, O.	11225
White limestone from Joliet, Ill.	12775
Marbles,	
From East Chester, N. Y.	12950
Common Italian	11250
Vermont (Southerland Falls Co.)	10750
Vermont, Dorset, Vt.	7612
Drab, North Bay Quarry, Wis.	20025

Average Ultimate Crushing-Load — *Continued.*

	Lbs. per Sq. In.
Sandstones	6000
Brown, Little Falls, N. Y.	9850
Brown, Middletown, Conn.	6950
Red, Haverstraw, N. Y.	4350
Red-brown, Seneca freestone, Ohio	9687
Freestone, Dorchester, N. B.	9150
Longmeadow sandstone, Springfield, Mass.	8000 to 14000

MISCELLANEOUS MATERIALS.

Weight of Round Bolt Copper Per Foot.

Inches.	Pounds.	Inches.	Pounds.	Inches.	Pounds.
$\frac{3}{8}$	.425	1	3.02	$1\frac{5}{8}$	7.99
$\frac{1}{2}$	.756	$1\frac{1}{8}$	3.83	$1\frac{3}{4}$	9.27
$\frac{5}{8}$	1.18	$1\frac{1}{4}$	4.72	$1\frac{7}{8}$	10.64
$\frac{3}{4}$	1.70	$1\frac{3}{8}$	5.72	2	12.10
$\frac{7}{8}$	2.31	$1\frac{1}{2}$	6.81		

Weight of Sheet and Bar Brass.

Thickness. Inches.	Sheets per sq. ft.	Square Bars 1 ft. long.	Round Bars 1 ft. long.	Thickness. Inches.	Sheets per sq. ft.	Square Bars 1 ft. long.	Round Bars 1 ft. long.
	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.
$\frac{1}{16}$	2.7	.015	.011	$1\frac{1}{16}$	45.95	4.08	3.20
$\frac{1}{8}$	5.41	.055	.045	$1\frac{1}{8}$	48.69	4.55	3.57
$\frac{3}{16}$	8.12	.125	.1	$1\frac{3}{16}$	51.4	5.08	3.97
$\frac{1}{4}$	10.76	.225	.175	$1\frac{1}{4}$	54.18	5.65	4.41
$\frac{5}{16}$	13.48	.350	.275	$1\frac{5}{16}$	56.85	6.22	4.86
$\frac{3}{8}$	16.25	.51	.395	$1\frac{3}{8}$	59.55	6.81	5.35
$\frac{7}{16}$	19.	.69	.54	$1\frac{7}{16}$	62.25	7.45	5.85
$\frac{1}{2}$	21.65	.905	.71	$1\frac{1}{2}$	65.	8.13	6.37
$\frac{9}{16}$	24.3	1.15	.9	$1\frac{9}{16}$	67.75	8.83	6.92
$\frac{5}{8}$	27.12	1.4	1.1	$1\frac{5}{8}$	70.35	9.55	7.48
$\frac{11}{16}$	29.77	1.72	1.35	$1\frac{11}{16}$	73.	10.27	8.05
$\frac{3}{4}$	32.46	2.05	1.66	$1\frac{3}{4}$	75.86	11.	8.65
$\frac{13}{16}$	35.18	2.4	1.85	$1\frac{13}{16}$	78.55	11.82	9.29
$\frac{7}{8}$	37.85	2.75	2.15	$1\frac{7}{8}$	81.25	12.68	9.95
$\frac{15}{16}$	40.55	3.15	2.48	$1\frac{15}{16}$	84.	13.5	10.58
1	43.29	3.65	2.85	2	86.75	14.35	11.25

Composition of Various Grades of Rolled Brass.

Trade Name.	Copper.	Zinc.	Tin.	Lead.	Nickel.
Common high brass	61.5	38.5	...	...	...
Yellow metal	60	40	...	...	...
Cartridge brass	$66\frac{2}{3}$	$33\frac{1}{3}$	...	...	...
Low brass	80	20	...	...	...
Clock brass	60	40	...	$1\frac{1}{2}$	...
Drill rod	60	40	...	$1\frac{1}{2}$ to 2	...
Spring brass	$66\frac{2}{3}$	$33\frac{1}{3}$	$1\frac{1}{2}$	...	...
18 per cent German silver	$61\frac{1}{2}$	$20\frac{1}{2}$	...	...	18

Weight of Copper and Brass Wire and Plates.

B. & S. Gauge No.	Size of Each No.	Weight of Wire per 1000 Lineal Feet.		Weight of Plates per Square Foot.		No. of Gauge.	Size of Each No.	Weight of Wire per 1000 Lineal Feet.		Weight of Plates per Square Foot.	
		Copper.	Brass.	Copper.	Brass.			Copper.	Brass.	Copper.	Brass.
	Inch.	Lbs.	Lbs.	Lbs.	Lbs.		Inch.	Lbs.	Lbs.	Lbs.	Lbs.
0000	.46000	640.5	605.28	20.84	19.69	21	.028462	2.45	2.317	1.29	1.22
000	.40964	508.0	479.91	18.55	17.53	22	.025347	1.94	1.838	1.15	1.08
00	.36480	402.0	380.77	16.52	15.61	23	.022571	1.54	1.457	1.02	.966
0	.32476	319.5	301.82	14.72	13.90	24	.020100	1.22	1.155	.911	.860
1	.28930	253.3	239.45	13.10	12.38	25	.017900	.699	.916	.811	.766
2	.25763	200.9	189.82	11.67	11.03	26	.01494	.769	.727	.722	.682
3	.22942	159.3	150.52	10.39	9.82	27	.014195	.610	.576	.643	.608
4	.20431	126.4	119.48	9.25	8.74	28	.012641	.484	.457	.573	.541
5	.18194	100.2	94.67	8.24	7.79	29	.011257	.383	.362	.510	.482
6	.16202	79.46	75.08	7.34	6.93	30	.010025	.304	.287	.454	.429
7	.14428	63.01	59.55	6.54	6.18	31	.008928	.241	.228	.404	.382
8	.12849	49.98	47.22	5.82	5.50	32	.007950	.191	.181	.360	.340
9	.11443	39.64	37.44	5.18	4.90	33	.007080	.152	.143	.321	.303
10	.10189	31.43	29.69	4.62	4.36	34	.006304	.120	.114	.286	.270
11	.090742	24.92	23.55	4.11	3.88	35	.005614	.096	.0915	.254	.240
12	.080808	19.77	18.68	3.66	3.46	36	.005000	.0757	.0715	.226	.214
13	.071961	15.65	14.81	3.26	3.08	37	.004453	.0600	.0567	.202	.191
14	.064084	12.44	11.75	2.90	2.74	38	.003965	.0476	.0450	.180	.170
15	.057068	9.86	9.32	2.59	2.44	39	.003531	.0375	.0357	.160	.151
16	.050820	7.82	7.59	2.30	2.18	40	.003144	.0299	.0283	.142	.135
17	.045257	6.20	5.86	2.05	1.94						
18	.040303	4.92	4.65	1.83	1.72						
19	.035890	3.90	3.68	1.63	1.54						
20	.031961	3.09	2.92	1.45	1.37						

Galvanized Iron Wire Rope.

CHARCOAL ROPE. For Ship's Rigging and Guys for Derricks.

Circumference in Inches.	Weight per Fathom in Pounds.	Cir. of New Manila Rope of Equal Strength.	Breaking Strain in Tons of 2000 Lbs.	Circumference in Inches.	Weight per Fathom in Pounds.	Cir. of New Manila Rope of Equal Strength.	Breaking Strain in tons of 2000 Lbs.
5½	26½	11	43	2½	5½	5	9
5¼	24½	10½	40	2¼	4½	4¾	8
5	22	10	35	2	3½	4½	7
4¾	21	9½	33	1¾	2½	3¾	5
4½	19	9	30	1½	2	3	3½
4¼	16½	8½	26	1¼	1¾	2½	2½
4	14¼	8	23	1⅛	1¼	2½	2¼
3¾	12¾	7½	20	1	⅞	2¼	2
3½	10¾	6½	16	⅞	¾	1¾	1
3¼	9½	6	14	¾	½	1½	¾
3	8	5¾	12	⅝	⅜	1¼	⅝
2¾	6¾	5¼	10	½	¼	1⅛	⅜

Transmission or Haulage Rope. (Roebling.)

Composed of 6 Strands and a Hemp Center, 7 Wires to the Strand.

Trade Number.	Diameter in Inches.	Approximate Circumference in Inches.	Weight per Foot in Pounds.	Approximate Breaking Strain in Tons of 2,000 Lbs.	Allowable Working Strain in Tons of 2,000 Pounds.	Minimum Size of Drum or Sheave in Feet.
SWEDISH IRON.						
11	1½	4¾	3.55	34	6.80	13
12	1⅜	4¼	3.00	29	5.80	12
13	1¼	4	2.45	24	4.80	10¾
14	1⅛	3½	2.00	20	4.00	9½
15	1	3	1.58	16	3.20	8½
16	⅞	2¾	1.20	12	2.40	7½
17	¾	2¼	0.89	9.3	1.86	6¾
18	11/16	2⅛	0.75	7.9	1.58	6
19	⅝	2	0.62	6.6	1.32	5¼
20	9/16	1¾	0.50	5.3	1.06	4½
21	½	1½	0.39	4.2	0.84	4
22	7/16	1¼	0.30	3.3	0.66	3¼
23	⅜	1⅛	0.22	2.4	0.48	2¾
24	5/16	1	0.15	1.7	0.34	2½
25	9/32	⅞	0.125	1.4	0.28	2¼
CAST STEEL.						
11	1½	4¾	3.55	68	13.6	8½
12	1⅜	4¼	3.00	58	11.6	8
13	1¼	4	2.45	48	9.60	7¼
14	1⅛	3½	2.00	40	8.00	6¼
15	1	3	1.58	32	6.40	5¾
16	⅞	2¾	1.20	24	4.80	5
17	¾	2¼	0.89	18.6	3.72	4½
18	11/16	2⅛	0.75	15.8	3.16	4½
19	⅝	2	0.62	13.2	2.64	3
20	9/16	1¾	0.50	10.6	2.12	3
21	½	1½	0.39	8.4	1.68	2½
22	7/16	1¼	0.30	6.6	1.32	2¼
23	⅜	1⅛	0.22	4.8	0.96	2
24	5/16	1	0.15	3.4	0.68	1¾
25	9/23	⅞	0.125	2.8	0.56	1½

Standard Hoisting Rope.

Composed of 6 Strands and a Hemp Center, 19 Wires to the Strand.

SWEDISH IRON.

Trade Number.	Diameter in Inches.	Ap. Circumference in Inches.	Weight per Foot in Lbs.	Ap. Breaking Strain in Tons of 2,000 Lbs.	Allowable Working Strain in Tons of 2,000 Lbs.	Min. Size of Drum or Sheave in Foot.
...	$2\frac{3}{4}$	$8\frac{5}{8}$	11.95	114	22.8	16
...	$2\frac{1}{2}$	$7\frac{7}{8}$	9.85	95	18.9	15
1	$2\frac{1}{4}$	$7\frac{1}{8}$	8.00	78	15.60	13
2	2	$6\frac{1}{4}$	6.30	62	12.40	12
3	$1\frac{3}{4}$	$5\frac{1}{2}$	4.85	48	9.60	10
4	$1\frac{5}{8}$	5	4.15	42	8.40	$8\frac{1}{2}$
5	$1\frac{1}{2}$	$4\frac{3}{4}$	3.55	36	7.20	$7\frac{1}{2}$
$5\frac{1}{2}$	$1\frac{3}{8}$	$4\frac{1}{4}$	3.00	31	6.20	7
6	$1\frac{1}{4}$	4	2.45	25	5.00	$6\frac{1}{2}$
7	$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	21	4.20	6
8	1	3	1.58	17	3.40	$5\frac{1}{4}$
9	$\frac{7}{8}$	$2\frac{3}{4}$	1.20	13	2.60	$4\frac{1}{2}$
10	$\frac{3}{4}$	$2\frac{1}{4}$	0.89	9.7	1.94	4
$10\frac{1}{4}$	$\frac{5}{8}$	2	0.62	6.8	1.36	$3\frac{1}{2}$
$10\frac{1}{2}$	$\frac{9}{16}$	$1\frac{3}{4}$	0.50	5.5	1.10	$2\frac{3}{4}$
$10\frac{3}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	0.39	4.4	0.88	$2\frac{1}{4}$
10*a*	$\frac{7}{16}$	$1\frac{1}{4}$	0.30	3.4	0.68	2
10*b*	$\frac{3}{8}$	$1\frac{1}{8}$	0.22	2.5	0.50	$1\frac{1}{2}$
10*c*	$\frac{5}{16}$	1	0.15	1.7	0.34	1
10*d*	$\frac{1}{4}$	$\frac{3}{4}$	0.10	1.2	0.24	$\frac{3}{4}$
CAST STEEL.						
...	$2\frac{3}{4}$	$8\frac{5}{8}$	11.95	228	45.6	10
...	$2\frac{1}{2}$	$7\frac{7}{8}$	9.85	190	37.9	$9\frac{1}{2}$
1	$2\frac{1}{4}$	$7\frac{1}{8}$	8.00	156	31.2	$8\frac{1}{2}$
2	2	$6\frac{1}{4}$	6.30	124	24.8	8
3	$1\frac{3}{4}$	$5\frac{1}{2}$	4.85	96	19.2	$7\frac{1}{4}$
4	$1\frac{5}{8}$	5	4.15	84	16.8	$6\frac{1}{4}$
5	$1\frac{1}{2}$	$4\frac{3}{4}$	3.55	72	14.4	$5\frac{3}{4}$
$5\frac{1}{2}$	$1\frac{3}{8}$	$4\frac{1}{4}$	3.00	62	12.4	$5\frac{1}{2}$
6	$1\frac{1}{4}$	4	2.45	50	10.0	5
7	$1\frac{1}{8}$	$3\frac{1}{2}$	2.00	42	8.40	$4\frac{1}{2}$
8	1	3	1.58	34	6.80	4
9	$\frac{7}{8}$	$2\frac{3}{4}$	1.20	26	5.20	$3\frac{1}{2}$
10	$\frac{3}{4}$	$2\frac{1}{4}$	0.89	19.4	3.88	3
$10\frac{1}{4}$	$\frac{5}{8}$	2	0.62	13.6	2.72	$2\frac{1}{4}$
$10\frac{1}{2}$	$\frac{9}{16}$	$1\frac{3}{4}$	0.50	11.0	2.20	$1\frac{3}{4}$
$10\frac{3}{4}$	$\frac{1}{2}$	$1\frac{1}{2}$	0.39	8.8	1.76	$1\frac{1}{2}$
10*a*	$\frac{7}{16}$	$1\frac{1}{4}$	0.30	6.8	1.36	$1\frac{1}{4}$
10*b*	$\frac{3}{8}$	$1\frac{1}{8}$	0.22	5.0	1.00	1
10*c*	$\frac{5}{16}$	1	0.15	3.4	0.68	$\frac{2}{3}$
10*d*	$\frac{1}{4}$	$\frac{3}{4}$	0.10	2.4	0.48	$\frac{1}{2}$

STEAM.

STEAM BOILERS.

Points to Remember in Selecting a Boiler.

(*a*) Suitability of furnace and boiler to kind of fuel.
(*b*) Efficiency as to evaporative results.
(*c*) Rapidity of steaming including
(I.) Water capacity for given power.
(II.) Water surface for given power.
(*d*) Steam keeping qualities.
(*e*) Safety from explosion.
(*f*) Floor space required.
(*g*) Portability, and ease with which boiler can be removed when old, for replacement by a new boiler.
(*h*) Amount of, ease of, and rapidity of repairs.
(*i*) Simplicity and fewness of parts.
(*j*) Ability to stand forcing in case of necessity.
(*k*) Price, including cost of freight and setting.
(*l*) Durability and reliability.
(*m*) Ease of cleaning and inspection both inside and outside.
(*n*) Freedom from excessive strains due to unequal expansion and ability to withstand same.
(*o*) Efficient natural circulation of water.
(*p*) Absence of joints or seams where flames may impinge.

For central stations it is necessary to arrange for a number of boilers rather than one or two large ones. The size of unit adopted will depend to some extent on the character of the expected load diagram. With a number of boilers the cost of the reserve plant is reduced, though beyond, say six, there is less object in increasing the number on this account.

Types.

Horizontal Return Tubular. — More generally used in United States than any other. Fire first passes under the shell, returns to front through tubes, thence up the chimney, except in some cases gases are again returned over top of the shell. Limited as to size and pressures carried by reason of external firing.

Water-tube. — Very largely used where high steam pressures or safety from explosion are desirable. Fire passes about the exterior of tubes and in most cases under about one-half the circumference of the steam drums. Can be built for any size or pressure. Tubes are generally placed in a slanting position, from one set of headers to another, as in the Babcock & Wilcox, Heine & Co.; or vertically, as in the Sterling and Cahall.

Vertical Fire Tube. — Used considerably in New England. Special design by Captain Manning; tubes 15 feet long 2½ inches diameter, arranged in vertical shell with large combustion chamber surrounded by a water leg. Gases mingle in combustion chamber, and in passing through the long narrow tubes give up nearly all the heat, practicably leaving flue gases 450° to 500° F. By controlling height of water, steam can be superheated. Can be built for high pressures and of large size.

Scotch or Marine Boilers. — Not much used for electrical purposes. Shell of thick material, short in length and large in diameter. Furnaces internal, with return tubes from combustion chamber to uptake.

Old types are the *cylinder boiler*, of small diameter and considerable length (20 to 35 feet). Fired externally, and gases pass under full length to chimney. *Flue boiler*, has two or three large tubes running full length of shell, which is long and of small diameter. Fired externally under the shell, gases return through the flues to uptake. Neither of these types is now used for electrical purposes.

The Horse-Power of Steam Boiler.

The committee of the A. S. M. E. on "Trials of Steam Boilers in 1884" (Trans., vol. vi. p. 265), discussed the question of the horse-power of boilers:

The Committee) A.S.M.E. see Trans. vol. xxi.) approves the conclusions of the 1885 Code to the effect that the standard "unit of evaporation" should be one pound of water at 212° F. evaporated into dry steam of the same temperature. This unit is equivalent to 965.7 British thermal units.

The committee recommends that, as far as possible, the capacity of a boiler be expressed in terms of the "number of pounds of water evaporated per hour from and at 212°." It does not seem expedient, however, to abandon the widely recognized measure of capacity of stationary or land boilers expressed in terms of "boiler horse-power."

The unit of commercial boiler horse-power adopted by the Committee of 1885 was the same as that used in the reports of the boiler tests made at the Centennial Exhibition in 1876. The Committee of 1885 reported in favor of this standard in language of which the following is an extract:

"Your Committee, after due consideration, has determined to accept the Centennial standard, and to recommend that in all standard trials the commercial horse-power be taken as an evaporation of 30 pounds of water per hour from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure, which shall be considered to be equal to 34½ units of evaporation; that is, to 34½ pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour."

The present Committee accepts the same standard, but reverses the order of two clauses in the statement, and slightly modifies them to read as follows:

The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour; that is, 34½ pounds of water evaporated per hour from a feed-water temperature of 212° F. into dry steam of the same temperature. This standard is equal to 33,317 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure.*

The Committee also indorses the statement of the Committee of 1885 concerning the commercial rating of boilers, changing somewhat its wording, so as to read as follows:

A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and, further, the boiler should develop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed and the fires being crowded; the available draft at the damper, unless otherwise understood, being not less than ½ inch water column.

Heating Surface of Boilers.

Although authorities disagree on what is to be considered the heating surface of boilers, it is generally taken as all surfaces that transmit heat from the flame or gases to the water. The outside surface of all tubes is used in calculations.

Kent gives the following rule for finding the heating surface of

Vertical Tubular Boilers. — Multiply the circumference of the fire-box (in inches) by its height above the grate. Multiply the combined circumference of all the tubes by their length, and to these two products add the area of the lower tube sheet; from this sum subtract the area of all the tubes, and divide by 144: the quotient is the area of heating surface in square feet.

Horizontal Return Tubular Boilers. — (Christie). Multiply the length of that part of circumference of the shell (in inches) exposed to the fire by its length; multiply the circumferences of the tubes by their number, by their length in inches; to the sum of these products add two-thirds of the area of both tube sheets less twice the area of tubes, and divide the remainder by 144. The result is the heating surface in square feet.

Heating Surface of Tubes. — Multiply the number of tubes by the diameter of a tube in inches, by its length in feet, and by .2618. The diameter used should be that of the fire side of the tube.

* *According to the tables in Porter's Treatise on the Richards Steam Engine Indicator, an evaporation of 30 pounds of water from 100° F. into steam at 70 pounds pressure is equal to an evaporation of 34.488 pounds from and at 212°; and an evaporation of 34½ pounds from and at 212° F. is equal to 30.010 pounds from 100° F. into steam at 70 pounds pressure.*

The "unit of evaporation" being equivalent to 965.7 thermal units, the commercial horse-power = 34.5 × 965.7 = 33,317 thermal units.

Heating Surface per Horse-power.—There is little uniformity of practice among builders as to the amount of heating surface per horse-power, but 12 square feet may be taken as a fair average. Babcock & Wilcox ordinarily allow 10 square feet, but usually specify the number of square feet of heating surface. The Heine Boiler Company allow $7\frac{1}{2}$ square feet, and the water-tube type in general will develop a horse-power for that amount of surface.

Specifications for boilers should always clearly state the amount of heating surface required.

Grate Surface.—The amount of grate surface per horse-power varies with the character of fuel used and the draught that is available. With good quality of coal about equal results can be obtained with strong draught and small grate surface, and with large grate surface and light draught. Pittsburg coal gives best results with strong draught and a small grate surface. The following table shows the usual requirements, but in general grate surface should be liberal in size, and a rate of combustion of about 10 lbs. per hour will be found good practice.

Grate Surface per Horse-Power. (Kent.)

	Lbs. Water from and at 212° per lb. Coal.	Lbs. Coal per H.P. per hour.	Pounds of Coal burned per square foot of Grate per hour.								
			8	10	12	15	20	25	30	35	40
			Square Feet Grate per H.P.								
Good coal and boiler . . .	10	3.45	.43	.35	.28	.23	.17	.14	.11	.10	.09
	9	3.83	.48	.38	.32	.25	.19	.15	.13	.11	.10
Fair coal or boiler . . .	8.61	4.	.50	.40	.33	.26	.20	.16	.13	.12	.10
	8	4.31	.54	.43	.36	.29	.22	.17	.14	.13	.11
	7	4.93	.62	.49	.41	.33	.24	.20	.17	.14	.12
Poor coal or boiler . . .	6.9	5.	.63	.50	.42	.34	.25	.20	.17	.15	.13
	6	5.75	.72	.58	.48	.38	.29	.23	.19	.17	.14
	5	6.9	.86	.69	.58	.46	.35	.28	.23	.22	.17
Lignite and poor boiler .	3.45	10.	1.25	1.00	.83	.67	.50	.40	.33	.29	.25

Area of Gas-Passages and Flues.

This is commonly stated in a ratio to the grate area. Mr. Barrus says the highest efficiency for anthracite coal, when burning 10 to 12 lbs. per square foot of grate per hour, is with tube area $\frac{1}{9}$ to $\frac{1}{10}$ of grate surface; and for soft coal the tube area should be $\frac{1}{6}$ to $\frac{1}{7}$ of the grate surface.

Other rules in common use are to make the area over bridge walls (for horizontal return tubular boilers) $\frac{1}{7}$ the grate surface; tube area $\frac{1}{8}$ and chimney area $\frac{1}{9}$.

Air-space in Grates.—Usual practice is 30% to 50% area of grate for air space. If fuel clinkers easily, use the largest air space available. With coal free from clinker smaller air space may be used.

Distance between Under Side of Boiler and Top of Grate.

(For Horizontal Tubular Boiler.)

For anthracite coal this should be 24 inches for the larger sizes, and can be 20 inches for the smaller sizes, such as pea, buckwheat, and rice. For bituminous coals non-caking, the grate should be about 30 inches below the boiler, and for fatty or gaseous coals from 36 to 48 inches. For average bituminous coals the distance can be 36 inches. Anthracite and bituminous coals cannot be economically burned in the same furnace.

Steam Boiler Efficiency.

The ratio of the heat units utilized in making steam in a boiler, to the total heat units in the coal used is called the efficiency of the boiler, and is rated in *per cent.* For example, the heating value of good anthracite coal is about 14,500 B. T. U., and will evaporate from and at 212° 15 lbs. water (14,500 ÷ 966). If a boiler under test evaporates 12 lbs. water per pound of combustible, the efficiency will be $\frac{12 \times 100}{15} = 80\%$, a figure not often obtained, but possible under special conditions. The heating value of bituminous coals varies so much that it is necessary to determine it by a coal calorimeter before it is possible to determine the boiler efficiency.

Strength of Riveted Shell.

(Abridged from Barr on "Boilers and Furnaces.")

Wrought-iron boiler-plates should average 45,000 lbs., and mild steel 55,000 lbs., tensile strength per square inch of section; but the gross strength of plate is lessened by the amount which has been taken out of it for the insertion of rivets.

The following tables give the calculated working pressure for double-riveted and triple-riveted lap joints, and for butt-joints triple riveted, the factor of safety being 5. The rule for calculating the safe working pressure is: Multiply together the tensile strength of the plate, the thickness of the plate in parts of an inch, and the efficiency of the joint (see Riveting); divide the product by one-half the diameter of the boiler multiplied by the factor of safety.

Working Pressure for Cylindrical Shells of Steam Boilers.

Factor of Safety, 5. (Barr.)

Diameter Inches.	Thickness in 16ths of an Inch.	Lap-Joints, Double-Riveted.			Lap-Joints, Triple-Riveted.		
		Iron Shell, Iron Rivets.	Steel Shell, Iron Rivets.	Steel Shell, Steel Rivets.	Iron Shell, Iron Rivets.	Steel Shell, Iron Rivets.	Steel Shell, Steel Rivets.
36	4	91	111	111	100	121	123
	5	112	128	137	124	139	151
40	4	82	100	100	90	109	110
	5	101	115	123	112	125	136
44	4	74	91	91	83	99	100
	5	91	105	112	101	114	124
48	5	84	96	102	93	104	114
	6	99	107	121	110	118	135
52	5	77	89	95	86	96	105
	6	92	99	112	102	109	124
54	5	75	85	91	83	93	101
	6	88	96	108	98	105	120
56	5	72	82	88	80	89	97
	6	85	92	104	95	101	116
60	5	67	77	82	74	83	91
	6	79	85	97	88	95	108
62	6	77	83	94	85	92	104
	7	88	92	108	98	103	120
64	6	74	81	91	83	89	101
	7	86	89	105	95	100	117
66	6	72	78	88	80	86	98
	7	83	87	102	93	97	113
68	6	70	76	86	78	84	95
	7	81	80	99	90	94	110
70	6	68	74	83	76	81	92
	7	78	82	96	87	91	107
72	7	76	79	93	85	89	104
	8	85	89	104	97	98	117

Working Pressure for Cylindrical Shells of Steam Boilers. (Barr.)

Butt Joints, Triple Riveted. *Factor of Safety*, 5.

Diameter Inches.	Thickness in 16ths of an inch.	Iron Shell, Iron Rivets.	Steel Shell, Iron or Steel Rivets.	Diameter, Inches.	Thickness in 16ths of an inch.	Iron Shell. Iron Rivets.	Steel Shell, Iron or Steel Rivets.
	4	108	134		6	83	102
36	5	135	165	70	7	97	118
	6	161	197		8	110	134
	4	102	127		9	123	151
38	5	128	156		6	80	99
	6	152	187	72	7	94	115
	4	97	120		8	107	131
40	5	121	148		9	120	147
	6	145	178		7	90	110
	4	93	115	75	8	102	125
42	5	116	141		9	115	141
	6	138	169		10	128	157
	4	89	109		7	87	106
44	5	110	135	78	8	99	121
	6	132	161		9	111	135
	4	85	105		10	123	151
46	5	106	129		8	92	112
	6	126	154		9	103	126
	5	101	124	84	10	115	140
48	6	121	148		11	126	158
	7	141	172		12	137	167
	5	97	119		8	86	105
50	6	116	142		9	96	117
	7	135	165	90	10	107	131
	5	93	114		11	117	143
52	6	111	137		12	128	156
	7	130	159		8	80	98
	5	90	110		9	90	110
54	6	107	132	96	10	100	123
	7	125	153		11	110	134
	5	87	106		12	120	146
56	6	103	127		8	75	92
	7	121	148		9	85	104
	5	84	102	102	10	94	115
58	6	100	123		11	104	127
	7	117	142		12	113	138
	6	97	118		8	71	87
60	7	111	138		9	80	98
	8	128	157	108	10	89	109
	6	93	115		11	98	120
62	7	109	133		12	107	130
	8	124	152		8	68	83
	6	90	111		9	76	93
64	7	106	129	114	10	84	103
	8	120	147		11	93	113
	9	135	165		12	101	123
	6	88	108		8	64	78
66	7	102	125		9	71	88
	8	117	143	120	10	80	98
	9	131	160		11	88	108
	6	85	105		12	96	117
68	7	99	121				
	8	113	138				
	9	127	155				

Safe Working Pressure for Shell Plate.

U. S. Statutes.—

d = diameter of boiler in inches.
P = safe working pressure, lbs. per square inch.
t = thickness of metal in inches.
w = tensile strength of metal.
k = factor of safety = 6 for U. S. and 4.5 for Great Britain.

$P = \frac{t \times 2 \times w}{d \times 6}$ for single-riveted. For double-riveted, add 20%.

Board of Trade.—

$$P = \frac{w \times B \times t \times 2}{d \times k \times 100}$$

where the notation is the same as in U. S. rule, and B = percentage of strength of joint as compared with solid plate.

Rules Governing Inspection of Boilers in Philadelphia.

In estimating the strength of the longitudinal seams in the cylindrical shells of boilers, the inspector shall apply two formulæ, A and B:

A, $\left\{ \frac{\text{Pitch of rivets} - \text{diameter of holes punched to receive the rivets}}{\text{pitch of rivets}} \right. =$

percentage of strength of the sheet at the seam.

B, $\left\{ \frac{\text{Area of hole filled by rivet} \times \text{No. of rows of rivets in seam} \times \text{shearing strength of rivet}}{\text{pitch of rivets} \times \text{thickness of sheet} \times \text{tensile strength of sheet}} \right. =$

percentage of strength of the rivets in the seam.

Take the lowest of the percentages as found by formulæ A and B, and apply that percentage as the "strength of the seam" in the following formula, C, which determines the strength of the longitudinal seams:

C, $\left\{ \frac{\text{Thickness of sheet in parts of inch} \times \text{strength of seam as obtained by formula A or B} \times \text{ultimate strength of iron stamped on plates}}{\text{internal radius of boiler in inches} \times 5 \text{ as a factor of safety}} \right. =$

safe working pressure.

Safe Working Pressure for Flat Plates.

U. S. Statutes.—

P = safe working pressure.
S = surface supported, square inches.
t = thickness of metal in sixteenths of an inch.
k = constant for plates of different thickness, and for various conditions.
p = greatest pitch in inches.

$$P = \frac{t \times k}{p^2}.$$

K = 112 for $\frac{7}{16}$-inch plates and less, fitted with screw stay bolts and nuts, or plain bolt fitted with single nut and socket, or riveted head and socket.
K = 120 for plates more than $\frac{7}{16}$ inch thick, under same conditions.
K = 140 for flat surfaces where the stays are fitted with nuts inside and out.
K = 200 for flat surfaces under same conditions, but with washer riveted to plate, washer to be one-half as thick as plate, and of a diameter $\frac{2}{3}$ pitch.

No brace or stay on marine boilers to have a greater pitch than $10\frac{1}{2}$ inches on fire boxes and back connections. Plates fitted with double-angle irons riveted to plate, and with leaf at least two-thirds thickness of plate, and depth at least one-fourth of pitch, allowed the same pressure as plate with washer riveted on.

Board of Trade. — Using same notation as in U. S. rules :

$$P = \frac{k\,(t+1)^2}{S-6}.$$

$K = 125$ for plates not exposed to heat or flame, the stays fitted with nuts and washers, the latter at least three times the diameter of the stay and $\frac{2}{3}$ the thickness of the plate ;
$K = 187.5$ for the same condition, but the washers $\frac{2}{3}$ the pitch of stays in diameter, and thickness not less than plate ;
$K = 200$ for the same condition, but doubling plates in place of washers, the width of which is $\frac{2}{3}$ the pitch, and thickness the same as the plate ;
$K = 112.5$ for the same condition, but the stays with nuts only ;
$K = 75$ when exposed to impact of heat or flame and steam in contact with the plates, and the stays fitted with nuts and washers three times the diameter of the stay, and $\frac{2}{3}$ the plate's thickness ;
$K = 67.5$ for the same condition, but stays fitted with nuts only ;
$K = 100$ when exposed to heat or flame, and water in contact with the plates, and stays screwed into the plates, and fitted with nuts ;
$K = 66$ for the same condition, but stays with riveted heads.

Ductility of Boiler Plate. — U. S. Inspectors of Steam Vessels.

In test for tensile strength, sample shall show reduction of area of cross-section not less than the following percentages :

Iron.

45,000 lbs. tensile strength and under	15 per cent.
For each additional 1000 t. s. up to 55,000 t. s. add .	1 "
55,000 lbs. tensile strength, and above	25 "

Steel.

All steel plates $\frac{1}{2}$ inch thick and under	50 per cent.
" " " $\frac{1}{2}$ to $\frac{3}{4}$ inch	45 "
" " " $\frac{3}{4}$ inch and above	40 "

Boiler Head Stays.

The United States Regulations on braces are : "No braces or stays hereafter employed in the construction of boilers shall be allowed a greater strain than 6,000 lbs. per square inch of section. Braces must be put in sufficiently thick so that the area in inches which each has to support, multiplied by the pressure per square inch, will not exceed 6,000 when divided by the cross-sectional area of the brace or stay.

"Steel stay-bolts exceeding a diameter of $1\frac{1}{4}$ inches, and not exceeding a diameter of $2\frac{1}{2}$ inches at the bottom of the thread may be allowed a strain not exceeding 8,000 lbs. per square inch of cross-section ; steel stay bolts exceeding a diameter of $2\frac{1}{2}$ inches at bottom of thread may be allowed a strain not exceeding 9,000 lbs. per square inch of cross-section ; but no forged or welded steel stays will be allowed.

"The ends of such stay may be upset to a sufficient thickness to allow for truing up, and including the depth of the thread. And all such stays after being upset, shall be thoroughly annealed."

Direct Braces. — The following table is given by Mr. Wm. M. Barr in "Boilers and Furnaces," p. 122. The working strength assumes an ultimate strength of 6000 lbs. per square inch of section.

Diameter of Brace Inches.	Wrought Iron Stays.		Inches square each Brace will Support for Pressures per Square Inch.			
	Area sq. in.	Working Strength Pounds.	75 Pounds.	100 Pounds.	125 Pounds.	150 Pounds.
$\frac{7}{8}$	.60	3600	7.0	6.0	5.4	4.9
1	.78	4712	7.9	6.9	6.1	5.6
$1\frac{1}{8}$	.99	5964	8.9	7.7	6.9	6.4
$1\frac{1}{4}$	1.23	7362	9.9	8.6	7.7	7.0
$1\frac{3}{8}$	1.48	8880	10.7	9.5	8.5	7.7
$1\frac{1}{2}$	1.77	10620	11.9	10.4	9.2	8.5

Diagonal Braces. — ("Boilers and Furnaces," p. 129.) These must be calculated separately.

Let

A = surface to be supported in square inches.
B = working pressure in lbs.
H = length of diagonal stay in inches.
L = length of line drawn at right angles from surface, to be supported to end of diagonal stay in inches.
S = working stress per square inch on stay in lbs.
a = area required for direct stay in square inches.
a_1 = area of diagonal stay in square inches.
T = diameter of diagonal stay in inches.

Then

$a_1 = a \times H \div L$;
$H = a_1 \times L \div a$.

$$T = \sqrt{\frac{a_1}{.7854}} = \sqrt{\frac{A \times B \times H}{.7854\, S \times L}};$$

$$B = \frac{.7854 \times T^2 \times S \times L}{A \times H}.$$

Boiler Settings.

Water tube and special types of boilers require special settings largely controlled by local conditions, location of flues, etc., and cannot be tabulated here.

The setting of *horizontal return tubular* boilers has become so nearly standardized that the table following, taken in connection with the cuts, will give all the general dimensions of brick-work required.

For all special boiler settings, furnaces, etc., the reader is referred to the makers of each.

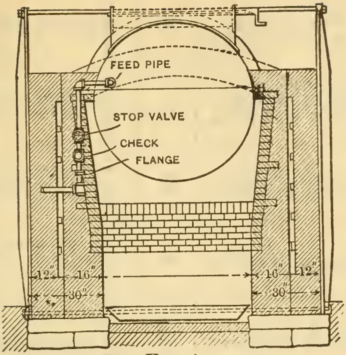


FIG. 1.

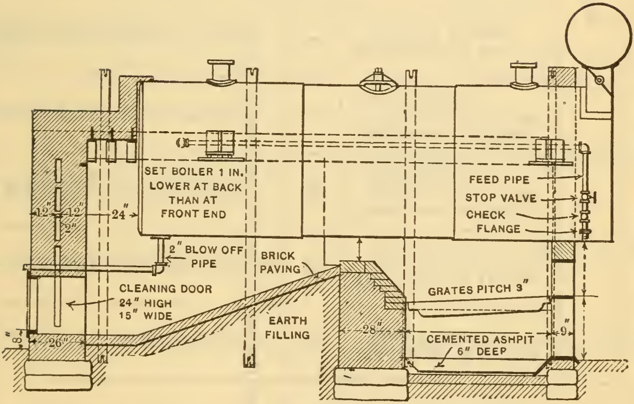


FIG. 2.

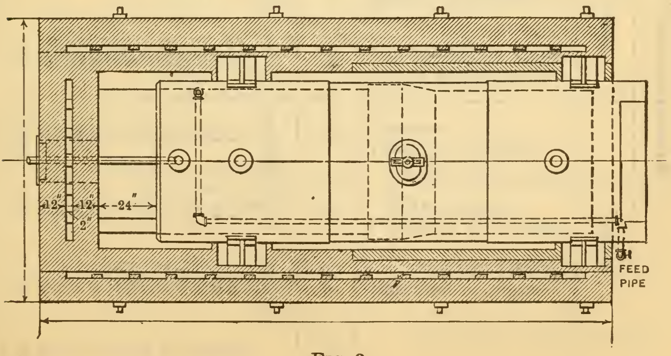


FIG. 3.

Measurements for Setting Return Tubular Boilers Arch Fronts.

	Boiler.			Dome.		Walls.									
	Diameter of Boiler.	Length of Boiler less Curtain Sheet.	Length of Curtain Sheet.	Top of Boiler to Top of Flange on Dome.	Center of Dome to Front of Boiler.	Thickness of Outside Side Walls.	Thickness of Inside Side Walls.	Thickness of 2 Side Walls, with 2-inch Air Space.	Thickness of 2 Rear Walls, with 2-inch Air Space.	Thickness of Front Wall at Bottom.	Length of Foundation for Side Walls.	Width of Walls over all.	Height of Walls from Top of Floor.	Thickness of Bridge Wall at Bottom.	Thickness of Bridge Wall at Top.
H. P.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Inches.	Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Ft. In.	Ft. In.	Ft. In.	Inches.	Inches.
15	36	8	11	22	39	8	12	22	18	13	11– 7	6– 8	7– 0	32	15
20	36	10	11	22	51	8	12	22	18	13	13– 7	6– 8	7– 0	32	15
25	42	10	12	26	49	8	12	22	18	13	13– 7	7– 2	7– 7	36	15
30	42	12	12	26	78	8	12	22	18	13	15– 7	7– 2	7– 7	36	15
35	44	12	12	28	78	8	12	22	18	13	15– 7	7– 4	7–10	36	15
40	48	12	14	30	79	8	12	22	18	15½	15– 7	7– 8	8– 0	36	15
45	50	13	14	32	85	8	12	22	18	15½	16– 7	7–10	8– 1	36	15
50	54	13	14	32	85	8	12	22	18	15½	15– 9	8– 2	8– 6	36	15
60	54	15	14	32	97	8	12	22	18	15½	18– 9	8– 2	8– 6	36	15
70	60	14	16	32	92	8	16	26	18	15½	17–11	9– 4	8–11	40	15
75	60	15	16	32	98	8	16	26	18	15½	18–11	9– 4	8–11	40	15
80	60	16	16	38	104	8	16	26	18	15½	19–11	9– 4	8–11	40	15
90	66	15	17	38	98	8	16	26	18	15½	19– 3	9–10	9– 8	40	15
100	66	16	17	38	104	8	16	26	18	15½	20– 3	9–10	9– 8	40	15
125	72	16	18	38	105	8	16	26	18	16	20– 5	10– 4	10– 1	40	15

	Furnace.					Setting.								
	Floor Line to Top of Grates at the Front.	Floor Line to Top of Grates at the Rear.	Top of Grates to Under Side of Boiler.	Length of Furnace.	Width of Furnace.	Top of Floor to Under Side of Boiler at Front.	Top of Floor to Under Side of Boiler at Rear.	Top of Floor to Top of Flange on Dome.	Top of Bridge Wall to Under Side of Boiler.	Space in Rear between Boiler and Wall.	Space between Boiler and Wall at the Side.	No. of Common Brick above Floor Line.	No. of Fire Brick.
H. P.	P	Q	R	S	T	U	V	W	X	Y	Z		
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Ft. In.					
15	25	23½	26	36	36	51	50½	9– 1	10	20	2	6250	650
20	25	23½	26	42	36	51	50½	9– 1	10	20	2	7100	700
25	27	25½	26	42	42	53	52½	10– 1	10	20	2	8200	725
30	27	25½	26	48	42	53	52½	10– 1	10	20	2	8750	780
35	27	25½	26	48	44	53	52½	10– 5	10	20	2	9250	800
40	30	28	26	48	48	56	55½	11– 2	10	20	2	10700	850
45	30	28	26	48	50	56	55½	11– 6	12	20	2	11700	910
50	30	28	28	54	54	58	57½	12–	12	22	2	14450	900
60	30	28	28	60	54	58	57½	12–	12	22	2	17680	1000
70	30	28	30	60	60	60	59½	12– 8	12	24	2	16600	1000
75	30	28	30	60	60	60	59½	12– 8	12	24	2	17900	1000
80	30	28	30	60	60	60	59½	13– 2	12	24	2	19000	1200
90	33	31	30	66	66	63	62½	13–11	14	28	2	19600	1200
100	33	31	30	66	66	63	62½	13–11	14	28	2	21550	1400
125	34	32	30	72	72	64	63½	14– 6	14	30	2	22500	1500

CHIMNEYS.

THE DRAUGHT POWER OF A CHIMNEY varies as the square root of the height.

The retarding friction of the chimney may be taken as equivalent to a diminution of its actual area by a layer of gas two inches thick all the way around the perimeter of its flue.

A = actual area of flue in square feet.
E = effective area of flue in square feet.
H = height in feet.
D = diameter of flue in feet.
D_1 = side of a square chimney equivalent to A.

Then: $E = A - 0.6\sqrt{A}$. (1)

$D_1 = \sqrt{E} + 4$ inches. (2)

Horse-power $= 3.33\ E\sqrt{H}$. (3)

The above formulæ are by Kent, and are based on a consumption of 5 lbs. coal per h. p. per hour. W. W. Christie, in a paper read before the A.S.M.E., Trans., vol. xviii., p. 387, gives as his opinion that all chimneys should be compared and rated by using coal capacity as a basis, not horse-power. In the following table, coal capacity can be found by multiplying h.p. by 4.

Size of Chimneys for Steam-Boilers.

(W. W. Christie.)

Diam. Inches.	Height of Chimney.													
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	225 ft.	250 ft.	300 ft.
	Boiler Horse-power $= 3.25\ A\sqrt{H}$; 4 lbs. of coal burned considered 1 H.P.													
18	42	46	49	52	..	..	..	..	..	...	...	...	...	...
21	55	62	65	68	..	..	..	..	..	...	...	...	...	...
24	72	78	85	91	98	..	..	..	..	...	...	...	...	...
27	91	101	107	114	124	..	..	..	..	...	...	...	...	...
30	114	124	133	143	153	159	..	..	..	...	...	...	...	...
33	..	149	163	172	182	192	202	..	..	...	...	...	...	...
36	..	179	192	205	218	228	241	257	..	...	...	...	...	...
39	..	..	224	241	257	270	283	302	..	...	...	...	...	...
42	..	..	263	282	296	312	332	351	390	...	...	...	...	...
48	..	..	..	364	387	410	429	458	510	...	...	...	...	...
54	..	..	..	..	491	517	543	579	647	683	...	...	...	...
60	..	..	..	..	605	637	669	715	797	845	...	...	...	...
66	..	..	..	..	..	774	809	865	965	1021	1092	...	...	...
72	..	..	..	..	..	920	962	1051	1147	1215	1300	1378	...	...
78	..	..	..	..	..	..	1131	1206	1349	1459	1524	1619	1706	...
84	..	..	..	..	..	..	1310	1401	1563	1654	1768	1875	1976	2165
90	..	..	..	..	..	..	..	1609	1794	1898	2031	2155	2269	2486
96	..	..	..	..	..	..	..	1830	2041	2161	2311	2451	2584	2831
102	..	..	..	..	..	..	..	2067	2304	2434	2607	2766	2915	3195
108	..	..	..	..	..	..	..	2314	2584	2734	2925	3101	3269	3578
114	..	..	..	..	..	..	..	..	2879	3045	3257	3455	3643	3991
120	..	..	..	..	..	..	..	..	3191	3374	3611	3829	4037	4420
132	..	..	..	..	..	..	..	..	3861	4082	4368	4651	4882	5350
144	..	..	..	..	..	..	..	..	4596	4859	5200	5515	5811	6367

The following table* will prove useful to those having to do with electric installations, and gives the horse-power of chimneys to be used in power plants having very efficient engines, such as compound or triple expansion engines, when 2 lbs. of coal burned under the boiler produce one horse-power at the engine.

Size of Chimney for Steam Boilers.

(W. W. Christie.)

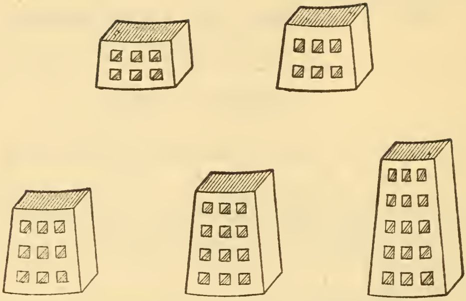
Diam. Inches.	Height of Chimney.													
	50′	60′	70′	80′	90′	100′	110′	125′	150′	175′	200′	225′	250′	300′
	Horse-power $= 6.5\ A\sqrt{H}$. When 2 lbs. coal burned per hour = 1 H.P.													
18	84	92	98	104	..	..	..	..	..	...	...	...	...	...
21	110	124	130	136	..	..	..	..	..	...	...	...	...	...
24	144	156	170	182	196	..	..	..	..	...	...	...	...	...
27	182	202	214	228	248	..	..	..	..	...	...	...	...	...
30	228	248	266	286	306	318	..	..	..	...	...	...	...	...
33	..	298	326	344	364	384	404	..	..	...	...	...	...	...
36	..	358	384	410	436	456	482	514	..	...	...	...	...	...
39	..	..	448	482	514	540	566	604	..	...	...	...	...	...
42	..	..	526	564	592	624	662	702	780	...	...	...	...	...
48	..	..	..	728	774	820	858	916	1020	...	...	...	...	...
54	..	..	..	..	982	1034	1086	1158	1294	1366	...	...	...	...
60	..	..	..	..	1210	1274	1338	1430	1594	1690	...	...	...	...
66	..	..	..	..	..	1548	1618	1730	1930	2042	2184	...	...	...
72	..	..	..	..	..	1840	1924	2102	2294	2430	2600	2756	...	...
78	..	..	..	..	..	..	2262	2412	2698	2918	3048	3238	3412	...
84	..	..	..	..	..	..	2620	2802	3126	3308	3536	3750	3952	4330
90	..	..	..	..	..	..	..	3218	3588	3796	4062	4310	4538	4972
96	..	..	..	..	..	..	..	3660	4082	4322	4622	4902	5168	5662
102	..	..	..	..	..	..	..	4134	4608	4868	5214	5532	5830	6360
108	..	..	..	..	..	..	..	4628	5168	5468	5850	6202	6538	7156
114	..	..	..	..	..	..	..	..	5758	6090	6514	6910	7286	7982
120	..	..	..	..	..	..	..	..	6382	6748	7222	7658	8074	8840
132	..	..	..	..	..	..	..	..	7722	8164	8736	9262	9764	10700
144	..	..	..	..	..	..	..	..	9192	9718	10400	11030	11622	12734

Chimney Construction.

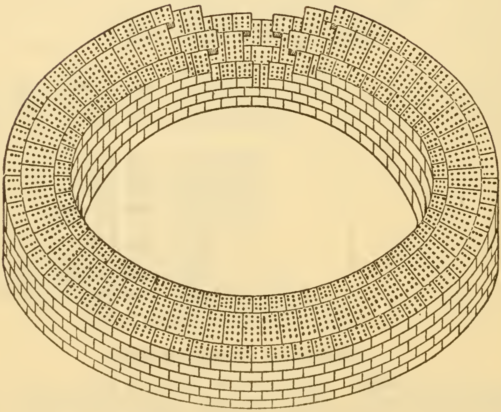
A brick chimney shaft is made up of a series of steps, each of which is of uniform thickness, but as we ascend each succeeding step is thinner than the one it rests upon. These bed joints at which the thickness changes are the joints of least stability. The joints and the one at the ground line are the only ones to which it is necessary to apply the formulas for determining the stability of the stack.

The height of the different steps of uniform thickness varies greatly, according to the judgment of the engineer, but 170 feet is, approximately, the extreme height that any one section should be made. This length is seldom approached even in the tallest chimneys, as the brick-work has to bear, in addition to its weight, that due to the pressure of the wind. The steps should not exceed about 90 feet, unless the chimney stack is inside a tower which protects it from the wind. In chimneys from 90 to 120 feet high the steps vary from 17 to 25 feet, the top step being one brick thick; in chim-

* *"Chimney Design and Theory," W. W. Christie, D. Van Nostrand Company.*



Perforated radial bricks used for chimneys.



Bond in radial brick work.

Fig. 4.

neys from 130 to 150 feet the steps vary from 25 to 35 feet; in chimneys from 150 to 200 feet the steps vary from 35 to 50 feet; in chimneys from 200 to 300 feet and over, the steps vary from 50 to 90 feet, the top step being one and one-half bricks thick. The outside dimensions of a chimney at the base should generally not be less than one-tenth of the height of the stack for square chimneys; one-eleventh for octagonal, and one-twelfth for round. The battery may be 2½ inches for every 10 feet.

The foundation of a chimney is one of the most important points to be considered. When this is upon solid rock it is only necessary to excavate to a depth sufficient to prevent the heat of the gases from materially affecting the natural stone, and to secure the spread of the base. In cases where chimneys are to be built upon alluvial clays or made ground, it is necessary to excavate until a good stiff clay, hard sand, or rock bottom is reached. The excavation is filled with concrete in various ways, or filled according to the judgment of the engineer, so as to economize material without endangering the structure.

Babcock and Wilcox give the following formula for the ability of brick chimneys to withstand wind pressure.

w = weight of chimney in lbs. (brickwork = 100 to 130 lbs. per cubic foot.)
d = average diameter in feet, or width if square.
h = height in feet.
b = width of base.
k = constant, for square chimneys = 56.
for round chimneys = 28.
for octagonal chimneys = 35.

$$c = k\frac{d\,y^2}{w} \text{ and } w = k\frac{d\,h^2}{b}.$$

Radial Brick Chimneys.

Another type of chimney now much used in the East, is built of radial brick, perforated vertically with holes about 1″ square, passing entirely through them.

The advantage of these bricks is said to be a better bond, as the cement makes a dowel in the perforations.

They are made of a special quality of clay, having greater care in the making, are burned at a greater heat than the red brick, and are said to be of a more uniform grade.

Radial brick chimneys as built in the United States do not always have lining, for the brick are supposed to be capable of withstanding the heat of the gases usually met with, but in special cases a lining is built in them, and is carried by the outer shell.

The less number of joints to the weather is also given as a point in favor of the radial brick chimney.

In making comparisons of the costs of the several types of chimneys, if of brick, they should have the same

- height,
- inside diameter,
- lightning protection details,
- ladder equipment,
- quality of workmanship,
- same factor of stability.

Draft Power for Combustion of Fuels.

(R. H. Thurston.)

Fuel.	Draft of Chimney in Inches of Water.	Fuel.	Draft in Ins. of Water.
Wood.	0.20 to 0.25	Coal-dust	0.80 to 1.25
Sawdust	0.35 " 0.50	Semi Anthracite coal	0.90 " 1.25
Sawdust mixed with small coal	0.60 " 0.75	Mixture of breeze and slack	1.00 " 1.33
Steam coal	0.40 " 0.75	Anthracite	1.25 " 1.50
Slack, ordinary . .	0.60 " 0.90	Mixture of breeze and coal-dust	1.25 " 1.75
Slack, very small . .	0.75 " 1.25	Anthracite slack . .	1.30 " 1.80

Height of Chimney for Burning Given Amounts of Coal.

Professor Wood (Trans. A. S. M. E., vol. xi.) derives a formula from which he calculates the height of chimney necessary to burn stated quantity of coal per square foot of grate per hour, for certain temperatures of the chimney gas.

Temp. Outside Air.	Absolute Temp. Chimney Gases.	Pounds of Coal per Square Foot Grate Area. 16	20	24
		Height of Chimney, Feet.		
520° Absolute, or 59° Fahr.	700	67.8	157.6	250.9
	800	55.7	115.8	172.4
	1000	48.7	100.0	149.1
	1100	48.2	98.9	148.8
	1200	49.1	100.9	152.0
	1400	51.2	105.6	159.9
	1600	53.5	110.9	168.8
	2000	63.0	132.2	206.5

Rate of Combustion Due to Height of Chimney.

Prof. Trowbridge (" Heat and Heat Engines," p. 153) gives the following table, showing the heights of chimneys for producing certain rates of combustion per square foot of area of section of the chimney. The ratio of the grate to the chimney section being 8 to 1.

Height in Feet.	Lbs. Coal burned per Hour per sq. ft. of Section of Chimney.	Lbs. Coal burned per Hour per sq. ft. of Grate.	Height in Feet.	Lbs. Coal burned per Hour per sq. ft. Section of Chimney.	Lbs. Coal burned per Hour per sq. ft. Grate.
25	68	8.5	70	126	15.8
30	76	9.5	75	131	16.4
35	84	10.5	80	135	16.9
40	93	11.6	85	139	17.4
45	99	12.4	90	144	18.0
50	105	13.1	95	148	18.5
55	111	13.8	100	152	19.0
60	116	14.5	105	156	19.5
65	121	15.1	110	160	20.0

Dimensions and Cost of Brick Chimneys.

(Buckley.)

Approx. Horse-Power.	Height, Feet.	Diameter Flue Inside.	Outside Dimensions, Base, Square.	Outside Wall.		Cost Fire Brick Lining, ½ Height.	Cost Concrete Foundations.	Total Cost Chimney.
				No. Brick.	Cost @ $14 per M.			
85	80	25 in.	7 ft. 5 in.	32,000	$ 448.00	$ 60.00	$ 90.00	$ 598.00
135	90	30 in.	8 " 3 "	40,000	560.00	82.00	144.00	786.00
200	100	35 in.	9 " 10 "	65,000	910.00	118.00	198.00	1,226.00
300	110	43 in.	10 " 2 "	75,000	1,050.00	190.00	252.00	1,492.00
450	120	51 in.	11 " 2 "	87,000	1,218.00	261.00	306.00	1,785.00
750	130	61 in.	12 " 6 "	131,000	1,834.00	334.00	360.00	2,528.00
1000	140	74 in.	13 " 11 "	151,000	2,114.00	432.00	414.00	3,060.00
1650	150	88 in.	15 " 1 "	200,000	2,800.00	482.00	468.00	3,750.00
2500	160	110 in.	17 " 10 "	275,000	3,850.00	720.00	525.00	5,095.00

Steel Plate Chimneys have long been used in the iron and coal regions, but have only recently come into use in the East, except in the old style thin sheet iron guyed stack, which lasts but a short time.

Many of the manufacturers of steel structures are now erecting very substantial steel-plate stacks lined with fire bricks, that are of artistic outline, strong, and when kept well painted are durable and need no guys, as they are spread at the base, and bolted to a heavy foundation. They are usually designed to stand a wind pressure of 50 lbs. per square foot.

Sizes of Foundations for Steel Chimney.

(Selected from Circular of Philadelphia Engineering Works.)

HALF-LINED CHIMNEYS.

Diameter, clear, feet . . .	3	4	5	6	7	9	11
Height, feet.	100	100	150	150	150	150	150
Least diameter foundation .	15′9″	16′4″	20′4″	21′10′	22′7″	23′8′	24′8″
Least depth foundation . .	6′	6′	9′	8′	9′	10′	10′
Height, feet	. . .	125	200	200	250	275	300
Least diameter foundation .	. . .	18′5″	23′8″	25′	29′8″	33′6″	36′
Least depth foundation . .	. . .	7′	10′	10′	12′	12′	14′

Brick Lining for Steel Stacks.

Allowing 1¾ inches air space between stack and lining:

Bricks 8¼ × 4 × 2 inches, laid without mortar;
Lining 8¼ inches (one brick) thick;
Number of bricks per foot in diameter of stack, and per foot of height = 47.

Allowing 1 inch air space between stack and lining:

Bricks 8¼ × 4 × 2 inches, laid without mortar;
Lining 4 inches (one brick) thick;
Number of bricks per foot in diameter of stack, and per foot of height = 25.

Dimensions and Cost of Iron Stacks. (Guyed.)

(Buckley.)

Horse-Power.	Height, Feet.	Diameter, Inches.	Number of Iron.	Price Stack Complete.	Price per Foot.
25	40	16	12 and 14	$ 61.00	$ 1.52
. . .	40	18	12 and 14	71.00	1.78
. . .	50	18	12 and 14	84.00	1.68
75	50	20	12 and 14	87.00	1.75
. . .	50	26	12 and 14	105.00	2.10
. . .	60	22	12 and 14	111.00	1.85
100	60	24	12 and 14	125.00	2.08
. . .	60	26	12 and 14	133.00	2.22
. . .	60	28	12 and 14	148.00	2.45
125	60	28	10 and 12	190.00	3.18
. . .	60	32	10 and 12	203.00	3.38
150	60	34	12 and 14	165.00	2.75
200	60	36	10 and 12	215.00	3.58
225	60	38	10 and 12	228.00	3.80
250	60	42	10 and 11	257.00	4.28
300	60	46	10 and 12	286.00	4.76
400	60	52	10 and 12	340.00	5.66

For general details of construction of the various types of chimneys used in the U. S. the reader is referred to "Chimney Design and Theory," by W. Wallace Christie, published by D. Van Nostrand Co.

Blowers for Forced Draught.*

Forced Draught Capacity Table for Blowers.

Temperature air, 62 degrees F.; 18 lbs. air per 1 lb. coal; 34.5 lbs. water per H.P.; barometer, 29.92; 234 cubic ft. per 1 lb. coal; evaporation, 6.9 lbs. water per 1 lb. coal; pressure, 1½ ounces; 5 lbs. coal per H.P. hour.

Size of Blower.	Diameter Wheel, Inches.	Width at Periphery.	Diameter of Inlet.	Diameter of Outlet.	Speed R.P.M. for 1½ oz. Pressure.	Capacity Blower, Cu. Ft. per Min., Temp. 62° F.	Lbs. Coal per Hour 234 Cu. Ft. Air per Lb. Coal.	H.P. Boiler Capacity 5 Lbs. Coal per H.P. Hour.	Evaporation per Hour 34.5 Lbs. Water per H.P.	Brake H.P. to drive Blower at Speed.
1	8½	2	4⅜	4⅝	3300	348	90	18	620	.35
2	10¼	2¾	5⅛	5⅝	2650	512	131	26	896	.52
3	12	3¼	6⅛	6⅝	2320	711	182	36	1240	.73
4	15½	4⅜	8	8½	1800	1210	310	62	2140	1.24
5	19	5½	10	10½	1470	1830	468	93	3210	1.87
6	22½	6½	12	12½	1240	2600	666	133	4590	2.66
7	26	7½	14	14½	1075	3420	875	175	6030	3.50
8	29½	8½	15¾	16¼	950	4130	1055	211	7280	4.54
9	33	9½	17¾	18¼	845	5580	1425	285	9820	5.72

(American Blower Co.)

* From "Furnace Draft; Its Production, by Mechanical Methods" — W. W. Christie.

Fans for Induced Draft.

Induced Draft Capacity Table for Steel Plate Fans.

Temperature gases, 550° F.; barometer, 29.92; 34.5 lbs. water per H.P.; temperature air, 62° F.; 18 lbs. air per 1 lb. coal; evaporation, 6.9 lbs. water per 1 lb. coal; draft pressure, 1 in. W.G.; 5 lbs. coal per H.P. hour; CO_2=90 per cent weight coal.

Size of Fan.	Diameter Wheel, Inches.	Width at Periphery.	Diam. of Inlet.	Size of Outlet. Inches Square.	Speed R. P. M. for 1-inch Draft.	Capacity of Fan in Cubic Feet per Minute, Temp. Gases 550° F.	H.P. Boiler Capacity from Fan Capacity.	Pounds Coal per Hour at 5 Pounds per H.P. Hour.	Evaporation per Hour at 34.5 Pounds Water per H.P.	Brake H.P. to Drive Fan at Speed.	Capacity of Fan per Inch Width at Periphery.	H.P. per Inch Width at Periphery.	Cubic Feet Air per Minute for Combustion, Temp. 62° F.
50	30	12½	20	18	740	5,030	116	580	4,000	2.02	403	.162	2,260
60	36	14¼	23	21½	615	6,900	159	795	5,500	2.76	485	.194	3,100
70	42	16½	26	24½	530	9,325	215	1,075	7,425	3.72	563	.226	4,200
80	48	17½	30	27	460	11,300	261	1,305	9,000	4.50	645	.258	5,100
90	54	20¾	34	30½	410	15,100	349	1,745	12,050	6.03	728	.290	6,800
100	60	23¼	38	34½	370	18,750	433	2,165	14,950	7.50	844	.322	8,450
110	66	26	42	37½	335	23,000	532	2,660	18,300	9.20	885	.354	10,370
120	72	30¼	46	41½	310	29,250	677	3,385	23,350	11.72	970	.387	13,200
140	84	34⅜	53	48	265	38,800	896	4,480	30,900	15.50	1,132	.452	17,450
160	96	38	60	54	230	49,000	1,130	5,650	39,000	19.60	1,290	.516	22,000
180	108	41¼	68	60	205	59,900	1,385	6,925	47,800	24.00	1,453	.581	27,000
200	120	47	76	66	185	75,500	1,746	8,730	60,250	30.25	1,610	.644	34,000
220	132	50	84	72	170	88,600	2,050	10,250	70,750	35.50	1,775	.710	40,000
240	144	54	92	78	155	104,600	2,420	12,100	83,500	41.80	1,940	.775	47,000

The effect of the temperature of the gases, on the power required to operate a fan, is shown very clearly by the following:

Effect of Temperature of Gases on Fan Load.

Induced Draft.	1	2	3
Draft in inches of water	0.42	0.46	0.24
Temperature of gases at fan, degree F.	199.6	162.5	330.
Speed of fan, revolution per minute	154.	179.	230.
Current required by fan motor — amperes . . .	10.3	13.3	20.4
Current generated by plant — amperes	896.	1236.	960.
Proportion used by fan — per cent	1.15	1.17	2.08
Boiler H.P. developed	521.7	600.6	439.2

The blower used was an American Blower Co.'s centrifugal fan with 28 × 84 inch wheel.

The third test, gases 130 deg. hotter than first, requires about 100 per cent more power, and yet the boiler evaporation is about 20 per cent less than in the first test. — *Curtis Pub. Co.*, by Davis & Griggs.

The cost of the above Mechanical Draft outfit (2 fans), including motors, was $5.53 per boiler H.P.

All of the blower methods of draft production must be considered in connection with, and be planned with especial regard to, the quantity of fuel to be burned in a given time, and the amount of air needed for the complete combustion of the fuel, which air must necessarily pass through the blowers.

18 to 25 lbs. of coal per square foot of grate per hour is all the coal that should or can be burned with economy under natural draft; a greater amount necessitates forced draft.

Another thing which should not be lost sight of in connection with the burning of small coals, is the unburnt coal falling through the grate, which in the case of anthracite culm has reached 58 per cent (found in the ashes).

Kinds and Ingredients of Fuels.

The substances which we call fuel are: wood, charcoal, coal, coke, peat, certain combustible gases, and liquid hydrocarbons.

Combustion or burning is a rapid chemical combination.

The imperfect combustion of carbon produces carbonic oxide (CO), and carbonic acid or dioxide (CO_2).

From certain experiments and comparisons Rankine concludes "that the total heat of combustion of any compound of hydrogen and carbon is nearly the sum of the quantities of heat which the hydrogen and carbon contained in it would produce separately by their combustion (CH_4 — marsh gas or fire-damp excepted)."

In computing the total heat of combustion of a compound, it is convenient to substitute for the hydrogen a quantity of carbon which would give the same quantity of heat; this is accomplished by multiplying the weight of hydrogen by $62032 \div 14500 = 4.28$.

From experiments by Dulong, Despretz, and others, "when hydrogen and oxygen exist in a compound in the proper proportion to form water (by weight nearly 1 part H to 8 parts O), these constituents have no effect on the total heat of combustion.

"If hydrogen exists in a greater proportion, take into the heat account only the surplus."

Dulong's formula for the total heat of combustion of carbon, hydrogen, oxygen, and sulphur, where C, H, O, and S refer to the fractions of one pound of the compound, the remainder being ash, etc. Let h = total heat of combustion in B.T.U. per pound of compound.

$$h = 14500\ C + 62000 \left(H - \frac{O}{8}\right) + 4000\ S.$$ (A.S.M.E. Trans. vol. xxi.)

Rankine says: "The ingredients of every kind of fuel commonly used may be thus classed: (1) Fixed or free carbon, which is left in the form of charcoal or coke after the volatile ingredients of the fuel have been distilled away. These ingredients burn either wholly in the solid state, or part in the solid state and part in the gaseous state, the latter part being first dissolved by previously formed carbonic acid.

"(2) Hydrocarbons, such as olefiant gas, pitch, tar, naphtha, etc., all of which must pass into the gaseous state before being burned.

"If mixed on their first issuing from amongst the burning carbon with a large quantity of air, these inflammable gases are completely burned with a transparent blue flame, producing carbonic acid and steam. When raised to a red heat, or thereabouts, before being mixed with a sufficient quantity of air for perfect combustion, they disengage carbon in fine powder, and pass to the condition partly of marsh gas, and partly of free hydrogen ; and the higher the temperature, the greater is the proportion of carbon thus disengaged.

"If the disengaged carbon is cooled below the temperature of ignition before coming in contact with oxygen, it constitutes, while floating in the gas, smoke, and when deposited on solid bodies, soot.

"But if the disengaged carbon is maintained at the temperature of ignition, and supplied with oxygen sufficient for its combustion, it burns while floating in the inflammable gas, and forms red, yellow, or white flame. The flame from fuel is the larger the more slowly its combustion is effected.

"(3) Oxygen or hydrogen either actually forming water, or existing in combination with the other constituents in the proportions which form water. Such quantities of oxygen and hydrogen are to be left out of account in determining the heat generated by the combustion. If the quantity of water actually or virtually present in each pound of fuel is so great as to make its latent heat of evaporation worth considering, that heat is to be deducted from the total heat of combustion of the fuel. The presence of water or its constituents in fuel promotes the formation of smoke, or of the carbonaceous flame, which is ignited smoke, as the case may be, probably by mechanically sweeping along fine particles of carbon.

"(4) Nitrogen, either free or in combination with other constituents. This substance is simply inert.

"(5) Sulphuret of iron, which exists in coal and is detrimental, as tending to cause spontaneous combustion.

"(6) Other mineral compounds of various kinds, which are also inert, and form the ash left after complete combustion of the fuel, and also the clinker or glassy material produced by fusion of the ash, which tends to choke the grate."

Total Heat of Combustion of Fuels. (D. K. Clark.)

The following table gives the total heat evolved by combustibles and their equivalent evaporative power, with the weight of oxygen and volume of air chemically consumed.

Combustibles.	Weight of Oxygen Consumed per Pound of Combustible.	Quantity of Air Consumed per Pound of Combustible.		Total Heat of Combustion of 1 lb. of Combustible, B.T.U.	Equivalent evaporative Power of 1 lb. Combustible from and at 212° F.
	lbs.	lbs.	Cu. Ft. at 62°F.		
Hydrogen	8.0	34.8	457	62000	64.20
Carbon making CO	1.33	5.8	76	4452	4.61
Carbon making CO_2	2.66	11.6	152	14500	15.00
Carbonic oxide	0.57	2.48	33	4325	4.48
Light Carbureted Hydrogen	4.00	17.4	229	23513	24.34
Olefiant Gas	3.43	15.0	196	21343	22.09
Coal (adopted average desiccated)	2.45	10.7	140	14700	15.22
Coke (adopted average desiccated)	2.49	10.81	142	13548	14.02
Lignite, perfect	2.04	8.85	116	13108	13.57
Wood, desiccated	1.40	6.09	80	10974	11.36
Wood, 25 per cent moisture	1.05	4.57	60	7951	8.20
Petroleum	3.29	14.33	188	20411	21.13
Petroleum oils	4.12	17.93	235	27531	28.50
Sulphur	1.00	4.35	57	4000	4.17

Table of Combustibles.

("Steam," B. & W Co.)

Kind of Combustible.	Air Required.	Temperature of Combustion.				Theoretical Value.		Highest Attainable Value under Boiler.	
	In pounds Per Pound of Combustible.	With Theoretical Supply of Air.	With 1½ Times the Theoretical Supply of Air.	With Twice the Theoretical Supply of Air.	With Three Times the Theoretical Supply of Air.	In Pounds of Water raised 1° per Pound of Combustible.	In Pounds of Water evaporated from and at 212°, with 1 lb. Combustible.	With Chimney Draft.	With Blast, Theoretical Supply of Air at 60°, Gas 320°.
Hydrogen	36.00	5750	3860	2860	1940	62032	64.20		
Petroleum	15.43	5050	3515	2710	1850	21000	21.74	18.55	19.90
Carbon { Charcoal, Coke, Anthracite Coal }	12.13	4580	3215	2440	1650	14500	15.00	13.30	14.14
Coal, Cumberland	12.06	4900	3360	2550	1730	15370	15.90	14.28	15.06
Coking Bituminous	11.73	5140	3520	2680	1810	15837	16.00	14.45	15.19
Cannel	11.80	4850	3330	2540	1720	15080	15.60	14.01	14.76
Lignite	9.30	4600	3210	2490	1670	11745	12.15	10.78	11.46
Peat, Kiln-dried	7.68	4470	3140	2420	1660	9660	10.00	8.92	9.42
Air-dried, 25 per cent water	5.76	4000	2820	2240	1550	7000	7.25	6.41	6.78
Wood, Kiln-dried	6.00	4080	2910	2260	1530	7245	7.50	6.64	7.02
Air-dried, 20 per cent water	4.80	3700	2607	2100	1490	5600	5.80	4.08	4.39

Temperature of Fire.

By reference to the table of combustibles, it will be seen that the temperature of the fire is nearly the same for all kinds of combustibles, under similar conditions. If the temperature is known, the conditions of combustion may be inferred. The following table, from M. Pouillet, will enable the temperature to be judged by the appearance of the fire:

Appearance.	Temp. F.	Appearance.	Temp. F.
Red, just visible . .	977°	Orange, deep . . .	2010
" dull	1290	" clear . . .	2190
" cherry, dull . .	1470	White heat	2370
" " full . .	1650	" bright . . .	2550
" " clear .	1830	" dazzling . .	2730

To determine Temperature by Fusion of Metals, etc.

Substance.	Tem. F.	Metal.	Tem. F.	Metal.	Tem. F.
Tallow . . .	92°	Bismuth .	518°	Silver, pure . .	1830°
Spermaceti .	120	Lead . . .	630	Gold, coin . .	2156
Wax, white .	154	Zinc . . .	793	Iron, cast, med.	2010
Sulphur . .	239	Antimony .	810	Steel	2550
Tin	455	Brass . .	1650	Wrought iron .	2910

American Woods.

Kind of Wood.	Weight per Cord.	Value in Tons Coal.	
		Anthracite	Bituminous
Hickory — Shell bark.	4469	.608	.563
White oak	3821	.52	.481
Hickory — Red heart	3705	.504	.467
Southern pine	3375	.459	.425
Red oak	3254	.443	.41
Beech	3126	.425	.394
Hard maple	2878	.391	.363
Virginia pine	2680	.364	.338
Spruce.	2325	.316	.293
New Jersey pine	2137	.291	.269
Yellow pine	1904	.259	.24
White pine	1868	.254	.235

American Coals.

Coal.		Per Cent of Ash.	Theoretical Value.	
State.	Kind of Coal.		In Heat Units.	Pounds of Water Evap.
Pennsylvania.	Anthracite	3.49	14,199	14.70
"	"	6.13	13,535	14.01
"	"	2.90	14,221	14.72
"	Cannel	15.02	13,143	13.60
"	Connellsville	6.50	13,368	13.84
"	Semi-bituminous . .	10.70	13,155	13.62
"	Stone's Gas	5.00	14,021	14.51
"	Youghiogheny . . .	5.60	14,265	14.76
"	Brown	9.50	12,324	12.75
Kentucky.	Coking	2.75	14,391	14.89
"	Cannel	2.00	15,198	16.76
"	"	14.80	13,360	13.84
"	Lignite	7.00	9,326	9.65
Illinois.	Bureau Co.	5.20	13,025	13.48
"	Mercer Co..	5.60	13,123	13.58
"	Montauk	5.50	12,659	13.10
Indiana.	Block	2.50	13,588	14.38
"	Coking	5.66	14,146	14.64
"	Cannel	6.00	13,097	13.56
Maryland.	Cumberland	13.88	12,226	12.65
Arkansas.	Lignite	5.00	9,215	9.54
Colorado.	"	9.25	13,562	14.04
"	"	4.50	13,866	14.35
Texas.	"	4.50	12,962	13.41
Washington Ter.	"	3.40	11,551	11.96
Pennsylvania.	Petroleum	. . .	20,746	21.47

The weight of solid coal varies from 80 lbs. to 100 lbs. per cubic foot.

The Heating Value of Coals.

On page 1351 are given the results (*Sibley, Journal of Engineering*) of some experiments made at Cornell University with a coal calorimeter devised by Prof. R. C. Carpenter. It consists of two cylindrical chambers, in the inner one of which the sample of coal is burned in oxygen. The heated gases pass through a coiled copper tube about 10 feet long contained in the outer chamber. The coil is surrounded by water which expands, the expansion being measured in a finely graduated glass tube, thus giving the heat units in the coal. The calorimeter is calibrated by burning in it pure carbon. Following are the tables :

Anthracite Coal.—Table of Average Results.

Mine.	Locality.	Moisture.	Volatile Matter.	Ash.	Fixed Carbon.	Specific Gravity.	Per Cent Slate.	B.T.U. In 1 lb. Combustible Matter.
L. V. Buckwheat	W.-Barre, Pa.	1.34	6.42	15.3	76.94	1.3	9.75	11801
Jermyn	Schuyl. Co., Pa.	1.7	5.78	10.84	71.68	1.425	9.80	12036
Woodward	Scranton, Pa.	3.33	3.73	13.71	79.23	1.42	2.51	12149
Cayuga	Scranton, Pa.	.97	5.37	9.2	84.46	1.49	6.2	12294
Mt. Pleasant	Scranton, Pa.	1.27	7.54	10.65	80.54	1.42	0.162	12307
L. V. Pea	L. V. Region	1.44	7.36	16.00	75.2	1.52	8.21	12423
Forty Foot	Scranton, Pa.	1.12	4.99	9.91	83.98	1.415	3.54	12903
Manville Shaft	Scranton, Pa.	1.04	5.95	7.31	85.7	1.42	0.589	12934
Continental	Scranton, Pa.	1.27	5.98	9.62	83.13	1.615	5.48	12943
Avondale	Avondale, Pa.	1.28	5.89	6.15	86.68	1.44	0.228	13051
Oxford	Scranton, Pa.	1.35	5.03	2.17	91.45	1.415	0.11	13254
Mammoth	Drifton, Pa.	2.97	2.3	6.77	87.96	1.55	0.00	13324
Buck Mountain	Cross Creek, Pa.	3.62	1.96	5.23	89.19	1.56	0.63	13723

Bituminous Coal.—Table of Average Results.

Mine.	Locality.	Moisture.	Volatile Matter.	Ash.	Fixed Carbon	Specific Gravity	Average B.T.U.	Pounds Combustible Matter in Smoke from 1 Ton Coal.	B.T.U. In 1 lb. Combustible Matter.
Gillespie	Gillespie, Ill.	3.77	34.94	11.74	49.55	1.23	10506	11.8	13700
B'mr'nt Co'l Wks	Monongahela River, Pa.	2.27	31.29	7.83	58.61	1.275	13126	20.94	12043
Antrim	. . . .	1.23	18.51	10.9	69.3	1.42	13528	5.29	12724
Eureka	Clearfield Co., Pa.	1.03	23.55	5.73	69.69	1.32	13756	8.63	10899
Turtle Creek	Monongahela River, Pa.	2.11	34.22	4.22	59.45	1.28	14150	6.12	11827
Nova Scotia	No. 2 Slope, Nova Scotia	3.08	31.41	3.80	61.71	1.31	14864	5.33	11231
Reynold'sville	Reynold'sville, Pa.	1.09	21.4	5.3	69.21	1.34	14971	6.53	12217
Leisenring	Connellsville	1.93	28.71	6.1	63.26	1.34	15005	18.25	12855
Pocahontas	New River, Va.	1.25	17.62	3.65	77.48	1.255	15094	4.00	15255
Cooperstown	Nova Scotia	1.11	30.42	4.03	64.44	1.345	15266	9.88	11959

Proximate Analysis of Coal.

(Power.)

Designation of Coal.	Per Cent Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
ANTHRACITE.					
Beaver Meadow, Penn.	1.5	2.38	88.94	7.11	.01
Peach Mountain, Penn.	1.9	2.96	89.02	6.13	.01
Lackawanna, Penn.	2.12	3.91	87.74	6.35	.12
Lehigh, Penn.	3.01	3.28	88.15	5.56	.5
Welsh, Wales	1.2	6.25	88.	4.55	.92
SEMI-ANTHRACITE.					
Natural Coke, Virginia	1.12	12.44	75.08	11.38	.47
Cardiff, Wales	1.25	12.85	81.9	4.	.76
Lycoming Creek, Penn.	.67	13.84	71.53	13.96	.03
Arkansas, No. 16 Geol. Survey	1.35	14.93	74.06	9.66	....
SEMI-BITUMINOUS.					
Blossburg, Penn.	1.34	14.78	73.11	10.77	.85
Mexican	1.0	14.86	55.7	28.44	4.53
Fort Smith, Arkansas	1.07	17.2	73.05	8.68	....
Cliff, New South Wales, Australia	.85	17.7	71.8	9.65	1.26
Skagit River, State of Washington	1.19	18.8	71.66	8.35	....
Cumberland, Maryland	.97	19.87	72.26	6.12	.77
Cambria County, Penn.	2.46	20.52	69.37	9.15	1.5
Mount Kembla, New South Wales, Aus.	1.2	20.93	66.96	10.91	2.33
Fire Creek, West Virginia	.74	22.42	75.5	.8	.54
Arkansas, No. 12 Geol. Survey	.88	24.66	58.2	16.26	
BITUMINOUS.					
Wilkeson, Pierce County, Washington	1.33	25.88	66.75	6.04	Trace.
Cowlitz, Washington	1.16	26.12	61.9	10.69	0.13
New River, West Virginia	.67	26.64	70.66	1.53	.5
Pictou, Nova Scotia	2.57	27.83	56.98	13.39	.77
Big Muddy, Illinois	7.12	29.5	54.64	8.74	1.01
Bellingham Bay, Washington	3.98	29.54	59.9	6.	.58
Midlothian, Virginia	2.46	29.86	53.01	14.74	.06
Connellsville, Penn.	1.26	30.10	59.61	8.23	.78
Illinois, Average	8.93	30.14	45.93	15.	5.
Carbon Hill, Washington	2.16	31.73	55.8	10.31	2.33
Clover Hill, Virginia	1.34	32.21	56.83	10.13	.51
Wellington, Vancouver Island, B.C.	2.15	34.15	54.85	8.85	.27
Franklin, Washington	3.5	34.27	54.23	8.	
Rocky Mountains	7.55	34.65	42.85	14.95	1.1
Newcastle, England	1.5	34.7	59.3	4.5	.23
Mokihinui, Westport, New Zealand	3.96	34.94	57.92	3.18	....
Brunner Mine, Greymouth, New Zealand	1.59	35.68	56.62	6.11	....
Pittsburg, Penn.	1.7	36.	55.	7.3	.16
Nanaimo, Vancouver Island, B.C.	2.25	36.05	51.95	9.75	2.39
Hocking Valley, Ohio	6.95	36.15	51.3	5.56	.67
Pleasant Valley, Utah	5.43	37.73	49.40	7.44	1.28
Kentucky	2.	37.89	56.01	4.1	....
Ellensburg, Washington	2.	39.1	54.4	3.4	1.1
Olympic Mountains, Washington	5.1	39.15	47.01	7.77	.97
Scotch, Scotland	3.01	39.19	48.81	9.34	.36
Roslyn, Washington	3.1	39.7	52.65	4.55	Trace.
Cook's Inlet, Alaska	1.25	39.87	49.89	7.82	1.2
Kootznahoo Inlet, Admiralty I., Alaska	3.74	37.02	45.15	14.09	.72
Liverpool, England	.89	39.96	54.9	4.62	.38
Calispel, Washington	2.39	41.18	42.92	13.21	.3
Carbonado, Washington	1.8	42.27	52.11	3.82	Trace.
Upper Yakima, Washington	1.2	42.47	52.21	4.12	Trace.
Methow, Washington	2.5	43.71	49.27	4.26	.26

Proximate Analysis of Coal—*Continued.*

Designation of Coal.	Per Cent Moisture	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
Newcastle, King County, Washington .	2.12	46.7	43.9	7.15	.13
Black Diamond, King County, Washington	3.11	47.19	45.11	4.58	.01
Black Diamond, Mt. Diablo, California .	14.69	33.89	46.84	4.58	
LIGNITES.					
Otago (Kaitangata Cr.), New Zealand .	19.61	37.25	39.41	3.73	...
Gilman, Washington	4.8	47.07	37.19	10.06	.88
Coos Bay (Newport Mine), Oregon . .	15.45	41.55	34.95	8.05	2.53
Alaska	14.6	44.85	31.2	9.35	1.15
Huron, Fresno County, California . .	11.7	51.73	19.63	16.94	2.73
Ione, Amador County, California . . .	42.58	34.88	17.42	5.12	Trace.

Analysis of Coke.

(From report of John R. Procter, Kentucky Geological Survey.)

Where Made.	Fixed Carbon	Ash.	Sulphur.
Connellsville, Pa. (Average of 3 samples) . . .	88.96	9.74	0.810
Chattanocga, Tenn. " " 4 " . . .	80.51	16.34	1.595
Birmingham, Ala. " " 4 " . . .	87.29	10.54	1.195
Pocahontas, Va. " " 3 " . . .	92.53	5.74	0.597
New River, W. Va. " " 8 " . . .	92.38	7.21	0.562
Big Stone Gap, Ky. " " 7 " . . .	93.23	5.69	0.749

Space Required to Stow a Ton (2240 lbs.) of Various Kinds of Coal.

ANTHRACITE.

Welsh, Wales	39 cubic feet.
Peach Mountain, Penn.	41.6 " "
Beaver Meadow, Penn.	40.2 " "
Lehigh, Penn.	40.5 " "
Lackawanna, Penn.	45.8 " "
SEMI-ANTHRACITE.	
Cardiff, Wales	38.3 cubic feet.
Natural Coke, Virginia	50.2 " "
SEMI-BITUMINOUS.	
Cumberland, Virginia	41.7 cubic feet.
Blossburgh, Penn.	42.2 " "
Mt. Kembla, Australia	37.7 " "
Mexican	36.7 " "
BITUMINOUS.	
New River, Virginia.	46 cubic feet.
Wellington, Vancouver Island, B.C.	41.8 " "
Midlothian, Virginia	41.4 " "
Newcastle, England	44 " "
Pictou, Nova Scotia	45 " "
Scotch Splint, Fordel	40.7 " "
Pleasant Valley, Utah	42.3 " "
Sydney, N. S. W., Australia	47.2 " "
Takasima, Japan	46.4 " "
Pittsburgh, Penn.	47.8 " "
Liverpool, England	46.7 " "
Scotch, Dalkeith	43.8 " "
Carbon Hill, Washington	36.9 " "
Clover Hill, Virginia	49.2 " "
Rocky Mountain	41.2 " "
LIGNITE.	
Alaska	41.8 cubic feet.
WOOD.	
Dry pine wood	107 cubic feet.

COKE. — Coke from ovens, preferred to gas coke as fuel, weighs with few exceptions about 40 lbs. per bushel. Light coke will weigh 33 to 38 lbs. Heavy coke, 42 to 50 lbs.

Weights of Various Sizes of Coal.

	Lbs. per cubic foot.	Cu. foot per ton of 2000 lbs.
Lehigh buckwheat	54.04	37.01
" broken	56.85	35.18
" cupola	55.52	36.02
" dust	57.25	34.93
" egg	57.74	34.63
" lump	55.26	36.19
" nut	58.26	34.32
" pea	53.18	37.60
" stove	58.15	34.39
Free burning egg	56.07	35.67
" " nut	56.88	35.16
" " stove	56.33	35.50
Pittsburgh	46.48	43.03
Illinois	47.22	42.35
Hocking	49.30	40.56
Indiana Block	43.85	46.51
Erie	48.07	41.61
Ohio Cannel	49.18	40.66
Connellsville coke	26.30	76.04

Weights per Cubic Foot, Coal and Coke.

	Storage for long ton, cu. ft.	Pounds per cu. ft.
Anth. coal market sizes, loose	40–43	52–56
Anth. coal market sizes, moderately shaken	...	56–60
Anth. coal market sizes, heaped bushels loose 77–83 lbs.		
Bit. coals, broken — loose	43–48	47–52
Bit. coals, broken — moderately shaken	...	51–56
Bit. coals, broken — heaped bushels 70–78 lbs.	...	...
Dry coke	80–97	23–32
Dry coke, heaped bushel, (av. 38 lbs.) 35–42 lbs.	...	...

Sizing Tests — Anthracite.

Through round holes, punched in plates.

Chestnut	through	$1\frac{1}{2}$	over	$\frac{7}{8}$
Pea	"	$\frac{7}{8}$	"	$\frac{9}{16}$
Buckwheat	"	$\frac{9}{16}$	"	$\frac{3}{8}$
Rice	"	$\frac{3}{8}$	"	$\frac{3}{16}$
Barley	"	$\frac{3}{16}$	"	$\frac{3}{32}$
Culm	"	$\frac{3}{32}$		

Relative Values of Coals and How to Burn Them.

(By Jay M. Whitham.)

Given boilers and chimney operating under natural draft and having certain sizes and dimensions, the capacities measured in steam output, which can be produced therewith, when using good grades of these coals, are as follows :

	Per cent.
Semi-bituminous coal (8 to 10 per cent ash) . . .	100
No. 1 buckwheat anthracite (18 to 22 per cent ash in use)	80
No. 2 buckwheat anthracite, or rice (18 to 22 per cent ash in use)	68

It is more than likely that the percentage of ash and refuse obtained in service with Nos. 1 and 2 buckwheat will exceed the 18 to 22 per cent above noted, while it is equally probable that with soft coal the percentage will not exceed from 8 to 10 per cent.

It is, of course, a simple matter to increase the combustion of the small sizes of anthracite by the use of a fan or a steam blast. A fan blast uses from 2½ to 3 per cent of the steam produced in the boilers, while the steam blast, used for injecting air into a closed ash-pit, consumes from 7½ to 12 per cent of the steam produced by the boilers, and seldom operates under less than 10 per cent. Hence, in making any estimates as to the relative costs of operating with these fuels, these deductions must be made if an artificial draft must be used, in order to get net comparative results.

Given semi-bituminous and small-sized anthracite coals of the ash compositions noted above, my experience has shown that the relation between the costs of operating the plant with these coals, under natural draft, to produce a given output, are :

	Per Ton.
Semi-bituminous coal	$1.33
No. 1 buckwheat coal	1.00
No. 2 buckwheat (rice) coal	.83

Paying these prices, the costs for power under natural draft are the same, no matter which coal is used, provided the cost of removing ashes is ignored.

If the anthracite grades have to be burned with blasts, the relative prices which one can afford to pay for producing a given quantity of steam are as follows :

Draft.	Natural.	Fan Blast.	Steam Blast.
Semi-bituminous	$1.33	. . .	. . .
No. 1 buckwheat	. . .	$0.97	$0.90
No. 2 buckwheat (rice) . . .	. . .	.82½	.76½

Semi-bituminous coals are burned to advantage only by exercising great care in the handling of fires, and by the firemen exerting themselves beyond what is necessary when burning buckwheat and rice anthracite grades.

Wood as Fuel.

Green wood contains from 30 to 50 per cent of moisture. After about a year in open air the moisture is 20 to 25 per cent.

The woods of various trees are nearly identical in chemical composition, which is practically as follows, showing the composition of perfectly dry wood, and of ordinary firewood holding hygroscopic moisture:

	Desiccated Wood.	Ordinary Firewood.
Carbon	50 per cent	37.5 per cent
Hydrogen	6 per cent	4.5 per cent
Oxygen	41 per cent	30.75 per cent
Nitrogen	1 per cent	0.75 per cent
Ash	2 per cent	1.5 per cent
	100 per cent	75.0 per cent
Hygrometric water		25.0 per cent
		100.0

Some of the pines and others of the coniferous family contain hydrocarbons (turpentine). Ash varies in American woods from .03 per cent to 1.20 per cent.

In steam boiler tests wood is assumed as 0.4 the value of the same weight of coal.

The fuel value of the same weights of wood of all kinds is practically the same; and it is important that the wood be dry.

Weight of Wood per Cord.

	Weighs per Cord, Lbs.	Equal in value to Coal, in Lbs.
Average pine	2000	800 to 925
Poplar, chestnut, elm	2350	940 to 1050
Beech, red and black oak	3250	1300 to 1450
White oak	3850	1540 to 1715
Hickory and hard maple	4500	1800 to 2000

A *cord* of wood $= 4 \times 4 \times 8 = 128$ cubic feet. About 56 per cent is solid wood, and 44 per cent spaces.

Liquid Fuels.

Petroleum is a hydrocarbon liquid which is found in abundance in America and Europe. According to the analysis of M. Sainte-Claire Deville, the composition of 15 petroleums from different sources was found to be practically the same. The average specific gravity was .870. The extreme and the average elementary compositions were as follows:

Chemical Composition of Petroleum.

Carbon	82.0 to 87.1 per cent.	Average, 84.7 per cent.
Hydrogen	11.2 to 14.8 per cent.	Average, 13.1 per cent.
Oxygen	0.5 to 5.7 per cent.	Average, 2.2 per cent.
		100.0

The total heating and evaporative powers of one pound of petroleum having this average composition are as follows:

Total heating power $= 145\,[84.7 + (4.28 \times 13.1)] = 20411$ units.

Evaporative power: evaporating at 212°, water supplied at 62° = 18.29 lbs.

Evaporative power: evaporating at 212°, water supplied at 212° = 21.13 lbs.

Petroleum oils are obtained in great variety by distillation from petroleum. They are compounds of carbon and hydrogen, ranging from $C_{10}\,H_{24}$ to $C_{32}\,H_{64}$; or, in weight;

Chemical Composition of Petroleum Oils.

				Mean.
From	71.42 Carbon 28.58 Hydrogen	to	73.77 Carbon . . . 26.23 Hydrogen . .	72.60 27.40
	100.00		100.00	100.00

The specific gravity ranges from .628 to .792. The boiling point ranges from 86° to 495° F. The total heating power ranges from 28087 to 26975 units of heat; equivalent to the evaporation, at 212°, of from 25.17 to 24.17 lbs. of water supplied at 62°, or from 29.08 lbs. to 27.92 lbs. of water supplied at 212°.

Furnaces for the combustion of oil fuel need not be as large as when burning coal, as the latter, being solid matter, requires more time for decomposition, and the elimination of the products and supporters of combustion. Coal fuel requires a large fire chamber and the means for the introduction of air beneath the grate-bars to aid combustion. Compared with oil, the combustion of coal is tardy, and requires some aid by way of a strong draft. Oil having no ash or refuse, when properly burned, requires much less space for combustion, for the reason that, being a liquid, and the compound of gases that are highly inflammable when united in proper proportions, it gives off heat with the utmost rapidity, and at the point of ignition is all ready for consumption.

Prof. J. E. Denton has made a number of boiler evaporative tests, using oil for fuel. In the following table the results of tests where various fuels were used are brought together, and interesting comparisons are made between the cost of coal and cost of oil. See "Power," Feb., 1902.

Gaseous Fuels.—Mr. Emerson McMillin (Am. Gas. Lt. Asso., 1887) made an exhaustive investigation of the subject of fuel gas; he states that the relative values of these gases, considering that of natural gas as of unit value, are:

	By Weight.	By Volume.
Natural gas	1000	1000
Coal gas	949	666
Water gas	292	292
Producer gas	76.5	130

The water gas rated in the above table is the gas obtained in the decomposition of steam by incandescent carbon, and does not attempt to fix the calorific value of illuminating water gas, which may be carbureted so as to exceed, when compared by volume, the value of coal gas.

Composition of Gases.	Volume.			
	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
Hydrogen	2.18	46.00	45.00	6.00
Marsh gas	92.60	40.00	2.00	3.00
Carbonic oxide	0.50	6.00	45.00	23.50
Olefiant gas	0.31	4.00	0.00	0.00
Carbonic acid	0.26	0.50	4.00	1.50
Nitrogen	3.61	1.50	2.00	65.00
Oxygen	0.34	0.50	0.50	0.00
Water vapor	0.00	1.50	1.50	1.00
Sulphydric acid	0.20	. . .	. . .	. . .
	100.00	100.00	100.00	100.00

COMPARATIVE COSTS OF OIL AND COAL.

Weight of oil per gallon = 7.66 lbs. Weight of oil per barrel of 42 U.S. gallons = 322 lbs. These figures are net evaporation after allowing for steam consumed to produce the forced draft necessary for burning the fuel. By "wet coal" is meant coal containing 3% of water.	Bituminous coal mined west of Ohio and used in W. and S.W. States.	Small Sizes of Anthracite.				Pittsburg bituminous used in mills of Pennsylvania and on Great Lakes	Best Semi-Bituminous. Atlantic Ocean traffic and mills of Eastern and Middle States.		
			No. 3	No. 2	No 1			Mech'l Stokers and Patent Furnaces introducing air over fire.	
		Culm.	Buckwheat or barley.	Buckwheat or rice.	Buckwheat and pea.		Hand fired.	Ash 10%	Ash 5%
Pounds evaporation per lb of wet$_3$ coal from and at 212 degrees, at about 10 square feet of heating surface per boiler horse-power . .	7.5	7.75_2	8.25_2	8.50_2	8.75	9.50	10.00	10.50	11.00
Pounds evaporation per lb. of Beaumont oil from and at 212 degrees, at about 10 square feet of heating surface per boiler horse-power	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Ratio of evaporation of oil to coal = Line 2 ÷ Line 1 = R	1.97	1.91	1.79	1.74	1.69	1.56	1.48	1.41	1.35
Number of barrels of oil equivalent to a 2240-lb. ton of wet coal = 2240 ÷ (322R) = N . . .	3.54	3.64	3.90	4.00	4.12	4.46	4.70	4.94	5.15
Equivalent Price of Oil Per Barrel of 42 U.S. Gallons = Pc ÷ N = Po.									
Price of coal per ton of 2240 lbs. Pc. $1.00	$0.29	$0.28	$0.26	$0.25	$0.25	$0.23	$0.21	$0.20	$0.19
1.50	0.43	0.41	0.39	0.38	0.36	0.34	0.32	0.30	0.29
2.00	0.56	0.55	0.51	0.50	0.49	0.45	0.43	0.40	0.39
2.50	0.71	0.69	0.64	0.62	0.60	0.56	0.53	0.50	0.49
3.00	0.85	0.82	0.77	0.75	0.73	0.67	0.64	0.60	0.58
3.50	0.99	0.96	0.90	0.87	0.85	0.78	0.75	0.71	0.68
4.00	1.13	1.10	1.02	1.00	0.97	0.90	0.85	0.81	0.77
4.50	1.28	1.23	1.16	1.13	1.09	1.01	0.96	0.91	0.87

Mechanical Stoking.

In boiler installations that can be conveniently handled by one man it is doubtful if we can improve on the best hand firing; but where good firemen are scarce, or the installation is of considerable size, it is probable that the use of some form of mechanical stoker will result in economy, and especially in the prevention of large quantities of smoke, as the combustion is gradual and more nearly perfect.

The types may perhaps be limited to three : the straight feed, as the Murphy, Roney, Wilkinson, and Brightman ; the under-feed of which the "American" is a good representative ; and the chain stoker, by Coxe and the B. & W. Co.

Mechanical draught is generally used with the two last-mentioned types, and sometimes with the first.

Mr. Eckley B. Coxe developed the chain stoker in the most scientific manner for the use of the cheap coals of the anthracite region.

The advantages and disadvantages of mechanical stokers are stated by Mr. J. M. Whitham (Trans. A.S.M.E., vol. xvii. p. 558) to be as follows: *Advantages.* 1. Adaptability to the burning of the cheapest grades of fuel. 2. A 40 per cent labor saving in plants of 500 or more h. p., when provided with coal-handling machinery. 3. Economy in combustion, even under forced firing, with proper management. 4. Constancy and uniformity of furnace conditions, the fires being clean at all times, and responding to sudden demands made for power. This should result in prolonged life of boilers. 5. Smokelessness. *Disadvantages.* 1. High first cost, varying from $25 to $40 per square foot of grate area. 2. High cost of repairs per year, which, with some stokers, is as much as $5 per square foot. 3. The dependence of the power-plant upon the stoker engine's working. 4. Steam cost of running the stoker engine, which is from $\frac{1}{5}$ to $\frac{2}{5}$ of 1 per cent of the steam generated. This is about $50 a year on a 10-hour basis for 1000 h. p., where fuel is $2 per ton. 5. Cost of steam used for a steam blast, or for driving a fan blast, whenever either is used. This, for a steam blast, is from 5 per cent to 11 per cent of the steam generated by the boilers, and from 3 per cent to 5 per cent for a fan blast. This amounts to about $1000 per year for a steam blast, and $500 a year in fuel for a fan blast, for a 1000 h. p. plant on a 10-hour basis, when fuel is $2 per ton. 6. Skill required to operate the stoker. Careless management causes either loss of fuel in the ash, or loss due to poor combustion when the coal is too soon burned out on the grate, thus permitting cold air to freely pass through the ash. 7. The stoker is a machine subject to a severe service, and, like any other machine, wears out and requires constant attention.

W. W. Christie, in article in the *Engineering Magazine* on the "Economy of Mechanical Stoking," says in part: The influence of the mechanical stoker upon boiler efficiency has been discussed, but definite information is not readily obtained, although general opinions as to the advantage of mechanical stoking are numerous.

The efficiency of a boiler, and consequently of a group of boilers, depends upon several independent and distinct factors.

Thus we have the furnace efficiency, a measure of the completeness of the combustion in the furnace ; this is measured by the ratio of the temperature in the furnace to the temperature of the escaping gases. We have also the efficiency of the boiler proper, measured by the quantity of heat transmitted to the water compared with that generated in the furnace.

There are also two other kinds of efficiencies — one the heat efficiency, per pound of fuel, the other the so-called "investment efficiency," which takes into account the cost of building, apparatus, boilers, chimneys, wages, and fuel.

It has been maintained that the most economical rate for steam-making is that of an evaporation of 4 lbs. of steam per hour per square foot of heating surface, which some tests will show is the case. Other tests, however, show that it may vary, while the steam economy referred to 1 lb. of coal may remain constant.

The completeness of combustion can be told best by the temperature of the escaping gases, and by an analysis of their chemical composition. Thus, for an excellent combustion, the temperature of discharge gases should not be higher than 400–500° F. If the percentage of oxygen is 1.5

to 2 per cent, it indicates that the fires are too thick, and the rate of combustion too high for the draft employed.

If the oxygen exceeds 8 per cent, the fires are too thin, the draft too heavy, or too much cold air is entering the furnace above the fire.

If there is an excess of CO and of O, the boiler is faulty in design, and good results cannot be expected. The quantity of air fed to the fire also influences the economy of the boiler to a limited degree.

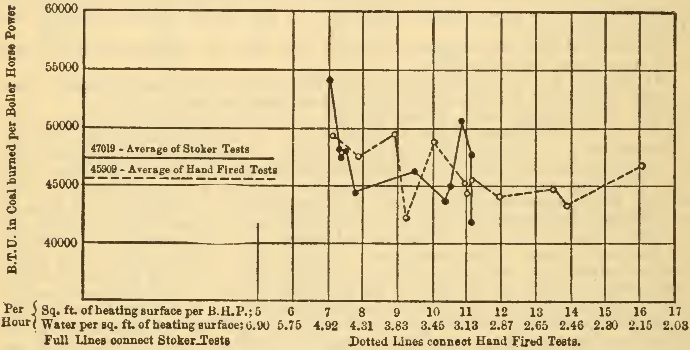


FIG. 5. Diagram Showing Comparative Economy of Mechanical and Hand Stoking.

This diagram was prepared from results of about twenty tests made by engineers of high standing and ability, and these special ones were selected because the heating values of the fuels had been determined by a calorimeter, and all the various details were reported in full.

WATER.

Weight of Water per Cubic Foot, from 32° to 212° F., and heat-units per pound, reckoned above 32° F. (Wm. Kent, Trans. A. S. M. E., vi. 90.)

Temp., deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Tempera. ture, deg. F.	Weight, lbs. per cubic foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per cubic foot.	Heat-units.
32	62.42	0.	41	62.42	9.	50	62.41	18.	59	62.38	27.01
33	62.42	1.	42	62 42	10.	51	62.41	19.	60	62.37	28.01
34	62.42	2.	43	62.42	11.	52	62.40	20.	61	62.37	29.01
35	62.42	3.	44	62.42	12.	53	62.40	21.01	62	62.36	30.01
36	62.42	4.	45	62.42	13.	54	62.40	22.01	63	62.36	31.01
37	62.42	5.	46	62.42	14.	55	62.39	23,01	64	62.35	32.01
38	62.42	6.	47	62.42	15.	56	62.39	24.01	65	62.34	33.01
39	62.42	7.	48	64.41	16.	57	62.39	25.01	66	62.34	34.02
40	62.42	8.	49	62.41	17.	58	62.38	26.01	67	62.33	35.02

Weight of Water — *Continued.*

Temp., deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.	Temperature, deg. F.	Weight, lbs. per Cubic Foot.	Heat-units.
68	62.33	36.02	105	61.96	73.10	141	61.36	109.25	177	60.62	145.52
69	62.32	37.02	106	61.95	74.10	142	61.34	110.26	178	60.59	146.52
70	62.31	38.02	107	61.93	75.10	143	61.32	111.26	179	60.57	147.53
71	62.31	39.02	108	61.92	76.10	144	61.30	112.27	180	60.55	148.54
72	62.30	40.02	109	61.91	77.11	145	61.28	113.28	181	60.53	149.55
73	62.29	41.02	110	61.89	78.11	146	61.26	114.28	182	60.50	150.56
74	62.28	42.03	111	61.88	79.11	147	61.24	115.29	183	60.48	151.57
75	62.28	43.03	112	61.86	80.12	148	61.22	116.29	184	60.46	152.58
76	62.27	44.03	113	61.85	81.12	149	61.20	117.30	185	60.44	153.59
77	62.26	45.03	114	61.83	82.13	150	61.18	118.31	186	60.41	154.60
78	62.25	46.03	115	61.82	83.13	151	61.16	119.31	187	60.39	155.61
79	62.24	47.03	116	61.80	84.13	152	61.14	120.32	188	60.37	156.62
80	62.23	48.04	117	61.78	85.14	153	61.12	121.33	189	60.34	157.63
81	62.22	49.04	118	61.77	86.14	154	61.10	122.33	190	60.32	158.64
82	62.21	50.04	119	61.75	87.15	155	61.08	123.34	191	60.29	159.65
83	62.20	51.04	120	61.74	88.15	156	61.06	124.35	192	60.27	160.67
84	62.19	52.04	121	61.72	89.15	157	61.04	125.35	193	60.25	161.68
85	62.18	53.05	122	61.70	90.16	158	61.02	126.36	194	60.22	162.69
86	62.17	54.05	123	61.68	91.16	159	61.00	127.37	195	60.20	163.70
87	62.16	55.05	124	61.67	92.17	160	60.98	128.37	196	60.17	164.71
88	62.15	56.05	125	61.65	93.17	161	60.96	129.38	197	60.15	165.72
89	62.14	57.05	126	61.63	94.17	162	60.94	130.39	198	60.12	166.73
90	62.13	58.06	127	61.61	95.18	163	60.92	131.40	199	60.10	167.74
91	62.12	59.06	128	61.60	96.18	164	60.90	132.41	200	60.07	168.75
92	62.11	60.06	129	61.58	97.19	165	60.87	133.41	201	60.05	169.77
93	62.10	61.06	130	61.56	98.19	166	60.85	134.42	202	60.02	170.78
94	62.09	62.06	131	61.54	99.20	167	60.83	135.43	203	60.00	171.79
95	62.08	63.07	132	61.52	100.20	168	60.81	136.44	204	59.97	172.80
96	62.07	64.07	133	61.51	101.21	169	60.79	137.45	205	59.95	173.81
97	62.06	65.07	134	61.49	102.21	170	60.77	138.45	206	59.92	174.83
98	62.05	66.07	135	61.47	103.22	171	60.75	139.46	207	59.89	175.84
99	62.03	67.08	136	61.45	104.22	172	60.73	140.47	208	59.87	176.85
100	62.02	68.08	137	61.43	105.23	173	60.70	141.48	209	59.84	177.86
101	62.01	69.08	138	61.41	106.23	174	60.68	142.49	210	59.82	178.87
102	62.00	70.09	139	61.39	107 24	175	60.66	143.50	211	59.79	179.89
103	61.99	71.09	140	61.37	108.25	176	60.64	144.51	212	59.76	180.90
104	61.97	72.09									

Weight of Water at Temperatures Above 212° F.

(Dr. R. H. Thurston, "Engine and Boiler Trials," p. 548.)

Temperature, Deg. F.	Weight, pounds per Cubic Foot.	Temperature, Deg. F.	Weight, pounds per Cubic Foot.	Temperature, Deg. F.	Weight, pounds per Cubic Foot.	Temperature, Deg. F.	Weight, pounds per Cubic Foot.	Temperature, Deg. F.	Weight, pounds per Cubic Foot.
212	59.71	280	57.90	350	55.52	420	52.86	490	50.03
220	59.64	290	57.59	360	55.16	430	52.47	500	49.61
230	59.37	300	57.26	370	54.79	440	52.07	510	49.20
240	59.10	310	56.93	380	54.41	450	51.66	520	48.78
250	58.81	320	56.58	390	54.03	460	51.26	530	48.36
260	58.52	330	56.24	400	53.64	470	50.85	540	47.94
270	58.21	340	55.88	410	53.26	480	50.44	550	47.52

Expansion of Water.

(Kopp: corrected by Porter.)

Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.
4°	39.2°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00171	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

Water for Boiler Feed.*

(Hunt and Clapp, A. I. M. E., 1888.)

Water containing more than 5 parts per 100,000 of free sulphuric or nitric acid is liable to cause serious corrosion, not only of the metal of the boiler itself, but of the pipes, cylinders, pistons, and valves with which the steam comes in contact.

The total residue in water used for making steam causes the interior linings of boilers to become coated, and often produces a dangerous hard scale, which prevents the cooling action of the water from protecting the metal against burning.

Lime and magnesia bicarbonates in water lose their excess of carbonic acid on boiling, and often, especially when the water contains sulphuric acid, produce, with the other solid residues constantly being formed by the evaporation, a very hard and insoluble scale. A larger amount than 100 parts per 100,000 of total solid residue will ordinarily cause troublesome scale, and should condemn the water for use in steam boilers, unless a better can not be obtained.

The following is a tabulated form of the causes of trouble with water for steam purposes, and the proposed remedies, given by Prof. L. M. Norton.

CAUSES OF INCRUSTATION.

1. Deposition of suspended matter.
2. Deposition of deposed salts from concentration.
3. Deposition of carbonates of lime and magnesia by boiling off carbonic Acid, which holds them in solution.
4. Deposition of sulphates of lime, because sulphate of lime is but slightly soluble in cold water, less soluble in hot water, insoluble above 270° F.
5 Deposition of magnesia, because magnesium salts decompose at high temperature.
6. Deposition of lime soap, iron soap, etc., formed by saponification of grease.

MEANS FOR PREVENTING INCRUSTATION.

1. Filtration.
2. Blowing off.
3. Use of internal collecting apparatus or devices for directing the circulation.
4. Heating feed-water.

* See also "Boiler Waters; Scale, Corrosion, Foaming" by W. Wallace Christie.

5. Chemical or other treatment of water in boiler.
6. Introduction of zinc into boiler.
7. Chemical treatment of water outside of boiler.

TABULAR VIEW.

Troublesome Substance.	*Trouble.*	*Remedy or Palliation.*
Sediment, mud, clay, etc.	Incrustation.	Filtration, Blowing off.
Readily soluble salts.	"	Blowing off.
Bicarbonates of lime, magnesia, iron.	"	Heating feed. Addition of caustic soda, lime, or magnesia, etc.
Sulphate of lime.	"	Addition of carb. soda, barium chloride, etc.
Chloride and sulphate of magnesium.	Corrosion.	Addition of carbonate of soda, etc.
Carbonate of soda in large amounts.	Priming.	Addition of barium chloride, etc.
Acid (in mine waters).	Corrosion.	Alkali.
Dissolved carbonic acid and oxygen.	"	Heating feed. Addition of caustic soda, slacked lime, etc.
Grease (from condensed water).	"	Slacked lime and filtering, Carbonate of soda. Substitute mineral oil.
Organic matter (sewage).	Priming.	Precipitate with alum or ferric chloride and filter.
Organic matter.	Corrosion.	Ditto.

Solubilities of Scale-making Materials.

(" Boiler Incrustation," F. J. Rowan.)

The salts of lime and magnesia are the most common of the impurities found in water. Carbonate of lime is held in solution in fresh water by an excess of carbonic acid. By heating the water the excess of carbonic acid is driven off and the greater part of the carbonate precipitated. At ordinary temperatures carbonate of lime is soluble in from 16,000 to 24,000 times its volume of water; at 212° F. it is but slightly soluble, and at 290° F. (43 lbs. pressure) it is insoluble.

The solubility of sulphate of lime is also affected by the temperature; according to Regnault, its greatest solubility is at 95° F., where it dissolves in 393 times its weight of water; at 212° F. it is only soluble in 460 times its weight of water, and according to M. Couté, it is insoluble at 290° F.

Carbonate of magnesia usually exists in much smaller quantity than the salts of lime. The effect of temperature on its solubility is similar to that of carbonate of lime.

Prof. R. H. Thurston, in his "Manual of Steam Boilers," p. 261, states that:

The temperatures at which calcareous matters are precipitated are:
Carbonate of lime between 176° and 248° F.
Sulphate of lime between 284° and 424° F.
Chloride of magnesium between 212° and 257° F.
Chloride of sodium between 324° and 364° F.

"INCRUSTATION AND SEDIMENT," Prof. Thurston says, "are deposited in boilers, the one by the precipitation of mineral or other salts previously held in solution in the feed-water, the other by the deposition of mineral insoluble matters, usually earths, carried into it in suspension or mechanical admixture. Occasionally also vegetable matter of a glutinous nature is held in solution in the feed-water, and, precipitated by heat or concentration, covers the heating-surfaces with a coating almost impermeable to heat, and hence liable to cause an over-heating that may be very dangerous to the structure. A powdery mineral deposit sometimes met with is equally dangerous, and for the same reason. The animal and vegetable oils and greases carried over from the condenser or feed-water heater are also very likely to cause trouble. Only mineral oils should be permitted to be thus introduced, and that in minimum quantity. Both the efficiency and the safety of the boiler are endangered by any of these deposits.

"The only positive and certain remedy for incrustation and sediment once deposited is periodical removal by mechanical means, at sufficiently frequent intervals to insure against injury by too great accumulation. Between times, some good may be done by special expedients suited to the individual case. No one process and no one antidote will suffice for all cases.

"Where carbonate of lime exists, sal-ammoniac may be used as a preventive of incrustation, a double decomposition occurring, resulting in the production of ammonium carbonate and calcium chloride — both of which are soluble, and the first of which is volatile. The bicarbonate may be in part precipitated before use by heating to the boiling-point, and thus breaking up the salt and precipitating the insoluble carbonate. Solutions of caustic lime and metallic zinc act in the same manner. Waters containing tannic acid and the acid juices of oak, sumach, logwood, hemlock, and other woods, are sometimes employed, but are apt to injure the iron of the boiler, as may acetic or other acid contained in the various saccharine matters often introduced into the boiler to prevent scale, and which also make the lime-sulphate scale more troublesome than when clean. Organic matters should never be used.

"The sulphate scale is sometimes attacked by the carbonate of soda, the products being a soluble sodium sulphate and a pulverulent insoluble calcium carbonate, which settles to the bottom like other sediments and is easily washed off the heating-surfaces. Barium chloride acts similarly, producing barium sulphate and calcium chloride. All the alkalies are used at times to reduce incrustations of calcium sulphate, as is pure crude petroleum, the tannate of soda, and other chemicals.

"The effect of incrustation and of deposits of various kinds is to enormously reduce the conducting power of heating-surfaces; so much so, that the power, as well as the economic efficiency of a boiler, may become very greatly reduced below that for which it is rated, and the supply of steam furnished by it may become wholly inadequate to the requirements of the case.

"It is estimated that a sixteenth of an inch thickness of hard 'scale' on the heating-surface of a boiler will cause a waste of nearly one-eighth its efficiency, and the waste increases as the square of its thickness. The boilers of steam vessels are peculiarly liable to injury from this cause where using salt water, and the introduction of the surface-condenser has been thus brought about as a remedy. Land boilers are subject to incrustation by the carbonate and other salts of lime, and by the deposit of sand or mud mechanically suspended in the feed-water."

Kerosene oil ("Boiler Incrustation," Rowan) has been used to advantage in removing and preventing incrustation. From extended experiments made on a 100 h. p. water tube boiler, fed with water containing 6.5 grains of solid matter per gallon, it was found that one quart kerosene oil per day was sufficient to keep the boiler entirely free from scale. Prior to the introduction of the kerosene oil, the water had a corrosive action upon some of the fittings attached to the boiler; but after the oil had been used for a few months it was found that the corrosive action had ceased.

It should be stated, however, that objection has been made to the introduction of kerosene oil into a boiler for the purpose of preventing incrustation, on account of the possibility of some of the oil passing with the steam into the cylinder of the engine, and neutralizing the effect of the lubricant in the cylinder.

When oil is used to remove scale from steam-boilers, too much care cannot be exercised to make sure that it is free from grease or animal oil. Nothing but pure mineral oil should be used. Crude petroleum is one thing; black oil, which may mean almost anything, is very likely to be something quite different.

The action of grease in a boiler is peculiar. It does not dissolve in the water, nor does it decompose, neither does it remain on top of the water; but it seems to form itself into "slugs," which at first seem to be slightly lighter than the water, so that the circulation of the water carries them about at will. After a short season of boiling, these "slugs," or suspended drops, acquire a certain degree of "stickiness," so that when they come in contact with shell and flues of the boiler, they begin to adhere thereto. Then under the action of heat they begin the process of "varnishing" the interior of the boiler. The thinnest possible coating of this varnish is sufficient to bring about over-heating of the plates.

The time when damage is most likely to occur is after the fires are banked, for then, the formation of steam being checked, the circulation of water stops, and the grease thus has an opportunity to settle on the bottom of the boiler and prevent contact of the water with the fire-sheets. Under these circumstances, a very low degree of heat in the furnace is sufficient to overheat the plates to such an extent that bulging is sure to occur.

Zinc as a Scale Preventive. — Dr. Corbigny gives the following hypothesis: he says that "the two metals, iron and zinc, surrounded by water at a high temperature, form a voltaic pile with a single liquid, which slowly decomposes the water. The liberated oxygen combines with the most oxydizable metal, the zinc, and its hydrogen equivalent is disengaged at the surface of the iron. There is thus generated over the whole extent of the iron influenced a very feeble but continuous current of hydrogen, and the bubbles of this gas isolate at each instant the metallic surface from the scale-forming substance. If there is but little of the latter, it is penetrated by these bubbles and reduced to mud; if there is more, coherent scale is produced, which, being kept off by the intervening stratum of hydrogen, takes the form of the iron surface without adhering to it."

Zinc, in the shape of blocks, slabs, or as shavings inclosed in a perforated vessel, should be suspended throughout the water space of a boiler, care being used in getting perfect metallic contact between the zinc and the boiler. It should not be suspended directly over the furnace, as the oxide might fall upon the surface and be the cause of the plate being over-heated. The quantity placed in a boiler should vary with the hardness of the water, and the amount used, and should be measured by the surface presented. Generally one square inch of surface for every 50 lbs. water in the boiler is sufficient. The British Admiralty recommends the renewing of the blocks whenever the decay of the zinc has penetrated the slab to a depth of $\frac{1}{4}$ inch below the surface.

Purification of Feed-Water by Boiling.

Sulphates can be largely removed from feed-water by heating it to the temperature due to boiler pressure in a feed-water heater, or "live steam purifier" before introduction to boiler. This precipitates those salts in the heater and the water can then if necessary be pumped through a filter into the boiler. The feed-water is first heated as hot as possible in the ordinary exhaust feed-water heater in which the carbonates are precipitated, and then run through the purifier, which is most generally a receptacle containing a number of shallow pans, that can be removed for cleaning, over which the feed-water is allowed to flow from one to the other in a thin sheet. Live steam at boiler-pressure is introduced into the purifier, heating the water to a temperature high enough to precipitate the salts which form scale on the pans. This method of treating feed-water is said to largely increase the efficiency of a boiler plant by the almost complete avoidance of scale. Purification of feed-water by filtration before introduction to the system is often practised with good results.

Table of Water Analyses.

Grains per U. S. Gallon of 231 Cubic Inches.

Where From.	Lime and Magnesia Carbonates.	Lime and Magnesia Sulphates.	Sodium Chloride. (Salt.)	Iron Oxide, Carb. Sulph., etc.	Volatile and Organic Matter.	Total Solids in Grains.
Buffalo, N. Y., Lake Erie	5.66	3.32	0.58	. . .	0.18	9.74
Pittsburgh, Allegheny River . . .	0.37	3.78	0.58	0.37	1.50	6.60
Pittsburgh, Monongahela River . .	1.06	5.12	0.64	0.78	3.20	10.80
Pittsburgh, Pa., artesian well . .	23.45	5.71	18.41	1.04	0.82	49.43
Milwaukee, Wisconsin River . . .	6.23	4.67	1.76	20.14	6.50	39.30
Galveston, Texas, 1	13.68	13.52	326.64	Trace	Trace	353.84
Galveston, Texas, 2	21.79	29.15	398.99	. . .	4.00	453.93
Columbus, Ohio	20.76	11.74	7.02	0.58	6.50	46.60
Washington, D. C., city supply . .	2.87	3.27	Trace	0.36	2.10	8.60
Baltimore, Md., city supply . . .	2.77	0.65	Trace	0.10	3.80	7.30
Sioux City, Ia., city supply	19.76	1.24	1.17	1.03	4.40	27.60
Los Angeles, Cal., 1	10.12	5.84	3.51	2.63	4.10	26.20
Los Angeles, Cal., 2	3.72	12.59	. . .	0.76	6.00	23.07
Bay City, Michigan, Bay	8.47	10.36	20.48	1.15	8.74	49.20
Bay City, Michigan, River	4.84	33.66	126.78	3.00	10.92	179.20
Cincinnati, Ohio River	3.88	0.78	1.79	. . .	Trace	6.73
Watertown, Conn.	1.47	4.51	1.76	Trace	1.78	9.52
Fort Wayne, Ind.	8.78	6.22	3.51	1.59	10.98	31.08
Wilmington, Del.	10.04	6.02	4.29	8.48	6.17	35.00
Wichita, Kansas	14.14	25.91	24.34	. . .	2.00	66.39
Springfield, Ill., 1	12.99	7.40	1.97	2.19	8.62	33.17
Springfield, Ill., 2	5.47	4.31	1.56	4.28	5.83	21.45
Hillsboro, Ill.	14.56	2.97	2.39	1.63	Trace	21.55
Pueblo, Colo.	4.32	16.15	1.20	1.97	5.12	28.76
Long Island City, L. I.	4.0	28.0	16.0	. . .	1.0	39.0
Mississippi River, above Missouri River	8.24	1.02	0.50	. . .	5.25	15.01
Mississippi River, below mouth of Missouri River	10.64	7.41	1.36	1.22	15.86	36.49
Mississippi River at St. Louis, W. W.	9.64	6.94	1.54	1.57	9.85	29.54
Hudson River, above Poughkeepsie, N. Y.	1.06	. . .	.11	10.76	.77	12.70
Croton River, above Croton Dam, N. Y.	4.57	.16	.40	1.92	.67	7.72
Croton River water from service pipes in New York City.	2.36	. . .	. . .	1.36	. . .	3.72
Schuylkill River, above Philadelphia, Pa.	2.16	.29	.49	1.30	. . .	4.24

PUMPS.

Feed-Pumps.

These should be at least double the capacity found by calculation from the amount of water required for the engines, to allow for blowing off, leakage, slip in the pumps themselves, etc., and to enable the pump to keep down steam in case of sudden stoppage of the engines when the fires happen to be brisk, and in fact should be large enough to supply the boilers when run at their full capacity. In addition, for all important plants, there should be either a duplicate feed-pump or an injector to act as stand-by in case of accident. The speed of the plunger or piston may be 50 feet per minute and should never exceed 100 feet per minute, else undue wear and tear of the valves results, and the efficiency is reduced. If the pump be required to stand idle without continually working, the plunger or piston and rod should be of brass.

If

$D =$ diameter of barrel in inches,
$S =$ stroke in inches,
$n =$ number of useful strokes per minute,
$w =$ cubic feet of water pumped per hour,
$W =$ lbs. of water pumped per hour;

$$w = 1.7\,D^2 S\,n.$$

$$W = \frac{D^2\,S\,n}{36.6}.$$

If

$$S\,n = 50,$$

$$W = 1.36\,D^2,$$

and

$$D = \sqrt{\frac{W}{1.36}}.$$

Rubber valves may be used for cold water, but brass, rubber composition, or other suitable material is required for hot water or oil.

If a new pump will not start, it may be due to its imperfect connections or temporary stiffness of pump.

Unless the suction lift and length of supply pipe be moderate, a foot-valve, a charging connection, and a vacuum chamber are desirable. The suction-pipe must be entirely free from air leakage. If the pump refuses to start lifting water with full pressure on, on account of the air in the pump-chamber not being dislodged, but only compressed each stroke, arrange for running without pressure until the air is expelled and water flows. This is done with a check-valve in the delivery-pipe, and a waste delivery which may be closed when water flows.

Pumping Hot Water.—With a free suction-pipe, any good pump fitted with metal valves and with hot-water packing will pump water having a temperature of 212°, or higher, if so placed that the water will flow into it.

Robert D. Kinney, in "Power," gives the following formula for determining to what height water of temperatures below the boiling point can be lifted by suction.

$D =$ lift in feet,
$A =$ absolute pressure on surface of water; if open to air $= 14.7$ lbs.
B and $W =$ constants. See table.

$$D = \frac{144\,(A - B)}{W} \times 0.8 = 115.2\,\frac{A - B}{W}.$$

Water Temp. Degrees F.	B.	W.	Water Temp. Degrees F.	B.	W.
40	0.122	62.42	130	2.215	61.56
50	0.178	62.41	140	2.879	61.39
60	0.254	62.37	150	3.708	61.20
70	0.360	62.31	160	4.731	61.01
80	0.503	62.22	170	5.985	60.80
90	0.693	62.12	180	7.511	60.59
100	0.942	62.00	190	9.335	60.37
110	1.267	61.87	200	11.526	60.13
120	1.685	61.72	210	14.127	59.89

Speed of Water through Pump-Passages and Valves.

The speed of water flowing through pipes and passages in pumps varies from 100 to 200 feet per minute. The loss from friction will be considerable if the higher speed is exceeded.

The area of valves should be sufficient to permit the water to pass at a speed not exceeding 250 feet per minute.

The amount of steam which an average engine will require per indicated horse-power is usually taken at 30 pounds. It varies widely, however, from about 12 pounds in the best class of triple expansion condensing engines up to considerably over 90 pounds in many direct-acting pumps. Where an engine is overloaded or underloaded more water per horse-power will be required than when operated at rated capacity. Horizontal tubular boilers will evaporate on an average from 2 to 3 pounds of water per square foot heating-surface per hour, but may be forced up to 6 pounds if the grate surface is too large or the draught too great for economical working.

Sizes of Direct-acting Pumps.

The two following tables are selected as representing the two common types of direct-acting pump, viz., the single-cylinder and the duplex.

Efficiency of Small Direct-acting Pumps.

In "Reports of Judges of Philadelphia Exhibition," 1876, Group xx., Chas. E. Emery says : " Experiments made with steam-pumps at the American Institute Exhibition of 1867 showed that average size steam-pumps do not, on the average, utilize more than 50 per cent of the indicated power in the steam cylinders, the remainder being absorbed in the friction of the engine, but more particularly in the passage of the water through the pump. Again, all ordinary steam-pumps for miscellaneous use, require that the steam-cylinder shall have three to four times the area of the water-cylinder to give sufficient power when the steam is accidentally low ; hence, as such pumps usually work against the atmospheric pressure, the net or effective pressure forms a small percentage of the total pressure, which, with the large extent of radiating surface exposed and the total absence of expansion, makes the expenditure of steam very large. One pump tested required 120 pounds weight of steam per indicated horse-power per hour, and it is believed that the cost will rarely fall below 60 pounds ; and as only 50 per cent of the indicated power is utilized, it may be safely stated that ordinary steam pumps rarely require less than 120 pounds of steam per hour for each horse-power utilized in raising water, equivalent to a duty of only 15,000,000 foot pounds per 100 pounds of coal. With larger steam-pumps, particularly when they are proportioned for the work to be done, the duty will be materially increased.

Single-Cylinder Direct-acting Pump.

(Standard Sizes for ordinary service.)

Diameter of Steam-Cylinder in Inches.	Diameter of Water-Cylinder in Inches.	Length of Stroke in Inches.	Gallons per Stroke.	Maximum Number of Strokes per Minute.	Capacity per Minute at Given Speed.		Extreme Length in Inches.	Extreme Width in Inches.	Diameter of			
					Strokes.	Gallons.			Steam-Pipe.	Exhaust-Pipe.	Suction-Pipe.	Discharge-Pipe.
4	3½	5	.14	300	130	18	33	9½	½	¾	2	1½
4	4	5	.27	300	130	35	33	9½	½	¾	2	1½
5	4	7	.39	300	125	49	45½	15	¾	1	3	2½
5½	5	7	.51	275	125	64	45½	15	¾	1	3	2½
5½	5½	7	.72	275	125	90	45½	15	¾	1	3	2½
7	7	10	1.64	250	110	180	58	17	1	1½	5	4
7½	7½	10	1.91	250	110	210	58	17	1	1½	5	4
7½	8	10	2.17	250	110	239	58	17	1	1½	5	4
8	6	12	1.47	250	100	147	67	20½	1	1½	4	4
8	7	12	2.00	250	100	200	67	20½	1	1½	5	4
8	8	12	2.61	250	100	261	68	30	1	1½	5	5
8	10	12	4.08	250	100	408	68	20½	1	1½	8	8
10	8	12	2.61	250	100	261	68½	30	1½	2	5	5
10	10	12	4.08	250	100	408	68½	30	1½	2	8	8
10	12	12	5.87	250	100	587	68½	30	1½	2	8	8
12	10	12	4.08	250	100	408	64	24	2	2½	8	8
12	10	18	6.12	200	70	428	68½	30	2	2½	8	8
12	12	12	5.87	250	100	587	64	28½	2	2½	8	8
12	12	18	8.80	175	70	616	88	28½	2	2½	8	8
12	14	18	12.00	175	70	840	88	28½	2	2½	8	8
14	10	12	4.08	250	100	408	69	30	2	2½	8	8
14	10	18	6.12	175	70	428	93	25	2	2½	8	8
14	10	24	8.16	150	50	408	112	26	2	2½	8	8
14	12	12	5.87	250	100	587	69	30	2	2½	8	8
14	12	18	8.80	175	70	616	88	28½	2	2½	8	8
14	12	24	11.75	150	50	587	112	26	2	2½	10	8
14	14	24	15.99	150	50	800	112	34	2	2½	12	10
14	16	16	13.92	175	80	1114	84	34	2	2½	12	10
14	16	24	20.88	150	50	1044	112	38	2	2½	12	10
16	14	18	12.00	175	70	840	89	27	2	2½	8	8
16	14	24	15.99	150	50	800	109	34	2	2½	12	10
16	16	16	13.92	175	80	1114	85	34	2	2½	12	10
16	16	24	20.88	150	50	1044	115	34	2	2½	12	10
16	18	24	26.43	125	50	1322	115	40	2	2½	14	12
18	16	24	20.88	125	50	1044	118	38	3	3½	12	10
18	18	24	26.43	125	50	1322	118	40	3	3½	14	12
18	20	24	32.64	125	50	1632	118	40	3	3½	16	14
20	18	24	26.43	125	50	1322	118	40	3	3½	14	12
20	20	24	32.64	125	50	1632	118	40	3	3½	16	14
20	22	24	39.50	125	50	1975	120	40	3	3½	18	14

Duplex-Cylinder Direct-acting Pump.

(Standard sizes for ordinary service.)

Diameter of Steam-Cylinders, Inches.	Diameter of Water-Plungers, Inches.	Length of Stroke, Inches.	Displacement in Gallons per Stroke of one Plunger.	Proper Strokes per Minute of One Plunger, varying with kind of Work and Pressure.	Gallons Delivered per Minute by Both Plungers at Stated Number of Strokes.	Diameter of Plunger required in any Single-Cylinder Pump to do the same Work at same Speed.	Sizes of Pipes for Short Lengths. To be Increased as Length Increases.			
							Steam-Pipe.	Exhaust-Pipe.	Suction-Pipe.	Discharge-Pipe.
3	2	3	.04	100 to 250	8 to 20	2⅞	⅜	½	1¼	1
4½	2¾	4	.10	100 " 200	20 " 40	4	½	¾	2	1½
5¼	3½	5	.20	100 " 200	40 " 80	5	¾	1¼	2½	1½
6	4	6	.33	100 " 150	70 " 100	5⅝	1	1½	3	2
7½	4½	6	.42	100 " 150	85 " 125	6⅜	1½	2	4	3
7½	5	6	.51	100 " 150	100 " 150	7	1½	2	4	3
7½	4½	10	.69	75 " 125	100 " 170	6⅜	1½	2	4	3
9	5¼	10	.93	75 " 125	135 " 230	7½	2	2½	4	3
10	6	10	1.22	75 " 125	180 " 300	8½	2	2½	5	4
10	7	10	1.66	75 " 125	245 " 410	9⅞	2	2½	6	5
12	7	10	1.66	75 " 125	245 " 410	9⅞	2½	3	6	5
14	7	10	1.66	75 " 125	245 " 410	9⅞	2½	3	6	5
12	8½	10	2.45	75 " 125	365 " 610	12	2½	3	6	5
14	8½	10	2.45	75 " 125	365 " 610	12	2½	3	6	5
16	8½	10	2.45	75 " 125	365 " 610	12	2½	3	6	5
18½	8½	10	2.45	75 " 125	365 " 610	12	3	3½	6	5
20	8½	10	2.45	75 " 125	365 " 610	12	4	5	6	5
12	10¼	10	3.57	75 " 125	530 " 890	14¼	2½	3	8	7
14	10¼	10	3.57	75 " 125	530 " 890	14¼	2½	3	8	7
16	10¼	10	3.57	75 " 125	530 " 890	14¼	2½	3	8	7
18½	10¼	10	3.57	75 " 125	530 " 890	14¼	3	3½	8	7
20	10¼	10	3.57	75 " 125	530 " 890	14¼	4	5	8	7
14	12	10	4.89	75 " 125	730 " 1220	17	2½	3	10	8
16	12	10	4.89	75 " 125	730 " 1220	17	2½	3	10	8
18½	12	10	4.89	75 " 125	730 " 1220	17	3	3½	10	8
20	12	10	4.89	75 " 125	730 " 1220	17	4	5	10	8
18½	14	10	6.66	75 " 125	990 " 1660	19¾	3	3½	12	10
20	14	10	6.66	75 " 122	990 " 1660	19¾	4	5	12	10
17	10	15	5.10	50 " 100	510 " 1020	14	3	3½	10	8
20	12	15	7.34	50 " 100	730 " 1460	17	4	5	12	10
20	15	15	11.47	50 " 100	1145 " 2290	21	. . .	. . .	. . .	. . .
25	15	15	11.47	50 " 100	1145 " 2290	21	. . .	. . .	. . .	. . .

INJECTORS.

Live Steam Injectors.

Let

$W =$ water injected in pounds her hour.
$P =$ steam pressure in pounds per square inch.
$D =$ diameter of throat in inches.
$T =$ diameter of throat in millimeters.

Then $W = 1280\ D^2 \sqrt{P}$

$= 1.98\ d^2 \sqrt{P}$

The rule given by Rankine, "Steam Engine," p. 477, for finding the proper sectional area in square inches for the narrowest part of the nozzle is as follows :

$$\text{area} = \frac{\text{cubic feet per hour gross feed-water}}{800 \sqrt{\text{pressure in atmospheres}}}$$

The expenditure of steam is about one-fourteenth the volume of water injected.

The following table gives the water delivered for different sizes of injectors at different pressures ; but when the injector has to lift its water a deduction must be made varying from 10 to 30 per cent according to the lift.

Deliveries for Live Steam Injectors.

Size of Injector in Millimeters.	Pressure of Steam.						Size of Pipes and Fittings.
	30 lbs.	60 lbs.	80 lbs.	100 lbs.	120 lbs.	140 lbs.	
	Delivery in Gallons per Hour.						In.
2	43	61	71	80	87	93	½
3	97	138	160	178	196	211	½
4	173	246	285	317	348	376	1
5	272	385	445	496	545	587	1
6	392	555	640	715	783	846	1¼
7	533	755	871	973	1067	1152	1¼
8	696	985	1137	1272	1393	1505	1½
9	882	1247	1440	1610	1763	1905	1½
10	1088	1540	1777	1987	2177	2352	2
11	1317	1863	2150	2405	2633	2846	2
12	1567	2217	2560	2861	3136	3387	2¼
13	1840	2602	3005	3358	3680	3975	2¼
14	2133	3018	3485	3895	4267	4610	2½
15	2450	3465	4000	4471	4900	5292	2½
16	2787	3942	4551	5087	5575	6022	2¾
17	3146	4450	5138	5743	6291	6798	2¾
18	3527	4990	5760	6438	7055	7633	2¾
19	3930	5560	6418	7175	7861	8492	2¾
20	4355	6160	7110	7950	8710	9410	3

1 millimeter $= \frac{1}{25}$ inch, nearly.

As the vertical distance the injector lifts is increased, a greater steam pressure is required to start the injector, and the highest steam pressure at which it will work is gradually decreased.

If the feed-water is heated a greater steam pressure is required to start the injector, and it will not work with as high steam pressure.

The capacity of an injector is decreased as the lift is increased or the feed-water heated.

Performance of Injectors. — W. Sellers & Co. state that one of their injectors delivered 25.5 lbs. water to a boiler per pound of steam ; steam pressure 65 lbs.; temperature of feed, 64° F.

Schaeffer & Budenberg state that their injectors will deliver 1 gallon water to a boiler for from 0.4 to 0.8 lbs. steam. They also state that the temperatures of feed-water taken by their injector, if non-lifting or at a low lift, can be as follows :

Pressure, lbs.	35 to 45,	50 to 85,	90, 105,	120,	135,	150.
Temperature, °F.,	144 to 136,	133 to 130,	129, 122,	118 to 113,	109 to 105,	104 to 100.

The Hayden & Derby Mfg. Co. state that the results given below are from actual tests of Metropolitan Double-Tube Injectors.

With Cold Feed-Water.

On a 2-foot lift:	Starts with 14 lbs. steam pressure. Works up to 250 lbs. steam pressure.
On an 8-foot lift:	Starts with 23 lbs. steam pressure. Works up to 220 lbs. steam pressure.
On a 14-foot lift:	Starts with 27 lbs. steam pressure. Works up to 175 lbs. steam pressure.
On a 20-foot lift:	Starts with 42 lbs. steam pressure. Works up to 135 lbs. steam pressure.
When not lifting:	Starts with 14 lbs. steam pressure. Works up to 250 lbs. steam pressure.

With Feed-Water at 100° F.

On a 2-foot lift:	Starts with 15 lbs. steam pressure. Works up to 210 lbs. steam pressure.
On an 8-foot lift:	Starts with 26 lbs. steam pressure. Works up to 160 lbs. steam pressure.
On a 14-foot lift:	Starts with 37 lbs. steam pressure. Works up to 120 lbs. steam pressure.
On a 20-foot lift:	Starts with 46 lbs. steam pressure. Works up to 70 lbs. steam pressure.
When not lifting:	Starts with 15 lbs. steam pressure. Works up to 210 lbs. steam pressure.

With Feed-Water at 120° F.

On a 2-foot lift:	Starts with 20 lbs. steam pressure. Works up to 185 lbs. steam pressure.
On an 8-foot lift:	Starts with 30 lbs. steam pressure. Works up to 120 lbs. steam pressure
On a 14-foot lift:	Starts with 42 lbs. steam pressure. Works up to 75 lbs. steam pressure.
When not lifting:	Starts with 20 lbs. steam pressure. Works up to 185 lbs. steam pressure.

With Feed-Water at 140° F.

On a short lift, or when not lifting, this injector will work with steam pressures from 20 lbs. to 120 lbs., and on an 8-foot lift with steam pressures from 35 lbs. to 70 lbs.

Exhaust Injectors working with exhaust steam from an engine, at about atmospheric pressure will deliver water against boiler pressure not exceeding 80 lbs. per square inch. The temperature of the water may be as high as 190° F., while 12 per cent of the water delivered will be condensed steam. For pressures over 80 lbs. it is necessary to supplement the exhaust steam with a jet of live steam.

Injector vs. Pump for Feeding Boilers.

The relative value of injectors, direct-acting steam pumps, and pumps driven from the engine, is a question of importance to all steam-users. The following table ("Stevens Indicator," 1888) has been calculated by D. S. Jacobs, M. E., from data obtained by experiment. It will be noticed that when feeding cold water direct to boilers, the injector has a slight economy, but when feeding through a heater a pump is much the most economical.

Method of Supplying Feed-Water to Boiler. Temperature of Feed-Water as delivered to the Pump or to the Injector, 60° F. Rate of Evaporation of Boiler, 10 lbs. of Water per pound of Coal from and at 212° F.	Relative Amount of Coal Required per Unit of Time, the Amount for a Direct-Acting Pump, Feeding Water at 60°, without a Heater, being taken as Unity.	Saving of Fuel over the Amount Required when the Boiler is Fed by a Direct-Acting Pump without Heater.
Direct-acting pump feeding water at 60°, without a heater	1.000	.0
Injector feeding water at 150°, without a heater	.985	1.5 per cent.
Injector feeding through a heater in which the water is heated from 150° to 200°	.938	6.2 "
Direct-acting pump feeding water through a heater, in which it is heated from 60° to 200°	.879	12.1 "
Geared pump, run from the engine, feeding water through a heater, in which it is heated from 60° to 200°	.868	13.2 "

Sizes for Feed-Water Pipes.

Three and six-tenths gallons of feed-water are required for each h. p. per hour. This makes 6 gallons per minute for a 100 h. p. boiler. In proportioning pipes, however, it is well to remember that boiler-work is seldom perfectly steady, and that as the engine cuts off just as much steam as the work demands at each stroke, *all the discrepancies of demand and supply have to be equalized in the boiler*. Therefore we may often have to evaporate during one-half hour 50 to 75 per cent more than the normal requirements. For this reason it is sound policy to arrange the feed-pipes so that 10 gallons per minute may flow through them, without undue speed or friction, for each 100 h. p. of boiler capacity. The following tables will facilitate this work.

Table Giving Rate of Flow of Water, in Feet per Minute, Through Pipes of Various Sizes, for Varying Quantities of Flow.

Gallons per Min.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30	. . .	735	451	327	183	117	81	46
35	. . .	857½	549½	381½	213½	136½	94½	53⅔
40	. . .	980	628	436	244	156	108	61⅓
45	. . .	1102½	706½	490½	274½	175½	121½	69
50	. . .	. . .	785	545	305	195	135	76⅔
75	. . .	. . .	1177½	817½	457½	292½	202½	115
100	. . .	. . .	. . .	1090	610	380	270	153⅓
125	. . .	. . .	. . .	. . .	762½	487½	337½	191⅔
150	. . .	. . .	. . .	. . .	915	585	405	230
175	. . .	. . .	. . .	. . .	1067½	682½	472½	268⅓
200	. . .	. . .	. . .	. . .	1220	780	540	306⅔

Table Giving Loss in Pressure due to Friction, in Pounds per Square Inch, for Pipe 100 Feet Long.

(By G. A. Ellis, C. E.)

Gallons Discharged per Min.	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.	4 in.
5	3.3	0.84	0.31	0.12	...	...	...	...
10	13.0	3.16	1.05	0.47	0.12	...	...	...
15	28.7	6.98	2.38	0.97	...	...	...	...
20	50.4	12.3	4.07	1.66	0.42	...	...	...
25	78.0	19.0	6.40	2.62	...	0.21	0.10	...
30	...	27.5	9.15	3.75	0.91	...	...	...
35	...	37.0	12.4	5.05	...	...	...	...
40	...	48.0	16.1	6.52	1.60	...	...	...
45	...	...	20.2	8.15	...	...	...	...
50	...	...	24.9	10.0	2.44	0.81	0.35	0.09
75	...	...	56.1	22.4	5.32	1.80	0.74	...
100	...	...	...	39.0	9.46	3.20	1.31	0.33
125	...	...	...	...	14.9	4.89	1.99	...
150	...	...	...	...	21.2	7.0	2.85	0.69
175	...	...	...	...	28.1	9.46	3.85	...
200	...	...	...	...	37.5	12.47	5.02	1.22

Loss of Head due to Bends.

Bends produce a loss of head in the flow of water in pipes. Weisbach gives the following formula for this loss:

$H = f\frac{v^2}{2g}$ where $H =$ loss of head in feet, $f =$ coefficient of friction, $v =$ velocity of flow in feet per second, $g = 32.2$.

As the loss of head or pressure is in most cases more conveniently stated in pounds per square inch, we may change this formula by multiplying by 0.433, which is the equivalent in pounds per square inch for one foot head.

If $P =$ loss in pressure in pounds per square inch, $F =$ coefficient of friction.

$P = F\frac{v^2}{64.4}$, v being the same as before.

From this formula has been calculated the following table of values for F, corresponding to various exterior angles, A.

$A =$	20°	40°	45°	60°	80°	90°	100°	110°	120°	130°
$F =$	0.020	0.060	0.079	0.158	0.320	0.426	0.546	0.674	0,806	0.934

This applies to such short bends as are found in ordinary fittings, such as 90° and 45° Ells, Tees, etc.

A globe valve will produce a loss about equal to two 90° bends, a straightway valve about equal to one 45° bend. To use the above formula *find the speed p. second, being one-sixtieth of that found in Table p. 1373; square this speed, and divide the result by 64.4; multiply the quotient by the tabular value of F corresponding to the angle of the turn, A.*

For instance, a 400 h.p. battery of boilers is to be fed through a 2-inch pipe. Allowing for fluctuations we figure 40 gallons per minute, making 244 feet per minute speed, equal to a velocity of 4.6 per second. Suppose our pipe is in all 75 feet long; we have from Table No. 36, for 40 gallons per minute, 1.60 pounds loss; for 75 feet we have only 75 per cent of this = 1.20 pounds. Suppose we have 6 right-angled ells, each giving $F = 0.426$. We have then $4.06 \times 4.06 = 16.48$; divide this by 64.4 = 0,256. Multiply this by $F = 0.426$

pounds, and as there are 6 ells, multiply again by 6, and we have $6 \times 0.426 \times 0.256 = 0.654$. The total friction in the pipe is therefore $1.20 + 0.654 = 1.854$ pounds per square inch. If the boiler pressure is 100 pounds and the water level in the boiler is 8 feet higher than the pump suction level, we have first $8 \times 0.433 = 3.464$ pounds. The total pressure on the pump plunger then is $100 + 3.464 + 1.854 = 105.32$ pounds per square inch. If in place of 6 right-angled ells we had used three 45° ells, they would have cost us only $3 \times 0.079 = 0.237$ pounds; $0.237 \times 0.256 = 0.061$.

The total friction head would have been $1.20 + 0.061 = 1.261$, and the total pressure on the plunger $100 + 3.464 + 1.261 = 104.73$ pounds per square inch, a saving over the other plan of nearly 0.6 pounds.

To be accurate, we ought to add a certain head in either case, "to produce the velocity." But this is very small, being for velocities of:

2;	3;	4;	5;	6;	8;	10;	12 and 18 feet per sec.
0.027;	0.061;	0.108;	0.168;	0.244;	0.433;	0.672;	0.970 and 2.18 lbs. per sq. in.

Our results should therefore have been increased by about 0.11 pounds.

It is usual, however, to use larger pipes, and thus to materially reduce the frictional losses.

Feed Water Heaters.

(W. W. Christie.)

Feed Water Heaters may be classified in this way:

Closed Heaters (indirect)	Steam tube. / Water tube.
Open Heaters (direct)	Atmospheric. / Vacuum.

The open heater is usually made of cast iron, as this material will withstand the corrosive action of acids found in feed-waters better than any other metal. In this type of heater the exhaust steam from engines and pumps, and the feed-water broken up into drops by suitable means, are brought into immediate contact, and the steam not condensed in heating the water passes off to the atmosphere. The quantity of water that can be heated is only limited by the amount of steam and water that can be brought together. The steam condensed in heating the water is saved and utilized for boiler feed. An open heater should be provided with an efficient oil-separator, a large settling-chamber or hot well in which, if desired, a filtering bed of suitable material can be placed to insure the removal from the water, of all the impurities held in suspension, a device for skimming the surface of the water to remove the impurities floating on the water, and a large blow-off opening placed at the lowest point in the heater.

The closed heater is made with a wrought-iron or steel cylindrical shell and cast- or wrought-iron heads, having iron or brass tubes inside, set in tube plates so as to make steam- and water-tight joints, provision being made for the expansion and contraction of the tubes. According to the particular design of the heater, the exhaust steam passes through or around the tubes, the water being on the opposite of the walls of the tubes. The steam and water are separated by metal through which the heat of the exhaust steam is transmitted to the water. As an oil-separator is very seldom attached to a closed heater, the steam condensed in heating the water is wasted. The quantity of water that can be heated is limited by the amount of heat that can be transmitted through the tubes. The efficiency of heat transmission is decreased by the coating of oil that covers the steam side, and the crust of scale that coats the water side of the tubes. No provision can be made for purifying the water in a closed heater, as the constant circulation of the water prevents the impurities from settling. The impurities that are in the water pass on into the boiler. Purification must be done by means of an auxiliary apparatus.

When used with a condenser, the feed water heater will increase the vacuum 1 to 2 inches; when used with cold feed water, the economy is increased from 7 to 14 per cent; if feed water is from a hot well, 7 to 8 per cent.

Two things are very essential to the successful working of all heaters,— they must be kept clean from scale and oil deposits, and sufficient exhaust steam must be sent through them.

The probability of there being much scale ingredients thrown down in a closed heater where temperature never exceeds 212° F., and in an open heater where temperature approaches more nearly to steam temperature, is shown by this table.

Temperatures at which scale-forming ingredients are precipitated :

Carbonate of lime	176°–248° F.
Chloride of magnesium	212°–257° F.
Sulphate of lime	284° F.–424° F.
Chloride of sodium	324° F.–364° F.

The rating of a feed-water heater of the closed type is a subject about which little has been written, but the common rule is to give $\frac{1}{3}$ square feet of heating surface for one boiler horse-power.

In designing, however, the heating surface should be made large enough or ample to transmit the maximum number of heat units per unit of time, and then the water velocity should be adjusted to suit the capacity required.

For heat transmitted, one well-known manufacturer uses 350 B. T. Units per degree F. difference of temperature per square foot of heating surface per hour, as a maximum ; other types of heaters would use only 150 to 200 B. T. U.'s as the maximum.

As the tubes forming the heating surface in closed heaters are made of different materials, if we take

Copper as	100	Wrought iron as . . .	58
Brass as	87	Cast iron as	49

we can readily see that if one-third square foot surface area is right for a copper pipe, we will need $\frac{100}{58}$ of $\frac{1}{3}$ or $\frac{100}{174}$, or about six-tenths for iron coils, per boiler horse-power.

The power to transmit heat varies not only with the material, but also with the design of the heater, the velocity of the water, and water and steam capacity of the heater.

The velocity of the water through the heater should be from 100 to 200 feet per minute.

The proportions of open heaters depend largely upon the character of the water used in the heater, for it should have sufficient time to become thoroughly heated and the scale-forming ingredients settled and eliminated from the feed as it passes out of the heater.

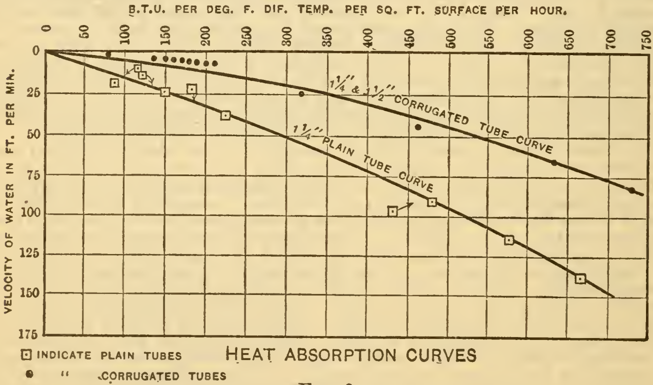


FIG. 6.

Saving by Heating Feed-Water.

(W. W. Christie.)

In converting water at 32° F. into steam at atmospheric pressure, it must be raised to 212° F., the boiling point.

The specific heat of water varies somewhat with its temperature, so that to raise a pound of water from 32° to 212° F. or 180° F., requires 180.8 heat units.

To convert it into steam, after it has reached 212° F., requires 965.8 heat units, or in all $180.8 + 965.8 = 1146.6$ units of heat, thermal units.

The saving to be obtained by the use of waste heat, as exhaust steam, heating the water by transfer of some of its heat through metal walls, is calculated by this formula:

$$\text{Gain in per cent} = \frac{100\,(h_2 - h_1)}{H - h_1} = \frac{100\,(t_2 - t_1)}{H - t_1 + 32} \text{ very nearly,}$$

in which H = total heat in steam at boiler pressure (above that in water at 32° F.) in B. T. U.

h_2 = heat in feed-water (above 32° F.) after heating.

h_1 = heat in feed-water (above 32° F.) before heating.

t_2 = temperature of feed-water after heating °F.

t_1 = temperature of feed-water before heating °F.

given $H = 1146.6$, $t_2 = 212$, $t_1 = 112$, or a difference of 100°; and we obtain by use of the above formula, gain in per cent = 9.37, or for 10° approximately .937 per cent, for 11° 1.02 per cent, so we may say that for every 11° F. added to the feed-water temperature by use of the exhaust steam, 1 per cent of fuel saving results.

The table which follows is taken from "Power."

Percentage of Saving in Fuel by Heating Feed-Water by Waste Steam, Steam at 70 Pounds Gauge Pressure.

Initial Temperature Feed.	Temperature of Water Entering Boiler.											
	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	250°
35°	7.24	8.09	8.95	9.89	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40
40°	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89
45°	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.36	14.22	15.09	18.37
50°	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87
55°	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	17.38
60°	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86
65°	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35
70°	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84
75°	3.96	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	11.95	12.84	15.33
80°	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.82
85°	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32
90°	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81
95°	2.25	3.15	4.05	4.96	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31
100°	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80

Pump Exhaust.

In many plants the only available exhaust steam comes from the steam pumps used for elevator service, boiler-feeding, etc.; or in condensing plants from the air-pumps, water-supply, and boiler feed-pumps. It should also be remembered that all direct-acting steam pumps are large consumers of steam, taking several boiler h. p. for each indicated h. p., and that the exhaust steam from them will heat about six times the same quantity by weight of cold water, from 50° to 212° F., and that these pumps, or the independent condenser pumps, are more economical when all the exhaust from them is used for heating feed-water than the best kind of triple expansion condensing engines. With the pumps all the heat not used in doing work can be conserved and returned to the boiler in the feed-water, whereas even with triple expansion engines at least 80 per cent of the total heat in the steam is carried away in the condensing water.

While the supply of exhaust from these pumps may not be sufficient to raise the temperature to the highest point, yet the saving is large and constant.

These results do not take any account of the purifying action in the "open" heaters on the feed-water, the improved condition of which, by diminishing the average deposit within the boiler, materially increases both the boiler capacity and the economy; while the more uniform temperature accompanying the use of a hot feed reduces the repairs and lengthens the life of all boilers.

If the quantity of water passing through the heater is only what is required to furnish steam for the engine from which the exhaust comes, more than four-fifths of this exhaust steam will remain uncondensed, and will thus become available for other purposes, such as heating buildings, dryer systems, etc.; in which case the returns can be sent back to the boiler by suitable means.

FUEL ECONOMIZERS.

Performance of a Green Economizer with a Smoky Coal.

(D. K. Clark, S. E., p, 286.)

From tests by M. W. Grosseteste, covering a period of three weeks on a Green economizer, using a smoke-making coal, with a constant rate of combustion under the boilers, it is apparent that there is a great advantage in cleaning the pipes daily — the elevation of temperature having been increased by it from 88° to 153°. In the third week, without cleaning, the elevation of temperature relapsed in three days to the level of the first week; even on the first day it was quickly reduced by as much as half the extent of relapse. By cleaning the pipes daily an increased elevation of temperature of 65° F. was obtained, whilst a gain of 6% was effected in the evaporative efficiency.

The action of Green's economizer was tested by M. W. Grosseteste for a period of three weeks. The apparatus consists of four ranges of vertical pipes, 6½ feet high, 3¾ inches in diameter outside, nine pipes in each range, connected at top and bottom by horizontal pipes. The water enters all the tubes from below, and leaves them from above. The system of pipes is enveloped in a brick casing, into which the gaseous products of combustion are introduced from above, and which they leave from below. The pipes are cleared of soot externally by automatic scrapers. The capacity for water is 24 cubic feet, and the total external heating-surface is 290 square feet. The apparatus is placed in connection with a boiler having 355 square feet of surface.

Green's Economizer. — Results of Experiments on its Efficiency as Affected by the State of the Surface.

(W. Grosseteste.)

TIME. February and March.	Temperature of Feed-water.			Temperature of Gaseous Products.		
	Entering Feed-heater.	Leaving Feed-heater.	Difference.	Entering Feed-heater.	Leaving Feed-heater.	Difference.
	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.
1st Week	73.5°	161.5°	88.0°	849°	261°	588°
2d Week	77.0	230.0	153.0	882	297	585
3d Week — Monday . .	73.4	196.0	122.6	831	284	547
Tuesday . .	73.4	181.4	108.0	871	309	562
Wednesday	79.0	178.0	99.0	——	——	——
Thursday .	80.6	170.6	90.0	952	329	623
Friday . .	80.6	169.0	88.4	889	338	551
Saturday .	79.0	172.4	93.4	901	351	550

	1st Week.	2d Week.	3d Week.
Coal consumed per hour	214 lbs.	216 lbs.	213 lbs.
Water evaporated from 32° F. per hour	1424	1525	1428
Water per pound of coal	6.65	7.06	6.70

The Fuel Economizer Company, Matteawan, N.Y., describe the construction of Green's economizer, thus: The economizer consists of a series of sets of cast-iron tubes about 4 inches in diameter and 9 feet in length, made in sections (of various widths) and connected by "top" and "bottom headers," these again being coupled by "top" and "bottom branch pipes" running lengthwise, one at the top and the other at the bottom, on opposite sides and outside the brick chamber which encloses the apparatus. The waste gases are led to the economizer by the ordinary flue from the boilers to the chimney.

The feed-water is forced into the economizer by the boiler pump or injector, at the lower branch pipe nearest the point of exit of gases, and emerges from the economizer at the upper branch pipe nearest the point where the gases enter.

Each tube is provided with a geared scraper, which travels continuously up and down the tubes at a slow rate of speed, the object being to keep the external surface clean and free from soot, a non-conductor of heat.

The mechanism for working the scrapers is placed on the top of the economizer, outside the chamber, and the motive power is supplied either by a belt from some convenient shaft or small independent engine or motor. The power required for operating the gearing, however, is very small.

The apparatus is fitted with blow-off and safety valves, and a space is provided at the bottom of the chamber for the collection of the soot, which is removed by the scrapers.

One boiler plant equipped with the Green economizer gave, under test, these results.

The total area of heating surface in the plant was 3,126 square feet, and the number of tubes in the economizer 160. The results were as follows: —

Particulars of Test.	Economizer working, Dec. 15.	Economizer not working, Dec. 16.
1. Duration of test . . . . hours	11.5	11.5
2. Weight of dry coal consumed . . . . . lbs.	8,743	9,694
3. Percentage of ash and refuse . . . per cent	7.5	7.7
4. Weight of coal consumed per hour per square foot grate surface . . . . lbs.	15.2	16.8
5. Weight of water evaporated . . . . . lbs.	84,078	82,725
6. Horse-power developed on basis of 30 lbs. per h.p. fed at 100° and evaporated at 70 lbs., h.p.	247.0	243.5
7. Average boiler pressure (above atmosphere), lbs.	68.2	67.2
8. Average temperature of feed-water entering economizer . . . . deg. Fahr.	84.2	. . .
9. Average temperature of feed-water entering boilers . . . . deg. Fahr.	196.2	82.0
10. Number of degrees feed-water was heated by economizer . . . . deg. Fahr.	112.	. . .
11. Average temperature of flue gases entering economizer . . . . deg. Fahr.	435.	. . .
12. Average temperature of flue gases entering chimney . . . . deg. Fahr.	279.	452.0
13. Number degrees flue gases were cooled by economizer . . . . deg. Fahr.	156.	. . .
14. Lbs. water evaporated per lb. of coal, as observed	9.617	8.533
15. Equivalent evaporation per lb. of coal from and at 212°	11.204	9.955
16. Percentage gained by using the economizer per cent	12.5	. . .

The steam in this test contained 1.3 per cent of moisture.

W. S. Hutton gives the following results of tests of a steam boiler with and without an economizer.

	With Economizer.	Without Economizer.
Duration of test, hours	$11\frac{1}{2}$	$11\frac{1}{2}$
Weight of coal, pounds	7856	10282
Steam pressure, pounds	58	57
Temp. water entering economizer, degrees	88	...
" " " boiler, degrees	225	85
Degrees feed-water heated by economizer	137	...
Temp. gases entering economizer, degrees	618	...
" " " chimney, degrees	365	645
Degrees gases cooled by economizer	253	...
Evaporation per lb. coal, from and at 212°, pounds	10.613	8.235
Saving by economizer, per cent	28.9	

Green's Fuel Economizer. — Clark gives the following average results of comparative trials of three boilers at Wigan used with and without economizers:

	Without Economizers.	With Economizers.
Coal per square foot of grate per hour	21.6	21.4
Water at 100° evaporated per hour	73.55	79.32
Water at 212° per pound of coal	9.60	10.56

Showing that in burning equal quantities of coal per hour the rapidity of evaporation is increased 9.3% and the efficiency of evaporation 10% by the addition of the economizer.

The average temperature of the gases and of the feed-water before and after passing the economizer were as follows:

	With 6-ft. grate.		With 4-ft. grate.	
	Before.	After.	Before.	After.
Average temperature of gases	649	340	501	312
Average temperature of feed-water	47	157	41	137

Taking averages of the two grates, to raise the temperature of the feed-water 100°, the gases were cooled down 250°.

STEAM SEPARATORS.

Carefully conducted experiments have shown that water, oil, or other liquids passing through pipes along with steam do not remain thoroughly mixed with the steam itself, but that the major portion of these liquids follows the inner contour of the pipe, especially in the case of horizontal pipes.

From this it would necessarily follow that a rightly designed separator to meet these conditions must interrupt the run of the liquid by breaking the continuity of the pipe, and offering a receptacle into which the liquid will flow freely, or fall by gravity — that this appliance must further offer the opportunity for the liquid to come to rest out of the current of steam, for it is not enough to simply provide a well or a tee in the pipe, since the current would jump or draw the liquid over this opening, especially if the velocity was high.

It is also evident that means must be provided in this appliance for interrupting the progress of those particles of the liquid which are traveling in the current of the steam, and do this in such a way that these particles will also be detained and allowed to fall into the receptacle provided, which receptacle must be fully protected from the action of the current of the steam; otherwise, the separated particles of water or oil will be picked up and carried on past the separator.

To prevent the current from jumping the liquid over the well, and to interrupt the forward movement of those particles traveling in or with the current, it follows that some obstruction must be interposed in the path of the current.

Steam separators should always be placed as near as possible to the steam inlet to the cylinder of the engine. Oil separators are placed in the run of the exhaust pipe from engines and pumps, for the purpose of removing the oil from the steam before it is used in any way where the presence of oil would cause trouble.

Prof. R. C. Carpenter conducted a series of tests on separators of several makes in 1891. The following table shows results under various conditions of moisture:

Make of Separator.	Test with Steam of about 10% of Moisture.			Tests with Varying Moisture.		
	Quality of Steam Before.	Quality of Steam After.	Efficiency per cent.	Quality of Steam Before.	Quality of Steam After.	Average Efficiency.
B	87.0%	98.8%	90.8	66.1 to 97.5%	97.8 to 99 %	87.6
A	90.1	98.0	80.0	51.9 " 98	97.9 " 99.1	76.4
D	89.6	95.8	59.6	72.2 " 96.1	95.5 " 98.2	71.7
C	90.6	93.7	33.0	67.1 " 96.8	93.7 " 98.4	63.4
E	88.4	90.2	15.5	68.6 " 98.1	79.3 " 98.5	36.9
F	88.9	92.1	28.8	70.4 " 97.7	84.1 " 97.9	28.4

Conclusions from the tests were: 1. That no relation existed between the volume of the several separators and their efficiency.

2. No marked decrease in pressure was shown by any of the separators, the most being 1.7 lbs. in E.

3. Although changed direction, reduced velocity, and perhaps centrifugal force are necessary for good separation, still some means must be provided to lead the water out of the current of the steam.

A test on a different separator from those given above was made by Mr. Charles H. Parker, at the Boston Edison Company's plant, in November, 1897, and the following results obtained:

Length of run	3-4 hrs.
Average pressure of steam	158 lbs. per sq. in.
Temperature of upper thermometer in calorimeter on outlet of separator	368.5° F.
Temperature of lower thermometer in calorimeter on outlet of separator	291.7° F.
Normal temperature of lower thermometer, when steam is at rest	292.9° F.
Degrees cooling as shown by lower thermometer	1.2° F.
Moisture in steam delivered by separator as shown by cooling of lower thermometer	.06 per cent.
Water discharged from separator per hour	52 lbs.
Steam and entrained water passing through engine, as shown by discharge from air pump of surface condenser	7359 lbs.
Steam and entrained water entering separator	7411 lbs.
Moisture taken out by separator	.72
Total moisture in steam (.06 plus .72)	.78 per cent.
Efficiency of separator	92.3 per cent.

SAFETY VALVES.

Calculation of Weight, etc., for Lever Safety-Valve.

Let W = weight of ball at end of lever, in pounds;
w = weight of lever itself, in pounds;
V = weight of valve and spindle, in pounds;
L = distance between fulcrum and center of ball, in inches;
l = distance between fulcrum and center of valve, in inches;
g = distance between fulcrum and center of gravity of lever, in inches;
A = area of valve, in square inches;
P = pressure of steam, in pounds per square inch at which valve will open.

$$\text{Then } PA \times l = W \times L + w \times g + V \times l;$$

$$\text{whence } P = \frac{WL + wg + Vl}{Al};$$

$$W = \frac{PAl - wg - Vl}{L};$$

$$L = \frac{PAl - wg - Vl}{W}.$$

EXAMPLE. — Diameter of valve, 4 inches; distance from fulcrum to center of ball, 36 inches; to center of valve, 4 inches; to center of gravity of lever, 16 inches; weight of valve and spindle, 6 lbs.; weight of lever, 10 lbs.; required the weight of ball to make the blowing-off pressure 100 lbs. per square inch; area of 4-inch valve = 12.566 square inches. Then

$$W = \frac{PAl - wg - Vl}{L} = \frac{100 \times 12.566 \times 4 - 10 \times 16 - 6 \times 4}{36} = 134.5 \text{ lbs.}$$

Rules Governing Safety-Valves.

(Rule of U. S. Supervising Inspectors of Steam-vessels as amended 1894.)

The distance from the fulcrum to the valve-stem must in no case be less than the diameter of the valve-opening; the length of the lever must not be more than ten times the distance from the fulcrum to the valve-stem; the width of the bearings of the fulcrum must not be less than three-quarters of an inch; the length of the fulcrum-link must not be less than four inches; the lever and fulcrum-link must be made of wrought iron or steel, and the knife-edged fulcrum points and the bearings for these points must be made of steel and hardened; the valve must be guided by its spindle, both above and below the ground seat and above the lever, through supports either made of composition (gun-metal) or bushed with it; and the spindle must fit loosely in the bearings or supports.

Lever safety-valves to be attached to marine boilers shall have an area of not less than 1 square inch to 2 square feet of the grate surface in the boiler, and the seats of all such safety-valves shall have an angle of inclination of 45° to the center line of their axes.

Spring-loaded safety-valves shall be required to have an area of not less than 1 square inch to 3 square feet of grate surface of the boiler, except as hereinafter otherwise provided for water-tube or coil and sectional boilers, and each spring-loaded valve shall be supplied with a lever that will raise the valve from its seat a distance of not less than that equal to one-eighth the diameter of the valve-opening, and the seats of all such safety-valves shall have an angle of inclination to the center line of their axes af 45°. All spring-loaded safety-valves for water-tube or coil and sectional boilers required to carry a steam-pressure exceeding 175 lbs. per square inch shall be required to have an area of not less than 1 square inch to 6 square feet of the grate surface of the boiler. Nothing herein shall be construed so as to prohibit the use of two safety-values on one water-tube or coil and sectional boiler, provided the combined area of such valves is equal to that required by rule for one such valve.

Rule on Safety-Valves in Philadelphia Ordinances. — Every boiler when fired separately, and every set or series of boilers when placed over one fire, shall have attached thereto, without the interposition of any other valve, two or more safety-valves, the aggregate area of which shall have such relations to the area of the grate and the pressure within the boiler as is expressed in schedule A.

SCHEDULE A. — Least aggregate area of safety-valve (being the least sectional area for the discharge of steam) to be placed upon all stationary boilers with natural or chimney draught (see note *a*).

$$A = \frac{22.5G}{P + 8.62},$$

in which A is area of combined safety-valves in inches; G is area of grate in square feet; P is pressure of steam in pounds per square inch to be carried in the boiler above the atmosphere.

The following table gives the results of the formula for one square foot of grate, as applied to boilers used at different pressures:

Pressures per square inch:

10 20 30 40 50 60 70 80 90 100 110 120 150 175

Valve area in square inches corresponding to one square foot of grate:

1.2 .79 .58 .46 .38 .33 .29 .25 .23 .21 .19 .17 .14 .12

[NOTE *a*.] — Where boilers have a forced or artificial draught, the inspector must estimate the area of grate at the rate of one square foot of grate surface for each 16 lbs. of fuel burned on the average per hour.

The various rules given to determine the proper area of a safety-valve do not take into account the effective discharge area of the valve. A correct rule should make the product of the diameter and lift proportional to the weight of steam to be discharged.

Mr. A. G. Brown (*The Indicator and its Practical Working*) gives the following as the lift of the lever safety-valve for 100 lbs. gauge pressure. Taking the effective area of opening at 70 per cent of the product of the rise and the circumference

Diameter of valve, inches	2	2½	3	3½	4	4½	5	6
Rise of valve, inches . .	.0583	.0523	.0507	.0492	.0478	.0462	.0446	.043

For "pop" safety-valves, Mr. Brown gives the following table for the rise, effective area, and quantity of steam discharged per hour, taking the effective area at 50 per cent of the actual on account of the obstruction which the lip of the valve offers to the escape of the steam.

Di. valve in.	1	1½	2	2½	3	3½	4	4½	5	6
Lift inches.	.125	.150	.175	.200	.225	.250	.275	.300	.325	.375
Area, sq. in.	.196	.354	.550	.785	1.061	1.375	1.728	2.121	2.553	3.535
Gauge-press.	Steam discharged per hour, lbs.									
30 lbs.	474	856	1330	1897	2563	3325	4178	5128	6173	8578
50	669	1209	1878	2680	3620	4695	5901	7242	8718	12070
70	861	1556	2417	3450	4660	6144	7596	9324	11220	15535
90	1050	1897	2947	4207	5680	7370	9260	11365	13685	18945
100	1144	2065	3208	4580	6185	8322	10080	12375	14895	20625
120	1332	2405	3736	5332	7202	9342	11735	14410	17340	24015
140	1516	2738	4254	6070	8200	10635	13365	16405	19745	27340
160	1696	3064	4760	6794	9175	11900	14955	18355	22095	30595
180	1883	3400	5283	7540	10180	13250	16595	20370	24520	33950
200	2062	3724	5786	8258	11150	14465	18175	22310	26855	37185

If we also take 30 lbs. of steam per hour, at 100 lbs. gauge-pressure = 1 h.p., we have from the above table:

Diameter inches .	1	1½	2	2½	3	3½	4	4½	5	6
Horse-power . .	38	69	107	153	206	277	336	412	496	687

A boiler having ample grate surface and strong draft may generate double the quantity of steam its rating calls for; therefore in determining the proper size of safety-valve for a boiler this fact should be taken into consideration and the effective discharge of the valve be double the rated steam-producing capacity of the boiler.

The Consolidated Safety-valve Co.'s circular gives the following rated capacity of its nickel-seat "pop" safety-valves:

Size, in . .	1	1¼	1½	2	2½	3	3½	4	4½	5	5½
Boiler H.P. from	8	10	20	35	60	75	100	125	150	175	200
Boiler H.P. to	10	15	30	50	75	100	125	150	175	200	275

RULES FOR CONDUCTING BOILER TESTS.

The Committee of the A. S. M. E. on Boiler-tests recommended the following revised code of rules for conducting boiler trials. (Trans. vol. xx. See also p. 34, vol. xxi, A. S. M. E., for latest code.

Code of 1897.

Preliminaries to a Trial.

I. *Determine at the outset* the specific object of the proposed trial, whether it be to ascertain the capacity of the boiler, its efficiency as a steam generator, its efficiency and its defects under usual working conditions, the economy of some particular kind of fuel, or the effect of changes of design, proportion, or operation; and prepare for the trial accordingly.

II. *Examine the boiler*, both outside and inside; ascertain the dimensions of grates, heating surfaces, and all important parts; and make a full record, describing the same, and illustrating special features by sketches. The area of heating surfaces is to be computed from the outside diameter of water-tubes and the inside diameter of fire-tubes. All surfaces below the mean water level which have water on one side and products of combustion on the other are to be considered water-heating surface, and all surfaces above the mean water level which have steam on one side and products of combustion on the other are to be considered as superheating surface.

III. *Notice the general condition* of the boiler and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy or capacity of the boiler as a steam generator, the boiler and all its appurtenances should be put in first-class condition. Clean the heating surface inside and outside, remove clinkers from grates and from sides of the furnace. Remove all dust, soot, and ashes from the chambers, smoke connections, and flues. Close air leaks in the masonry and poorly-fitted cleaning-doors. See that the damper will open wide and close tight. Test for air leaks by firing a few shovels of smoky fuel and immediately closing the damper, observing the escape of smoke through the crevices, or by passing the flame of a candle over cracks in the brickwork.

IV. *Determine the character of the coal* to be used. For tests of the efficiency or capacity of the boiler for comparison with other boilers the coal should, if possible, be of some kind which is commercially regarded as a standard. For New England and that portion of the country east of the Allegheny Mountains, good anthracite egg coal, containing not over 10 per cent of ash, and semi-bituminous Clearfield (Pa.), Cumberland (Md.), and Pocahontas (Va.) coals are thus regarded. West of the Allegheny Mountains, Pocahontas (Va.), and New River (W. Va.) semi-bituminous, and Youghiogheny or Pittsburg bituminous coals are recognized as standards.* There is no special grade of coal mined in the Western States which is widely recognized as of superior quality or considered as a standard coal for boiler testing. Big Muddy Lump, an Illinois coal mined in Jackson County, Ill., is

* *These coals are selected because they are about the only coals which contain the essentials of excellence of quality, adaptability to various kinds of furnaces, grates, boilers, and methods of firing, and wide distribution and general accessibility in the markets.*

suggested as being of sufficiently high grade to answer the requirements in districts where it is more conveniently obtainable than the other coals mentioned above.

For tests made to determine the performance of a boiler with a particular kind of coal, such as may be specified in a contract for the sale of a boiler, the coal used should not be higher in ash and in moisture than that specified, since increase in ash and moisture above a stated amount is apt to cause a falling off of both capacity and economy in greater proportion than the proportion of such increase.

V. *Establish the correctness of all apparatus* used in the test for weighing and measuring. These are:

1. Scales for weighing coal, ashes, and water.
2. Tanks, or water meters for measuring water. Water meters, as a rule, should only be used as a check on other measurements. For accurate work, the water should be weighed or measured in a tank.
3. Thermometers and pyrometers for taking temperatures of air, steam, feed-water, waste gases, etc.
4. Pressure gauges, draft gauges, etc.

The kind and location of the various pieces of testing apparatus must be left to the judgment of the person conducting the test; always keeping in mind the main object, i.e., to obtain authentic data.

VI. *See that the boiler is thoroughly heated* before the trial to its usual working temperature. If the boiler is new and of a form provided with a brick setting, it should be in regular use at least a week before the trial, so as to dry and heat the walls. If it has been laid off and become cold, it should be worked before the trial until the walls are well heated.

VII. *The boiler and connections* should be proved to be free from leaks before beginning a test, and all water connections, including blow and extra feed pipes, should be disconnected, stopped with blank flanges, or bled through special openings beyond the valves, except the particular pipe through which water is to be fed to the boiler during the trial. During the test the blow-off and feed-pipes should remain exposed.

If an injector is used, it should receive steam directly through a felted pipe from the boiler being tested.*

If the water is metered after it passes the injector, its temperature should be taken at the point at which it enters the boiler. If the quantity is determined before it goes to the injector, the temperature should be determined on the suction side of the injector, and if no change of temperature occurs other than that due to the injector, the temperature thus determined is properly that of the feed-water. When the temperature changes between the injector and the boiler, as by the use of a heater or by radiation, the temperature at which the water enters and leaves the injector and that at which it enters the boiler should all be taken. The final temperature corrected for the heat received from the injector will be the true feed-water temperature. Thus if the injector receives water at 50° and delivers it at 120° into a heater which raises it to 210°, the corrected temperature is $210 - (120 - 50) = 140°$.

See that the steam main is so arranged that water of condensation cannot run back into the boiler.

VIII. *Starting and Stopping a Test.* — A test should last at least ten hours of continuous running, but, if the rate of combustion exceeds 25 pounds of coal per square foot of grate per hour it may be stopped when a total of 250 pounds of coal has been burned per square foot of grate surface. A longer test may be made when it is desired to ascertain the effect of widely varying conditions, or the performance of a boiler under the working conditions of a prolonged run. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same; the water level the

* *In feeding a boiler undergoing test with an injector taking steam from another boiler, or the main steam pipe from several boilers, the evaporative results may be modified by a difference in the quality of the steam from such source compared with that supplied by the boiler being tested, and in some cases the connection to the injector may act as a drip for the main steam pipe. If it is known that the steam from the main pipe is of the same quality as that furnished by the boiler undergoing the test, the steam may be taken from such main pipe.*

same; the fire upon the grates should be the same in quantity and condition; and the walls, flues, etc., should be of the same temperature. Two methods of obtaining the desired equality of conditions of the fire may be used, viz.: those which were called in the Code of 1885 "the standard method" and "the alternate method," the latter being employed where it is inconvenient to make use of the standard method.

IX. *Standard Method.* — Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash-pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time and the water level while the water is in a quiescent state, just before lighting the fire.

At the end of the test remove the whole fire, which has been burned low, clean the grates and ash-pit, and note the water level when the water is in a quiescent state, and record the time of hauling the fire. The water level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating the pump after the test is completed.

X. *Alternate Method.* — The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the water level, and note this time as the time of starting the test. Fresh coal which has been weighed should now be fired. The ash-pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the bed of coal of the same depth, and in the same condition, on the grates, as at the start. The water level and steam pressures should previously be brought as nearly as possible to the same point as at the start, and the time of ending of the test should be noted just before fresh coal is fired. If the water level is not the same as at the start, a correction should be made by computation, and not by operating the pump after the test is completed.

XI. *Uniformity of Conditions.* — In all trials made to ascertain maximum economy or capacity, the conditions should be maintained uniformly constant. Arrangements should be made to dispose of the steam so that the rate of evaporation may be kept the same from beginning to end. This may be accomplished in a single boiler by carrying the steam through a waste steam pipe, the discharge from which can be regulated as desired. In a battery of boilers, in which only one is tested, the draft can be regulated on the remaining boilers, leaving the test boiler to work under a constant rate of production.

Uniformity of conditions should prevail as to the pressure of steam, the height of water, the rate of evaporation, the thickness of fire, the times of firing and quantity of coal fired at one time, and as to the intervals between the times of cleaning the fires.

XII. *Keeping the Records.* — Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation.

The coal should be weighed and delivered to the fireman in equal proportions, each sufficient for not more than one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the last of each portion. It is desirable that at the same time the amount of water fed into the boiler should be accurately noted and recorded, including the height of the water in the boiler, and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the test may be divided into several periods if desired, and the degree of uniformity of combustion, evaporation, and economy analyzed for each period. In addition to these records of the coal and the feed-water, half hourly observations should be made of the temperature of the feed-water, of the flue gases, of the external air in the boiler-room, of the temperature of the furnace when a furnace pyrometer is used, also of the pressure of steam, and of the readings of the instruments for determining the moisture in the steam. A log should be kept on properly prepared blanks containing columns for record of the various observations.

When the "standard method" of starting and stopping the test is used, the hourly rate of combustion and of evaporation and the horse-power may be computed from the records taken during the time when the fires are in active condition. This time is somewhat less than the actual time which elapses between the beginning and end of the run. This method of computation is necessary, owing to the loss of time due to kindling the fire at the beginning and burning it out at the end.

XIII. *Quality of Steam.*—The percentage of moisture in the steam should be determined by the use of either a throttling or a separating steam calorimeter. The sampling nozzle should be placed in the vertical steam pipe rising from the boiler. It should be made of ½-inch pipe, and should extend across the diameter of the steam pipe to within half an inch of the opposite side, being closed at the end and perforated with not less than twenty ⅛-inch holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than ½ inch to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. Whenever the indications of the throttling or separating calorimeter show that the percentage of moisture is irregular, or occasionally in excess of three per cent, the results should be checked by a steam separator placed in the steam pipe as close to the boiler as convenient, with a calorimeter in the steam pipe just beyond the outlet from the separator. The drip from the separator should be caught and weighed, and the percentage of moisture computed therefrom added to that shown by the calorimeter.

Superheating should be determined by means of a thermometer placed in a mercury well inserted in the steam pipe. The degree of superheating should be taken as the difference between the reading of the thermometer for superheated steam and the readings of the same thermometer for saturated steam at the same pressure as determined by a special experiment, and not by reference to steam tables.

XIV. *Sampling the Coal and Determining its Moisture.*—As each barrow load or fresh portion of coal is taken from the coal pile, a representative shovelful is selected from it and placed in a barrel or box in a cool place and kept until the end of the trial. The samples are then mixed and broken into pieces not exceeding one inch in diameter, and reduced by the process of repeated quartering and crushing until a final sample weighing about five pounds is obtained, and the size of the larger pieces is such that they will pass through a sieve with ¼-inch meshes. From this sample two one-quart, air-tight glass preserving jars, or other air-tight vessels which will prevent the escape of moisture from the sample, are to be promptly filled, and these samples are to be kept for subsequent determinations of moisture and of heating value, and for chemical analyses. During the process of quartering, when the sample has been reduced to about 100 pounds, a quarter to a half of it may be taken for an approximate determination of moisture. This may be made by placing it in a shallow iron pan, not over three inches deep, carefully weighing it, and setting the pan in the hottest place that can be found on the brickwork of the boiler setting or flues, keeping it there for at least twelve hours, and then weighing it. The determination of moisture thus made is believed to be approximately accurate for anthracite and semi-bituminous coals, and also for Pittsburg or Youghiogheny coal; but it cannot be relied upon for coals mined west of Pittsburg, or for other coals containing inherent moisture. For these latter coals it is important that a more accurate method be adopted. The method recommended by the Committee for all accurate tests, whatever the character of the coal, is described as follows:

Take one of the samples contained in the glass jars, and subject it to a thorough air-drying in a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill, adjusted so as to produce somewhat coarse grains (less than $\frac{1}{16}$ inch), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, weigh it in a balance which will easily show a variation as small as 1 part in 1,000, and dry it in an air or sand bath at a temperature between 240 and 280 degrees Fahr. for one hour. Weigh it and record the loss, then heat and weigh it again repeatedly, at intervals of an hour or less, until the minimum weight has been reached and the weight begins to increase by oxidation of a portion of the coal. The difference between the original and the minimum weight is taken as the moisture in the air-dried coal. This moisture should preferably be made on duplicate samples, and the results should agree within 0.3 to 0.4 of one per cent, the mean of the two determinations being taken as the correct result. The sum of the percentage of moisture thus found and the percentage of surface moisture previously determined is the total moisture.

XV. *Treatment of Ashes and Refuse.*—The ashes and refuse are to be weighed in a dry state. For elaborate trials a sample of the same should be procured and analyzed.

XVI. *Calorific Tests and Analysis of Coal.*—The quality of the fuel should be determined either by heat test or by analysis, or by both.

The rational method of determining the total heat of combustion is to burn the sample of coal in an atmosphere of oxygen gas, the coal to be sampled as directed in Article XIV. of this code.

The chemical analysis of the coal should be made only by an expert chemist. The total heat of combustion computed from the results of the ultimate analysis may be obtained by the use of Dulong's formula (with constants modified by recent determinations), viz.: $14{,}600\ C + 62{,}000 \left(H - \frac{O}{8}\right) + 4{,}000\ S$, in which C, H, O, and S refer to the proportions of carbon, hydrogen, oxygen, and sulphur respectively, as determined by the ultimate analysis.*

It is recommended that the analysis and the heat test be each made by two independent laboratories, and the mean of the two results, if there is any difference, be adopted as the correct figures.

It is desirable that a proximate analysis should also be made to determine the relative proportions of volatile matter and fixed carbon in the coal.

XVII. *Analysis of Flue Gases.*—The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing, or of different kinds of furnaces. In making these analyses, great care should be taken to procure average samples—since the composition is apt to vary at different points of the flue. The composition is also apt to vary from minute to minute, and for this reason the drawings of gas should last a considerable period of time. Where complete determinations are desired, the analyses should be intrusted to an expert chemist. For approximate determinations the Orsat or the Hempel apparatus may be used by the engineer.

XVIII. *Smoke Observations.*—It is desirable to have a uniform system of determining and recording the quantity of smoke produced where bituminous coal is used. The system commonly employed is to express the degree of smokiness by means of percentages dependent upon the judgment of the observer. The Committee does not place much value upon a percentage method, because it depends so largely upon the personal element, but if this method is used, it is desirable that, so far as possible, a definition be given in explicit terms as to the basis and method employed in arriving at the percentage.

XIX. *Miscellaneous.*—In tests for purposes of scientific research, in which the determination of all the variables entering into the test is desired, certain observations should be made which are in general unnecessary for ordinary tests. These are the measurement of the air supply, the determination of its contained moisture, the determination of the amount of heat lost by radiation, of the amount of infiltration of air through the setting, and (by condensation of all the steam made by the boiler) of the total heat imparted to the water.

As these determinations are not likely to be undertaken except by engineers of high scientific attainments, it is not deemed advisable to give directions for making them.

XX. *Calculations of Efficiency.*—Two methods of defining and calculating the efficiency of a boiler are recommended. They are:

1. $\text{Efficiency of the boiler} = \dfrac{\text{Heat absorbed per lb. combustible}}{\text{Heating value of 1 lb. combustible}}.$

2. $\text{Efficiency of the boiler and grate} = \dfrac{\text{Heat absorbed per lb. coal}}{\text{Heating value of 1 lb. coal}}.$

* *Favre and Silberman give 14,544 B.T.U. per pound carbon; Berthelot 14,647 B.T.U. Favre and Silberman give 62,032 B.T.U. per pound hydrogen; Thomson 61,816 B.T.U.*

The first of these is sometimes called the efficiency based on combustible, and the second the efficiency based on coal. The first is recommended as a standard of comparison for all tests, and this is the one which is understood to be referred to when the word "efficiency" alone is used without qualification. The second, however, should be included in a report of a test, together with the first, whenever the object of the test is to determine the efficiency of the boiler and furnace together with the grate (or mechanical stoker), or to compare different furnaces, grates, fuels, or methods of firing.

The heat absorbed per pound of combustible (or per pound coal) is to be calculated by multiplying the equivalent evaporation from and at 212° per pound combustible (or coal) by 965.7. (Appendix XXI.)

XXI. *The Heat Balance.*—An approximate "heat balance," or statement of the distribution of the heating value of the coal among the several items of heat utilized and heat lost, may be included in the report of a test when analyses of the fuel and of the chimney gases have been made. It should be reported in the following form:

Heat Balance, or Distribution of the Heating Value of the Combustible.

Total Heat Value of 1 lb. of Combustible . . . . . B. T. U.

	B. T. U	Per Cent.
1. Heat absorbed by the boiler = evaporation from and at 212° per pound of combustible × 965.7.		
2. Loss due to moisture in coal = per cent of moisture referred to combustible ÷ 100 × [(212 − t) + 966 + 0.48 (T − 212)] (t = temperature of air in the boiler-room, T = that of the flue gases).		
3. Loss due to moisture formed by the burning of hydrogen = per cent of hydrogen to combustible ÷ 100 × 9 × [(212 − t) + 966 + 0.48 (T − 212)].		
4.* Loss due to heat carried away in the dry chimney gases = weight of gas per pound of combustible × 0.24 × (T − t).		
5.† Loss due to incomplete combustion of carbon $= \frac{CO}{CO_2 + CO} + \frac{\text{per cent } C \text{ in combustible}}{100} \times 10{,}150$.		
6. Loss due to unconsumed hydrogen and hydrocarbons, to heating the moisture in the air, to radiation, and unaccounted for. (Some of these losses may be separately itemized if data are obtained from which they may be calculated.)		
Totals		100.00

* *The weight of gas per pound of carbon burned may be calculated from the gas analysis as follows:*

Dry gas per pound carbon $= \frac{11\,CO_2 + 8\,O + 7\,(CO + N)}{3\,(CO_2 + CO)}$, *in which* CO_2, *CO, O, and N are the percentages by volume of the several gases. As the sampling and analyses of the gases in the present state of the art are liable to considerable errors, the result of this calculation is usually only an approximate one. The heat balance itself is also only approximate for this reason, as well as for the fact that it is not possible to determine accurately the percentage of unburned hydrogen or hydrocarbons in the flue gases.*

The weight of dry gas per pound of combustible is found by multiplying the dry gas per pound of carbon by the percentage of carbon in the combustible, and dividing by 100.

† *CO_2 and CO are respectively the percentage by volume of carbonic acid and carbonic oxide in the flue gases. The quantity 10,150 = No. heat units generated by burning to carbonic acid one pound of carbon contained in carbonic oxide.*

XXII. *Report of the Trial.*—The data and results should be reported in the manner given in either one of the two following tables, omitting lines where the tests have not been made as elaborately as provided for in such tables. Additional lines may be added for data relating to the specific object of the test. The extra lines should be classified under the headings provided in the tables, and numbered, as per preceding line, with sub letters, *a*, *b*, etc. The Short Form of Report, Table No. 2, is recommended for commercial tests and as a convenient form of abridging the longer form for publication when saving of space is desirable.

Table No. 1.

Data and Results of Evaporative Test.

Arranged in accordance with the complete form advised by the Boiler Test Committee of the American Society of Mechanical Engineers.

Made by . . . . of . . . . boiler at . . . . . . to
determine . . . .
Principal conditions governing the trial . . . .
. . . .
. . . .
Kind of fuel . . . .
Kind of furnace . . . .
State of the weather . . . .
1. Date of trial . . . .
2. Duration of trial . . . . hours

Dimensions and Proportions.

(A complete description of the boiler should be given on an annexed sheet.)

3.	Grate surface . . . width . . . length . . . area . .	sq. ft.
4.	Water-heating surface	"
5.	Superheating surface	"
6.	Ratio of water-heating surface to grate surface	
7.	Ratio of minimum draft area to grate surface	

Average Pressures.

8.	Steam pressure by gauge	lbs.
9.	Force of draft between damper and boiler	ins. of water
10.	Force of draft in furnace	" "
11.	Force of draft or blast in ash-pit	" "

Average Temperatures.

12.	Of external air	deg.
13.	Of fireroom	"
14.	Of steam	"
15.	Of feed-water entering heater	"
16.	Of feed-water entering economizer	"
17.	Of feed-water entering boiler	"
18.	Of escaping gases from boiler	"
19.	Of escaping gases from economizer	"

Fuel.

20.	Size and condition	
21.	Weight of wood used in lighting fire	lbs.
22.	Weight of coal as fired *.	"

* *Including equivalent of wood used in lighting the fire, not including unburnt coal withdrawn from furnace at times of cleaning and at end of test. One pound of wood is taken to be equal to 0.4 pound of coal, or, in case greater accuracy is desired, as having a heat value equivalent to the evaporation of 6 pounds of water from and at 212° per pound (6 × 965.7 = 5,794 B.T.U.).*

23. Percentage of moisture in coal *	per cent.
24. Total weight of dry coal consumed	lbs.
25. Total ash and refuse	lbs.
26. Total combustible consumed	
27. Percentage of ash and refuse in dry coal	per cent

Proximate Analysis of Coal.

	Of Coal.	Of Combustible.
28. Fixed carbon	per cent.	per cent.
29. Volatile matter	"	"
30. Moisture	"	——
31. Ash	"	——
	100 per cent	100 per cent.
32. Sulphur, separately determined	"	"

Ultimate Analysis of Dry Coal.

33. Carbon (*C*)	per cent.
34. Hydrogen (*H*)	"
35. Oxygen (*O*)	"
36. Nitrogen (*N*)	"
37. Sulphur (*S*)	"
	100 per cent.
38. Moisture in sample of coal as received	"

Analysis of Ash and Refuse.

39. Carbon	per cent.
40. Earthy matter	"

Fuel per Hour.

41. Dry coal consumed per hour	lbs.
42. Combustible consumed per hour	"
43. Dry coal per square foot of grate surface per hour	"
44. Combustible per square foot of water-heating surface per hour	"

Calorific Value of Fuel.

45. Calorific value by oxygen calorimeter, per lb. of dry coal	B. T. U.
46. Calorific value by oxygen calorimeter, per lb. of combustible	"
47. Calorific value by analysis, per lb. of dry coal†	"
48. Calorific value by analysis, per lb. of combustible	"

Quality of Steam.

49. Percentage of moisture in steam	per cent.
50. Number of degrees of superheating	deg.
51. Quality of steam (dry steam = unity)	

Water.

52. Total weight of water fed to boiler ‡	lbs.
53. Equivalent water fed to boiler from and at 212°	"
54. Water actually evaporated, corrected for quality of steam	"
55. Factor of evaporation §	"
56. Equivalent water evaporated into dry steam from and at 212°. (Item 54 × Item 55)	"

* *This is the total moisture in the coal as found by drying it artificially.*

† *See formula for calorific value under Article XVI. of Code.*

‡ *Corrected for inequality of water level and of steam pressure at beginning and end of test.*

§ *Factor of evaporation* $= \frac{H - h}{965.7}$, *in which H and h are respectively the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.*

Water per Hour

57. Water evaporated per hour, corrected for quality of steam	lbs.
58. Equivalent evaporation per hour from and at 212°	"
59. Equivalent evaporation per hour from and at 212° per square foot of water-heating surface	"

Horse-Power.

60. Horse-power developed. (34½ lbs. of water evaporated per hour into dry steam from and at 212° equals one horse-power) *	H.P.
61. Builders' rated horse-power	"
62. Percentage of builders' rated horse-power developed . . .	per cent.

Economic Results.

63. Water apparently evaporated per lb. of coal under actual conditions. (Item 53 ÷ Item 22)	lbs.
64. Equivalent evaporation from and at 212° per lb. of coal (including moisture). (Item 56 ÷ Item 22)	"
65. Equivalent evaporation from and at 212° per lb. of dry coal. (Item 56 ÷ Item 24)	"
66. Equivalent evaporation from and at 212° per lb. of combustible. (Item 56 ÷ Item 26)	"
(If the equivalent evaporation, Items 64, 65, and 66, is not corrected for the quality of steam, the fact should be stated.)	

Efficiency.

67. Efficiency of the boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible †	per cent.
68. Efficiency of boiler, including the grate; heat absorbed by the boiler, per lb. of dry coal fired, divided by the heat value of one lb. of dry coal ‡	

Cost of Evaporation.

69. Cost of coal per ton of 2,240 lbs. delivered in boiler room .	$
70. Cost of fuel for evaporating 1,000 lbs. of water under observed conditions	$
71. Cost of fuel used for evaporating 1,000 lbs. of water from and at 212°	$

Smoke Observations.

72. Percentage of smoke as observed	
73. Weight of soot per hour obtained from smoke meter . . .	
74. Volume of soot obtained from smoke meter per hour . .	

Table No. 2.

Data and Results of Evaporative Test.

Arranged in accordance with the Short Form advised by the Boiler Test Committee of the American Society of Mechanical Engineers.

Made by . . . . on . . . . boiler, at . . . . . . to determine . . . .

* *Held to be the equivalent of 30 lbs. of water per hour evaporated from 100° Fahr. into dry steam at 70 lbs. gauge pressure.*

† *In all cases where the word "combustible" is used, it means the coal without moisture and ash, but including all other constituents. It is the same as what is called in Europe "coal dry and free from ash."*

‡ *The heat value of the coal is to be determined either by an oxygen calorimeter or by calculation from ultimate analysis. When both methods are used the mean value is to be taken.*

Grate surface . . . . sq. ft.
Water-heating surface . . . . “
Superheating surface . . . . “
Kind of fuel . . . .
Kind of furnace . . . .

Total Quantities.

1. Date of trial . . . .
2. Duration of trial . . . . hours.
3. Weight of coal as fired . . . . lbs.
4. Percentage of moisture in coal . . . . per cent.
5. Total weight of dry coal consumed . . . . lbs.
6. Total ash and refuse . . . . “
7. Percentage of ash and refuse in dry coal . . . . per cent.
8. Total weight of water fed to the boiler . . . . lbs.
9. Water actually evaporated, corrected for moisture or superheat in steam . . . . “

Hourly Quantities.

10. Dry coal consumed per hour . . . . lbs.
11. Dry coal per hour per square foot of grate surface . . . “
12. Water fed per hour . . . . “
13. Equivalent water evaporated per hour from and at 212° corrected for quality of steam . . . . “
14. Equivalent water evaporated per square foot of water-heating hour . . . . “

Average Pressures, Temperatures, etc.

15. Average boiler pressure . . . . lbs. per sq. in
16. Average temperature of feed-water . . . . deg.
17. Average temperature of escaping gases . . . . “
18. Average force of draft between damper and boiler . . . ins. of water
19. Percentage of moisture in steam, or number of degrees of superheating . . . .

Horse-Power.

20. Horse-power developed (Item 13 ÷ 34½) . . . . H.P.
21. Builders' rated horse-power . . . . “
22. Percentage of builders' rated horse-power . . . . per cent.

Economic Results.

23. Water apparently evaporated per pound of coal under actual conditions. (Item 8 ÷ Item 3) . . . . lbs.
24. Equivalent water actually evaporated from and at 212° per pound of coal as fired. (Item 9 ÷ Item 3) . . . . . “
25. Equivalent evaporation from and at 212° per pound of dry coal. (Item 9 ÷ Item 5) . . . . “
26. Equivalent evaporation from and at 212° per pound of combustible. [Item 9 ÷ (Item 5 — Item 6)] . . . . .
(If Items 23, 24, and 25 are not corrected for quality of steam, the fact should be stated.)

Efficiency.

27. Heating value of the coal per pound . . . . B.T.U.
28. Efficiency of boiler (based on combustible) . . . . “
29. Efficiency of boiler, including grate (based on coal) . . . “

Cost of Evaporation.

30. Cost of coal per ton of 2,240 pounds delivered in boiler-room $
31. Cost of coal required for evaporation of 1,000 pounds of water from and at 212° . . . . $

DETERMINATION OF THE MOISTURE IN STEAM.

The determination of the quality of steam supplied by a boiler is one of the most important items in a boiler test. The three conditions to be determined are:

a. If the steam is *saturated*, i.e., contains the quantity of heat due to the pressure.
b. If the steam is *wet*, i.e., contains less than the amount of heat due to the pressure.
c. If the steam is superheated, i.e., contains more than the amount of heat due to the pressure.

There are several methods of determining the quality of steam; one being to condense all the steam evaporated by a boiler in a surface condenser, and weigh the condensing water, taking the temperature at its entrance to and exit from the condenser. Another is by use of a barrel calorimeter, in which a sample of the steam is condensed directly in a barrel partly filled with cold water, the added weight and temperature taken, and by use of a formula the quality of steam can be determined.

Both the above-named methods are now practically obsolete, as their place has been taken by the *throttling* calorimeter, used for steam in which the moisture does not exceed 3 per cent, and the *separating* calorimeter, for steam containing a greater amount of moisture.

Throttling Calorimeter.

In its simplest form this instrument can be made up from pipe fittings, the only special parts necessary being the throttling nozzle, which is readily made by boring out a piece of brass rod that is the same diameter as a half-inch steam pipe, leaving a small hole in one end, say $\frac{1}{16}$ inch diameter. The inside end of the small hole should be tapered with the end of a drill so as not to cause eddies; and the thermometer well, which is a small piece of brass pipe, plugged at one end, and fitted into a half-inch brushing to fit into place. The following cut shows the instrument as made up from fittings. The whole must be carefully covered with some non-conductor, as hair felt.

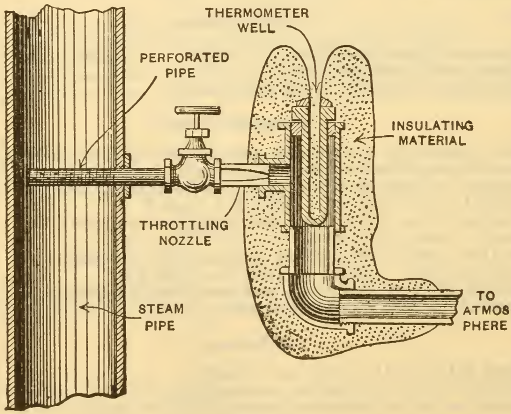


FIG. 7.

For more accurate work the instruments designed by George H. Barrus, M.E., and Prof. R. C. Carpenter, are to be preferred. Professor Carpenter's instrument is shown in the following cut, and differs from the primitive instrument previously described only by the addition of the *manometer*, which determines the pressure of the steam above the atmosphere in the body of the calorimeter. With a free exit to the air the pressure in the calorimeter may be taken as that of the atmosphere.

Carpenter's Throttling Calorimeter.

($\frac{1}{4}$ size. Schaeffer & Budenberg.)

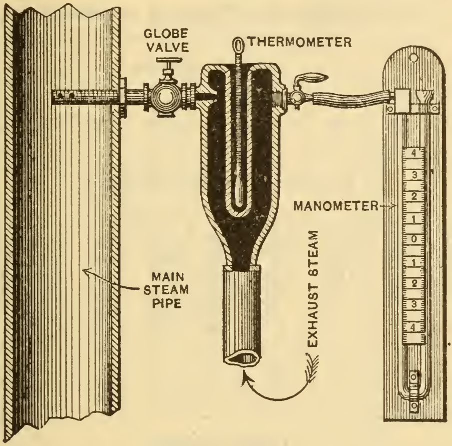


FIG. 8.

The perforated pipe for obtaining the sample of steam to be tested should preferably be inserted in a vertical pipe, and should reach nearly across its diameter.

Directions for Use. — Connect as shown in the preceding cuts, fill the thermometer cup with cylinder oil and insert the thermometer. Turn on the Globe valve for ten minutes or more in order to bring the temperature of the instrument to full heat, after which note the reading of the thermometer in the calorimeter, and of the attached manometer or of a barometer. The steam gauge should be carefully calebrated to see that it is correct. A barometer reading taken at the time the calorimeter is in use, gives greater accuracy in working up the results than taking the average atmospheric pressure as 14.65 pounds. Pressure in pounds may be determined from the mercury column of the barometer and manometer by dividing the inches rise by 2.03, or taking one pound for each two inches of mercury.

Following is the formula for determining the quality of steam by use of the *throttling calorimeter.*

$H =$ total heat in a pound of steam at the pressure in the pipe.
$h =$ total heat in a pound of steam at the pressure in the calorimeter.
$L =$ latent heat in a pound of steam at the pressure in the pipe.
$t =$ temperature in the calorimeter.
$b =$ temperature of boiling point at calorimeter pressure (taken as $212°$ with the "fittings" instrument).
$0.48 =$ specific heat of superheated steam.
$x =$ quality of the steam.
$y =$ percentage of moisture in the steam.

$$y = \frac{H - h - .48\,(t - b)}{L} \times 100.$$

$$x = 100 - y.$$

If h be taken as 212°, as it can be with but slight error, then

$$y = \frac{H - 1146.6 - .48\ (t - 212)}{L} \times 100.$$

Following are tables calculated from the above formula.

Moisture in Steam.

Determinations by Throttling Calorimeter.

$(t - b)$	Gauge-pressures.											
	5	10	20	30	40	50	60	70	75	80	85	90
	Per Cent of Moisture in Steam.											
0°	0.51	0.90	1.54	2.06	2.50	2.90	3.24	3.56	3.71	3.86	3.99	4.13
10°	0.01	0.39	1.02	1.54	1.97	2.36	2.71	3.02	3.17	3.32	3.45	3.58
20°	. . .	. . .	.51	1.02	1.45	1.83	2.17	2.48	2.63	2.77	2.90	3.03
30°	. . .	. . .	.00	.50	.92	1.30	1.64	1.94	2.09	2.23	2.35	2.49
40°	. . .	. . .	. . .	. . .	.39	.77	1.10	1.40	1.55	1.69	1.80	1.94
50°	. . .	. . .	. . .	. . .	. . .	.24	.57	.87	1.01	1.15	1.26	1.40
60°	. . .	. . .	. . .	. . .	. . .	. . .	.03	.33	.47	.60	.72	.85
70°	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	.06	.17	.31

$(t - b)$	Gauge-pressure.											
	100	110	120	130	140	150	160	170	180	190	200	250
	Per Cent of Moisture in Steam.											
0°	4.39	4.63	4.85	5.08	5.29	5.49	5.68	5.87	6.05	6.22	6.39	7.16
10°	3.84	4.08	4.29	4.52	4.73	4.93	5.12	5.30	5.48	5.65	5.82	6.58
20°	3.29	3.52	3.74	3.96	4.17	4.37	4.56	4.74	4.91	5.08	5.25	6.00
30°	2.74	2.97	3.18	3.41	3.61	3.80	3.99	4.17	4.34	4.51	4.67	5.41
40°	2.19	2.42	2.63	2.85	3.05	3.24	3.43	3.61	3.78	3.94	4.10	4.83
50°	1.64	1.87	2.08	2.29	2.49	2.68	2.87	3.04	3.21	3.37	3.53	4.25
60°	1.09	1.32	1.52	1.74	1.93	2.12	2.30	2.48	2.64	2.80	2.96	3.67
70°	.55	.77	.97	1.18	1.38	1.56	1.74	1.91	2.07	2.23	2.38	3.09
80°	.00	.22	.42	.63	.82	1.00	1.18	1.34	1.50	1.66	1.81	2.51
90°	. . .	. . .	. . .	.07	.26	.44	.61	.78	.94	1.09	1.24	1.93
100°	. . .	. . .	. . .	. . .	. . .	. . .	.05	.21	.37	.52	.67	1.34
110°	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	.10	.76

The easiest method of making the determinations from the observations is by use of the following diagram, prepared by Professor Carpenter.

Find in the vertical column at the left the pressure observed in the main pipe + atmospheric pressure (the absolute pressure), then move horizontally to the right until over the line giving the degree of superheat $(t - b)$, and the quality of steam will be found in a curve corresponding to one of those shown, and which may be interpolated where results do not some on one of the lines laid down.

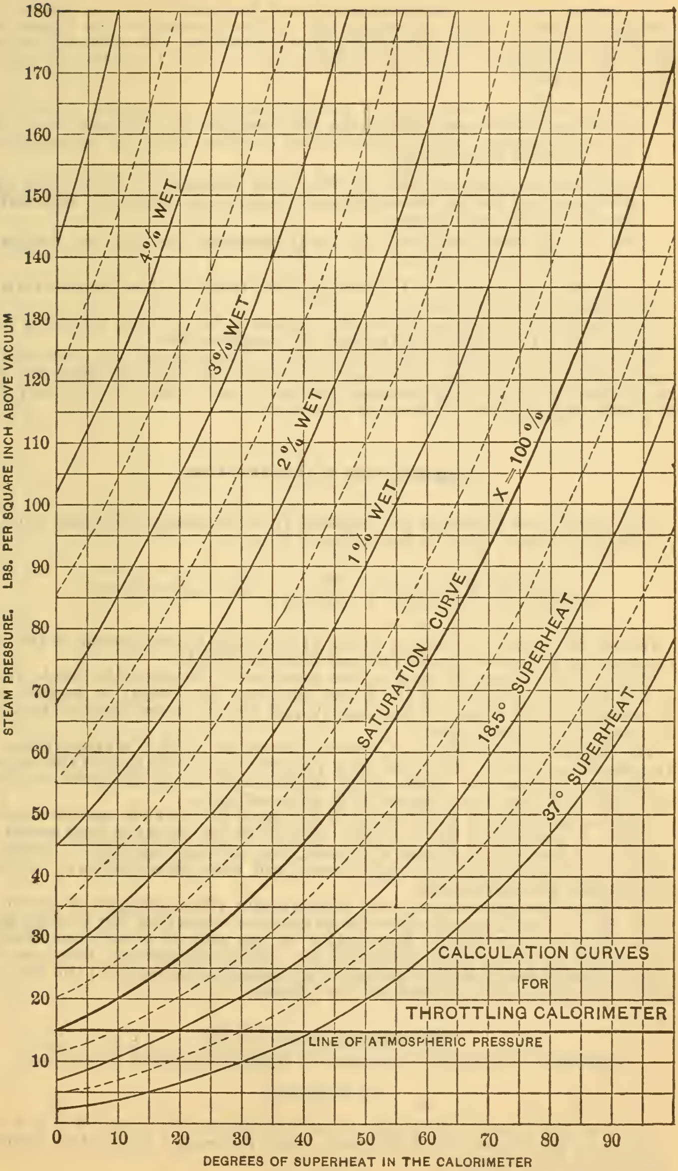


DIAGRAM GIVING RESULTS FROM THROTTLING CALORIMETER WITHOUT COMPUTATION

FIG. 9

By putting a valve in the discharge pipe of the calorimeter, being careful that when open it offers no obstruction to a free passage of the steam, determinations may be made from temperatures without reference to a steam table, and by using the following diagram by Professor Carpenter no calculation is necessary.

a. Determine the boiling-point of the instrument by opening supply and discharge valves, and showering the instrument with cold water to produce moisture in the calorimeter, in which case the boiling-point will be 212° or thereabouts.

b. Determine temperature due to the boiler pressure by closing the discharge-valve, leaving the supply-valve open, and obtain the full boiler pressure in the calorimeter.

c. Open the discharge-valve and let the thermometer settle to the temperature due to the superheat.

Deduct the temperature of the boiling-point from this last temperature to obtain the degrees superheat.

Suppose the boiling-point of the calorimeter to be 213°, the following diagram will give the result directly from the temperatures.

To use the diagram when the boiling-point differs from 212°, add to the temperature of superheat the difference between the true boiling-point and 212°, if less than 212°; and subtract the difference if the true boiling-point be greater than 212; use the result as before.

Separating Calorimeter.

This instrument separates the moisture from the sample of steam, and the percentage is then found by the ordinary formula.

$$\frac{\text{amount of moisture} \times 100}{\text{total steam discharged as sample}} = \text{per cent moisture.}$$

One of the most convenient forms of this type of calorimeter is the one designed by Professor Carpenter, and shown in Fig. 11.

The sample of steam is let into the instrument through the angle valve 6, the moisture gathers in the inner chamber, its weight in pounds and hundredths being shown on the scale 12, and the dry steam flows out through the small calibrated orifice 8.

By Napier's law the flow of steam through an orifice is proportional to the absolute pressure, until the back pressure equals .58 that of the supply.

The gauge 9 at the right shows in the outer scale the flow of steam through the orifice 8 in a period of 10 minutes' time.

After attaching the instrument to the pipe from which sample is taken through a perforated pipe as with the throttling or other instrument, it must be thoroughly wrapped with hair, felt, or other insulator. Steam is then turned on through the angle valve, and time enough allowed to thoroughly heat the instrument.

In taking an observation, first observe and record height of water on scale 12, then let the steam flow for 10 minutes, observing the average position of the pointer on the flow-gauge; at the end of 10 minutes observe the height of water in gauge 12, and the difference between this and the first observation will be the amount of moisture in the sample; the percentage of moisture will then be found as follows:

$$\frac{\text{difference in scale 12} \times 100}{\text{difference on scale 12} + \text{average for 10 minutes on the flow-gauge}}$$

$$= \%\ \text{moisture.}$$

For tests and data on "Calorimeters," see papers in Trans. A.S.M.E., by Messrs G. H. Barrus, A. A. Goubert, and Professors Carpenter, Denton, Jacobus, and Peabody.

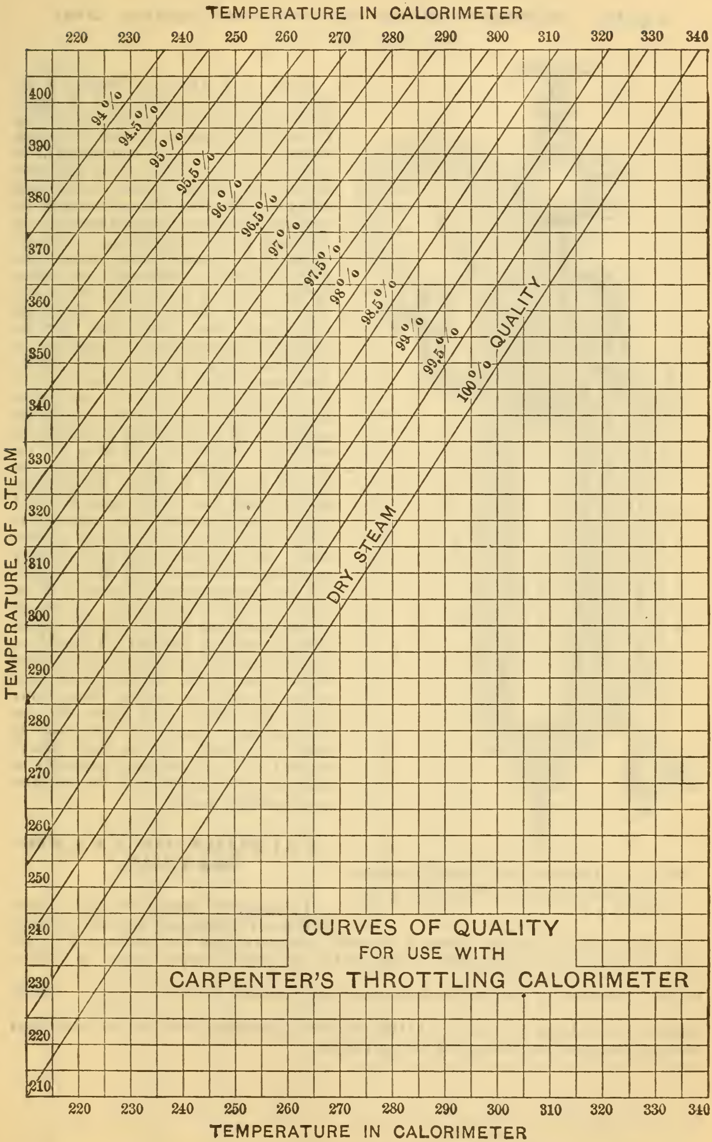


DIAGRAM FOR COMPUTING RESULTS WITH THROTTLING CALORIMETER.
FIG. 10.

Quality of Steam Shown by Color of Issuing Jet.

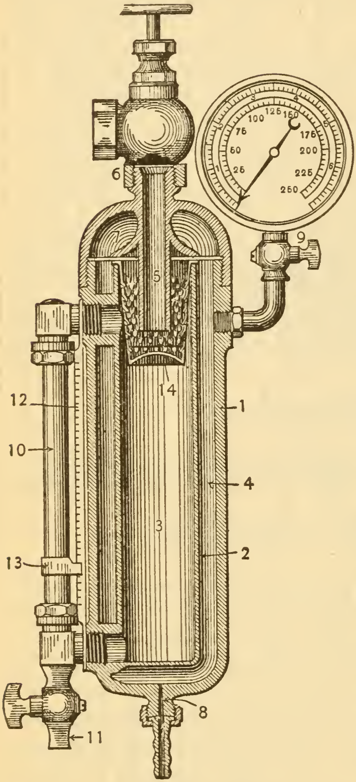


FIG. 11. Carpenter's New Evaporating Calorimeter. (Schaeffer & Budenberg.)

Prof. J. E. Denton (Trans. A. S. M. E., vol. x., p. 349) has demonstrated that jets of steam escaping from an orifice in a boiler or steam reservoir show unmistakable change of appearance to the eye when the steam varies less than one per cent from the condition of saturation either in the direction of wetness or superheating. Consequently if a jet of steam flow from a boiler into the atmosphere under circumstances such that very little loss of heat occurs through radiation, etc., and the jet be transparent close to the orifice, or be even a grayish white color, the steam may be assumed to be so nearly dry that no portable condensing calorimeter will be capable of measuring the amount of water therein. If the jet be strongly white, the amount of water may be roughly judged up to about 2 per cent, but beyond this a calorimeter only can determine the exact amount of moisture. With a little experience any one may determine by this method the conditions of steam within the above limits. A common brass pet cock may be used as an orifice, but it should, if possible, be set into the steam drum of the boiler and never be placed farther away from the latter than four feet, and then only when the intermediate reservoir or pipe is well covered, for a very short travel of dry steam through a naked pipe will cause it to become perceptibly moist.

FACTORS OF EVAPORATION.

In order to facilitate the calculation of reducing the actual rate of evaporation of water from a certain temperature into steam of a certain pressure, into the rate from water at 212° F. into steam of 212° a table of *factors of evaporation* is made up from the formula $\frac{H - h}{965.7}$ where H is the total heat of steam at the observed pressure, and h the total heat of feed-water of the observed temperature.

Table of Factors of Evaporation.

(W. W. Christie, M.E.)

Gauge Pressure. Temp. of Feed.	0 lbs.	10 lbs.	20 lbs.	30 lbs.	40 lbs.	45 lbs.	50 lbs.	52 lbs.	54 lbs.
212° F.	1.0003	1.0088	1.0149	1.0197	1.0237	1.0254	1.0271	1.0277	1.0283
209	1.0035	1.0120	1.0180	1.0228	1.0268	1.0286	1.0302	1.0309	1.0315
206	1.0066	1.0151	1.0212	1.0260	1.0299	1.0317	1.0334	1.0340	1.0346
203	1.0098	1.0183	1.0243	1.0291	1.0331	1.0349	1.0365	1.0372	1.0378
200	1.0129	1.0214	1.0275	1.0323	1.0362	1.0380	1.0397	1.0403	1.0409
197	1.0160	1.0246	1.0306	1.0354	1.0394	1.0412	1.0428	1.0434	1.0441
194	1.0192	1.0277	1.0338	1.0385	1.0425	1.0443	1.0460	1.0466	1.0472
191	1.0223	1.0308	1.0369	1.0417	1.0457	1.0474	1.0491	1.0497	1.0503
188	1.0255	1.0340	1.0400	1.0448	1.0488	1.0506	1.0522	1.0528	1.0535
185	1.0286	1.0371	1.0432	1.0480	1.0519	1.0537	1.0554	1.0560	1.0566
182	1.0317	1.0403	1.0463	1.0511	1.0551	1.0568	1.0585	1.0591	1.0598
179	1.0349	1.0434	1.0495	1.0542	1.0582	1.0600	1.0616	1.0623	1.0629
176	1.0380	1.0465	1.0526	1.0574	1.0613	1.0631	1.0648	1.0654	1.0660
173	1.0411	1.0497	1.0557	1.0605	1.0645	1.0663	1.0679	1.0685	1.0692
170	1.0443	1.0528	1.0589	1.0636	1.0676	1.0694	1.0710	1.0717	1.0723
167	1.0474	1.0559	1.0620	1.0668	1.0707	1.0725	1.0742	1.0748	1.0754
164	1.0505	1.0591	1.0651	1.0699	1.0739	1.0756	1.0773	1.0780	1.0786
161	1.0537	1.0622	1.0682	1.0730	1.0770	1.0788	1.0804	1.0811	1.0817
158	1.0568	1.0653	1.0714	1.0762	1.0801	1.0819	1.0836	1.0842	1.0848
155	1.0599	1.0684	1.0745	1.0793	1.0833	1.0850	1.0867	1.0873	1.0880
152	1.0631	1.0716	1.0776	1.0824	1.0864	1.0882	1.0898	1.0905	1.0911
149	1.0662	1.0747	1.0808	1.0855	1.0895	1.0913	1.0930	1.0936	1.0942
146	1.0693	1.0778	1.0839	1.0887	1.0926	1.0944	1.0961	1.0967	1.0973
143	1.0724	1.0810	1.0870	1.0918	1.0958	1.0975	1.0992	1.0998	1.1005
140	1.0756	1.0841	1.0901	1.0949	1.0989	1.1007	1.1023	1.1030	1.1036
137	1.0787	1.0872	1.0933	1.0980	1.1020	1.1038	1.1055	1.1061	1.1067
134	1.0818	1.0903	1.0964	1.1012	1.1051	1.1069	1.1086	1.1092	1.1098
131	1.0849	1.0934	1.0995	1.1043	1.1083	1.1100	1.1117	1.1123	1.1130
128	1.0881	1.0966	1.1026	1.1074	1.1114	1.1132	1.1148	1.1155	1.1161
125	1.0912	1.0997	1.1057	1.1105	1.1145	1.1163	1.1179	1.1186	1.1192
122	1.0943	1.1028	1.1089	1.1136	1.1176	1.1194	1.1211	1.1217	1.1223
119	1.0974	1.1059	1.1120	1.1168	1.1207	1.1225	1.1242	1.1248	1.1254
116	1.1005	1.1090	1.1151	1.1199	1.1239	1.1256	1.1273	1.1279	1.1286
113	1.1036	1.1122	1.1182	1.1230	1.1270	1.1288	1.1304	1.1310	1.1317
110	1.1068	1.1153	1.1213	1.1261	1.1301	1.1319	1.1335	1.1342	1.1348
107	1.1099	1.1184	1.1245	1.1292	1.1332	1.1350	1.1366	1.1373	1.1379
104	1.1130	1.1215	1.1276	1.1323	1.1363	1.1381	1.1398	1.1404	1.1410
101	1.1161	1.1246	1.1307	1.1355	1.1394	1.1412	1.1429	1.1435	1.1441
98	1.1192	1.1277	1.1338	1.1386	1.1426	1.1443	1.1460	1.1466	1.1473
95	1.1223	1.1309	1.1369	1.1417	1.1457	1.1475	1.1491	1.1497	1.1504
92	1.1255	1.1340	1.1400	1.1448	1.1488	1.1506	1.1522	1.1529	1.1535
89	1.1286	1.1371	1.1431	1.1479	1.1519	1.1537	1.1553	1.1560	1.1566
86	1.1317	1.1402	1.1463	1.1510	1.1550	1.1568	1.1584	1.1591	1.1597
83	1.1348	1.1433	1.1494	1.1541	1.1581	1.1599	1.1616	1.1622	1.1628
80	1.1379	1.1464	1.1525	1.1573	1.1612	1.1630	1.1647	1.1653	1.1659
77	1.1410	1.1495	1.1556	1.1604	1.1644	1.1661	1.1678	1.1684	1.1690
74	1.1441	1.1526	1.1587	1.1635	1.1675	1.1692	1.1709	1.1715	1.1722
71	1.1472	1.1558	1.1618	1.1666	1.1706	1.1723	1.1740	1.1746	1.1753
68	1.1504	1.1589	1.1649	1.1697	1.1737	1.1755	1.1771	1.1778	1.1784
65	1.1535	1.1620	1.1680	1.1728	1.1768	1.1786	1.1802	1.1809	1.1815
62	1.1566	1.1651	1.1711	1.1759	1.1799	1.1817	1.1833	1.1840	1.1846
59	1.1597	1.1682	1.1743	1.1790	1.1830	1.1848	1.1864	1.1871	1.1877
56	1.1628	1.1713	1.1774	1.1821	1.1861	1.1879	1.1896	1.1902	1.1908
53	1.1659	1.1744	1.1805	1.1852	1.1892	1.1910	1.1927	1.1933	1.1939
50	1.1690	1.1775	1.1836	1.1884	1.1923	1.1941	1.1958	1.1964	1.1970
47	1.1721	1.1806	1.1867	1.1915	1.1954	1.1972	1.1989	1.1995	1.2001
44	1.1752	1.1837	1.1898	1.1946	1.1986	1.2003	1.2020	1.2026	1.2032
41	1.1783	1.1868	1.1929	1.1977	1.2017	1.2034	1.2051	1.2057	1.2064
38	1.1814	1.1900	1.1960	1.2008	1.2048	1.2065	1.2082	1.2088	1.2095
35	1.1845	1.1931	1.1991	1.2039	1.2079	1.2096	1.2113	1.2119	1.2126
32	1.1876	1.1962	1.2022	1.2070	1.2110	1.2128	1.2144	1.2151	1.2157

Table of Factors of Evaporation.

Gauge Pressure. / Temp. of Feed.	56 lbs.	58 lbs.	60 lbs.	65 lbs.	70 lbs.	75 lbs.	80 lbs.	85 lbs.	90 lbs.	95 lbs.
212° F.	1.0290	1.0295	1.0301	1.0315	1.0329	1.0341	1.0353	1.0365	1.0376	1.0387
209	1.0321	1.0327	1.0333	1.0346	1.0360	1.0372	1.0385	1.0397	1.0408	1.0419
206	1.0352	1.0358	1.0364	1.0378	1.0391	1.0403	1.0416	1.0428	1.0439	1.0450
203	1.0384	1.0390	1.0396	1.0464	1.0423	1.0435	1.0448	1.0460	1.0471	1.0482
200	1.0415	1.0421	1.0427	1.0441	1.0454	1.0466	1.0479	1.0491	1.0502	1.0513
197	1.0447	1.0453	1.0458	1.0477	1.0486	1.0498	1.0511	1.0522	1.0533	1.0544
194	1.0478	1.0484	1.0490	1.0504	1.0517	1.0529	1.0542	1.0553	1.0565	1.0576
191	1.0510	1.0515	1.0521	1.0535	1.0549	1.0561	1.0573	1.0585	1.0596	1.0607
188	1.0541	1.0547	1.0553	1.0566	1.0580	1.0592	1.0605	1.0616	1.0628	1.0639
185	1.0572	1.0578	1.0584	1.0598	1.0611	1.0623	1.0636	1.0648	1.0659	1.0670
182	1.0604	1.0610	1.0615	1.0629	1.0643	1.0655	1.0668	1.0679	1.0690	1.0701
179	1.0635	1.0641	1.0647	1.0660	1.0674	1.0686	1.0699	1.0710	1.0722	1.0733
176	1.0666	1.0672	1.0678	1.0692	1.0705	1.0717	1.0730	1.0742	1.0753	1.0764
173	1.0698	1.0704	1.0709	1.0723	1.0737	1.0749	1.0762	1.0773	1.0784	1.0795
170	1.0729	1.0735	1.0741	1.0754	1.0768	1.0780	1.0793	1.0804	1.0816	1.0827
167	1.0760	1.0766	1.0772	1.0786	1.0799	1.0811	1.0824	1.0836	1.0847	1.0858
164	1.0792	1.0798	1.0803	1.0817	1.0831	1.0843	1.0856	1.0867	1.0878	1.0889
161	1.0823	1.0829	1.0835	1.0848	1.0862	1.0874	1.0887	1.0898	1.0910	1.0921
158	1.0854	1.0860	1.0866	1.0880	1.0893	1.0905	1.0918	1.0929	1.0941	1.0952
155	1.0886	1.0892	1.0897	1.0911	1.0925	1.0937	1.0949	1.0961	1.0972	1.0983
152	1.0917	1.0923	1.0929	1.0942	1.0956	1.0968	1.0981	1.0992	1.1004	1.1015
149	1.0948	1.0954	1.0960	1.0974	1.0987	1.0999	1.1012	1.1023	1.1035	1.1046
146	1.0979	1.0985	1.0991	1.1005	1.1018	1.1030	1.1043	1.1055	1.1066	1.1077
143	1.1011	1.1017	1.1022	1.1036	1.1050	1.1062	1.1074	1.1086	1.1097	1.1108
140	1.1042	1.1048	1.1054	1.1067	1.1081	1.1093	1.1106	1.1117	1.1129	1.1140
137	1.1073	1.1079	1.1085	1.1099	1.1112	1.1124	1.1137	1.1148	1.1160	1.1171
134	1.1104	1.1110	1.1116	1.1130	1.1143	1.1155	1.1168	1.1180	1.1191	1.1202
131	1.1136	1.1142	1.1147	1.1161	1.1175	1.1187	1.1199	1.1210	1.1222	1.1233
128	1.1167	1.1173	1.1179	1.1192	1.1206	1.1218	1.1231	1.1242	1.1253	1.1264
125	1.1198	1.1204	1.1210	1.1223	1.1237	1.1249	1.1262	1.1273	1.1285	1.1296
122	1.1229	1.1235	1.1241	1.1255	1.1268	1.1280	1.1293	1.1294	1.1316	1.1327
119	1.1260	1.1266	1.1272	1.1286	1.1299	1.1311	1.1324	1.1336	1.1347	1.1358
116	1.1292	1.1298	1.1303	1.1317	1.1331	1.1343	1.1355	1.1366	1.1378	1.1389
113	1.1323	1.1329	1.1334	1.1348	1.1362	1.1374	1.1387	1.1398	1.1409	1.1420
110	1.1354	1.1360	1.1366	1.1374	1.1393	1.1405	1.1418	1.1429	1.1441	1.1452
107	1.1385	1.1391	1 1397	1.1411	1.1424	1.1436	1.1449	1.1460	1.1472	1.1483
104	1.1416	1.1422	1.1428	1.1442	1.1455	1.1467	1.1480	1.1491	1.1503	1.1514
101	1.1447	1.1453	1.1459	1.1473	1.1486	1.1498	1.1511	1.1523	1.1534	1.1545
98	1.1479	1.1485	1.1490	1.1504	1.1518	1.1530	1.1542	1.1554	1.1565	1.1576
95	1.1510	1.1516	1.1521	1.1535	1.1549	1.1561	1.1574	1.1583	1.1596	1.1607
92	1.1541	1.1547	1.1553	1.1566	1.1580	1.1592	1.1605	1.1616	1.1628	1.1639
89	1.1572	1.1578	1.1584	1.1598	1.1611	1.1623	1.1636	1.1647	1.1659	1.1670
86	1.1603	1.1609	1.1615	1.1629	1.1642	1.1654	1.1667	1.1678	1.1690	1.1701
83	1.1634	1.1640	1.1646	1.1660	1.1673	1.1685	1.1698	1.1709	1.1721	1.1732
80	1.1665	1.1671	1.1677	1.1691	1.1704	1.1716	1.1729	1.1741	1.1752	1.1763
77	1.1696	1.1702	1.1708	1.1722	1.1735	1.1747	1.1760	1.1772	1.1783	1.1794
74	1.1728	1.1734	1.1739	1.1753	1.1767	1.1779	1.1791	1.1803	1.1814	1.1825
71	1.1759	1.1765	1.1770	1.1784	1.1798	1.1810	1.1823	1.1834	1.1845	1.1856
68	1.1790	1.1796	1.1802	1.1815	1.1829	1.1841	1.1854	1.1865	1.1877	1.1888
65	1.1821	1.1827	1.1833	1.1846	1.1860	1.1872	1.1885	1.1896	1.1908	1.1919
62	1.1852	1.1858	1.1864	1.1877	1.1891	1.1903	1.1916	1.1927	1.1939	1.1950
59	1.1883	1.1889	1.1895	1.1909	1.1922	1.1934	1.1947	1.1958	1.1970	1.2981
56	1.1914	1.1920	1.1926	1.1940	1.1953	1.1965	1.1978	1.1989	1.2001	1.2012
53	1.1945	1.1951	1.1957	1.1971	1.1984	1.1996	1.2009	1.2020	1.2032	1.2043
50	1.1976	1.1982	1.1988	1.2002	1.2015	1.2027	1.2040	1.2052	1.2063	1.2074
47	1.2007	1.2013	1.2019	1.2033	1.2046	1.2058	1.2071	1.2083	1.2094	1.2105
44	1.2039	1.2044	1.2050	1.2064	1.2078	1.2090	1.2102	1.2114	1.2125	1.2136
41	1.2070	1.2076	1.2081	1.2095	1.2109	1.2121	1.2133	1.2145	1.2156	1.2167
38	1.2101	1.2107	1.2112	1.2126	1.2140	1.2162	1.2164	1.2176	1.2187	1.2198
35	1.2132	1.2138	1.2143	1.2157	1.2171	1.2183	1.2196	1.2207	1.2218	1.2229
32	1.2163	1.2169	1.2175	1.2188	1.2202	1.2214	1.2227	1.2239	1.2249	1.2260

Table of Factors of Evaporation.

Gauge Pressure. / Temp. of Feed.	100 Lbs.	105 Lbs.	115 Lbs.	125 Lbs.	135 Lbs.	145 Lbs.	155 Lbs.	165 Lbs.	185 Lbs.
212° F,	1.0397	1.0407	1.0427	1.0445	1.0462	1.0478	1.0493	1.0509	1.0536
209	1.0429	1.0438	1.0458	1.0476	1.0493	1.0509	1.0524	1.0540	1.0567
206	1.0460	1.0470	1.0489	1.0510	1.0527	1.0543	1.0558	1.0574	1.0601
203	1.0492	1.0502	1.0521	1.0540	1 0557	1.0573	1.0588	1.0604	1.0631
200	1.0523	1.0533	1.0552	1.0571	1.0588	1.0604	1.0619	1.0635	1.0662
197	1.0555	1.0565	1.0584	1.0602	1.0619	1.0635	1.0650	1.0666	1.0693
194	1.0586	1.0596	1.0615	1.0635	1.0652	1.0668	1.0683	1.0699	1.0726
191	1.0617	1.0627	1.0647	1.0665	1.0682	1.0698	1.0713	1.0729	1.0756
188	1.0649	1.0659	1.0678	1.0696	1.0713	1.0729	1.0744	1.0760	1.0787
185	1.0680	1.0690	1.0709	1.0728	1.0745	1.0761	1.0776	1.0792	1.0819
182	1.0712	1.0722	1.0741	1.0759	1.0776	1.0792	1.0807	1.0823	1.0850
179	1.0743	1.0753	1.0772	1·0790	1.0807	1.0823	1.0838	1.0854	1.0881
176	1.0774	1.0784	1.0803	1.0822	1.0839	1.0855	1.0870	1.0886	1.0913
173	1.0806	1.0816	1.0835	1.0853	1.0870	1.0886	1.0901	1.0917	1.0944
170	1.0837	1.0847	1.0866	1.0884	1.0901	1.0917	1.0932	1.0948	1.0975
167	1.0868	1.0878	1.0897	1.0916	1.0933	1.0949	1.0964	1.0980	1.1007
164	1.0900	1.0910	1.0929	1.0946	1.0963	1.0979	1.0994	1.1010	1.1037
161	1.0931	1.0941	1.0960	1.0979	1.0996	1.1012	1.1027	1.1043	1.1070
158	1.0962	1.0972	1.0991	1.1010	1.1027	1.1043	1.1058	1.1074	1.1101
155	1.0993	1.1003	1.1023	1.1041	1.1058	1.1074	1.1089	1.1105	1.1132
152	1.1025	1.1035	1.1054	1.1073	1.1090	1.1107	1.1122	1.1138	1.1165
149	1.1056	1.1066	1.1085	1.1103	1.1120	1.1136	1.1151	1.1167	1.1194
146	1.1087	1.1097	1.1116	1.1135	1.1152	1.1168	1.1183	1.1199	1.1226
143	1.1118	1.1129	1.1148	1.1166	1.1183	1.1199	1.1214	1.1230	1.1257
140	1.1150	1.1160	1.1179	1.1197	1.1214	1.1230	1.1245	1.1261	1.1288
137	1.1181	1.1191	1.1210	1.1228	1.1245	1.1262	1.1277	1.1293	1.1320
134	1.1212	1.1222	1.1241	1.1260	1.1277	1.1293	1.1308	1.1324	1.1351
131	1.1243	1.1253	1.1273	1.1291	1.1308	1.1324	1.1339	1.1355	1.1382
128	1.1275	1.1285	1.1304	1.1322	1,1339	1.1355	1.1370	1.1386	1.1413
125	1.1306	1.1316	1.1335	1.1353	1.1370	1.1386	1.1401	1.1417	1.1444
122	1 1337	1.1347	1.1366	1.1384	1.1401	1.1417	1.1438	1.1448	1.1475
119	1.1368	1.1378	1.1397	1.1415	1.1432	1.1449	1.1464	1.1480	1.1507
116	1.1399	1.1409	1.1429	1.1447	1.1464	1.1480	1.1495	1.1511	1.1538
113	1.1431	1.1441	1.1460	1.1478	1.1495	1.1511	1.1526	1.1542	1.1569
110	1.1462	1.1472	1.1491	1.1509	1.1516	1.1542	1.1557	1.1573	1.1600
107	1.1493	1.1503	1.1522	1.1540	1.1557	1.1573	1.1588	1.1604	1.1631
104	1.1524	1.1534	1.1553	1.1571	1.1588	1.1605	1.1619	1.1635	1.1662
101	1.1555	1.1565	1.1584	1.1602	1.1620	1.1636	1.1652	1.1668	1.1695
98	1.1586	1.1596	1.1616	1.1634	1.1651	1.1667	1.1683	1.1699	1.1726
95	1.1618	1.1628	1.1647	1.1665	1.1682	1.1698	1.1713	1.1729	1.1756
92	1.1649	1.1660	1.1678	1.1696	1.1713	1.1729	1.1744	1.1760	1.1787
89	1.1680	1.1690	1.1709	1.1727	1.1744	1.1760	1.1775	1.1791	1.1818
86	1.1711	1.1721	1.1740	1.1758	1.1775	1.1791	1.1806	1.1822	1.1849
83	1.1742	1.1752	1.1771	1.1789	1.1806	1.1823	1.1837	1.1853	1.1880
80	1.1773	1.1783	1.1802	1.1820	1.1837	1.1854	1.1869	1.1885	1.1912
77	1.1804	1.1814	1.1834	1.1852	1.1869	1.1885	1.1900	1.1916	1.1943
74	1.1835	1.1845	1.1865	1.1883	1.1900	1.1916	1.1932	1.1948	1.1975
71	1.1867	1.1877	1.1896	1.1914	1.1931	1.1947	1.1961	1.1977	1.2004
68	1.1898	1.1908	1.1927	1.1945	1.1962	1.1978	1.1993	1.2009	1.2036
65	1.1929	1.1939	1.1958	1.1976	1.1993	1.2009	1.2024	1.2040	1.2067
62	1.1960	1.1970	1.1989	1.2007	1.2024	1.2040	1.2055	1.2071	1.2098
59	1.1991	1.2001	1.2020	1.2038	1.2055	1.2071	1.2086	1.2102	1.2129
56	1.2022	1.2032	1.2051	1.2069	1.2086	1.2102	1.2117	1.2133	1.2160
53	1.2053	1.2063	1.2082	1.2100	1.2117	1.2134	1.2148	1.2164	1.2191
50	1.2084	1.2094	1.2113	1.2131	1.2148	1.2165	1.2180	1.2196	1.2223
47	1.2115	1.2125	1.2144	1.2163	1.2180	1.2196	1.2211	1.2227	1.2254
44	1.2146	1.2156	1.2176	1.2194	1.2211	1.2227	1.2242	1.2258	1.2285
41	1.2177	1.2187	1.2207	1.2225	1.2242	1.2258	1.2273	1.2289	1.2316
38	1.2208	1.2219	1 2238	1.2256	1.2273	1.2289	1.2304	1.2320	1.2347
35	1.2240	1.2250	1 2269	1 2287	1.2304	1.2320	1.2335	1.2351	1.2378
32	1.2271	1.2281	1.2300	1.2318	1.2335	1.2351	1.2366	1.2382	1.2409

Table of Factors of Evaporation.
W. Wallace Christie.

Gauge Pressure. Temp. of Feed.	200 lbs.	215 lbs.	230 lbs.	245 lbs.	260 lbs.	275 lbs.	290 lbs.	300 lbs.
212° F.	1.0555	1.0574	1.0591	1.0608	1.0622	1.0639	1.0653	1.0663
209	1.0586	1.0605	1.0622	1.0639	1.0654	1.0670	1.0684	1.0694
206	1.0616	1.0635	1.0653	1.0669	1.0685	1.0700	1.0715	1.0724
203	1.0648	1.0668	1.0684	1.0701	1.0717	1.0732	1.0746	1.0756
200	1.0680	1.0699	1.0716	1.0733	1.0749	1.0764	1.0779	1.0788
197	1.0711	1.0730	1.0747	1.0764	1.0781	1.0795	1.0810	1.0819
194	1.0743	1.0762	1.0779	1.0796	1.0813	1.0827	1.0842	1.0851
191	1.0774	1.0793	1.0811	1.0827	1.0844	1.0858	1.0873	1.0882
188	1.0806	1.0825	1.0843	1.0859	1.0875	1.0890	1.0905	1.0914
185	1.0838	1.0857	1.0875	1.0891	1.0907	1.0923	1.0937	1.0946
182	1.0869	1.0888	1.0906	1.0923	1.0938	1.0954	1.0968	1.0977
179	1.0900	1.0917	1.0937	1.0954	1.0969	1.0985	1.0999	1.1009
176	1.0932	1.0950	1.0968	1.0985	1.1000	1.1016	1.1030	1.1040
173	1.0964	1.0983	1.1000	1.1017	1.1032	1.1048	1.1062	1.1072
170	1.0995	1.1014	1.1031	1.1048	1.1063	1.1079	1.1093	1.1103
167	1.1026	1.1045	1.1062	1.1079	1.1094	1.1110	1.1124	1.1134
164	1.1057	1.1076	1.1093	1.1110	1.1126	1.1141	1.1155	1.1165
161	1.1088	1.1107	1.1124	1.1141	1.1157	1.1172	1.1187	1.1196
158	1.1120	1.1139	1.1156	1.1173	1.1189	1.1204	1.1219	1.1228
155	1.1151	1.1170	1.1188	1.1204	1.1220	1.1235	1.1250	1.1259
152	1.1182	1.1201	1.1219	1.1235	1.1251	1.1266	1.1281	1.1290
149	1.1213	1.1232	1.1250	1.1266	1.1282	1.1297	1.1312	1.1321
146	1.1245	1.1264	1.1282	1.1298	1.1314	1.1329	1.1344	1.1353
143	1.1276	1.1295	1.1313	1.1329	1.1345	1.1361	1.1375	1.1384
140	1.1308	1.1326	1.1344	1.1360	1.1376	1.1392	1.1406	1.1415
137	1.1339	1.1357	1.1375	1.1392	1.1407	1.1424	1.1437	1.1447
134	1.1371	1.1389	1.1407	1.1424	1.1438	1.1456	1.1469	1.1479
131	1.1402	1.1421	1.1438	1.1455	1.1470	1.1487	1.1500	1.1510
128	1.1433	1.1452	1.1469	1.1486	1.1501	1.1518	1.1532	1.1541
125	1.1464	1.1483	1.1500	1.1517	1.1532	1.1549	1.1563	1.1572
122	1.1496	1.1515	1.1532	1.1549	1.1564	1.1580	1.1595	1.1604
119	1.1527	1.1546	1.1563	1.1580	1.1596	1.1611	1.1626	1.1635
116	1.1559	1.1577	1.1594	1.1611	1.1627	1.1642	1.1657	1.1666
113	1.1589	1.1608	1.1626	1.1642	1.1658	1.1673	1.1688	1.1697
110	1.1620	1.1639	1.1657	1.1673	1.1689	1.1704	1.1719	1.1728
107	1.1651	1.1670	1.1688	1.1704	1.1720	1.1735	1.1750	1.1760
104	1.1682	1.1701	1.1719	1.1735	1.1751	1.1766	1.1781	1.1790
101	1.1713	1.1732	1.1750	1.1766	1.1782	1.1797	1.1812	1.1821
98	1.1744	1.1763	1.1781	1.1797	1.1813	1.1829	1.1843	1.1853
95	1.1776	1.1794	1.1812	1.1829	1.1844	1.1860	1.1874	1.1884
92	1.1807	1.1826	1.1843	1.1860	1.1875	1.1891	1.1905	1.1915
89	1.1838	1.1857	1.1874	1.1891	1.1906	1.1922	1.1936	1.1946
86	1.1869	1.1888	1.1905	1.1922	1.1937	1.1953	1.1967	1.1977
83	1.1900	1.1919	1.1936	1.1953	1.1968	1.1984	1.1999	1.2008
80	1.1931	1.1950	1.1967	1.1984	1.2000	1.2015	1.2030	1.2039
77	1.1962	1.1981	1.1998	1.2015	1.2031	1.2046	1.2061	1.2070
74	1.1993	1.2012	1.2029	1.2046	1.2062	1.2077	1.2092	1.2101
71	1.2024	1.2043	1.2061	1.2077	1.2092	1.2108	1.2123	1.2132
68	1.2055	1.2074	1.2092	1.2108	1.2124	1.2139	1.2154	1.2163
65	1.2087	1.2105	1.2123	1.2139	1.2155	1.2170	1.2185	1.2194
62	1.2118	1.2136	1.2154	1.2172	1.2186	1.2201	1.2216	1.2225
59	1.2149	1.2167	1.2185	1.2202	1.2217	1.2233	1.2247	1.2256
56	1.2180	1.2198	1.2216	1.2232	1.2248	1.2264	1.2278	1.2288
53	1.2211	1.2229	1.2247	1.2264	1.2279	1.2295	1.2309	1.2319
50	1.2242	1.2261	1.2278	1.2295	1.2310	1.2326	1.2340	1.2350
47	1.2273	1.2292	1.2309	1.2326	1.2341	1.2357	1.2371	1.2381
44	1.2304	1.2323	1.2340	1.2357	1.2372	1.2388	1.2402	1.2412
41	1.2335	1.2354	1.2371	1.2388	1.2403	1.2419	1.2433	1.2443
38	1.2366	1.2385	1.2402	1.2419	1.2434	1.2450	1.2464	1.2474
35	1.2397	1.2416	1.2433	1.2450	1.2465	1.2481	1.2496	1.2505
32	1.2428	1.2447	1.2464	1.2481	1.2497	1.2512	1.2527	1.2536

Table of Factors of Evaporation.—*Continued.*

Gauge Pressure. Temp. of Feed.	0 Lbs.	10 Lbs.	20 Lbs.	30 Lbs.	40 Lbs.	45 Lbs.	50 Lbs.	52 Lbs.	54 Lbs.
300° F.	0.907	0.915	0.922	0.926	0.930	0.932	0.934	0.9347	0.9353
295	0.912	0.920	0.927	0.932	0.936	0.937	0.939	0.9399	0.9406
290	0.917	0.926	0.932	0.937	0.941	0.943	0.944	0.9453	0.9459
287	0.921	0.930	0.936	0.940	0.945	0.946	0.948	0.9485	0.9492
284	0.924	0.933	0.939	0.944	0.948	0.949	0.951	0.9517	0.9524
281	0.927	0.936	0.942	0.947	0.951	0.953	0.954	0.9548	0.9554
278	0.930	0.939	0.945	0.950	0.954	0.956	0.957	0.9580	0.9586
275	0.933	0.942	0.948	0.953	0.958	0.959	0.960	0.9612	0.9618
272	0.936	0.945	0.951	0.956	0.961	0.962	0.963	0.9642	0.9648
269	0.940	0.948	0.954	0.959	0.964	0.966	0.967	0.9675	0.9681
266	0.943	0.951	0.958	0.963	0.968	0.969	0.970	0.9708	0.9714
263	0.946	0.955	0.961	0.966	0.971	0.972	0.973	0.9738	0.9744
260	0.949	0.958	0.964	0.969	0.974	0.975	0.976	0.9770	0.9776
257	0.952	0.961	0.967	0.972	0.977	0.978	0.979	0.9801	0.9807
254	0.955	0.964	0.970	0.975	0.980	0.981	0.983	0.9833	0.9840
251	0.958	0.967	0.974	0.978	0.983	0.984	0.986	0.9865	0.9872
248	0.961	0.970	0.977	0.982	0.987	0.987	0.989	0.9897	0.9904
245	0.964	0.974	0.980	0.985	0.990	0.990	0.992	0.9929	0.9935
242	0.967	0.977	0.983	0.988	0.993	0.994	0.995	0.9960	0.9966
239	0.970	0.981	0.986	0.991	0.995	0.997	0.999	0.9992	1.0000
236	0.974	0.984	0.989	0.994	0.998	1.000	1.002	1.0024	1.0030
233	0.977	0.987	0.992	0.998	1.001	1.003	1.005	1.0055	1.0061
230	0.980	0.990	0.996	1.001	1.005	1.007	1.008	1.0087	1.0093
227	0.983	0.993	0.999	1.004	1.008	1.010	1.011	1.0118	1.0124
224	0.986	0.996	1.002	1.007	1.011	1.013	1.014	1.0149	1.0155
221	0.989	0.999	1.005	1.010	1.014	1.016	1.017	1.0180	1.0186
218	0.993	1.002	1.008	1.013	1.017	1.019	1.021	1.0212	1.0217
215	0.997	1.005	1.010	1.016	1.020	1.022	1.024	1.0244	1.0251

	56 Lbs.	58 Lbs.	60 Lbs.	65 Lbs.	70 Lbs.	75 Lbs.	80 Lbs.	85 Lbs.	90 Lbs.	95 Lbs.
300° F.	0.9359	0.9365	0.9370	0.9385	0.9398	0.9411	0.9423	0.9435	0.9446	0.9456
295	0.9412	0.9418	0.9423	0.9438	0.9451	0.9464	0.9476	0.9487	0.9499	0.9509
290	0.9465	0.9472	0.9477	0.9492	0.9505	0.9517	0.9530	0.9541	0.9553	0.9563
287	0.9498	0.9504	0.9509	0.9524	0.9537	0.9550	0.9562	0.9573	0.9585	0.9595
284	0.9530	0.9536	0.9541	0.9556	0.9569	0.9582	0.9594	0.9605	0.9617	0.9627
281	0.9561	0.9567	0.9572	0.9587	0.9600	0.9613	0.9625	0.9636	0.9648	0.9658
278	0.9592	0.9598	0.9603	0.9618	0.9631	0.9644	0.9656	0.9667	0.9679	0.9690
275	0.9624	0.9630	0.9635	0.9650	0.9663	0.9676	0.9688	0.9700	0.9711	0.9721
272	0.9654	0.9660	0.9665	0.9680	0.9694	0.9706	0.9718	0.9730	0.9741	0.9751
269	0.9687	0.9693	0.9699	0.9713	0.9726	0.9739	0.9752	0.9763	0.9774	0.9785
266	0.9720	0.9727	0.9732	0.9746	0.9760	0.9772	0.9784	0.9796	0.9807	0.9818
263	0.9750	0.9757	0.9762	0.9776	0.9790	0.9802	0.9815	0.9826	0.9837	0.9848
260	0.9782	0.9789	0.9794	0.9808	0.9822	0.9834	0.9847	0.9858	0.9869	0.9880
257	0.9814	0.9820	0.9825	0.9840	0.9853	0.9865	0.9878	0.9890	0.9901	0.9911
254	0.9846	0.9853	0.9857	0.9872	0.9885	0.9897	0.9910	0.9921	0.9933	0.9943
251	0.9877	0.9884	0.9889	0.9904	0.9917	0.9930	0.9942	0.9953	0.9965	0.9975
248	0.9910	0.9916	0.9921	0.9936	0.9949	0.9962	0.9974	0.9985	0.9997	1.0007
245	0.9941	0.9948	0.9953	0.9968	0.9980	0.9993	1.0005	1.0016	1.0028	1.0038
242	0.9972	0.9979	0.9984	0.9999	1.0011	1.0024	1.0036	1.0047	1.0059	1.0069
239	1.0004	1.0011	1.0016	1.0030	1.0043	1.0056	1.0068	1.0080	1.0091	1.0102
236	1.0036	1.0042	1.0048	1.0062	1.0076	1.0088	1.0100	1.0112	1.0123	1.0134
233	1.0067	1.0073	1.0089	1.0094	1.0107	1.0119	1.0132	1.0143	1.0154	1.0165
230	1.0099	1.0106	1.0111	1.0125	1.0139	1.0151	1.0134	1.0175	1.0186	1.0197
227	1.0130	1.0137	1.0142	1.0156	1.0170	1.0182	1.0195	1.0206	1.0217	1.0228
224	1.0161	1.0168	1.0173	1.0187	1.0201	1.0213	1.0226	1.0237	1.0248	1.0259
221	1.0193	1.0199	1.0204	1.0218	1.0232	1.0244	1.0257	1.0269	1.0280	1.0290
218	1.0225	1.0231	1.0236	1.0251	1.0264	1.0276	1.0289	1.0300	1.0312	1.0322
215	1.0257	1.0263	1.0268	1.0283	1.0296	1.0309	1.0321	1.0332	1.0344	1.0354

Table of Factors of Evaporation.—*Continued.*

Gauge Pressure. Temp. of Feed.	100 Lbs.	105 Lbs.	115 Lbs.	125 Lbs.	135 Lbs.	145 Lbs.	155 Lbs.	165 Lbs.	185 Lbs.
300° F.	0.9467	0.9477	0.9498	0.9514	0.9532	0.9548	0.9564	0.9579	0.9606
295	0.9520	0.9530	0.9551	0.9567	0.9585	0.9601	0.9617	0.9631	0.9659
290	0.9573	0.9584	0.9604	0.9621	0.9639	0.9655	0.9671	0.9685	0.9713
287	0.9605	0.9616	0.9636	0.9653	0.9671	0.9687	0.9703	0.9717	0.9745
284	0.9637	0.9648	0.9669	0.9685	0.9703	0.9719	0.9735	0.9749	0.9777
281	0.9669	0.9679	0.9700	0.9716	0.9734	0.9750	0.9766	0.9780	0.9808
278	0.9700	0.9710	0.9731	0.9747	0.9765	0.9781	0.9797	0.9812	0.9840
275	0.9732	0.9742	0.9763	0.9779	0.9797	0.9813	0.9829	0.9844	0.9872
272	0.9762	0.9772	0.9793	0.9810	0.9827	0.9844	0.9859	0.9874	0.9902
269	0.9795	0.9805	0.9826	0.9842	0.9860	0.9877	0.9892	0.9907	0.9935
266	0.9828	0.9838	0.9859	0.9876	0.9893	0.9910	0.9925	0.9940	0.9968
263	0.9858	0.9868	0.9889	0.9906	0.9923	0.9940	0.9955	0.9970	0.9998
260	0.9890	0.9901	0.9921	0.9938	0.9955	0.9972	0.9988	1.0002	1.0030
257	0.9921	0.9932	0.9952	0.9969	0.9986	1.0003	1.0019	1.0033	1.0061
254	0.9953	0.9964	0.9984	1.0001	1.0019	1.0035	1.0051	1.0065	1.0093
251	0.9985	0.9996	1.0017	1.0033	1.0051	1.0067	1.0083	1.0097	1.0125
248	1.0018	1.0028	1.0049	1.0065	1.0083	1.0099	1.0115	1.0129	1.0167
245	1.0049	1.0059	1.0080	1.0096	1.0114	1.0130	1.0146	1.0160	1.0188
242	1.0080	1.0090	1.0111	1.0127	1.0145	1.0162	1.0177	1.0192	1.0220
239	1.0112	1.0122	1.0143	1.0159	1.0177	1.0194	1.0209	1.0224	1.0252
236	1.0144	1.0154	1.0175	1.0192	1.0209	1.0226	1.0241	1.0256	1.0284
233	1.0175	1.0185	1.0206	1.0223	1.0240	1.0257	1.0272	1.0287	1.0315
230	1.0207	1.0217	1.0238	1.0255	1.0272	1.0289	1.0304	1.0319	1.0347
227	1.0238	1.0248	1.0269	1.0286	1.0303	1.0320	1.0335	1.0350	1.0378
224	1.0269	1.0280	1.0300	1.0317	1.0334	1.0351	1.0367	1.0381	1.0409
221	1.0300	1.0311	1.0331	1.0348	1.0365	1.0382	1.0398	1.0412	1.0440
218	1.0332	1.0343	1.0363	1.0380	1.0398	1.0414	1.0430	1.0444	1.0472
215	1.0364	1.0375	1.0395	1.0412	1.0430	1.0446	1.0462	1.0476	1.0504

Table of Factors of Evaporation.—*Concluded.*

Gauge Pressure. Temp. of Feed.	200 Lbs.	215 Lbs.	230 Lbs.	245 Lbs.	260 Lbs.	275 Lbs.	290 Lbs.	300 Lbs.
300 °F.	0.9626	0.9645	0.9662	0.9679	0.9694	0.9710	0.9724	0.9734
295	0.9679	0.9697	0.9715	0.9732	0.9747	0.9763	0.9777	0.9787
290	0.9733	0.9751	0.9769	0.9786	0.9801	0.9817	0.9831	0.9840
287	0.9765	0.9783	0.9801	0.9818	0.9833	0.9849	0.9863	0.9873
284	0.9797	0.9816	0.9833	0.9850	0.9865	0.9881	0.9895	0.9905
281	0.9828	0.9847	0.9864	0.9881	0.9896	0.9912	0.9926	0.9936
278	0.9859	0.9878	0.9895	0.9912	0.9927	0.9943	0.9957	0.9967
275	0.9891	0.9910	0.9927	0.9944	0.9959	0.9975	0.9989	0.9999
272	0.9921	0.9940	0.9958	0.9974	0.9990	1.0005	1.0020	1.0029
269	0.9954	0.9973	0.9991	1.0007	1.0023	1.0038	1.0053	1.0063
266	0.9987	1.0006	1.0024	1.0040	1.0056	1.0071	1.0086	1.0095
263	1.0017	1.0036	1.0054	1.0070	1.0086	1.0102	1.0116	1.0125
260	1.0049	1.0058	1.0086	1.0103	1.0118	1.0133	1.0148	1.0157
257	1.0081	1.0099	1.0117	1.0134	1.0149	1.0164	1.0179	1.0188
254	1.0113	1.0132	1.0149	1.0166	1.0181	1.0197	1.0211	1.0221
251	1.0145	1.0164	1.0181	1.0198	1.0213	1.0229	1.0243	1.0253
248	1.0177	1.0196	1.0213	1.0230	1.0245	1.0261	1.0275	1.0285
245	1.0208	1.0227	1.0244	1.0261	1.0276	1.0292	1.0306	1.0316
242	1.0239	1.0258	1.0275	1.0293	1.0308	1.0323	1.0337	1.0347
239	1.0271	1.0290	1.0307	1.0324	1.0340	1.0355	1.0370	1.0379
236	1.0303	1.0322	1.0340	1.0356	1.0372	1.0387	1.0402	1.0411
233	1.0334	1.0353	1.0371	1.0387	1.0403	1.0418	1.0433	1.0442
230	1.0367	1.0385	1.0403	1.0419	1.0435	1.0450	1.0465	1.0474
227	1.0398	1.0416	1.0434	1.0450	1.0466	1.0482	1.0496	1.0505
224	1.0429	1.0447	1.0465	1.0482	1.0497	1.0513	1.0527	1.0536
221	1.0460	1.0478	1.0496	1.0512	1.0528	1.0544	1.0558	1.0567
218	1.0492	1.0511	1.0528	1.0545	1.0560	1.0576	1.0590	1.0600
215	1.0524	1.0543	1.0562	1.0577	1.0592	1.0608	1.0622	1.0632

PROPERTIES OF SATURATED STEAM.

(W. W. Christie, M.E.)

Vacuum in Inches of Mercury.	Pounds per square inch—Absolute Pressure.	Temp. ° F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
			h in the Water.	L Latent Heat of Vapori-zation.	H = L + *h* Total Heat in Steam.	Relative: Cu. Ft. in 1 Cu. Ft. of Water.	Specific: Cu. Ft. in one Lb. of Steam.	
29.74	.089	32	0	1092.7	1092.7	208080	3387	.000295
29.72	.096	34	2	1090.37	1092.37	193180	3138	318
29.71	.104	36	4	1088.98	1092.98	179380	2910	344
29.70	.112	38	6	1087.59	1093.59	166380	2700	370
29.68	.122	40	8	1086.20	1094.20	154330	2506	399
29.65	.132	42	10	1084.81	1094.81	143220	2328	429
29.63	.142	44	12	1083.41	1095.41	133120	2164	462
29.61	.152	46	14	1082.02	1096.02	123840	2013	496
29.59	.164	48	16	1080.63	1096.63	115490	1874	533
29.56	.176	50	18	1079.25	1097.25	107630	1745	573
29.54	.190	52	20	1077.86	1097.86	100330	1626	615
29.51	.205	54	22	1076.47	1098.47	93680	1516	659
29.47	.220	56	24	1075.08	1099.08	87500	1415	706
29.44	.236	58	26	1073.69	1099.69	81740	1321	757
29.40	.254	60	28	1072.31	1100.31	76370	1234	810
29.37	.273	62	30	1070.92	1100.92	71330	1153	867
29.33	.292	64	32	1069.53	1101.53	66630	1078	927
29.28	.313	66	34	1068.14	1102.14	62290	1009	991
29.24	.335	68	36	1066.75	1102.75	58340	944.7	.001059
29.19	.359	70	38	1065.35	1103.35	54660	885.0	1130
29.14	.385	72	40	1063.96	1103.96	51210	829.5	1205
29.09	.411	74	42	1062.57	1104.57	48000	777.9	1286
29.03	.440	76	44	1061.18	1105.18	45060	729.9	1370
28.96	.470	78	46	1059.79	1105.79	42280	685.2	1459
28 90	.502	80	48	1058.40	1106.40	39690	643.8	1553
28.83	.535	82	50	1057.01	1107.01	37320	605.0	1653
28.76	.571	84	52	1055.62	1107.62	35100	568.8	1758
28.68	.609	86	54	1054.22	1108.23	33030	535.2	1869
28.60	.650	88	56	1052.83	1108.84	31100	503.7	1985
28.51	.692	90	58	1051.44	1109.45	29290	474.6	.002107
28.42	.738	92	60	1050.05	1110.06	27600	447.1	2237
28.32	.785	94	62	1048.66	1110.67	26020	421.5	2372
28.22	.834	96	64	1047.27	1111.28	24540	397.5	2516
28.11	.887	98	66	1045.87	1111.89	23140	375.1	2666
28.00	.943	100	68	1044.48	1112.50	21830	354.0	2824
27.89	1.001	102	70	1043.08	1113.10	20620	334.5	2900
27.76	1.062	104	72	1041.69	1113.71	19500	316.1	.003163
27.63	1.126	106	74	1040.29	1114.32	18460	298.8	3347
27.49	1.193	108	76	1038.90	1114.93	17470	282.7	3537
27.34	1.265	110	78	1037.52	1115.55	16520	267.5	3738
27.19	1.341	112	80	1036.12	1116.16	15640	253.3	3948
27.03	1.421	114	82	1034.74	1116.78	14820	239.9	.004168
26.86	1.504	116	84	1033.35	1117.39	14050	227.3	4399
26.68	1.591	118	86	1031.94	1117.99	13320	215.5	4640
26.49	1.682	120	88	1030.55	1118.60	12630	204.4	4892
26.30	1.779	122	90	1029.16	1119.21	11980	193.9	.005156

Vacuum in Inches of Mercury.	Pounds per square inch—Absolute Pressure.	Temp. ° F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
			h in the Water.	L Latent Heat of Vapori-zation.	H = L + *h* Total Heat in Steam.	Relative. Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. in one Lb. of Steam.	
26.09	1.879	124	92	1027.76	1119.82	11370	184.1	.005432
25.88	1.984	126	94	1026.37	1120.43	10800	174.8	5720
25.65	2.096	128	96	1024.97	1121.04	10265	166.1	6020
25.41	2.213	130	98	1023.58	1121.65	9760	157.8	6336
25.17	2.335	132	100	1022.18	1122.26	9276	150.1	6664
24.91	2.461	134	102	1020.79	1122.87	8826	142.8	7005
24.64	2.594	136	104	1019.39	1123.48	8401	135.8	7361
24.36	2.732	138	106	1018.00	1124.09	7991	129.3	7732
24.06	2.876	140	108.1	1016.60	1124.70	7613	123.2	8120
23.75	3.029	142	110.1	1015.20	1125.31	7258	117.3	8522
23.43	3.188	144	112.1	1013.81	1125.92	6920	111.8	8942
23.09	3.353	146	114.1	1012.41	1126.53	6595	106.6	9379
22.74	3.526	148	116.1	1011.01	1127.14	6290	101.7	.009833
22.37	3.707	150	118.1	1009.61	1127.75	6004	97.03	.01031
21.99	3.896	152	120.1	1008.22	1128.36	5734	92.61	.01080
21.59	4.090	154	122.1	1006.82	1128.97	5477	88.43	.01131
21.17	4.295	156	124.1	1005.42	1129.85	5232	84.47	.01184
20.74	4.507	158	126.1	1004.02	1130.19	5000	80.70	.01239
20.29	4.729	160	128.1	1002.62	1130.80	4779	77.14	.01296
19.82	4.960	162	130.1	1001.22	1131.41	4569	73.77	.01356
19.33	5.200	164	132.2	999.82	1132.02	4368	70.56	.01417
18.82	5.451	166	134.2	998.42	1132.63	4177	67.51	.01481
18.29	5.711	168	136.2	997.02	1133.24	3996	64.62	.01548
17.76	5.981	170	138.2	995.62	1133.85	3826	61.85	.01617
17.16	6.262	172	140.2	994.22	1134.46	3664	59.25	.01688
16.57	6.555	174	142.2	992.82	1135.07	3510	56.76	.01762
15.95	6.857	176	144.2	991.42	1135.68	3365	54.40	.01838
15.31	7.172	178	146.2	990.02	1136.29	3226	52.14	.01918
14.64	7.500	180	148.2	983.62	1136.90	3093	50.01	.02000
13.95	7.841	182	150.3	987.21	1137.51	2966	47.97	.02085
13.23	8.194	184	152.3	985.81	1138.12	2846	46.06	.02172
12.48	8.558	186	154.3	984.41	1138.73	2733	44.17	.02264
11.71	8.936	188	156.3	983.00	1139.34	2624	42.41	.02358
10.91	9.330	190	158.3	981.60	1139.95	2519	40.73	.02455
10.08	9.738	192	160.3	980.20	1140.56	2420	39.13	.02556
9.22	10.16	194	162.3	978.79	1141.17	2325	37.59	.02660
8.33	10.59	196	164.3	977.39	1141.78	2234	36.13	.02768
7.40	11.05	198	166.4	975.98	1142.39	2147	34.73	.02879
6.45	11.52	200	168.4	974.58	1143.00	2064	33.40	.02994
5.46	12.00	202	170.4	973.17	1143.61	1985	32.13	.03112
4.44	12.50	204	172.4	971.76	1144.22	1916	30.92	.03235
3.38	13.02	206	174.4	970.36	1144.83	1844	29.76	.03361
2.28	13.56	208	176.4	968.95	1145.44	1775	28.63	.03493
1.15	14.12	210	178.5	967.54	1146.05	1708	27.57	.03628
0.00	14.70	212	180.5	966.13	1146.66	1644	26.60	.03760

PROPERTIES OF SATURATED STEAM.

(Compiled by W. W. Christie.)

Pounds per Square Inch.		Temp. ° F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		*h* in the Water.	L Latent Heat of Vaporization.	H = L + *h* Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft, in one Lb. of Steam.	
...	1	102.	70.1	1042.9	1113.0	20623	330.4	.0030
...	2	126.2	94.4	1026.0	1120.4	16730	171.9	.0058
...	3	141.6	109.8	1015.2	1125.1	7325	117.3	.0085
...	4	153.0	121.4	1007.2	1128.6	5588	89.51	.0112
...	5	162.3	130.7	1000.7	1131.4	4530	72.56	.0138
...	6	170.1	138.5	995.2	1133.8	3816	61.14	.0164
...	7	176.9	145.4	990.4	1135.8	3302	52.89	.0189
...	8	182.9	151.4	986.2	1137.7	2912	46.65	.0214
...	9	188.3	156.9	982.4	1139.3	2607	41.77	.0239
...	10	193.2	161.9	978.9	1140.8	2361	37.83	.0264
...	11	197.7	166.5	975.7	1142.2	2159	34.59	.0289
...	12	201.9	170.7	972.8	1143.5	1990	31.87	.0314
...	13	205.8	174.7	970.0	1144.7	1845	29.56	.0338
...	14	209.5	178.4	967.4	1145.8	1721	27.58	.0363
.304	15	213.0	181.9	964.9	1146.9	1614	25.85	.0387
1.3	16	216.3	185.2	962.6	1147.9	1519	24.33	.0411
2.3	17	219.4	188.4	960.4	1148.8	1434	22.98	.0435
3.3	18	222.3	191.4	958.3	1149.7	1359	21.72	.0459
4.3	19	225.2	194.2	956.3	1150.6	1292	20.70	.0483
5.3	20	227.9	197.0	954.4	1151.4	1231	19.73	.0507
6.3	21	230.5	199.6	952.5	1152.2	1176	18.84	.0531
7.3	22	233.0	202.2	950.8	1153.0	1126	18.04	.0554
8.3	23	235.4	204.6	949.0	1153.7	1080	17.30	.0578
9.3	24	237.7	207.0	947.4	1154.4	1038	16.62	.0602
10.3	25	240.0	209.3	945.8	1155.1	998.4	16.00	.0625
11.3	26	242.1	211.5	944.2	1155.8	962.3	15.42	.0649
12.3	27	244.2	213.6	942.7	1156.4	928.8	14.88	.0672
13.3	28	246.3	215.7	941.3	1157.0	897.6	14.38	.0695
14.3	29	248.3	217.7	939.9	1157.6	868.5	13.91	.0719
15.3	30	250.2	219.7	938.9	1158.2	841.3	13.48	.0742
16.3	31	252.1	221.6	937.1	1158.8	815.8	13.07	.0765
17.3	32	253.9	223.5	935.9	1159.3	791.8	12.68	.0788
18.3	33	255.7	225.3	934.6	1159.9	769.2	12.32	.0812
19.3	34	257.4	227.1	933.3	1160.4	748.0	11.98	.0835
20.3	35	259.1	228.8	932.1	1160.9	727.9	11.66	.0858
21.3	36	260.8	230.5	931.0	1161.5	708.8	11.37	.0881
22.3	37	262.4	232.1	929.8	1161.9	690.8	11.07	.0904
23 3	38	264.0	233.8	928.6	1162.4	673.7	10.79	.0927
24.3	39	265.6	235.3	927.5	1162.9	657.5	10.53	.0949
25.3	40	267.1	236.9	926.4	1163.4	642.0	10.28	.0972
26.3	41	268.6	238.4	925.4	1163.8	627.3	10.05	.0995
27.3	42	270.0	239.9	924.3	1164.3	613.3	9.826	.1018

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.			Heat Units in one Pound above 32° F.			Volume.		
Gauge Pressure.	Absolute Pressure.	Temp. °F. at Pressure.	*h* in the Water.	L Latent Heat of Vaporization.	H = L + *h* Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. in one Lb. of Steam.	Weight of one Cubic Foot of Steam.
28.3	43	271.5	241.4	923.3	1164.7	599.9	9.609	.1041
29.3	44	272.9	242.8	922.3	1165.1	587.0	9.403	.1063
30.3	45	274.3	244.2	921.3	1165.6	574.7	9.207	.1086
31.3	46	275.6	245.6	920.3	1166.0	563.0	9.018	.1109
32.3	47	276.9	247.0	919.4	1166.4	551.7	8.838	.1131
33.3	58	278.2	248.3	918.4	1166.8	540.9	8.665	.1154
34.3	49	279.5	249.6	917.5	1167.2	530.5	8.498	.1177
35.3	50	280.8	250.9	916.6	1167.6	520.5	8.338	.1199
36.3	51	282.1	252.2	915.7	1167.9	510.9	8.185	.1222
37.3	52	283.3	253.5	914.8	1168.3	501.7	8.037	.1244
38.3	53	284.5	254.7	913.9	1168.7	492.8	7.894	.1267
39.3	54	285.7	255.9	913.1	1169.0	484.2	7.756	.1289
40.3	55	286.9	257.1	912.2	1169.4	475.9	7.624	.1312
41.3	56	288.0	258.3	911.4	1169.7	467.9	7.496	.1334
42.3	57	289.1	259.5	910.6	1170.1	460.2	7.372	.1357
43.3	58	290.3	260.6	909.8	1170.4	452.7	7.252	.1379
44.3	59	291.4	261.7	909.0	1170.8	445.5	7.136	.1401
45.3	60	292.5	262.9	908.2	1171.1	438.5	7.024	.1424
46.3	61	293.6	264.0	907.4	1171.4	431.7	6.916	.1446
47.3	62	294.6	265.1	906.7	1171.8	425.2	6.811	.1468
48.3	63	295.7	266.1	905.9	1172.1	418.8	6.709	.1491
49.3	64	296.7	267.2	905.2	1172.4	412.6	6.610	.1513
50.3	65	297.7	268.3	904.4	1172.7	406.6	6.515	.1535
51.3	66	298.7	269.3	903.7	1173.0	400.8	6.422	.1557
52.3	67	299.7	270.3	903.0	1173.3	395.2	6.332	.1579
53.3	68	300.7	271.3	902.3	1173.6	389.8	6.244	.1602
54.3	69	301.7	272.3	901.5	1173.9	384.5	6.159	.1624
55.3	70	302.7	273.3	900.9	1174.2	379.3	6.076	.1646
56.3	71	303.6	274.3	900.2	1174.5	374.3	5.995	.1668
57.3	72	304.6	275.3	899.5	1174.8	369.4	5.917	.1690
58.3	73	305.5	276.2	898.8	1175.1	364.6	5.841	.1712
59.3	74	306.4	277.2	898.1	1175.4	360.0	5.767	.1734
60.3	75	307.3	278.1	897.5	1175.6	355.5	5.694	.1756
61.3	76	308.2	279.0	896.8	1175.9	351.1	5.624	.1778
62.3	77	309.1	280.0	896.2	1176.2	346.8	5.555	.1800
63.3	78	310.0	280.9	895.5	1176.5	342.6	5.488	.1822
64.3	79	310.9	281.8	894.9	1176.7	338.5	5.422	.1844
65.3	80	311.8	282.7	894.3	1177.0	334.5	5.358	.1866
66.3	81	312.6	283.5	893.7	1177.3	330.6	5.296	.1888
67.3	82	313.5	284.4	893.1	1177.5	326.8	5.235	.1910
68.3	83	314.3	285.3	892.4	1177.8	323.1	5.176	.1932
69.3	84	315.1	286.1	891.8	1178.0	319.5	5.118	.1954

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temp. °F. at Pressure.	Heat Units in one Pounds above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		*h* in the Water.	L Latent Heat of Vaporization.	H = L + *h* Total Heat in Steam.	Relative. Cu. Ft. in 1 Cu. Ft. of Water.	Specific. Cu. Ft. n 1 Lb. of Steam.	
70.3	85	316.0	287.0	891.2	1178.3	315.9	5.061	.1976
71.3	86	316.8	287.8	890.6	1178.5	312.5	5.006	.1998
72.3	87	317.6	288.7	890.1	1178.8	309.1	4.951	.2020
73.3	88	318.4	289.5	889.5	1179.0	305.8	4.898	.2042
74.3	89	319.2	290.3	888.9	1179.3	302.5	4.846	.2063
75.3	90	320.0	291.1	888.3	1179.5	299.4	4.796	.2085
76.3	91	320.8	291.9	887.8	1179.8	296.3	4.746	.2107
77.3	92	321.6	292.7	887.2	1180.0	293.2	4.697	.2129
78.3	93	322.3	293.5	886.6	1180.2	290.2	4.650	.2151
79.3	94	323.1	294.3	886.1	1180.4	287.3	4.603	.2173
80.3	95	323.8	295.1	885.5	1180.7	284.5	4.557	.2194
81.3	96	324.6	295.9	885.0	1180.9	281.7	4.513	.2216
82.3	97	325.3	296.6	884.5	1181.1	279.0	4.469	.2238
83.3	98	326.1	297.4	883.9	1181.4	276.3	4.426	.2260
84.3	99	326.8	298.1	883.4	1181.6	273.7	4.384	.2281
85.3	100	327.5	298.9	882.9	1181.8	271.1	4.342	.2303
86.3	101	328.2	299.6	882.3	1182.0	268.5	4.302	.2325
87.3	102	329.0	300.4	881.8	1182.2	266.0	4.262	.2346
88.3	103	329.7	301.1	881.3	1182.5	263.6	4.223	.2368
89.3	104	330.4	301.8	880.8	1182.7	261.2	4.185	.2390
90.3	105	331.1	302.5	880.3	1182.9	258.9	4.147	.2411
91.3	106	331.8	303.3	879.8	1183.1	256.6	4.110	.2433
92.3	107	332.4	304.0	879.3	1183.3	254.3	4.074	.2455
93.3	108	333.1	304.7	878.8	1183.5	252.1	4.038	.2476
94.3	109	333.8	305.4	878.3	1183.7	249.9	4.003	.2498
95.3	110	334.5	306.1	877.8	1183.9	247.8	3.969	.2519
96.3	111	335.1	306.8	877.3	1184.1	245.7	3.935	.2541
97.3	112	335.8	307.4	876.9	1184.3	243.6	3.902	.2563
98.3	113	336.5	308.1	876.4	1184.5	241.6	3.870	.2584
99.3	114	337.1	308.8	875.9	1184.7	239.6	3.838	.2606
100.3	115	337.8	309.5	875.4	1184.9	237.6	3.806	.2627
101.3	116	338.4	310.1	875.0	1185.1	235.7	3.775	.2649
102.3	117	339.1	310.8	874.5	1185.3	233.8	3.745	.2670
103.3	118	339.7	311.4	874.0	1185.5	231.9	3.715	.2692
104.3	119	340.3	312.1	873.6	1185.7	230.1	3.685	.2713
105.3	120	340.9	312.7	873.1	1185.9	228.3	3.656	.2735
106.3	121	341.6	313.4	872.7	1186.1	226.5	3.628	.2757
107.3	122	342.2	314.0	872.5	1186.3	224.7	3.600	.2778
108.3	123	342.8	314.7	871.8	1186.5	223.0	3.572	.2800
109.3	124	343.4	315.3	871.3	1186.6	221.3	3.545	.2821
110.3	125	344.0	315.9	870.9	1186.8	219.6	3.518	.2842
111.3	126	344.6	316.6	870.4	1187.0	218.0	3.492	.2864

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature °F. at Pressure.	Heat Units in one Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	H = L + h Total Heat in Steam.	Relative Cu. Ft. in 1 Cu Ft. of Water.	Specific Cu. Ft. in 1 Lb. of Steam.	
112.3	127	345.2	317.2	870.0	1187.2	216.4	3.466	.2885
113.3	128	345.8	317.8	869.6	1187.4	214.8	3.440	.2907
114.3	129	346.4	318.4	869.1	1187.6	213.2	3.415	.2928
115.3	130	347.0	319.0	868.7	1187.8	211.6	3.390	.2950
116.3	131	347.6	319.6	868.3	1187.9	210.1	3.366	.2971
117.3	132	348.2	320.2	867.8	1188.1	208.6	3.342	.2992
118.3	133	348.8	320.8	867.4	1188.3	207.1	3.318	.3014
119.3	134	349.3	321.4	867.0	1188.5	205.7	3.295	.3035
120.3	135	349.9	322.0	866.6	1188.6	204.2	3.272	.3057
121.3	136	350.5	322.6	866.2	1188.8	202.8	3.249	.3078
122.3	137	351.0	323.2	865.7	1189.0	201.4	3.227	.3099
123.3	138	351.7	323.8	865.3	1189.1	200.0	3.204	.3121
124.3	139	352.2	324.3	864.9	1189.3	198.7	3.182	.3142
125.3	140	352.7	324.9	864.5	1189.5	197.3	3.161	.3163
126.3	141	353.3	325.5	864.1	1189.7	196.0	3.140	.3185
127.3	142	353.8	326.1	863.7	1189.8	194.7	3.119	.3206
128.3	143	354.4	326.8	863.3	1190.0	193.4	3.099	.3227
129.3	144	354.9	327.2	862.9	1190.2	192.2	3.078	.3249
130.3	145	355.5	327.8	862.5	1190.3	190.9	3.058	.3270
131.3	146	356.0	328.3	862.1	1190.4	189.7	3.038	.3291
132.3	147	356.5	328.9	861.7	1190.6	188.5	3.019	.3313
133.3	148	357.1	329.4	861.4	1190.8	187.3	3.000	.3334
134.3	149	357.6	330.0	861.0	1191.0	186.1	2.981	.3355
135.3	150	358.1	330.5	860.6	1191.1	184.9	2.962	.3376
136.3	151	358.6	331.1	860.2	1191.3	183.7	2.943	.3398
137.3	152	359.2	331.6	859.8	1191.4	182.6	2.925	.3419
138.3	153	359.7	332.2	859.4	1191.6	181.5	2.908	.3439
139.3	154	360.2	332.7	859.1	1191.8	180.4	2.890	.3460
140.3	155	360.7	333.2	858.7	1191.9	179.2	2.870	.3484
141.3	156	361.2	333.7	858.3	1192.1	178.1	2.853	.3505
142.3	157	361.7	334.3	857.9	1192.2	177.0	2.835	.3526
143.3	158	362.2	334.8	857.6	1192.4	176.0	2.819	.3547
144.3	159	362.7	335.3	857.2	1192.5	174.9	2.802	.3568
145.3	160	363.2	335.8	856.8	1192.7	173.9	2.786	.3589
146.3	161	363.7	336.3	856.5	1192.8	172.9	2.770	.3610
147.3	162	364.2	336.9	856.1	1193.0	171.9	2.754	.3631
148.3	163	364.7	337.4	855.7	1193.1	171.0	2.739	.3650
149.3	164	365.2	337.9	855.4	1193.3	170.0	2.723	.3672
150.3	165	365.7	338.4	855.0	1193.5	169.0	2.707	.3693
151.3	166	366.2	338.9	854.7	1193.6	168.1	2.693	.3714
152.3	167	366.7	339.4	854.3	1193.7	167.1	2.677	.3735
153.3	168	367.1	339.9	853.9	1193.9	166.2	2.662	.3756

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temperature °F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of one Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		*h* in the Water.	L Latent Heat of Vaporization.	H = L + *h* Total Heat in Steam.	Relative	Specific	
						Cu. Ft. in 1 Cu. Ft. of Water.	Cu. Ft. in 1 Lb. of Steam.	
154.3	169	367.6	340.4	853.6	1194.0	165.3	2.648	.3777
155.3	170	368.1	340.9	853.2	1194.2	164.3	2.631	.3799
156.3	171	368.6	341.4	852.9	1194 3	163.4	2.617	.3820
157.3	172	369.1	341.9	852.6	1194.5	162.5	2.603	.3842
158.3	173	369.5	342.4	852.2	1194.6	161.6	2.588	.3863
159.3	174	370.0	342.8	851.9	1194.8	160.7	2.574	.3885
160.3	175	370.5	343.3	851.5	1194.9	159.8	2.560	.3906
161.3	176	370.9	343.8	851.2	1195.0	158.9	2.545	.3928
162.3	177	371.4	344.3	850.8	1195.2	158.1	2.533	.3949
163.3	178	371.9	344.8	850.5	1195.3	157.2	2.518	.3970
164.3	179	372.3	345.3	850.2	1195.5	156.4	2.505	.3991
165.3	180	372.8	345.7	849.8	1195.6	155.6	2.493	.4012
166.3	181	373.2	346.2	849.5	1195.7	154.8	2.480	.4033
167.3	182	373.7	346.7	849.2	1195.9	154.0	2.467	.4054
168.3	183	374.1	347.1	848.8	1196.0	153.2	2.454	.4075
169.3	184	374.6	347.6	848.5	1196.2	152.4	2.441	.4096
170.3	185	375.0	348.1	848.2	1196.3	151.6	2.428	.4118
171.3	186	375.5	348.6	847.8	1196.4	150.8	2.416	.4140
172.3	187	375.9	349.0	847.5	1196.6	150.0	2.403	.4162
173.3	188	376.4	349.5	847.2	1196.7	149.2	2.390	.4183
174.3	189	376.8	349.9	846.9	1196.8	148.5	2.379	.4204
175.3	190	377.2	350.4	846.5	1197.0	147.8	2.367	.4225
176.3	191	377.7	350.8	846.2	1197.1	147.0	2.355	.4246
177.3	192	378.1	351.3	845.9	1197.2	146.3	2.344	.4267
178.3	193	378.5	351.7	845.6	1197.4	145.6	2.332	.4287
179.3	194	379.0	352.2	845.3	1197.5	144.9	2.321	.4308
180.3	195	379.4	352.6	845.0	1197.6	144.2	2.310	.4329
181.3	196	379.9	353.1	844.6	1197.8	143.5	2.299	.4350
182.3	197	380.3	353.5	844.3	1197.9	142.8	2.287	.4372
183.3	198	380.7	354.0	844.0	1198.0	142.1	2.276	.4393
184.3	199	381.1	354.4	843.7	1198.1	141.4	2.265	.4414
185.3	200	381.5	354.8	843.4	1198.3	140.8	2.255	.4435
186.3	201	381.9	355.3	843.1	1198.4	140.1	2.244	.4456
187.3	202	382.4	355.7	842.8	1198.5	139.5	2.235	.4477
188.3	203	382.8	356.1	842.5	1198.7	138.8	2.223	.4498
189.3	204	383.2	356.6	842.2	1198.8	138.1	2.212	.4520
190.3	205	383.6	357.0	841.8	1198.9	137.5	2.203	.4540
191.3	206	384.0	357.4	841.5	1199.0	136.9	2.193	.4560
192.3	207	384.4	357.9	841.2	1199.2	136.3	2.183	.4580
193.3	208	384.8	358.3	841.0	1199.3	135.7	2.174	.4600
194.3	209	385.2	358.7	840.7	1199 4	135.1	2.164	.4621
195.3	210	385.6	359.1	840.4	1199.5	134.5	2.154	.4642

PROPERTIES OF SATURATED STEAM — *Continued.*

Pounds per Square Inch.		Temp. ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of 1 Cubic Foot of Steam.
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	$H = L + h$ Total Heat in Steam.	Relative Cu. Ft. in 1 Cu. Ft. of Water.	Specific Cu. Ft. in 1 Lb. of Steam.	
196.3	211	386.1	359.6	840.1	1199.7	133.9	2.145	.4663
197.3	212	386.5	360.0	839.8	1199.8	133.3	2.135	.4684
198.3	213	386.9	360.4	839.5	1199.9	132.8	2.126	.4705
199.3	214	387.3	360.9	839.2	1200.1	132.2	2.117	.4726
200.3	215	387.7	361.3	838.9	1200.2	131.6	2.108	.4747
201.3	216	388.1	361.7	838.6	1200.3	131.0	2.098	.4768
202.3	217	388.5	362.1	838.3	1200.4	130.4	2.089	.4789
203.3	218	388.9	362.5	838.0	1200.5	129.9	2.080	.4810
204.3	219	389.3	362.9	837.8	1200.7	129.3	2.070	.4831
205.3	220	389.6	363.3	837.5	1200.8	128.7	2.061	.4852
206.3	221	390.1	363.7	837.3	1201.0	128.1	2.052	.4873
207.3	222	390.5	364.1	837.0	1201.1	127.6	2.043	.4894
208.3	223	390.8	364.5	836.7	1201.2	127.0	2.035	.4915
209.3	224	391.2	364.9	836.4	1201.3	126.5	2.027	.4936
210.3	225	391.6	365.3	836.1	1201.4	126.0	2.018	.4956
211.3	226	392.0	365.8	835.8	1201.6	125.4	2.010	.4977
212.3	227	392.4	366.1	835.6	1201.7	124.9	2.002	.4998
213.3	228	392.8	366.5	835.3	1201.8	124.4	1.993	.5019
214.3	229	393.2	366.9	835.0	1201.9	123.9	1.984	.5040
215.3	230	393.5	367.3	834.7	1202.0	123.3	1.976	.5061
216.3	231	393.9	367.7	834.4	1202.1	122.9	1.968	.5082
217.3	232	394.3	368.1	834.1	1202.2	122.4	1.960	.5103
218.3	233	394.7	368.5	833.9	1202.4	121.9	1.952	.5124
219.3	234	395.1	368.9	833.6	1202.5	121.4	1.944	.5145
220.3	235	395.5	369.2	833.4	1202.6	120.9	1.936	.5165
221.3	236	395.9	369.6	833.1	1202.7	120.4	1.928	.5186
222.3	237	396.3	370.	832.8	1202.8	119.9	1.921	.5207
223.3	238	396.6	370.4	832.5	1202.9	119.4	1.913	.5228
224.3	239	397.0	370.8	832.2	1203.0	119.0	1.905	.5249
225.3	240	397.4	371.1	832.0	1203.1	118.5	1.898	.5270
226.3	241	397.8	371.5	831.7	1203.2	118.0	1.891	.5291
227.3	242	398.1	371.9	831.4	1203.3	117.5	1.884	.5312
228.3	243	398.5	372.3	831.1	1203.4	117.1	1.857	.5332
229.3	244	398.9	372.7	830.8	1203.5	116.7	1.868	.5353
230.3	245	399.2	373.1	830.6	1203.7	116.2	1.861	.5374
231.3	246	399.6	373.4	830.4	1203.8	115.7	1.853	.5395
232.3	247	400.0	373.8	830.1	1203.9	115.3	1.846	.5416
233.3	248	400.3	374.2	829.8	1204.0	114.9	1.839	.5436
234.3	249	400.7	374.6	829.5	1204.1	114.4	1.832	.5457
235.3	250	401.1	375.0	829.2	1204.2	114.0	1.825	.5478
238.3	253	402.1	376.0	828.5	1204.5	112.7	1.806	.5540
241.3	256	403.1	377.0	827.9	1204.9	111.4	1.785	.5603

PROPERTIES OF SATURATED STEAM—*Continued.*

Pounds per Square Inch.		Temperature ° F. at Pressure.	Heat Units in One Pound above 32° F.			Volume.		Weight of 1 Cubic Foot of Steam.
						Relative.	Specific	
Gauge Pressure.	Absolute Pressure.		h in the Water.	L Latent Heat of Vaporization.	H = L + h Total Heat in Steam.	Cu. Ft. in 1 Cu. Ft. of Water.	Cu. Ft. in 1 Lb. of Steam.	
244.3	259	404.2	378.1	827.1	1205.2	110.2	1.766	.5665
247.3	262	405.2	379.2	826.3	1205.5	109.2	1.746	.5727
250.3	265	406.1	380.2	825.6	1205.8	107.8	1.728	.5789
253.3	268	407.2	381.2	824.9	1206.1	106.7	1.709	.5852
256.3	271	408.1	382.3	824.1	1206.4	105.6	1.691	.5914
259.3	274	409.1	383.3	823.4	1206.7	104.5	1.673	.5976
262.3	277	410.0	384.3	822.7	1207.0	103.4	1.656	.6039
265.3	280	411.1	385.3	822.0	1207.3	102.3	1.639	.6101
268.3	283	412.1	386.3	821.3	1207.6	101.3	1.621	.6164
271.3	286	413.0	387.3	820.6	1207.9	100.3	1.606	.6226
274.3	289	414.0	388.3	819.9	1208.2	99.3	1.591	.6288
277.3	292	415.0	389.2	819.3	1208.5	98.35	1.575	.6350
280.3	295	415.9	390.2	818.6	1208.8	97.42	1.560	.6412
283.3	298	416.9	391.1	818.0	1209.1	96.47	1.545	.6474
285.3	300	417.4	391.9	817.4	1209.3	95.8	1.535	.6515
290.3	305	418.9	394.5	815.2	1209.7	94.37	1.510	.6618
295.3	310	420.5	396.0	814.2	1210.2	92.92	1.488	.6721
300.3	315	421.9	397.6	813.0	1210.6	91.52	1.465	.6824
305.3	320	423.4	399.1	812.0	1211.1	90.16	1.443	.6927
310.3	325	424.8	400.6	810.9	1211.5	88.84	1.422	.7030
315.3	330	426.3	402.1	809.8	1211.9	87.55	1.401	.7133
320.3	335	427.7	403.6	808.8	1212.4	86.31	1.382	.7236
325.3	340	429.1	404.8	808.1	1212.9	85.10	1.394	.7339
330.3	345	430.5	406.1	807.2	1213.3	83.92	1.343	.7442
335.3	350	431.96	407.3	806.4	1213.7	82.71	1.325	.7545
385.3	400	444.9	420.8	796.9	1217.7	72.8	1.167	.8572
435.3	450	456.6	433.2	788.1	1221.3	65.1	1.042	.9595
485.3	500	467.4	444.5	780.0	1224.5	58.8	.942	1.0617
535.3	550	477.5	455.1	772.5	1227.6	53.6	.859	1.1638
585.3	600	486.9	465.2	765.3	1230.5	49.3	.790	1.2659
635.3	650	495.7	474.6	758.6	1233.2	45.6	.731	1.3679
685.3	700	504.1	483.4	752.3	1235.7	42.4	.680	1.4699
735.3	750	512.1	491.9	746.1	1238.0	39.6	.636	1.5720
785.3	800	519.6	499.9	740.4	1240.3	37.1	.597	1.6740
835.3	850	526.8	507.7	734.8	1242.5	34.9	.563	1.7760
885.3	900	533.7	515.0	729.7	1244.7	33.0	.532	1.8780
935.3	950	540.3	523.3	723.4	1246.7	31.4	.505	1.9800
985.3	1000	546.8	529.3	719.4	1248.7	30.0	.480	2.0820

SUPERHEATED STEAM.

Dry saturated steam, after being heated to a higher temperature than that corresponding to its pressure, is called superheated steam.

The behavior of superheated steam is similar to that of gases; it is a bad conductor of heat, and can lose some of its heat without becoming saturated or wet steam.

Superheated steam has a greater volume per unit of weight than saturated steam at the same pressure.

Pressure, Pounds.	70	115	170
Vol.* at 390° F.	1.1	1.06	1.02 "Lenke"
Vol. at 570° F.	1.33	1.29	1.24
Vol. at 750° F.	1.57	1.52	1.46

Saturated steam in engines condenses during admission to 20% to 25% of the quantity admitted, causing a large part of the low theoretical efficiency when it is used.

Superheated steam does not condense during this period if sufficiently superheated. 600° to 700° F. is the temperature to which steam should be superheated to get its fullest benefit. Engines must be built to stand this high temperature, or its use should not be attempted.

For piping to convey superheated steam, copper is not suitable, as it loses about 40% of its strength at the high temperature.

Wrought iron and steel with long lengths, and few flange joints, have proved to be the best.

The expansion at 100° F. is about 4½ inches in 100 ft., and must be taken care of in the design of steam lines.

Superheated steam can travel at 30 to 40% higher velocity through steam ports than saturated steam.

Lubrication of Engines Using Superheated Steam.

A 120 I.H.P. Engine uses 4 lbs. of oil per 24 hours for lubrication.

A 300 I.H.P. Corliss Comp. Engine uses 2.2 lbs. of oil per 10 hours, both cylinders.

Superheaters.

Superheating is accomplished by passing the steam, immediately before use, through a series of pipes placed in the path of the furnace gases, or placed over a furnace of their own, where the steam can be given the higher temperature.

The manufacture of separate superheaters in the United States is at present very limited, but abroad many types are in use, and are described in Dawson's Pocket Book.

Economy of Different Types of Steam Engines Using Superheated Steam.

(W. W. Christie, in *Railroad Gazette*, March, 1903.)

The various results given herewith should not be compared with each other on the basis of water per horse-power per hour, as pressures and other conditions are different, but the economy arising from the use of superheated steam over the use of saturated steam in the same engine can properly be compared by one percentage diagram.

The following tests (A. S. M. E., Vol. xxi, p. 788) were made by Mr. E. H. Foster, on a Worthington duplex direct acting triple expansion pumping engine, having six cylinders arranged in tandems of three on each side. The engine was fitted with the Schwoerer patented superheater.

* Compared with saturated steam.

Test No.	1.	2.	3.	4.	5.
I.H.P.	106.3	106.8	103.	105.	105.1
Superheat, deg. F.	0.	0.	118.6	122.5	117.7
Steam per pump H.P. per hr., lbs.	21.8	21.2	18.9	18.5	18.0

The average economy as shown by the above tests in using steam superheated 119.6° F. is 14.1 per cent over that of saturated steam.

Perry, in the "Steam Engine," gives the results of several tests on a Corliss compound engine with steam jacketed cylinders when developing about 500 H.P. With saturated steam at 96 lbs. pressure the steam consumption was 19.8 lbs. per indicated horse-power per hour, but when the steam was superheated 118° F. the steam consumption dropped to 15.6 lbs., a gain of 20.8 per cent. Other tests on a single expansion engine equipped with a Schmidt superheater gave, when using saturated steam, an economy of 38 lbs. per I.H.P. per hour. When using steam with 300° superheat the steam consumption was 17 lbs., showing 55.3 per cent increase in favor of the latter method.

In a paper read before the Society of German Engineers in 1900, Oscar Hunger reported a test of a vertical cross compound pumping engine with 23.6 in. and 37.4 in. x 31.5 in. cylinders and running at 40 r.p.m. At 75 lbs. pressure the steam consumption was 20.5 lbs. with saturated steam. With steam superheated 180.5° and a pressure of 150 lbs., the steam consumption became 12.9 lbs., or a gain of 30.7 per cent over saturated steam at the lower pressure.

Again, tests of a 3,000 H.P. vertical triple expansion engine at the Berlin electric light works (*Engineering Record*, vol. xlii, p. 345) show that a gain of 12.5, 17.9 and 18.7 per cent results from superheating the steam 181, 235 and 264° F. respectively.

Other tests in Bavaria, with a Sulzer compound engine (*Engineering News*, vol. xli, p. 213), give a gain of 16 per cent with steam superheated 114°, 18.5 per cent when superheated 121°, and 25.9 per cent when superheated 173° F.

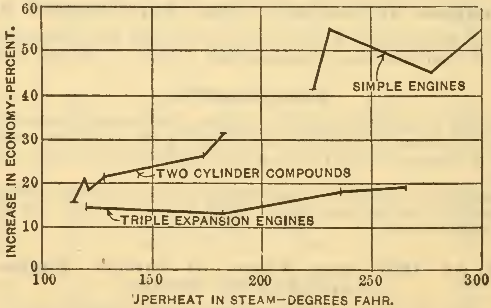


FIG. 12.

Economy of Superheated Steam.

The accompanying diagram* has been obtained from the above tests by plotting the degrees F. of superheat as abscissæ and the per cent of economy as ordinates. Inspection of this diagram shows that the greatest economy results in the use of superheated steam in simple engine, as might be expected. On the other hand, marked economies are shown for compound and triple expansion engines, but the percentage of gain decreases as the number of expansions increases.

* W. W. Christie.

CONDENSATION IN STEAM-PIPES.

(W. W. C.)

No very satisfactory figures are found for the absolute condensation losses in steam pipes, most of reported tests being compared with hair felt. 0.012 lbs. per 24 hours per sq. ft. of pipe per degree Fahr., difference in temperature of steam and external air, which may be used in calculations, is based on the following :

Test by.	Sq. ft. Surface.	Lbs. of Water. in 24 hrs.	Lbs. of Water. per sq. ft. in 24 hrs.	Difference in temperature Deg. F.	Lbs. Water per degree 24 hours.	Covering.
Bedle & Bauer.	4130	11315	2.74	262	.0104	Asbestos.
Norris.	3892	9360	2.40	234	.0103	Asbestos.
Brill.				308	.0105	Magnesia sect'l.
Norton.				315	.0125	Magnesia.

The last test by C. L. Norton (Trans. A. S. M. E., 1898) was made with the utmost care. Mr. Norton found that a pipe boxed in with charcoal 1 inch minimum thickness was 20 per cent better insulated than when magnesia was used, corroborating Mr. Reinhart's statements concerning his experience using flue dust to insulate pipes.

Aboard Ship. — The battleship "Shikishima" carries 25 Belleville boilers capable under full steam of developing 15,000 I.H.P. in the main engines besides working the auxiliaries, each boiler supplying steam for 150 I.H.P. When at anchor, one boiler under easy steam, i.e., evaporating from 9 lb. to 10 lbs. of water from and at 212° F., per pound of coal — was just able to work one 48 K.W. steam dynamo at about half power, together with one feed pump, and the air and circulating pumps connected with the auxiliary condenser, into which the dynamo engine exhausted, besides working a fire and bilge pump occasionally.

The dynamo was about 160 ft. of pipe length away from the boiler, the total range of steam pipe length connected being 500–600 ft.

Performing the first-mentioned service with only one boiler under steam, the coal burned varied from 3½ to 5 tons per day of 18 hours, for about 65 I.H.P., or about 7 lbs. per indicated horse-power at the best to 10 lbs. at the worst, an average of 8 lbs. and over, which shows that more than half the fuel must have been expended in keeping the pipes warm. All pipes were well covered and below decks, and machinery in first-class condition. (London-Engr.)

Heating Pipes. — To determine the boiler H.P. necessary for heating, it may be assumed that each sq. ft. of radiating surface will condense about 0.3 lbs. of steam per hour as a maximum when in active service; thus 20,000 sq. ft. times 0.3 = 6000 lbs. of condensation, which divided by 30 gives 200 boiler horse-power.

Condensed steam in which there is no oil may be returned to the boiler with the feed-water to be re-evaporated.

OUTFLOW OF STEAM FROM A GIVEN INITIAL PRESSURE INTO VARIOUS LOWER PRESSURES.

(D. K. Clark.)

Absolute Pressure in Boiler per Sq. Inch.	Outside Pressure per Sq. Inch.	Ratio of Expansion.	Velocity of Outflow at Constant Density.	Actual Velocity of Outflow Expanded.	Weight Discharged per Sq. In. of Orifice per Minute.
Lbs.	Lbs.	Ratio.	Ft. per Sec.	Ft. per Sec.	Lbs.
75	74	1.012	227.5	230	16.68
75	72	1.037	386.7	401	28.35
75	70	1.063	490	521	35.93
75	65	1.136	660	749	48.38
75	61.62	1.198	736	876	53.97
75	60	1.219	765	933	56.12
75	50	1.434	873	1252	64.
75	45	1.575	890	1401	65.24
75	43.46, 58 %	1.624	890.6	1446.5	65.3
75	15	1.624	890.6	1446.5	65.3
75	0	1.624	890.6	1446.5	65.3

When, however, steam of varying initial pressure is discharged into the atmosphere — pressures of which the atmospheric pressure is not more than 58 per cent — the velocity of outflow at constant density, that is, supposing the initial density to be maintained, is given by the formula —

$$V = 3.5953 \sqrt{h},$$

where V = the velocity of outflow in feet per minute, as for steam of the initial density. h = the height in feet of a column of steam of the given absolute initial pressure of uniform density, the weight of which is equal to the pressure on the unit of base.

The following table is calculated from this formula :

OUTFLOW OF STEAM INTO THE ATMOSPHERE.

(D. K. Clark.)

Absolute Initial Pressure in Boiler in Lbs. per Sq. Inch.	Outside Pressure in Lbs. per Sq. Inch.	Ratio of Expansion in Nozzle.	Velocity of Outflow at Constant Density.	Actual Velocity of Outflow, Expanded.	Weight Discharged per Sq. Inch of Orifice per Min.
Lbs.	Lbs.	Ratio.	Ft. per Sec.	Ft. per Sec.	Lbs.
25.37	14.7	1.624	863	1401	22.81
30	14.7	1.624	867	1408	26.84
40	14.7	1.624	874	1419	35.18
45	14.7	1.624	877	1424	39.78
50	14.7	1.624	880	1429	44.06
60	14.7	1.624	885	1437	52.59
70	14.7	1.624	889	1444	61.07
75	14.7	1.624	891	1447	65.30
90	14.7	1.624	895	1454	77.94
100	14.7	1.624	898	1459	86.34
115	14.7	1.624	902	1466	98.76
135	14.7	1.624	906	1472	115.61
155	14.7	1.624	910	1478	132.21
165	14.7	1.624	912	1481	140.46
215	14.7	1.624	919	1493	181.58

STEAM PIPES.

Rankine says the velocity of steam flow in pipes should not exceed 6000 feet per minute (100 feet per second). As increased size of pipe means increased loss by radiation, care should be taken that in order to decrease the velocity of flow, the losses by radiation do not become considerable.

The quantity discharged per minute may be approximately found by Rankine's formula ("Steam Engine," p. 298), $W = 60\ ap \div 70 = 6\ ap \div 7$, in which W = weight in pounds, a = area of orifice in square inches, and p = absolute pressure. The results must be multiplied by $k = 0.93$ for a short pipe, and by $k = 0.63$ for their openings as in a safety valve.

Where steam flows into a pressure greater than two-thirds the pressure in the boiler, $W = 1.9\ ak\sqrt{(p-d)\ d}$, in which d = difference in pressure in pounds per square inch between the two sides, and a, p, and k as above. Multiply the results by 2 to reduce to h.p. To determine the necessary difference in pressure where a given h.p. is required to flow through a given opening,

$$d = \frac{p}{2} - \sqrt{\frac{p^2}{4} - \frac{HP^2}{14\ a^2k}}.$$

Flow of Steam Through Pipes.

(G. H. Babcock in "Steam.")

The approximate weight of any fluid which will flow in a minute through any given pipe with a given head or pressure may be found by the formula

$$W = 87\sqrt{\frac{D(p_1 - p_2)\ d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

in which W = weight in pounds, d = diameter in inches, D = density or weight per cubic foot, p_1 = initial pressure, p_2 = pressure at the end of the pipe, and L = length in feet.

The following table gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure through straight smooth pipes, each having a length of 240 times its own diameter. For sizes below 6 inches, the flow is calculated from the actual areas of "standard" pipe of such nominal diameters.

For h.p. multiply the figures in the table by two. For any other loss of pressure, multiply by the square root of the given loss. For any other length of pipe, divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient, which will give the flow for 1 pound loss of pressure. Conversely dividing the given length by 240 will give the loss of pressure for the flow given in the table.

Table of Flow of Steam Through Pipes.

Initial Pressure by Gauge. Lbs. per Sq. Inch.	Diameter of Pipe in Inches. Length of each = 240 Diameters.						
	¾	1	1½	2	2½	3	4
	Weight of Steam per Min. in Lbs., with 1 Lb. Loss of Pressure.						
1	1.16	2.07	5.7	10.27	15.45	25.38	46.85
10	1.44	2.57	7.1	12.72	19.15	31.45	58.05
20	1.70	3.02	8.3	14.94	22.49	36.94	68.20
30	1.91	3.40	9.4	16.84	25.35	41.63	76.84
40	2.10	3.74	10.3	18.51	27.87	45.77	84.49
50	2.27	4.04	11.2	20.01	30.13	49.48	91.34
60	2.43	4.32	11.9	21.38	32.19	52.87	97.60
70	2.57	4.58	12.6	22.65	34.10	56.00	103.37
80	2.71	4.82	13.3	23.82	35.87	58.91	108.74
90	2.83	5.04	13.9	24.92	37.52	61.62	113.74
100	2.95	5.25	14.5	25.96	39.07	64.18	118.47
120	3.16	5.63	15.5	27.85	41.93	68.87	127.12
150	3.45	6.14	17.0	30.37	45.72	75.09	138.61

Table of Flow of Steam Through Pipes.—*Continued.*

Initial Pressure by Gauge. Lbs. per Sq. Inch.	Diameter of Pipe in Inches. Length of Each = 240 Diameters.						
	5	6	8	10	12	15	18
	Weight of Steam per Min. in Lbs., with 1 Lb. Loss of Pressure.						
1	77.3	115.9	211.4	341.1	502.4	804	1177
10	95.8	143.6	262.0	422.7	622.5	996	1458
20	112.6	168.7	307.8	496.5	731.3	1170	1713
30	126.9	190.1	346.8	559.5	824.1	1318	1930
40	139.5	209.0	381.3	615.3	906.0	1450	2122
50	150.8	226.0	412.2	665.0	979.5	1567	2294
60	161.1	241.5	440.5	710.6	1046.7	1675	2451
70	170.7	255.8	466.5	752.7	1108.5	1774	2596
80	179.5	269.0	490.7	791.7	1166.1	1866	2731
90	187.8	281.4	513.3	828.1	1219.8	1951	2856
100	195.6	293.1	534.6	862.6	1270.1	2032	2975
120	209.9	314.5	573.7	925.6	1363.3	2181	3193
150	228.8	343.0	625.5	1009.2	1486.5	2378	3481

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe and passing elbows and valves, will reduce the flow given in the table. The resistance at the opening and that at a globe valve are each about the same as that for a length of pipe equal to 114 diameters divided by a number represented by $1+\frac{3.6}{d}$. For the sizes of pipes given in the table these corresponding lengths are:

$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to $\frac{2}{3}$ that of a globe valve. These equivalents — for opening, for elbows, and for valves — must be added in each instance to the actual length of pipe. Thus a 4-inch pipe, 120 diameters (40 feet) long, with a globe valve and three elbows, would be equivalent to $120 + 60 + 60 + (3 \times 40) = 360$ diameters long; and $360 \div 240 = 1\frac{1}{2}$. It would therefore have $1\frac{1}{2}$ lbs. loss of pressure at the flow given in the table, or deliver ($1 \div \sqrt{1\frac{1}{2}} = .816$), 81.6 per cent of the steam with the same (1 lb.) loss of pressure.

Equation of Pipes (Steam).

It is frequently desirable to know what number of one size of pipes will equal in capacity another given pipe for delivery of steam or water. At the same velocity of flow two pipes deliver as the squares of their internal diameters, but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary as the square root of the fifth power of the diameter. The friction of a fluid within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is, of course, greater in proportion to the contents of a small pipe than of a large. It may be approximated in a given pipe by a constant multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter by the diameter increased by a constant. Careful comparisons of a large number of experiments, by different investigators, has developed the following as a close approximation to the relative flow in pipes of different sizes under similar conditions:

$$W \propto \frac{d^3}{\sqrt{d+3.6}}$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

The diameters of "standard" steam and gas pipe, however, vary from the nominal diameters, and in applying this rule it is necessary to take the true measurements, which are given in the following table :

Table of Standard Sizes Steam and Gas Pipes.

Size, Inches.	Diameter. Internal.	Diameter. External.	Size, Inches.	Diameter. Internal.	Diameter. External.	Size, Inches.	Diameter. Internal.	Diameter. External.
$\frac{1}{8}$	.27	.40	$2\frac{1}{2}$	2.47	2.87	9	8.94	9.62
$\frac{1}{4}$	.36	.54	3	3.07	3.5	10	10.02	10.75
$\frac{3}{8}$	.49	.67	$3\frac{1}{2}$	3.55	4	11	11	11.75
$\frac{1}{2}$	.62	.84	4	4.03	4.5	12	12	12.75
$\frac{3}{4}$	.82	1.05	$4\frac{1}{2}$	4.51	5	13	13.25	14
1	1.05	1.31	5	5.04	5.56	14	14.25	15
$1\frac{1}{4}$	1.38	1.66	6	6.06	6.62	15	15.43	16
$1\frac{1}{2}$	1.61	1.90	7	7.02	7.62	16	16.4	17
2	2.07	2.37	8	7.98	8.62	17	17.32	18

The following table gives the number of pipes of one size required to equal in delivery other larger pipes of the same length and under the same conditions. The upper portion above the diagonal line of blanks pertains to "standard" steam and gas pipes, while the lower portion is for pipe of the actual internal diameters given. The figures given in the table opposite the intersection of any two sizes is the number of the smaller-sized pipes required to equal one of the larger.

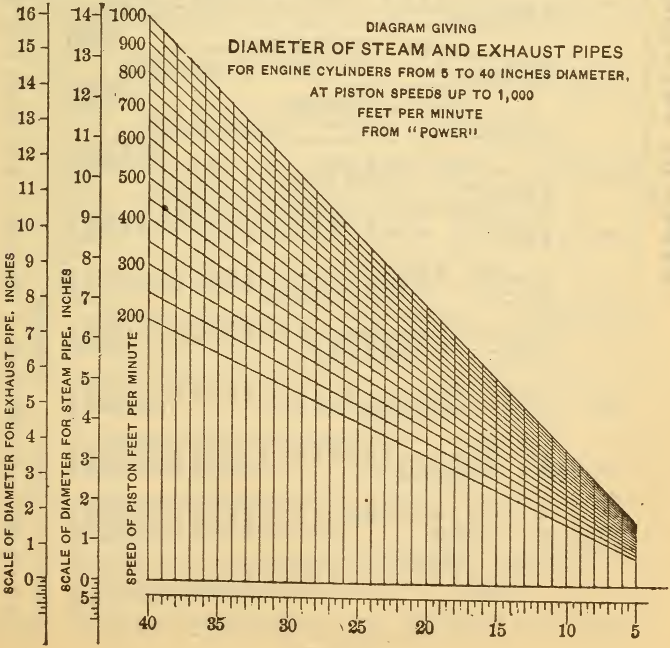


FIG. 13.

TABLE OF EQUATION OF PIPES.

(Standard Steam and Gas Pipes.)

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1292	1767	2488	3014	3786	4904	5927	7321	8535	9717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1096	1328	1668	2161	2615	3226	3761	4282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1070	1263	1576	1837	2092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3335	1281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4393	1688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5642	2168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7087	2723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8657	3326	1146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10600	4070	1403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12824	4927	1698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14978	5758	1984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17537	6738	2322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20327	7810	2691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26676	10249	3532	1102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42624	16376	5644	1761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75453	28990	9990	3117	1378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120100	46143	15902	4961	2193	1172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177724	68282	23531	7341	3245	1734	1044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249351	95818	33020	10301	4554	2434	1465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	
Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

Actual internal diameters.

PROTECTION OF STEAM-HEATED SURFACES.

This table showing the losses of heat from a bare steam pipe, is the result of tests by Dr. C. E. Emery, made at the Massachusetts Institute of Technology.

Table of Loss of Heat from Steam Pipes.

Steam pressure, 75 lbs. Air, 60° F.

Thickness of Covering in Inches.	Outside Diameter of Pipe, without Felt.														
	2 in. diameter.			4 in. diameter.			6 in. diameter.			8 in. diameter.			12 in. diameter.		
	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.	Loss in Units per Foot Run per Hour.	Ratio of Loss.	Feet in Length per H. P. Lost.
0	219.0	1.00	152	390.8	1.00	86	624.1	1.000	53	729.8	1.000	46	1077.4	1.000	31
$\frac{1}{4}$	100.7	.46	331	180.9	.46	182									
$\frac{1}{2}$	65.7	.30	507	117.2	.30	284	187.2	.300	177	219.6	.301	151	301.7	.280	114
1	43.8	.20	761	73.9	.18	451	111.0	.178	300	128.3	.176	259	185.3	.172	179
2	28.4	.13	1173	44.7	.11	745	66.2	.106	504	75.2	.103	443	98.0	.091	340
4	19.8	.09	1683	28.1	.07	1186	41.2	.066	808	46.0	.063	724	60.3	.056	553
6				23.4	.06	1424	33.7	.054	989	34.3	.047	972	45.2	.042	735

RELATIVE VALUE OF STEAM PIPE COVERING.

(By H. G. Stott.)

Before awarding a contract for covering the steam pipes in the Manhattan Railway Company's power-house, a careful investigation and test of different types and thicknesses of covering was made under the author's direction.

The method adopted consisted in coupling up about 200 feet of 2-in. iron pipe.

Sections 15 feet in length were marked off on the straight portions of the pipe, and so arranged as not to include any pipe couplings or bends. Two feet from each end of each section heavy potential wires were soldered on to the pipe, and at the extreme ends of the pipe, cream copper insulated cables were soldered on, the openings in the pipe having been previously closed by means of a standard coupling and plug. One of these cables ran direct to one terminal of a 250-kilowatt 250-volt steam-driven direct-coupled exciter. The cable connected to the other end of the pipe was then connected to three ammeter shunts in series, in order to enable the readings to be easily checked, after which it was carried through a circuit breaker and switch to the other exciter terminal.

Invitations for bids were sent to all the principal pipe covering manufacturers and jobbers, specifying that each one would be expected to cover one or more sections of the 2-inch pipe for a competitive test, and that samples from the successful bidders' covering would be analyzed in the company's chemical laboratory, and no covering accepted which departed more than 3 per cent from this analysis.

A special Weston Milli-Voltmeter was ordered, with which readings were taken from the potential wires, the latter all being brought to mercury cups on a testing table near which the ammeters were also located.

Current sufficient to heat the pipe to approximately 370 degrees Fahr. (corresponding to a steam gauge pressure of 160 pounds) was kept on for three days continuously in order to dry out the various coverings, after which they were allowed to cool off to the air temperatures before starting the test.

The temperature of the room was kept between 27 and 31 degrees Cent. (80 and 88 degrees Fahr., about) during the entire test. Each section has about 600 readings taken.

The method of test was to put a current of sufficient quantity through the pipe to heat to, say, 220 degrees Fahr., and keep this current on for a sufficient time to enable all sections to maintain a constant temperature (this period was found to be about ten hours), when readings of the milli-volt-meter were taken on each section with simultaneous ammeter readings.

A constant temperature having been obtained, it is evident that the watts lost in each section give an exact measure of the energy lost in maintaining a constant temperature, and from the watts lost the B. T. U. are readily calculated. Diagram No. 1 shows the result of the test values being reduced to loss in B. T. U. per square foot of pipe surface at various temperatures in the curves, and at a temperature corresponding to steam at 160 pounds pressure in the table.

After a series of readings had been completed, the current was raised sufficiently to give approximately 50 degrees Fahr. rise in the least efficient covering, and maintained constant for ten hours, when another series of readings was taken, and so on until the temperature of the pipe had reached a point far above anything used in practice.

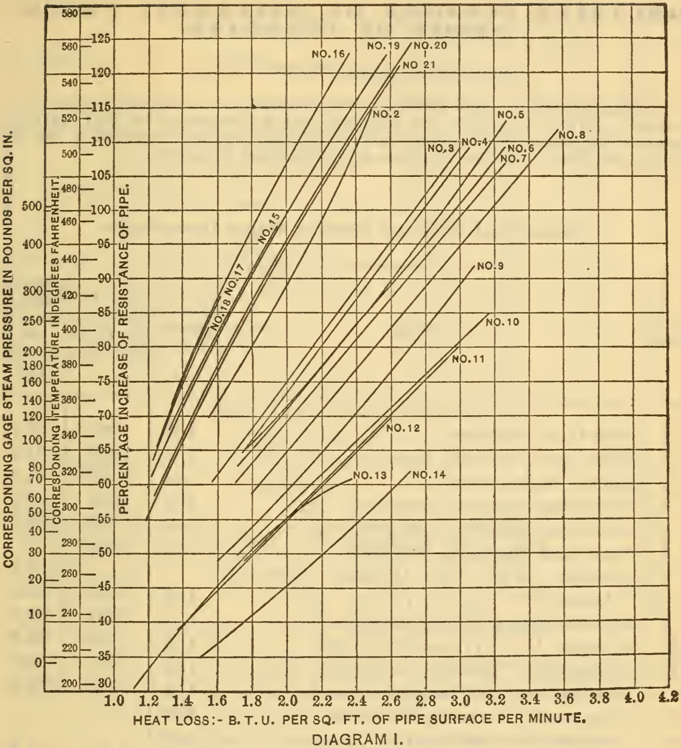

CORRESPONDING GAGE STEAM PRESSURE IN POUNDS PER SQ. IN.
CORRESPONDING TEMPERATURE IN DEGREES FAHRENHEIT.
PERCENTAGE INCREASE OF RESISTANCE OF PIPE.
NO.16
NO.19
NO.20
NO 21
NO.2
NO.5
NO.8
NO.3
NO.4
NO.6
NO.7
NO.15
NO.17
NO.18
NO.9
NO.10
NO.11
NO.12
NO.13
NO.14
1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2
HEAT LOSS:- B. T. U. PER SQ. FT. OF PIPE SURFACE PER MINUTE.
DIAGRAM I.

FIG. 14.

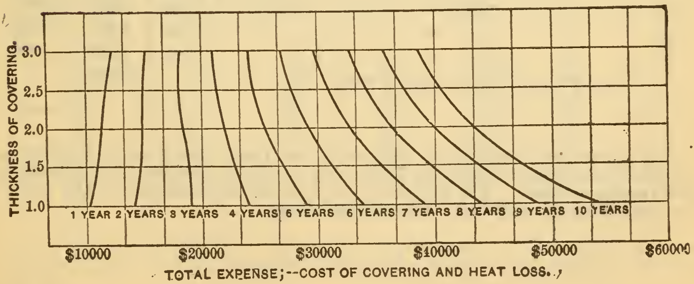

THICKNESS OF COVERING.
3.0
2.5
2.0
1.5
1.0
1 YEAR 2 YEARS 3 YEARS 4 YEARS 5 YEARS 6 YEARS 7 YEARS 8 YEARS 9 YEARS 10 YEARS
$10000 $20000 $30000 $40000 $50000 $60000
TOTAL EXPENSE;--COST OF COVERING AND HEAT LOSS.

FIG. 15.

RELATIVE ECONOMY OF DIFFERENT THICKNESSES OF COVERING.

85 per cent magnesia used as basis.

The diagram shows that for two years, covering an inch thick is most economical. After two years the relative cost decreases quite fast with increase in thickness; and at ten years, covering three inches thick is far the most economical, and this without regard to pipe diameter.

Electrical Test of Steam Pipe Coverings.

No of Curve	Covering.	Aver. Thickness.	B.T.U. Loss per Sq. ft. at 100 lb.pr.	per cent Heat Saved by Covering.
2	Solid Cork, Sectional	1.68	1,462	87.1
3	85 per cent Magnesia, Sectional	1.18	2,008	84.5
4	Solid Cork, Sectional	1.20	2,048	84.2
5	85 per cent Magnesia, Sectional	1.19	2,130	83.6
6	Laminated Asbesto Cork, Sectional..........	1.48	2,123	83.7
7	85 per cent Magnesia, Sectional..............	1.12	2,190	
8	Asbestos Air Cell [Indent] Sectional			83.2
	(Imperial)	1.26	2,333	83.1
9	Asbestos Sponge Felted, Sectional	1.24	2,552	80.3
10	Asbestos Air Cell [Long] Sectional	1.70	2,750	78.8
11	"Asbestocel" [Radial], Sectional............	1.22	2,801	78.5
12	Asbestos Air Cell [Long], Sectional..........	1.29	2,812	78.4
13	"Standard" Asbestos, Sectional	1.12		
14	"Magnesian", Sectional.....................	1.28		
15	"Romanit" [Silk] Wrapped	1.51	1,452	88.8
16	85 per cent Magnesia 2 Sectional and ½″ Block	2.71	1,381	89.4
17	" " " " " "½″ Plaster	2.45	1,387	88.7
18	" " 2-1″ "	2.50	1,412	89.0
19	" " 2-1″ "	2.24	1,465	88.7
20	" " 2″ "	2.34	1,555	88.0
21	" " 2″ "	2.20	1,568	87.9
	Bare Pipe [From Outside Tests]............		13,000	

In a paper read before the A. S. M. E. in June, 1898, Prof. C. L. Norton of the Massachusetts Institute Technology, gave a series of tables showing the results of tests. For the sake of brevity the descriptions of the different materials are omitted. The tables follow:

Specimen.	Name.	B.T.U. Loss per Sq. Ft. Pipe Surfac per Min.	Ratio of Loss to Loss from Bare Pipe.	Thickness in Inches.	Weight in Oz. per Ft. of Length 4 In. Diam.
A . . .	Nonpareil Cork Standard .	2.20	15.9	1.00	27
B . . .	Nonpareil Cork Octagonal .	2.38	17.2	.80	16
C . . .	Manville High Pressure . .	2.38	17.2	1.25	54
D . . .	Magnesia	2.45	17.7	1.12	35
E . . .	Imperial Asbestos	2.49	18.0	1.12	45
F . . .	W. B.	2.62	18.9	1.12	59
G . . .	Asbestos Air Cell	2.77	20.0	1.12	35
H . . .	Manville Infusorial Earth .	2.80	20.2	1.50	. . .
I . . .	Manville Low Pressure . .	2.87	20.7	1.25	. . .
J . . .	Manville Magnesia Asbestos	2.88	20.8	1.50	65
K . . .	Magnabestos	2.91	21.0	1.12	48
L . . .	Molded Sectional	3.00	21.7	1.12	41
O . . .	Asbestos Fire Board . . .	3.33	24.1	1.12	35
P . . .	Calcite	3.61	26.1	1.12	66
	Bare Pipe	13.84	100.	. . .	. . .

Miscellaneous Substances.

Specimen.	B.T.U. per sq. ft. per min. at 200 lbs.	Specimens.	B.T.U. per sq. ft. per min. at 200 lbs.
Box A, 1 with sand	3.18	Pine wood 1 inch thick . .	3.56
2 with cork, powdered . .	1.75	Hair felt 1 inch thick . . .	2.51
3 with cork and infusorial earth	1.90	Cabot's seaweed quilt . . .	2.78
		Spruce 1 inch thick	3.40
4 with sawdust	2.15	Spruce 2 inches thick . .	2.31
5 with charcoal	2.00	Spruce 3 inches thick . . .	2.02
6 with ashes	2.46	Oak 1 inch thick	3.65
Brick wall 4 inches thick . .	5.18	Hard pine 1 inch thick . . .	3.72

Prof. R. C. Carpenter says that there is great difference in the flow of heat through a metal plate between different media. In discussing Professor Norton's paper he gave the values as shown in the following table as the result of experiments conducted in his laboratory.

Heat Transmitted in Thermal Units Through Clean Cast-Iron Plate $\frac{7}{16}$ Inch Thick. (Carpenter.)

Difference of Temperature. Degrees F.	Steam to Water. Per Square Foot.		Lard Oil to Water. Per Square Foot.		Air to Water. Per Square Foot.	
	Per Deg per hour B. T. U	Total per minute B. T. U.	Per Deg. per hour B. T. U.	Total per minute B. T. U.	Per Deg. per hour B. T. U.	Total per minute B. T. U.
25	21	8.8	6.5	2.7	1.2	0.5
50	48	40	13	10.8	2.5	2.7
75	84	110	19.5	24.5	3.7	5.8
100	127	211	26	43.3	5.0	8.3
125	185	375	31.5	65.5	6.2	13
150	255	637	39	72.5	7.5	18.7
175			45.5	132	8.7	25.4
200			52	173	10	33
300			78	390	15	75
400					20	133
500					25	208

The above investigation indicates that the substance which surrenders the heat is of material importance, as is also the temperature of the surrounding media.

In estimating the effective steam-heating or boiler surface of tubes, the surface in contact with air or gases of combustion (whether internal or external to the tubes) is to be taken.

For heating liquids by steam, superheating steam, or transferring heat from one liquid or gas to another, the mean surface of the tubes is to be taken.

WROUGHT-IRON WELDED STEAM, GAS, AND WATER PIPE.

Table of Standard Dimensions.

Diameter.			Thickness.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Length of Pipe Containing one Cubic Foot.	Nominal Weight per Foot.	Number of Threads per Inch of Screw.
Nominal Internal.	Actual External.	Actual Internal.		External.	Internal.	External.	Internal.	Metal.	External Surface	Internal Surface			
Inches.	Inches.	Inches	Inches.	Inches.	Inches.	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet.	Feet.	Feet.	Pounds.	
1/8	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
1/4	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
1/2	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
3/4	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8
11	12.	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8
13	14.	13.25	.375	43.982	41.626	153.938	137.887	16.051	.273	.288	1.04	53.921	8
14	15.	14.25	.375	47.124	44.768	176.715	159.485	17.23	.255	.268	.903	57.893	8
15	16.	15.25	.375	50.265	47.909	201.062	182.655	18.407	.239	.250	.788	61.77	8
. . .	18.	17.25	.375	56.549	54.192	254.47	233.706	20.764	.212	.221	.616	69.66	
. . .	20.	19.25	.375	62.832	60.476	314.16	291.04	23.12	.191	.198	.495	77.57	
. . .	22.	21.25	.375	69.115	66.759	380.134	354.657	25.477	.174	.179	.406	85.47	
. . .	24.	23.25	.375	75.398	73.042	452.39	424.558	27.832	.159	.164	.339	93.37	

WROUGHT-IRON WELDED EXTRA STRONG PIPE.

Table of Standard Dimensions.

Diameter.			Thickness.	Nearest Wire Gauge.	Circumference.		Transverse Areas.			Length of Pipe per Square Foot of		Nominal Weight per Foot.
Nominal Internal.	Actual External	Actual Internal.			External.	Internal.	External.	Internal.	Metal.	External Surface.	Internal Surface.	
Inches.	Inches.	Inches.	Inches.	No.	Inches.	Inches.	Sq. Ins.	Sq. Ins.	Sq. Ins.	Feet.	Feet.	Pounds.
1/8	.405	.205	.1	12½	1.272	.644	.129	.033	.086	9.433	18.632	.29
1/4	.54	.294	.123	11	1.696	.924	.229	.068	.161	7.075	12.986	.54
3/8	.675	.421	.127	10½	2.121	1.323	.358	.139	.219	5.657	9.07	.74
1/2	.84	.542	.149	9	2.639	1.703	.554	.231	.323	4.547	7.046	1.09
3/4	1.05	.736	.157	8½	3.299	2.312	.866	.452	.414	3.637	5.109	1.39
1	1.315	.951	.182	7	4.131	2.988	1.358	.71	.648	2.904	4.016	2.17
1¼	1.66	1.272	.194	6½	5.215	3.996	2.164	1.271	.893	2.301	3.003	3.
1½	1.9	1.494	.203	6	5.969	4.694	2.835	1.753	1.082	2.01	2.556	3.63
2	2.375	1.933	.221	5	7.461	6.073	4.43	2.935	1.495	1.608	1.975	5.02
2½	2.875	2.315	.28	2	9.032	7.273	6.492	4.209	2.283	1.328	1.649	7.67
3	3.5	2.892	.304	1	10.996	9.085	9.621	6.569	3.052	1.091	1.328	10.25
3½	4.	3.358	.321	0	12.566	10.549	12.566	8.856	3.71	.955	1.137	12.47
4	4.5	3.818	.341	0	14.137	11.995	15.904	11.449	4.455	.849	1.	14.97
5	5.563	4.813	.375	00	17.477	15.120	24.306	18.193	6.12	.687	.793	20.54
6	6.625	5.75	.437	000	20.813	18.064	34.472	25.967	8.505	.577	.664	28.58

Standard Sizes, etc., of Lap-Welded Charcoal-Iron Boiler-Tubes.

(Morris, Tasker & Company, Limited.)

External Diameter.	Internal Diameter.	Standard Thickness.	Internal Circumference.	External Circumference.	Internal Area.		External Area.		Length of Tube per Sq. Ft. of Inside Surface.	Length of Tube per Sq. Ft. of Outside Surface.	Length of Tube per Sq. Ft. of Mean Surface.	Weight per Lineal Foot.
Inches.	Inches.	Inches.	Inches.	Inches.	Sq. In.	Sq. Ft.	Sq. In.	Sq. Ft.	Feet.	Feet.	Feet.	Lbs.
1	.856	.072	2.689	3.142	.575	.004	.785	.0055	4.460	3.819	4.139	.708
$1\frac{1}{4}$	1.106	.072	3.474	3.927	.960	.0067	1.227	.0085	3.455	3.056	3.255	.9
$1\frac{1}{2}$	1.334	.083	4.191	4.712	1.396	.0097	1.767	.0123	2.863	2.547	2.705	1.25
$1\frac{3}{4}$	1.560	.095	4.901	5.498	1.911	.0133	2.405	.0167	2.448	2.183	2.315	1.665
2	1.804	.098	5.667	6.283	2.556	.0177	3.142	.0218	2.118	1.909	2.013	1.981
$2\frac{1}{4}$	2.054	.098	6.484	7.069	3.314	.0230	3.976	.0276	1.850	1.698	1.774	2.238
$2\frac{1}{2}$	2.283	.109	7.172	7.854	4.094	.0284	4.909	.0341	1.673	1.528	1.600	2.755
$2\frac{3}{4}$	2.533	.109	7.957	8.639	5.039	.035	5.940	.0412	1.508	1.390	1.449	3.045
3	2.783	.109	8.743	9.425	6.083	.0422	7.069	.0491	1.373	1.273	1.323	3.333
$3\frac{1}{4}$	3.012	.119	9.462	10.210	7.125	.0495	8.296	.0576	1.268	1.175	1.221	3.958
$3\frac{1}{2}$	3.262	.119	10.248	10.995	8.357	.058	9.621	.0668	1.171	1.091	1.131	4.272
$3\frac{3}{4}$	3.512	.119	11.033	11.781	9.687	.0673	11.045	.0767	1.088	1.018	1.053	4.590
4	3.741	.130	11.753	12.566	10.992	.0763	12.566	.0872	1.023	.955	.989	5.32
$4\frac{1}{2}$	4.241	.130	13.323	14.137	14.126	.0981	15.904	.1104	.901	.849	.875	6.01
5	4.720	.140	14.818	15.708	17.497	.1215	19.635	.1364	.809	.764	.786	7.226
6	5.699	.151	17.904	18.849	25.509	.1771	28.274	.1963	.670	.637	.653	9.346
7	6.657	.172	20.914	21.991	34.805	.2417	38.484	.2673	.574	.545	.560	12.435
8	7.636	.182	23.989	25.132	45.795	.318	50.265	.3490	.500	.478	.489	15.109
9	8.615	.193	27.055	28.274	58.291	.4048	63.617	.4418	.444	.424	.434	18.002
10	9.573	.214	30.074	31.416	71.975	.4998	78.540	.5454	.399	.382	.391	22.19
11	10.560	.22	33.175	34.557	87.479	.6075	95.033	.6601	.361	.347	.354	25.489
12	11.542	.229	36.26	37.699	103.749	.7205	113.097	.7854	.330	.318	.324	28.516
13	12.524	.238	39.345	40.840	123.187	.8554	132.732	.9213	.305	.293	.299	32.208
14	13.504	.248	42.414	43.982	143.189	.9943	153.938	1.069	.282	.272	.277	36.271
15	14.482	.259	45.496	47.124	164.718	1.1438	176.715	1.2272	.263	.254	.258	40.612
16	15.458	.271	48.562	50.265	187.667	1.3032	201.062	1.188	.247	.238	.242	45.199
17	16.432	.284	51.662	53.407	212.227	1.4738	226.980	1.5762	.232	.224	.228	49.902
18	17.416	.292	54.714	56.548	238.224	1.6543	254.469	1.7671	.219	.212	.215	54.816
19	18.400	.3	57.805	59.690	265.903	1.8465	283.529	1.969	.207	.200	.203	59.479
20	19.360	.32	60.821	62.832	294.373	2.0443	314.159	2.1817	.197	.190	.193	66.765
21	20.320	.34	63.837	65.973	324.311	2.2522	346.361	2.4053	.188	.181	.184	73.404

Collapsing Pressure.

Bessemer Steel Tubes, Lap Welded.

A. S. M. E. Trans. 1906—R. T. Stewart.

$$P = 1000\left(1 - \sqrt{1 - 1600\frac{t^2}{d^2}}\right) \quad \ldots\ldots \quad (A)$$

$$P = 86670\frac{t}{d} - 1386 \quad \ldots\ldots \quad (B)$$

$P =$ collapsing pres. lbs. per sq. in.
$d =$ outs. diam. of tube — inches.
$t =$ thickness of wall — inches.

Use A for values of P less than 581 lbs.

for values of $\frac{t}{d}$ less than 0.023.

Use B for values greater than these.
Material tested was 56000 — 60000 lbs. tensile strength.
Up to 8″ diam. and 20 ft. long.

Resistance of Tubes to Collapse.

Bulletin, No. 5, Exp. Station — Univ. Ill., 1906 — A. P. Carman

Where ratio $\frac{t}{d}$ is greater than 0.03.

a. For brass:

$$P = 93365\frac{t}{d} - 2474.$$

b. For seamless cold drawn steel:

$$P = 95520\frac{t}{d} - 2090.$$

c. For lap-welded steel:

$$P = 83270\frac{t}{d} - 1025.$$

Where $\frac{t}{d}$ is less than 0.06.

For seamless cold drawn steel:

$$P = 1{,}000{,}000\left(\frac{t}{d}\right)^2.$$

For lap-welded steel:

$$P = 1{,}250{,}000\left(\frac{t}{d}\right)^2.$$

TABLE OF DIMENSIONS—HIGH PRESSURE, CAST IRON SCREW FLANGES.

A—Diameter of Port	In.	2	2 1/2	3	3 1/2	4	4 1/2	5	6	7	8	9	10	12	14	16
B—Diameter of Flange	In.	6 1/2	7 1/2	9	9	10	10 1/2	11	13	14	15	16	17 1/2	20	23	25
C—Thickness of Flange	In.	7/8	1	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 3/8	1 7/16	1 1/2	1 9/16	1 5/8	1 7/8	2	2 1/4
G—Length of Pipe Thread	In.	1 3/16	1 5/16	1 5/8	1 3/4	1 13/16	1 7/8	2	2	2 3/16	2 1/4	2 3/8	2 7/16	2 13/16	3 1/16	3 5/16
Diameter of Bolt Circle	In.	5	5 7/8	6 5/8	7 1/4	7 7/8	8 1/2	9 1/4	10 5/8	11 7/8	13	14	15 1/4	17 3/4	20 1/4	22 5/8
No. of Bolts	In.	4	4	8	8	8	8	8	8	12	12	12	12	16	16	20
Size of Bolts	In.	5/8	3/4	5/8	5/8	3/4	3/4	3/4	7/8	7/8	7/8	7/8	1	1	1	1
Diameter of Bolt Holes	In.	3/4	7/8	3/4	3/4	7/8	7/8	7/8	1	1	1	1	1 1/8	1 1/8	1 1/8	1 1/8
I—Inside Diameter of Tongue	In.	3 1/8	3 5/8	4 1/4	4 3/4	5 1/4	5 3/4	6 1/4	7 1/2	8 5/8	9 5/8	10 5/8	11 5/8	13 5/8	15 7/8	18 3/8
O—Outside Diameter of Tongue	In.	4 1/8	4 5/8	5 1/4	5 3/4	6 1/4	6 3/4	7 1/4	8 1/2	9 5/8	10 7/8	11 7/8	13 1/8	15 1/8	17 3/8	20 1/8
E—Height of Tongue	In.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	1/4	1/4	1/4	1/4	1/4	1/4	1/4
K—Inside Diameter of Groove	In.	3 1/16	3 9/16	4 3/16	4 11/16	5 3/16	5 11/16	6 3/16	7 7/16	8 9/16	9 9/16	10 9/16	11 9/16	13 9/16	15 13/16	18 5/16
H—Outside Diameter of Groove,	In.	4 3/16	4 11/16	5 5/16	5 13/16	6 5/16	6 13/16	7 5/16	8 9/16	9 11/16	10 15/16	11 15/16	13 3/16	15 3/16	17 7/16	20 3/16
F—Depth of Groove	In.	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	3/16	3/16	3/16	3/16	3/16	3/16	3/16
T—Diameter of Tongue	In.	3 7/8	4 3/8	4 7/8	5 1/2	6	6 1/2	7	8 1/8	9 1/4	10 1/4	11 1/4	12 1/4	14 3/8	16 3/4	17 7/8
D—Diameter of Recess	In.	3 15/16	4 7/16	4 15/16	5 9/16	6 1/16	6 9/16	7 1/16	8 3/16	9 5/16	10 5/16	11 5/16	12 5/16	14 7/16	16 13/16	17 15/16
R—Diameter of Calking Recess	In.	2 3/4	3 1/4	3 7/8	4 3/8	4 7/8	5 3/8	5 15/16	7	8 1/8	9 1/8	10 3/16	11 3/8	13 3/8	15 5/8	16 3/4
S—Depth of Calking Recess	In.	7/16	7/16	7/16	7/16	7/16	7/16	7/16	7/16	1/2	1/2	1/2	9/16	9/16	9/16	5/8
Thickness of Calking Ring	In.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	1/4	1/4	1/4	5/16	5/16	5/16	3/8
G—H't of Flange, without Recess,	In.	1 3/16	1 5/16	1 5/8	1 3/4	1 13/16	1 7/8	2	2	2 3/16	2 1/4	2 3/8	2 7/16	2 13/16	3 1/16	3 5/16
Height of Flange, with Recess,	In.	1 5/8	1 3/4	2 1/16	2 3/16	2 1/4	2 5/16	2 7/16	2 7/16	2 11/16	2 3/4	2 7/8	3	3 3/8	3 5/8	3 15/16

The Template in the above table is in multiples of four, so that Valves or Fittings may be made to face in any quarter, and the holes are drilled to straddle center-line.

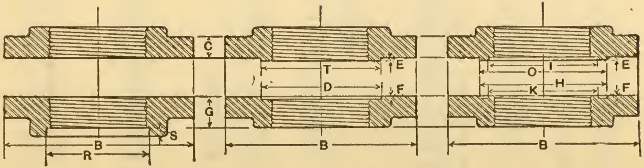


FIG. 16.

Tensile Strain of Bolts.

Diameter of Bolt in inches.	Area at bottom of Thread.	At 7,000 lbs. per sq. inch.	At 10,000 lbs. per sq. inch.	At 12,000 lbs. per sq. inch.	At 15,000 lbs. per sq. inch.	At 20,000 lbs. per sq. inch.
½	.125	875	1,250	1,500	1,875	2,500
⅝	.196	1,372	1,960	2,350	2,940	3,920
¾	.3	2,100	3,000	3,600	4,500	6,000
⅞	.42	2,940	4,200	5,040	6,300	8,400
1	.55	3,850	5,500	6,600	8,250	11,000
1⅛	.69	4,830	6,900	8,280	10,350	13,800
1¼	.78	5,460	7,800	9,300	11,700	15,600
1⅜	1.06	7,420	10,600	12,720	15,900	21,200
1½	1.28	8,960	12,800	15,360	19,200	25,600
1⅝	1.53	10,710	15,300	18,360	22,950	30,600
1¾	1.76	12,320	17,600	21,120	26,400	35,200
1⅞	2.03	14,210	20,300	24,360	30,450	40,600
2	2.3	16,100	23,000	27,600	34,500	46,000
2½	3.12	21,840	31,200	37,440	46,800	62,400
2½	3.7	25,900	37,000	44,400	55,500	74,000

The breaking strength of good American bolt iron is usually taken at 50,000 lbs. per sq. in., with an elongation of 15 per cent before breaking. It should not set under a strain of less than 25,000 lbs. The proof strain is 20,000 lbs. per sq. in., and beyond this amount iron should never be strained in practice.

PIPE BENDS.

Made from Wrought Iron or Steel Pipe.

(Crane Co.)

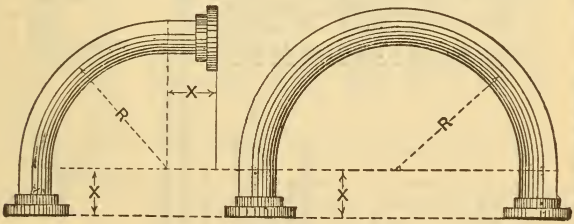


FIG. 17.

The radius of any bend should not be less than 5 diameters of the pipe, and a larger radius is much preferable. The length X of straight pipe at each end of bend should be not less than as follows:

5-inch Pipe $X =$ 6 inches,
6-inch Pipe $X =$ 7 inches,
7-inch Pipe $X =$ 8 inches,
8-inch Pipe $X =$ 9 inches,
10-inch Pipe $X =$ 12 inches,
12-inch Pipe $X =$ 14 inches,
14-inch Pipe $X =$ 16 inches.

TABLE OF DIMENSIONS—HIGH PRESSURE CAST IRON SHRINK FLANGES.

(Crane Co.)

A — Diameter of Port	In.	2	2 1/2	3	3 1/2	4	4 1/2	5	6	7	8
B — Diameter of Flange	In.	6 1/2	7 1/2	9	9	10	10 1/2	11	13	14	15
H — Diameter of Bolt Circle	In.	5	5 7/8	6 5/8	7 1/4	7 7/8	8 1/2	9 1/4	10 5/8	11 7/8	13
No. of Bolts	In.	4	4	8	8	8	8	8	8	12	12
Size of Bolts	In.	5/8	3/4	5/8	5/8	3/4	3/4	3/4	7/8	7/8	7/8
U — Diameter of Hub	In.	3 7/16	4 1/8	4 7/8	5 1/2	6 3/16	6 11/16	7 3/8	8 1/2	9 3/4	10 7/8
G — Length of Hub	In.	7/8	1	1 1/8	1 3/16	1 3/16	1 5/16	1 5/16	1 1/2	1 1/2	1 1/2
C — Thickness of Flange	In.	7/8	1	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 3/8	1 7/16	1 1/2
T — Diameter of Tongue	In.	3 7/8	4 3/8	4 7/8	5 1/2	6	6 1/2	7	8 1/8	9 1/4	10 1/4
E — Length of Tongue	In.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	1/4	1/4
D — Diameter of Recess	In.	3 15/16	4 7/16	4 15/16	5 9/16	6 1/16	6 9/16	7 1/16	8 3/16	9 5/16	10 5/16
E — Depth of Recess	In.	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	3/16	3/16
R — Diameter of Calking Recess	In.	2 3/4	3 1/4	3 7/8	4 3/8	4 7/8	5 3/8	5 15/16	7	8 1/8	9 1/8
S — Depth of Calking Recess	In.	7/16	7/16	7/16	7/16	7/16	7/16	7/16	7/16	1/2	1/2
Thickness of Calking Ring	In.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	1/4	1/4
O — Height of Flange without Recess	In.	1 3/4	2	2 1/4	2 3/8	2 7/16	2 5/8	2 11/16	2 7/8	2 15/16	3
W — Height of Flange with Recess	In.	2 3/16	2 7/16	2 11/16	2 15/16	2 7/8	3 1/16	3 1/8	3 5/16	3 7/16	3 1/2

A — Diameter of Port	In.	9	10	12	14	16	18	20	22	24
B — Diameter of Flange	In.	16	17 1/2	20	23	25	27 1/2	29	31	34
H — Diameter of Bolt Circle	In.	14	15 1/4	17 3/4	20 1/4	22 5/8	25	26 1/4	28 1/2	31 1/4
No. of Bolts	In.	12	12	16	16	20	24	24	24	24
Size of Bolts	In.	7/8	1	1	1	1	1	1 1/8	1 1/8	1 1/4
U — Diameter of Hub	In.	11 7/8	13 1/8	15 3/8	17 7/8	19 1/4	21 1/2	23 3/4	26	28 1/4
G — Length of Hub	In.	1 5/8	1 11/16	1 7/8	2	2 3/16	2 1/4	2 3/8	2 9/16	2 3/4
C — Thickness of Flange	In.	1 9/16	1 5/8	1 7/8	2	2 1/4	2 5/16	2 3/8	2 9/16	2 11/16
T — Diameter of Tongue	In.	11 1/4	12 1/4	14 3/8	16 3/4	17 7/8	20	22	24	26
E — Length of Tongue	In.	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
D — Diameter of Recess	In.	11 5/16	12 5/16	14 7/16	16 13/16	17 15/16	20 1/16	22 1/16	24 1/16	26 1/16
E — Depth of Recess	In.	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16	3/16
R — Diameter of Calking Recess	In.	10 3/16	11 3/8	13 3/8	15 5/8	16 3/4	18 3/4	20 3/4	22 3/4	24 3/4
S — Depth of Calking Recess	In.	1/2	9/16	9/16	9/16	5/8	5/8	5/8	5/8	5/8
Thickness of Calking Ring	In.	1/4	5/16	5/16	5/16	3/8	3/8	3/8	3/8	3/8
O — Height of Flange without Recess	In.	3 3/16	3 5/16	3 3/4	4	4 7/16	4 9/16	4 3/4	5 1/8	5 7/16
W — Height of Flange with Recess	In.	3 11/16	3 7/8	4 5/16	4 9/16	5 1/16	5 3/16	5 3/8	5 3/4	6 1/16

The Template in the above table is in multiples of four, so that Valves or Fittings may be made to face in any quarter, and the holes are drilled to straddle center-line.

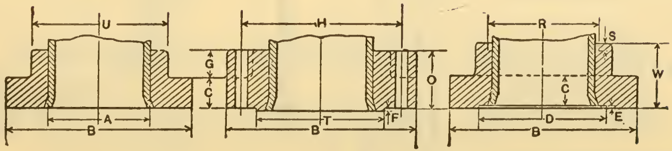


FIG. 18.

STANDARD PIPE FLANGES.

A. S. M. E. and Master Steam and Hot Water Fitters' Association standard, adopted **August**, 1894. Medium pressure includes pressures ranging below 75 pounds. High pressure ranges up to 200 pounds per square inch.

Pipe Size, Inches.	Pipe Thickness, $\frac{P+100}{.4s}d + .333\left(1-\frac{d}{100}\right)$	Thickness, nearest Fraction, Inches.	Stress on Pipe per Square Inch @ 200 Lbs.	Radius of Fillet, Inches.	Flange Diameters, Inches.		Flange Thickness, Inches.		Width Flange Face, Inches.		Bolt Circle Diameter, Inches.		Number of Bolts.	Bolt Diameter, Inches.	Bolt Length, Inches.	Stress on each Bolt, per Square Inch, at Bottom of Thread @ 200 Lbs.
2	.409	7/16	460	1/8		6		5/8		2		4¾	4	5/8	2	825
2½	.429	7/16	550	1/8		7		11/16		2¼		5½	4	5/8	2¼	1050
3	.448	7/16	690	1/8		7½		3/4		2¼		6	4	5/8	2½	1330
3½	.466	1/2	700	1/8		8½		13/16		2½		7	4	5/8	2½	2530
4	.486	1/2	800	1/8		9		15/16		2½		7½	4	3/4	2¾	2100
4½	.498	1/2	900	1/8		9¼		15/16		2⅜		7¾	8	3/4	3	1430
5	.525	1/2	1000	1/8		10		15/16		2½		8½	8	3/4	3	1630
6	.563	9/16	1060	1/8		11		1		2½		9½	8	3/4	3	2360
7	.60	5/8	1120	1/8		12½		1 1/16		2¾		10¾	8	3/4	3¼	3200
8	.639	5/8	1280	1/8		13½		1⅛		2¾		11¾	8	3/4	3½	4190
9	.678	11/16	1310	3/16		15		1⅛		3		13¼	12	3/4	3½	3610
10	·713	3/4	1330	3/16		16		1 3/16		3		14¼	12	7/8	3⅝	2970
12	.79	13/16	1470	3/16		19		1¼		3½		17	12	7/8	3¾	4280
14	.864	7/8	1600	3/16		21		1⅜		3½		18¾	12	1	4¼	4280
15	.904	15/16	1600	3/16		22¼		1⅜		3⅝		20	16	1	4¼	3660
16	.946	1	1600	3/16		23½		1 7/16		3¾		21¼	16	1	4¼	4210
18	1.02	1 1/16	1690	3/16		25		1 9/16		3½		22¾	16	1⅛	4¾	4540
20	1.09	1⅛	1780	3/16		27½		1 11/16		3¾		25	20	1⅛	5	4490
22	1.18	1 3/16	1850	1/4		29½		1 13/16		3¾		27¼	20	1¼	5½	4320
24	1.25	1¼	1920	1/4	31½	32	1¼	1⅞	3¾	4	29¼	29½	20	1¼	5½	5130
26	1.30	1 5/16	1980	1/4	33¾	34¼	1⅜	2	3⅞	4⅛	31¼	31¾	24	1¼	5¾	5030
28	1.38	1⅜	2040	1/4	36	36½	1 7/16	2 1/16	4	4¼	33½	34	28	1¼	6	5000
30	1.48	1½	2000	1/4	38	38¾	1½	2⅛	4	4⅜	35½	36	28	1⅜	6¼	4590
36	1.71	1¾	1920	1/4	44½	45¾	1¾	2⅜	4¼	4⅞	42	42¾	32	1⅜	6½	5790
42	1.87	2	2100	1/4	51	52¾	1⅞	2⅝	4½	5⅜	48½	49½	36	1½	7¼	5700
48	2.17	2¼	2130	1/4	57½	59½	2	2¾	4¾	5¾	54¾	56	44	1½	7¾	6090

NOTES. — Sizes up to 24 inches are designed for 200 lbs. or less.

Sizes from 24 to 48 inches are divided into two scales, one for 200 lbs., the other for less.

The sizes of bolts given are for high pressure. For medium pressures the diameters are ⅛ inch less for pipes 2 to 20 inches diameter inclusive, and ¼ inch less for larger sizes, except 48-inch pipe, for which the size of bolt is 1⅜ inches.

When two lines of figures occur under one heading, the single columns up to 24 inches are for both medium and high pressures. Beginning with 24 inches, the left-hand columns are for medium and the right-hand lines are for high pressures.

The sudden increase in diameters at 16 inches is due to the possible insertion of wrought-iron pipe, making with a nearly constant width of gasket a greater diameter desirable.

When wrought-iron pipe is used, if thinner flanges than those given are sufficient, it is proposed that bosses be used to bring the bolts up to the standard lengths. This avoids the use of a reinforcement around the pipe.

Figures in the third, fourth, fifth, and last columns refer only to pipe for 200 lbs. pressure.

In drilling valve flanges a vertical line parallel to the spindles should be midway between two holes on the upper side of the flanges.

STEAM ENGINES.

Steam engines are often classed according to the number of cylinders the steam passes in succession, and which are different in size,

Simple expansion,
Compound,
Triple,
Quadruple.

Any one of the above classes, if run non-condensing, is called low-pressure, or non-condensing; and if run with condenser is called high-pressure, or condensing.

Nowadays the above classes are made in two types: *high speed*, including all engines running above, say, 150 revolutions per minute; and *low speed*, all those running at less than 150 revolutions.

This division is scarcely correct, as some of the long-stroke engines running at 125 revolutions have more than 1000 feet piston speed, while few of the so-called *high speed* machines exceed 600 feet per minute piston speed.

In selecting an engine for electrical work it is necessary to see that the machine is extra heavy in all its parts; especially so for electric railway work, as the changes in load are often great and sudden, and in case of short circuit, engines are liable to be called on for tremendous increase in output, and should have no weak parts. This especially applies to fly-wheels, of which a large number have burst on the large, slow-running engines used in railway power-houses.

Bearings should all be of extra large size, especially so on the main shaft journals of large direct-connected units.

The selection of size (horse-power) depends largely upon the rating of the connected electrical machinery and the number of hours it runs, much being left to the judgment of the advising engineer. For direct-connected units it is not necessary to install an engine of greater rated capacity than the rated output of the generator, as the engine will easily care for overload on the generator if rated at ¼ cut-off, as is usual.

Some builders of engines rate their sizes for connections to dynamos so as to supply 1½ h. p per k.w. capacity of the dynamo.

The selection of condensing or high-pressure engines has in the past depended largely on availability of an adequate supply of water for condensing purposes; but to-day the cooling tower with water enough to fill a supply-tank once, and a regular supply for boiler-feed, is a very satisfactory arrangement.

A DIGEST OF THE FINAL REPORT OF COMMITTEE ON STANDARDIZATION OF ENGINES AND DYNAMOS.

(Transactions, A. S. M. E., Vol. 23, 1902.)

1. The Committee of Standardization of Engines and Dynamos has the pleasure to submit its final report.

2. The Committee's investigation has covered the standardization of the following points :

(1) The standard sizes of units recommended.
(2) The corresponding revolutions per minute for these units.
(3) The sizes of shafts for the two classes of center-crank and side-crank engines.
(4) The length along the shaft required for the generator.
(5) The height of axis of shaft over top of sub-base.
(6) The width of top of sub-base.
(7) Armature fit.
(8) Overload capacity of engines and generators.
(9) Brush holders.
(10) Holding-down bolts, keys, and outboard bearings.

Size of Units.

3. Our endeavor has been to reduce the number of standard units to the fewest sizes. For reasons previously stated, the largest size embraced in our list is 200-kilowatt capacity.

In this connection our report covers the standardization of DIRECT-CURRENT generators only.

Revolutions.

4. These standard speeds have been chosen after investigation of the practice of all the engine and generator builders in the country. It will be observed that we have provided for a permissible variation of speed of five per cent above or below the mean speed, which we recommend.

Shaft Diameters.

5. These are the result of analysis of the existing practice of all manufacturers, and a consideration of all the conditions affecting the diameter of the shaft.

In order that the reason for the diameters of shafts that we have recommended shall be thoroughly understood, we may explain that (especially in shafts for side-crank engines) the permissible deflection has determined the diameter. This, in some cases, is larger than would have been necessary for torsion and bending if deflection did not have to be considered.

As cases sometimes arise where cross-compound engines or double engines are connected to generators coming within our recommendation, and, as such units require considerable larger shafts than those given in our tables, we deem it necessary to state, specifically, that our recommendations apply only to engines of usual proportions, with the generator attached at the side of, instead of between, the cranks.

Length of Generator along the Shaft.

6. We found that the practice of manufacturers required provision for two classes, which may be called "long" and "short" generators.

We have carefully considered the fact that for these varying lengths of generator and shaft, the engine builder has to provide different lengths of sub-base, and in order to reduce the expense of patterns here to a minimum, our idea is that these patterns would be made so that the end away from the commutator can be extended the necessary amount, five or six inches, to take care of the increased length of bed.

Height of Shaft.

7. There are two classes of generators to be provided for under this head: Those which are split vertically, and those which are split horizontally. The former have a flat base which rests directly upon the flat top of the sub-base, while the latter have feet which take the weight of the generator.

In order to arrange that the engine builders' patterns may be reduced to a minimum and still be stock patterns, which will fit every style of machine, we have chosen dimensions for height of axis of shaft above top of sub-base, sufficient to allow for the vertically-split machines, and also, except as stated later, to clear the periphery of the horizontally-split machines.

As will be seen, the scheme provides for a main pattern to which patterns for the stools and seatings for both horizontally-and vertically-split generators can be attached before the pattern is sent to the foundry — stools for the horizontally-split machines, and rectangular seatings for the vertically-split machines.

In the case of the 150 and 200-kilowatt units, we have provided for a recess in the top of the sub-base to allow the lower part of some horizontally-split generator frames to be accommodated, and so to avoid unduly raising the center of the shaft. In the case of the vertically-split machines and those which are split horizontally and do not need this recess, the top of the sub-base will be flat and continuous.

Width of Top of Sub-Base.

8. This has been decided by examination of existing practice, and we believe that the figures we have recommended will cover the necessities for all sizes of generators.

Armature Fit.

9. In the matter of armature fit, our recommendation is for what is known as a single fit.

We have obtained the opinions of manufacturers in respect to the allowance to be made for a pressed fit, and find that allowances of $\frac{1}{1000}$ inch for shafts 4 inches to 6 inches, inclusive, and $\frac{2}{1000}$ inch for shafts $6\frac{1}{2}$ inches to 11 inches, inclusive, represent the best existing practice.

The armature bore is to be the exact size given in the table, and the allowance is to be made by the increase of diameter of engine shaft.

We believe, that in order to secure the best results, it will be necessary to work to a definite gauge; to this end we recommend that the generator builder furnish a gauge the exact diameter of the bore, and the engine builder make the necessary allowance for the press fit, as recommended.

Overload Capacity of Engines and Generators.

10. Generator builders are frequently called upon to provide, during short periods, for overloads of as much as 50 per cent, and, in occasional cases, of even 100 per cent.

Bearing in mind that our recommendations are entirely for standard practice, we recommend that the standard overload rating of any direct-connected unit should not, in any case, exceed 25 per cent of the rated capacity.

Brush Holders.

11. We recommend that the brush-holder rigging shall be supported upon the generator frame.

Holding-down Bolts, Keys, and Outboard Bearings.

12. We recommend that the holding-down bolts, shaft keys for securing the generator hub to the shaft, and the outboard bearings, should be furnished by the engine builders.

In the table will be found columns showing sizes of shaft keys which we recommend; also the number and size of holding-down bolts.

It will be noticed that we do not give any lengths for keys. We believe it best to leave the determination of the length of key for adjustment by engine and generator builders in each individual case.

Sizes of keys have been taken, so that standard rolled stock can be employed.

We recommend that the keys be made straight, and be used as feathers. They should therefore fit accurately on the edges, and not on the top. proper allowance should be made in cutting the keyway in the armature hub, so that there will be sufficient clearance at the top of the key.

Suggestions.

13. In the course of our investigation our attention has been called to a number of points, which, from their nature, are not exactly in the same category as those on which we have made recommendations, but we consider them of such importance that we desire to offer them as suggestions for consideration by members of the Society, with a view to their adoption if considered sufficiently meritorious.

A. Pressing Armature on Shaft. — Usually the contract definitely provides by whom this is to be done, but our suggestion is that if there is no such provision in the contract, it should be understood that the engine and generator builders shall agree who is to do this work, so as to avoid any dispute when the separate portions of the unit are delivered on the premises.

B. Floor-Line. — For convenience in operation, and for the information of engine and generator builders, we suggest that for units up to 75 kilowatts, inclusive, the floor line should come at the bottom of the sub-base; and for units 100 kilowatts to 200 kilowatts, inclusive, the floor line should be one inch below the rough top of the sub-base.

C. Protecting Commutators from Oil. — In view of the fact that in some cases the distance between bearing and commutator is very small, it is well for engine builders to bear in mind that provision should be made to prevent oil from the bearing getting on the commutator.

D. Some generator builders have asked that the end of the shaft shall be drilled and tapped to facilitate, if necessary, the removal or placing of the armature on the shaft at the place of erection; we suggest that this be done.

E. In some cases, generator builders require special nuts, bolts, or fixtures for attaching generators to the shaft. Under these conditions we suggest that the generator builders should furnish all attachments to their apparatus that are not already specified in our report.

Table of Sizes, Speeds, and Standardized Dimensions of Direct-Connected Generating Sets.

(To accompany Diagram.)

Capacity of Unit, Kilowatts.	Revolutions per Minute.	Armature Bore.		Diameter of Engine Shaft at Armature Fit.		Space Occupied on Shaft between the Limit Lines.		*B*, Length of Extension Pieces (In.).	*C*, Height of Axis of Shaft above Top of Base (In.).	*R* (In.).	*D*, Width of Top of Sub-Base (In.).	Key (a Feather).				Holding-Down Bolts.	
		Center Crank Engines (In.).	Side Crank Engines (In.).	Center Crank Engines (In.).	Side Crank Engines (In.).	Long Class *A* (In.).	Short Class *A′* (In.).					Width (In.).	Thickness (In.).	Depth in Shaft at Edge (In.).	Projection above Shaft at Edge (In.).	Diameter (In.).	Number.
25	310	4	$4\frac{1}{2}$	$4+\frac{1}{1000}$	$4\frac{1}{2}+\frac{1}{1000}$	30	25	5	$23\frac{1}{2}$	Flat.	48	1	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	1	4
35	300	4	$5\frac{1}{2}$	$4+\frac{1}{1000}$	$5\frac{1}{2}+\frac{1}{1000}$	33	28	5	25	Flat.	54	1	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	1	4
50	290	$4\frac{1}{2}$	$6\frac{1}{2}$	$4\frac{1}{2}+\frac{1}{1000}$	$6\frac{1}{2}+\frac{2}{1000}$	37	31	6	28	Flat.	60	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	1	4
75	275	$5\frac{1}{2}$	$7\frac{1}{2}$	$5\frac{1}{2}+\frac{1}{1000}$	$7\frac{1}{2}+\frac{2}{1000}$	43	37	6	31	Flat.	66	$1\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{4}$	4
100	260	6	$8\frac{1}{2}$	$6+\frac{1}{1000}$	$8\frac{1}{2}+\frac{2}{1000}$	48	42	6	34	Flat.	72	$1\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{4}$	4
150	225	7	10	$7+\frac{2}{1000}$	$10+\frac{2}{1000}$	51	45	6	$37\frac{3}{4}$	$41\frac{1}{4}$	84	$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	4
200	200	8	11	$8+\frac{2}{1000}$	$11+\frac{2}{1000}$	54	48	6	$42\frac{3}{4}$	$47\frac{1}{2}$	96	2	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{2}$	4

NOTE 1. — Five per cent variation of speed permissible above and below speeds in table.

NOTE 2. — Distance from center of shaft to top of base of outboard bearing may be less than *C* (to suit engine builder), though not less than possible outside radius of armature.

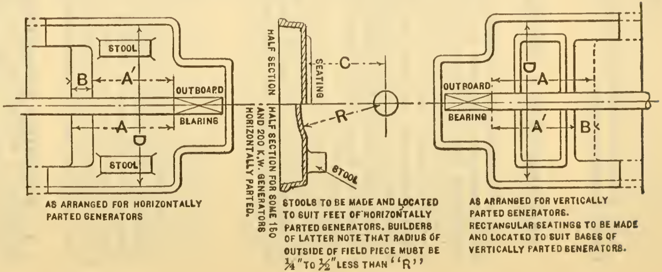


FIG. 19.

Summary of Tests of Steam Engines of Various Types.

By Prof. R. C. Carpenter.

Style of Engine.	No. of Test.	H.P. of Engines.	Steam per I.H.P. per Hour.	Actual coal per I.H.P. per Hour.	Mean Observed I.H.P.	Per Cent Observed H.P. to Capacity.	Boiler Evap. per lb. Combus. B. & A. 212.	Kind of Coal.
Simple non-condensing slide valve.	6	200	34.8	4.47	110	55	11.50	Pea A.
	1	405	34.5	6.54	257	63.4	9.11	Culm
	7	1975	35.7	4.60	862	51.	9.46	Soft Pa.
	11	300	37.3	4.49	90	44.	12.20	" "
	11	300	34.3	4.72	95	46.7	10.20	" Ill.
	24	1000	31.8	5.38	717	71.7	9.15	"
	31	270	41.5	5.50	126	47.5	10.60	Hard, Buck
	33	270	31.6	4.61	147	54.5	10.70	" Pea
Average.			35.1	5.07		54.2	10.24	
Simple non-condensing Corliss.	17	300	30.1	3.09	139	46	11.45	Clearfield
	19	150	26.9	3.5	90	60	9.73	Hard, Buck
	22	350	28.	3.77	153	44.7	8.55	Soft, Ohio
Average.			28.3	3.45		50.3		
Compound non-condensing.	2	1000	30.5	4.22	603.5	60.3	9.03	1 Soft, 3 Hard
	4	1250	36.8	4.33	674	53.8	9.92	Culm and slack
	21	400	34.20	4.17	203	51.	10.23	Soft, Pa.
	24	1200	30.37	4.93	754	62.7	9.01	" Ill.
Average of.			32.28	4.55				
Compound condensing high-speed automatic.	3*a*	600	29.4	4.43	174	29	10.38	1 Soft, 3 hard
	3	600	23.2	3.50	190	32	9.93	" "
	8	400	20.2	3.14	154	38	8.29	Soft, Ohio
	8*b*	400	16.7	2.40	180	45	7.75	" "
	13	250	24.6	2.95	86	34.5	10.51	" Pa.
	16	350	22.7	3.41	164	47	9.50	Hard pea
	18	1200	25.6	3.61	904	75	10.58	" "
	21	400	29.3	3.81	188	47	10.23	Soft
Average.			23.96	3.41			9.64	
Compound condensing Corliss, Greene, McIntosh & Seymour, etc., etc.	10	825	22.7	4.06	482	58.2	8.29	Culm & Slack
	14	1000	21.9	2.56	277	27.7	10.96	" "
	14	1000	20.		314	31.4	10.96	" "
	28	350	16.64	2.10	182	52.2	11.80	Soft
	27	500	16.90	2.61	290	58.	9.36	"
	30	2000	14.5	1.80	814	40.7	10.7	"
	34	200	17.3	2.91	145	72.	11.14	"
	35	1600	20.5	2.18			11.14	"
Average.			18.8	2.60			10.54	

Horse-power of Steam Engines.

Nominal Horse-power. — Now very little used.

D = dia. cyl. in inches.
A = area of piston in sq. inches.
L = length of stroke in feet.

$$\text{Watt gives, nominal H.P.} = \frac{D^2L}{47}.$$

$$\text{Boulton \& Watt, nominal H.P.} = \frac{D^2}{28}.$$

Kent gives as handy rule for estimating the h.p. of a single cylinder engine, $\frac{D^2}{2}$. This rule is correct when the product of the m.e.p. and piston speed = 21,000.

The above rule also applies to compound triple and quadruple engines, and is referred to the diameter of the low-pressure cylinder, and the h.p. of such an engine then becomes

$$\frac{(\text{dia. low-pres. cyl.})^2}{2} = \text{H.P. (roughly.)}$$

Indicated Horse Power: I.H.P. — The power developed in the cylinder of a steam engine is correctly determined only by use of the indicator, and comparisons and steam consumption are always calculated on that basis.

M.E.P. = mean pressure in pounds per square inch, as shown by the indicator card.
L = stroke of piston in feet.
n = number of revolutions per min.
a = effective area of head side of piston.
$a_{/}$ = effective area of crank side of piston.

$$\text{I.H.P.} = \frac{[(a \times \text{m.e.p.}) + (a_{/} \times \text{m.e.p.})] \times Ln}{33{,}000}.$$

For multiple cylinder engines, compute I.H.P. for each cylinder, and add results together for total power.

Brake Horse-power. — The brake horse-power (B.H.P.) of an engine is the actual or available horse-power at the engine pulley; at any given speed and given brake-load, the B.H.P is less than the corresponding I.H.P. by the horse-power required to drive the engine itself at the given speed, and with the pressures at the bearings, guides, etc., corresponding to the given brake-load.

If W = load in lbs. on brake lever or rope,
f = distance in feet of center of brake-wheel from line of action of brake-load,
N = revolutions per minute;

then $\text{B.H.P.} = \frac{WfN}{5252.1}$.

The mechanical efficiency of any given engine is less the greater the expansion ratio employed, and of two engines of the same type, developing the same power at the same speed, that which uses the higher degree of expansion will have the lower mechanical efficiency. The effect of this, though not usually important, is to make the best ratio of expansion in any given case somewhat less than that which makes the steam consumption per I.H.P.-hour a minimum.

The mechanical efficiencies on full load of modern engines range from 80 to 95 per cent. Large engines have, of course, higher mechanical efficiencies than small ones (a very small engine may have as low a mechanical efficiency as 40 to 50 per cent, but this is generally due to bad design and insufficient care being taken of the engine), simple than compound engines, and compound than triple engines — at any rate when not very large.

Prof. Thurston estimates that the total mechanical loss in non-condensing engines having balanced valves may be apportioned as follows: — main bearings 40 to 47 per cent, pistons and rods 33 per cent, crank-pins 5½ per cent slide-valves and rolls 2½ per cent, and eccentric straps 5 per cent. An unbalanced slide-valve may absorb 26 per cent, and in a condensing engine the air pump 12 % of the total mechanical loss.

Cylinder Ratios in Compound Engines.

The object of building multiple cylinder engines is,
a, to use high steam pressure,
b, to get the greatest number of expansions from the steam,
c, to reduce the cylinder condensation.

Prof. Thurston says: "Maximum expansion, as nearly adiabatic as practicable, is the secret of maximum efficiency."

Although the theory of determining the sizes of cylinders is perfectly understood, yet there are so many causes for varying the results that practically to-day but little attention is given to calculations, the plan being to use dimensions such as have proved best practice in the past.

The proportions of cylinders are supposed to be such as to equally divide the number of expansions and work among them, and these dimensions have to be varied somewhat to meet the experience of the engineer.

Given the initial pressure (absolute) *i.P.* and the terminal pressure (absolute) *t.P.*, then the total number of expansions is $E = \frac{i.P.}{t.P.}$, and the number of expansions for each cylinder is as follows:

For compound $\sqrt{E}$,
For triple expansion $\sqrt[3]{E}$,
For quadruple expansion $\sqrt[4]{E}$.

Better results are often obtained by cutting off a trifle earlier in the high-pressure cylinder; and this fact, in connection with the extent of reheaters and receivers, changes the actual ratios from the ideal to the practical ones shown in the following table:

Number of Expansions for Condensing Engines.

Type.	*i.P.* Absolute.	Total Expansions.	Expansions in Each Cylinder.			
			1st.	2d.	3d.	4th.
Single cylinder	65	7	7.	—	—	—
Compound	145	22	4.8	4.6	—	—
Triple compound . . .	185	30	3.2	3.1	3.0	—
Quadruple compound .	265	48	2.7	2.65	2.6	2.55

For triple engines, Jay M. Whitham * recommends the following relative sizes of cylinders when the piston-speed is from 750 to 1,000 ft. per minute:

Boiler Pressure (above Atmosphere).	High-Pressure Cylinder.	Intermediate Cylinder.	Low-Pressure Cylinder.
130	1	2.25	5.00
140	1	2.40	5.85
150	1	2.55	6.90
160	1	2.70	7.25

The following are the maximum, average, and minimum values of the relative cylinder volumes of triple-expansion condensing engines, working with boiler pressures of 150 or 160 lbs. per square inch above atmosphere, on board 65 boats launched within the last three or four years: —

——	High-Pressure Cylinder.	Intermediate Cylinder.	Low-Pressure Cylinder.
Maximum value	1	2.84	7.56
Average "	1	2.58	6.71
Minimum "	1	1.89	4.59

* *American Society of Mechanical Engineers, 1889.*

Table Showing Mean Effective Pressure Per Pound Absolute Initial Pressure.

	Apparent Ratio of Expansion	$\frac{1}{10}$ or .1	$\frac{2}{19}$ or .105	$\frac{1}{9}$ or .111	$\frac{2}{17}$ or .118	$\frac{1}{8}$ or .125	$\frac{2}{15}$ or .133	$\frac{1}{7}$ or .143	$\frac{2}{13}$ or .154	$\frac{1}{6}$ or .167	$\frac{2}{11}$ or .182	$\frac{1}{5}$ or .2	$\frac{2}{9}$ or .222	$\frac{1}{4}$ or .25	$\frac{3}{10}$ or .3	$\frac{1}{3}$ or .333	$\frac{3}{8}$ or .375	$\frac{2}{5}$ or .4	$\frac{1}{2}$ or .5	$\frac{3}{5}$ or .6	$\frac{5}{8}$ or .625	$\frac{2}{3}$ or .667	$\frac{7}{10}$ or .7	$\frac{3}{4}$ or .75
	Cut off at	10	9.5	9	8.5	8	7.5	7	6.5	6	5.5	5	4.5	4	3.33	3	2.67	2.5	2	1.67	1.6	1.5	1.43	1.33
Clearance	0	.330	.342	.355	.369	.385	.402	.421	.442	.465	.492	.522	.556	.596	.661	.699	.743	.766	.846	.906	.919	.937	.949	.966
	1	.344	.355	.368	.382	.397	.413	.432	.452	.475	.501	.530	.564	.603	.666	.704	.747	.770	.849	.909	.920	.937	.949	.966
	2	.357	.367	.379	.394	.408	.424	.442	.462	.484	.509	.538	.571	.609	.671	.708	.750	.773	.851	.911	.921	.936	.952	.964
	3	.369	.379	.391	.405	.419	.434	.452	.471	.493	.517	.545	.577	.615	.676	.712	.753	.776	.853	.913	.922	.940	.951	.966
	4	.381	.392	.402	.416	.429	.443	.461	.480	.502	.525	.552	.583	.621	.681	.716	.756	.779	.855	.914	.923	.939	.954	.969
	5	.392	.402	.413	.426	.439	.452	.470	.489	.510	.532	.559	.589	.626	.685	.720	.759	.782	.857	.914	.925	.938	.952	.966
	6	.403	.412	.423	.436	.448	.461	.479	.497	.517	.539	.566	.595	.631	.689	.724	.762	.785	.859	.914	.925	.941	.950	.970
	7	.413	.422	.433	.445	.457	.470	.487	.505	.524	.546	.572	.601	.636	.693	.728	.765	.787	.861	.915	.925	.941	.953	.966
	8	.423	.431	.442	.454	.466	.478	.495	.512	.531	.553	.578	.607	.641	.697	.731	.768	.789	.862	.915	.926	.944	.951	.969
	9	.432	.440	.451	.463	.474	.486	.503	.519	.538	.560	.584	.613	.646	.701	.734	.770	.791	.863	.916	.924	.943	.954	.970
	10	.441	.449	.460	.471	.482	.494	.510	.526	.545	.566	.590	.618	.651	.704	.737	.772	.793	.864	.916	.929	.941	.957	.966
	11	.450	.458	.469	.479	.490	.502	.517	.533	.552	.572	.595	.623	.655	.707	.740	.774	.795	.865	.917	.929	.946	.955	.969
	12	.458	.466	.476	.487	.497	.509	.524	.540	.559	.578	.600	.627	.659	.710	.743	.776	.797	.866	.920	.927	.943	.958	.971
	13	.466	.474	.483	.494	.504	.516	.531	.547	.565	.584	.605	.631	.663	.713	.746	.778	.799	.867	.920	.931	.946	.955	.967
	14	.474	.482	.490	.501	.511	.523	.538	.553	.570	.589	.610	.635	.667	.716	.749	.780	.801	.868	.921	.930	.944	.957	.970
	15	.482	.489	.497	.508	.518	.529	.544	.559	.574	.594	.615	.639	.671	.719	.752	.781	.803	.869	.919	.929	.947	.955	.972

Receiver Capacity.—In compound engines with cranks at right angles the receiver capacity should be from 1 to 1.5 times that of the high-pressure cylinder (Seaton), or not less than the capacity of the low-pressure cylinder ("Practical Engineer"). When the cranks are opposite, the receiver capacity need not exceed that of the steam passage from the high-pressure to the low-pressure cylinder. The general effect of large receiver capacity is to cause a drop between the pressure at the end of the high-pressure expansion stroke and the beginning of the high-pressure exhaust stroke and low-pressure admission, thus increasing the power developed in the high-pressure, and decreasing the power developed in the low-pressure cylinder; this leads to a loss of power in the engine, and one which—at any rate in engines with cranks at right angles—is greater the more the receiver capacity exceeds that necessary for free passage of the steam.

Steam Ports and Passages.—The areas of these should be such that the mean linear velocity of the steam does not exceed 5,000 to 6,000 feet per minute; hence, if

D = diameter of cylinder in inches,
A = area of cylinder in square inches,
a = area of port or passage in square inches,
S = piston-speed in feet per minute;

$$a = \frac{AS}{6,000} = \frac{D^2S}{7,639}$$

for mean velocity of steam 6,000 feet per minute;

$$a = \frac{AS}{5,000} = \frac{D^2S}{6,366}$$

for mean velocity of steam 5,000 feet per minute.

The lengths of the steam passages between the cylinders and valves should be as small as possible, in order to minimize clearance and resistance to flow of steam.

Condensers and Pumps.

Condensers are principally of two types, viz., Jet Condensers, in which the steam and condensing water mix in a common vessel, from which both are pumped by the air-pump; and Surface Condensers, in which the steam generally passes into a chamber containing a number of brass tubes, through which the condensing water is made to circulate. The latter form is usually adopted where water is bad, as it enables the same feed-water to be passed through the boiler over and over again.

The capacity of a jet condenser should not be less than one-fourth of the low-pressure cylinder, but need not exceed one-half, unless the engines are very quick running; one-third is a good average ratio. Large condensers require more time for forming the vacuum, while small condensers are liable to flood and overflow back to the cylinders. The amount of condensing water required per pound of steam condensed varies with the temperature of the exhaust, of the "hot-well," and of the condensing water. (The "hot-well" is the receptacle into which the air-pump delivers the water from the condenser.) The feed-water is obtained from the "hot-well," which should be maintained at 110° to 120° F. Sometimes even 130° F. can be obtained with care.

The amount of cooling or tube surface depends upon the difference between the temperature of the exhaust steam and the average temperature of the cooling water, and on the thermal conductivity and thickness of the metal tubes. For copper and brass tubes in good condition the rate of transmission is about 1,000 units (equivalent to about 1 lb. of steam condensed) per square foot per 1° F. difference of temperature per hour. With the hot-well at 110° and the cooling water at 60°, the average difference is 25°, and 25 lbs. of steam should be condensed per hour per square foot. In practice allowance must be made for the working conditions of the tubes, and half the above, *i.e.*, ½ lb. of steam per 1° F. difference is nearer the usual allowance; and under the above conditions about 12.5 lbs. of steam would be condensed per square foot per hour, which is considered very fair work.

The tubes are generally of brass, No. 18 S.W.G. thick, and from ½ to 1 in. diameter, according to the length of the tubes; they are usually ¾ in. in diameter, and spaced at a pitch of $1\frac{1}{4}$ in., while the tube-plates, which are also of brass, are $1\frac{1}{8}$ to $1\frac{1}{4}$ in. thick for $\frac{3}{4}$ in tubes. The length of the tubes, when unsupported between plates, should not exceed 120 diameters.

If $H =$ total heat of 1 lb. of exhaust steam in B T.U.,
$t =$ temperature F.° of hot-well,
$t_1 =$ temperature F.° of cooling water on entering,
$t_2 =$ temperature F.° of cooling water on leaving,
$Q_1 =$ quantity in lbs. of cooling water per lb of steam for jet condenser.
$Q_2 =$ ditto for surface condenser;

$$Q_1 = \frac{H - t}{t - t_1},$$

$$t = \frac{H + Q_1 t_1}{1 + Q_1} \text{ for jet condenser,}$$

$$Q_2 = \frac{H - t}{t_2 - t_1},$$

$$t = H - Q_2 (t_2 - t_1), \text{ for surface condensers.}$$

N.B. $H - t = 1{,}050$ approximately.

Values of Q_1 and Q_2 for different temperatures of cooling water, when $H = 1150$, $t = 110$, and $t_2 = 100$ in case of Q_2:—

	Values of t_1.				
	40	50	60	70	80
Q_1	15	17	21	26	35
Q_2	17	21	26	35	52

Area of injection orifice should be such as to allow a velocity of flow of water not exceeding 1,500 feet per minute. It is better to have a large orifice and to control the flow of water by an injection valve.

Area of orifice in square inches.
= lbs. water per minute ÷ 650 to 750.
= area of piston ÷ 250.

The cooling or circulating water in surface condensers should travel some 20 ft. lineally through the tubes. In small condensers, where this is not convenient, and the water only circulates twice through short tubes, the rate of flow must be reduced.

A replenishing cock should be fitted to allow of the passage of part of the circulating water into the air-pump suction to provide for water lost in drains, blowing off, leakage, etc. This may have one-tenth the area of the feed-pipe.

A cock should be fitted close to the exhaust inlet for introducing caustic soda when required to dissolve grease off the tubes.

Assume your engine to require 20 pounds of steam per horse-power per hour, or one-third of a pound per minute, and to exhaust at atmospheric pressure. One pound of steam at atmospheric pressure contains 1146.1 heat units above 32°. One pound of water at this temperature contains approximately 120 — 32 = 88 heat units above 32°, so that to change a pound of steam at atmospheric pressure into water at 120°, we should have to take from it 1146.1 — 88 = 1058.1 heat units, and for one-third of a pound, 1058.1 ÷ 3 = 352.7 heat units. Suppose the injection water to be 60°. In heating to 120° each pound will absorb approximately 60 heat units, so that it would take 352.7 ÷ 60 = 5.88 pounds of injection water per minute per horse-power under the assumed conditions. A higher terminal pressure, higher temperature of injection, less efficiency in the engine, or lower hot-well temperature, will increase this figure.

In order to cover all conditions, makers and dealers figure that a condenser should be able to supply from a gallon to a gallon and a half of injection water per minute for each indicated horse-power developed. The capacity of a single-acting vertical air-pump should be from one-tenth to one-twelfth that of the cylinder; of a double-acting horizontal pump, from one-sixteenth to one-nineteenth.

Ejector Condensers are made on the principle of steam injectors except that the action is reversed, the cooling water taking the place of the steam in the injector, and the exhaust steam that of the feed-water. In order to ensure their successful working, the cooling water should be supplied at a head of 15 feet to 25 feet, either from a tank above or from a centrifugal or other pump. The amount of cooling water required is about the same as for jet condensing; the vacuum is from 20 in. to 25 in.

Some builders of ejector condensers advise that the exhaust pipe from engine be carried up to a height of 30 feet above the level of condenser discharge, then drop straight to condenser.

Increased momentum of the steam is very beneficial to a vacuum.

Thirty feet provides an ample safeguard against water flooding the engine cylinder.

Ejector Condenser Capacities.

Exhaust Pipe Dia.	Water.		Steam Condensed per Hour, Lbs.	Condensing Water req. per Hour, Gallons.	Suitable for Engines of
	Inlet.	Outlet.			
1½	1	1	200	550	5–10 I.H.P.
2½	2	1½	400	1,100	10–20 "
3	2½	2	800	2,200	20–40 "
4	3	2½	1,500	4,000	35–70 "
5	3½	3	2,000	5,500	50–100 "
6	4	3½	3,000	8,250	75–150 "
7	5	4	4,000	11,000	100–200 "
8	6	5	6,000	16,500	150–300 "
10	7	6	8,000	22,000	200–400 "
12	8	7	12,000	33,000	300–600 "
14	10	9	20,000	55,000	500–1,000 "
16	11	10	28,000	77,000	700–1,400 "
18	12	12	36,000	99,000	1,000–2,000 "
24	. . .	. . .	60,000	176,000	2,000–4,000 "

This type of condenser finds favor in large electric plants which are situated near abundant water supplies. An example of this is the Edison Station of the Public Service Corporation at Paterson, N.J., where they have been in use with great success for some years.

Air-pumps are used to draw the condensed water from the condenser to the hot-well, together with the air originally contained in the water, or which may find its way in through glands, etc., and with jet condensers they also draw the cooling water. A cubic foot of ordinary water contains about .05 cubic foot of air at atmospheric pressure, which expands in the condenser to about .4 cubic foot of air; hence the term air-pump.

The efficiency of a single-acting air-pump may be taken at .6 to .4, and generally .5, while that of the double-acting pump may be .5 to .3, say .4 on average. For jet condensing, the volume of the air-pump should be theoretically 1.4 times the volume of condensed + cooling water; for good working it should be from twice to thrice that required by theory. Or if

v = volume of condensed water per minute in cubic feet,
V = volume of cooling water per minute in cubic feet,
n = number of strokes (useful) of air-pump per minute,
A = volume of air-pump in cubic feet;

$$A = 2.8\,\frac{v+V}{n} \text{ for single-acting pumps,}$$

$$= 3.5\,\frac{v+V}{n} \text{ for double-acting pumps.}$$

Since, for surface condensing, the air-pump does not draw the cooling water, and as the feed-water, being used over again, should not contain so much air, it would appear that the air-pump might be much smaller than for jet condensing. However, surface condensers are frequently arranged for use as jet condensers in case of mishap, and with surface condensing a better vacuum is expected, so that for surface condensing the air-pump is only slightly less than for jet condensing. In actual practice the air-pump is made from one-tenth to one-twenty-fifth the capacity of the low-pressure cylinder, according to the number of expansions and nature of condenser, while a comparison of a number of marine engines by different makers shows a ratio of one-sixteenth to one twenty-first.

If expansion joints are used in the exhaust pipe, a copper bellows joint is better than the ordinary gland and stuffing-box type, through which air is apt to leak.

Air-pump valves should have sufficient area that the full quantity of cooling and condensed water in jet condensation in passing does not exceed a velocity of 400 feet per minute; in practice the area is larger than this. A large number of small valves is perhaps better than one or two large valves which are sluggish, owing to their inertia. The clearance space between head and foot valves should not exceed one-fifteenth the capacity of the pump as ordinarily constructed.

If a = area through foot valves in square inches,
a_1 = area through head valves in square inches,
d = diameter of discharge pipe in inches,
D = diameter of the air-pump in inches,
S = speed (useful) in feet per minute;

$$a = \frac{1}{1{,}000} D^2 S.$$

$$a_1 = \frac{1}{800} D^2 S.$$

$$d = \frac{1}{35} D\sqrt{S}.$$

If there be no air vessel or receiver, d should be 10 per cent larger.

An air-pipe should be fitted to the hot-well one-fourth the diameter of the discharge pipe.

Circulating Pumps.—The size of these depend chiefly on conditions mentioned for air-pumps, and they may bear a constant relation to the air-pump as to size, or to the L.P. cylinders.

Air-pump.	*Circulating Pump.*	*Ratio.*
Single acting	Single acting	.6
Single acting	Double acting	.31
Double acting	Double acting	.52

or if V = volume of cooling water in cubic feet per minute,
S = length of stroke in feet,
n = number of strokes (useful) per minute,
C = capacity of pump in cubic feet,
D = diameter of pump in inches;

$$C = \frac{V}{n}, \qquad D = 13.55\sqrt{\frac{V}{nS}}.$$

Circulating pump valves should be of sufficient area so that the mean velocity of flow does not exceed 3 or 4 feet per sec. High velocities tend to wear out the valves, and cause undue resistance in the pump. In the suction and delivery pipes the velocity should not exceed 500 feet per minute, or for large and easy leads 600 feet per minute. Better results, however, will be obtained by using larger pipes, so as to reduce the velocity, especially if the pipes are long. For single-acting pumps the suction may be smaller than the delivery, if the pump be below the water-level.

If a = minimum area through valves in square inches,
d = minimum diameter of pipe in inches,
A = area of pump in square inches,
D = diameter of pump in inches,
S = mean speed (useful) of pump in feet per minute;

$$a = \frac{AS}{180}, \qquad d = \frac{D\sqrt{S}}{K},$$

where K varies from 22 for small pumps to 25 for large pumps, while for the suction of single-acting pumps it may be 27.

Air chambers should always be fitted, which for single-acting pumps may be twice the capacity of the pump. An air-pipe should be fitted to the highest points of the water passages for escape of air to enable the condenser and pipes to run full. If the speed of the circulating pump cannot be varied independently, it is advisable to fit a water valve between the two ends of the pump. so that the discharge may be varied to suit the requirements.

Strainers should be fitted to the inlet of the suction pipe, and the aggregate area of the passages should be from two to four times the area of the pipe, according to the velocity of flow in the pipe. Owing to difficulty experienced in cleaning strainers when under water, they are sometimes fixed in a cast-iron vessel near the suction entrances to the pump, with a door arranged in some convenient position for cleaning.

Foot Valve.— When the water level is below that of the pump, a foot valve should be fitted just above the surface of the water. A door should be provided for examining the valve without disturbing the suction pipe, or an air ejector may be used to charge the pump.

COOLING TOWER TEST.

On August 2, 1898, during a run from 7 A.M. till 12 midnight, from the daily records, the following data is reported by Vail, A.S.M.E. Trans. Vol. 20.

	Maximum.	Minimum.
Temperature, atmosphere	103°	83°
Temperature, condenser discharge to tower	128°	106°
Temperature, condenser suction	98°	91°
Degrees of heat extracted, through tower	32°	21°
Speed of fans, revolutions per minute	160	140
Vacuum at condenser	26	20
Strokes of condenser pump	50	38
Pounds, boiler feed	121	100
Temperature, boiler feed	212°	200°
Engine, horse-power developed	900 H.P.	400 H.P.

A continuous heavy load was carried during the entire 17 hours' run. This was not a test record, but simply daily service.

Another day, November 5, 1898, from a 20 and 36 × 42 tandem compound condensing Corliss engine, the conditions were as follows :

Engine revolutions	120 per min.	
Steam pressure	112	
Vacuum at condenser	25	
The area of the cards shows the work done in high pressure cylinder to be		311.8 H.P.
And in low-pressure cylinder to be		331.5 H.P.
Total		643.3 H.P.

Work done in low-pressure cylinder below atmospheric line 185.1 horsepower. Simultaneously with the engine, the pump and fan engines were indicated. Tower used was Barnard Type of Cooling Tower.

The work done by the pump	13.75 H.P.
The work done by the fan engines	13.5 H.P
Total external work	27.25 H.P.

23.6 I.H.P. of Engine per I.H.P. of Pump and Fans.

GAS ENGINES.*

Nearly all commercially successful gas engines are those in which the cycle of operation is that proposed and patented by M. Bean de Rochas, in France in 1862.

He states as necessary to economy with an explosion engine four conditions:

1. The greatest possible cylinder volume with the least possible cooling surface.
2. The greatest possible rapidity of expansion, or piston speed.
3. The greatest possible expansion: and
4. The greatest possible pressure at the commencement of the expansion.

From the above Bean de Rochas reasoned these operations:

a. Suction during an entire outstroke of the piston.
b. Compression during the following instroke.
c. Ignition at the dead point and expansion during the third stroke.
d. Forcing out of the burned gases from the cylinder on the fourth and last return stroke.

He proposed to accomplish ignition by increase of temperature due to compression.

The otto engine uses the above cycle and flame ignition.

Classification.

Gas engines may be classified in accordance with the principles of the cycle of operations:

1. Explosion of gases without compression.
2. Explosion of gases with compression.
3. Combustion of gases with compression.
4. Atmospheric motors.

According to the gas used they may be classified thus:—

A. Coal gas.
B. Carburetted gas.
C. Producer or Dowson gas.

The methods of igniting the charge are

f. Electrical arc.
g. Flame.
k. Incandescence.
m. Chemical or catalytic action.

The Otto engine is a good example of flame ignition.

Diameter of gas main from meter to engine should be dia $=$ .027 Brake H.P. $+$ 0.79 inches.

Atmospheric air is the working fluid of all gas engines and the fuel which heats it is inflammable gas.

The air and gas are mixed thoroughly before passing into the cylinder itself.

Two-cycle engine.	More wasteful of fuel than four-cycle engine. Back-firing, or premature explosion of gas and air mixture. Used in large power units, with blast furnace gas.
Four-cycle engine.	More readily governed than two cycle. No pumps. No inclosed crank chambers. Must be built heavy in comparison with power produced. Heavy flywheels.

There is but little difference between gas and gasoline engines, the main difference being a special fitting to supply the oil in the form of a vapor or atomized spray.

Gasoline being richer than gas, by its use a much larger H.P. can be obtained from a given size of engine.

The theoretical efficiency of a gas engine is about three times greater than that of a steam engine.

Contrary to steam engine experience, when underloaded it is a comparatively efficient heat engine.

* W. W. Christie.

The highest recorded efficiency is the consumption of 8000 B.T.U.'s per Brake H.P., or a thermal efficiency of 31.75 per cent. Governing is not quite as easily accomplished under quickly varying loads, as in the steam engine, although late models leave little to be desired.

In general, governing is accomplished by three methods : (1) the hit-and-miss, where the gas valve is closed during one or more revolutions of the engine ; (2) by varying the mixture of air and gas in the cylinder, thereby producing explosions of greater or less pressure intensity ; (3) advancing or retarding the point of ignition.

The average mixture is 1 part of gas to 8 to 12 parts of air in a gas engine.

Gas engines can be run successfully and with a fair degree of economy to within 3 or 4 per cent of their normal rating.

B. A. Thwaite says the "lean gases of low calorific power, such as are obtainable as a by-product of the manufacture of iron, are the very ones which enable the highest efficiency to be secured in internal-combustion engines."

A gas rich in thermal units enables a larger power to be derived from a given engine than can be obtained by the use of a lean gas.

Less air is required to mix with lean gas, and a higher compression is reached, for the mixture has a higher ignition point than rich gas mixtures.

High compression conduces to high efficiency.

Compression varies inversely as the calorific value of the gas, high for a lean gas, and vice-versa.

For natural gas the compression displacement is made about 30 per cent of piston displacement.

Water for cylinder jacket should flow through at a rate of 4 to 5 gallons per H.P. per hour ; best conditions are when jacket water removes 4000 B.T.U. per H.P. per hour.

Best piston speed is about 600′ per minute.

Comparative Economy.

	Lbs. of Coal per Brake H.P. per Annum.
Steam engine plant — simple non-condensing	11,250
Steam engine plant — compound condensing	6,400
Gas engine plant with producer gas	3,050

	Per Cent.
Thermal efficiency simple non-condensing plant	5.5
Thermal efficiency compound condensing plant	9.7
Thermal efficiency gas engine plant using producer gas . .	20.3
Thermal efficiency gas engine plant using waste blast furnace gas	23.5

The standard gas is the natural gas of western Pennsylvania, whose calorific value is about 1000 B.T.U.'s per cubic foot.

Ordinary illuminating gas has 750 B.T.U's. per cubic foot.

Producer gas may be as low as 120–130 B.T.U.'s per cubic foot.

Consumption of gas or gasoline by engines is, conservatively:

- Natural gas . . . . 10–12 cu. ft. per Br. H.P. hour.
- Illuminating gas . . . . . . 18–20 cu. ft. per Br. H.P. hour.
- Commercial 74° gasoline . . $\frac{1}{9}$–$\frac{1}{8}$ gallon per H.P. hour.

Gas engines operate on, say, 1¼ lbs. of good anthracite or bituminous coal, approximately, in some cases as low as 1 lb. anthracite or bituminous coal.

Gas generated from wood in Riche's retort, according to James M. Neil, has a calorific power of 3029 calories per cubic meter, or :

340.8 B.T.U. per cubic foot } is given for water gas.
324.5 B.T.U. per cubic foot }
590.0 B.T.U. per cubic foot is given for coal gas.

1 ton of wood produces 25,000 cu. ft. of gas and 400 lbs. charcoal, and costs 14 cents per 1000 cu. ft. with wood at $3.00 a ton, neglecting in this calculation the charcoal.

Mr. T. Fairly, Leeds, England, gives the heating power of coal gas corresponding to lighting powers as follows: no correction being made for the condensation of the steam produced by the combustion of hydrogen.

Lighting power: —

C.P.	11	12	13	14	15	16	17	18
B.T.U.	533	555	578	601	624	648	678	704

Value of Coal Gas of Different Candle Powers for Motive Power.

(C. Hunt.)

Candle Power.	Consumption Cubic Feet per I.H.P.	Relative Value for Motive Power.	Relative Value for Lighting.
11.96	30.31	1.000	1.000
15.00	24.41	1.241	1.254
17.20	22.70	1.335	1.438
22.85	17.73	1.700	1.910
26.00	16.26	1.864	2.173
29.14	15.00	2.020	2.436

Gas Engine Power Plant.

Lackawanna Steel Co., Buffalo, N.Y., uses Blast Furnace Gases.

8–1000 H.P. Gas Engines in place, 1903. 16–2000 H.P. Gas Engines to go in later.

Electric Generating plant consists of:

5–500 K.W. 3 phase, 25 cycle, 440 volt machines. (Gen. Elec. Co.)

4–500 K.W. 250 volt, direct current machines. (Sprague.)

Eight of the above are direct connected to horizontal, duplex, 2 cycle, double-acting, Korting Gas Engines.

One is direct connected to a 1000 H.P. Porter-Allen steam engine.

Engines use the waste gas from the furnaces.

By volume: CO, 24%; CO_2, 12%; N, 60%; H, 2%; CH_4, 2%.

Calorific Power, 90 B.T.U.'s per cubic foot.

The steam boilers in this plant are 250 H.P. Vertical Cahall Boilers; 48 have Roney Stokers, others are gas fired.

They each have a two-part cylindrical monitor on the roof of the boiler house, that is easily removed, enabling rapid and easy cleaning of tubes.

"Power," Dec., 1903.

Gas Engine Pumping Plant Test.

Midvale, N.J. Triplex pump driven by a 5 H.P. gasoline engine, 7th trial. Discharge 153 gallons per minute. Lift, 65 ft. total. Used $5\frac{1}{2}$ gallons of gasoline or 0.312 gallons per H.P. hour.

Greensburg, Ind. Triplex pump driven by a 6 H.P. crude oil engine (Indianapolis, Ind., Eng. Co.), 9th trial. Discharge 184 gallons per minute, total lift 81.3 feet. Montpelier Crude Oil, 2 cents a gallon —0.47 gallons per H.P. hour. (Eng. Rec. V. 38, 508.)

Cost of Lifting Water.

With gas at $22\frac{1}{2}$ cents per 1000 ft. One H.P. for 3000 hours, with a gas engine at, —

Wilmerding, Pa.	$9.58
Pitcairn, Pa.	10.99
E. Pittsburg, Pa.	12.70 — $\frac{1}{2}$ load on during test.

(Eng. Rec. V. 38, 397.)

The **Heat Energy** from burning gas is disposed of in the Otto gas engine as follows:

Averages of Many Tests.

1. Actual work and friction	17 per cent.
2. Hot expelled gases	15½ per cent.
3. Water jacket	52 per cent.
4. Conduction and radiation	15½ per cent.

Gas Engine Pumping Plant.

Pittsburg Plate Glass Co., Ford City, Pa., uses natural gas of 1000 B.T.U.'s, obtained on the premises.

Each pumping unit of six units (5 now in —1903) consists of:

One 11″ × 12″ — 3 cyl. Westinghouse Vertical Gas Engine direct geared to a 16″ × 15″ single acting triplex pump, Stillwell-Bierce & Smith-Vaile Co.

Compressed air is used to start the engines, being tanked in 3 steel storage tanks for this purpose. A 3 H.P. electric motor supplies this air at 180 lbs. pressure.

Total head pumped against, 215 ft.

Gallons per minute, 1101.

Total cost per million gallons, $7.02.

Steam plant doing same work cost $1,700 per month (average) for fuel alone.

Gas method cost $180 per month for fuel alone.

Full test and diagram of engine efficiency in "Power," Dec., 1903, p. 708.

STEAM TURBINES.*

Steam turbines, machines in which jets of steam striking vanes or buckets at a high velocity, are used as a motive power, may be classified thus:

1. Radial flow { Outward. / Inward.
2. Parallel or axial flow { De Laval. / Parsons. / Rateau. / Curtis.
3. Mixed flow.

If steam at a high pressure be allowed to escape through a suitably designed diverging nozzle into a lower pressure, a large proportion of its heat energy will be converted into kinetic energy, and the steam will expand adiabatically to the pressure of the medium or fluid into which it is discharged.

There is a wide difference between steam turbines and water turbines, for the nozzle velocity of steam is, say, 2,000 feet per second against 96 feet for water.

Then again, 1 cubic foot of water gives the same amount of kinetic energy as 1 cubic foot of steam at 50 lbs. pressure.

The efficiencies of all types depend very largely upon the terminal pressure at the exhaust end, and likewise on the completeness of the vacuum, where condensers are used; which accords with reciprocating steam-engine practice.

The absence of lubrication in the internal or steam spaces, permits the use of condensation and return of all water of condensation to the boilers.

Both the above factors, as well as the use of superheated steam, assist in securing the high efficiencies already obtained with this motor.

Experience shows that water carried over from the boiler does no harm in them.

One point which is made in their favor, is, no boiler scale when the same feed water is used continuously. In that event, boilers may suffer even more seriously from corrosion from the water being too pure, unless raw water is added from time to time to neutralize the corrosive tendency.

The steam turbine has opened up a field of usefulness all its own; for ex-

* W. W. Christie.

ample, the driving of centrifugal pumps, where in reciprocating engine practice great efficiency was only obtained with low heads, turbine efficiency is maintained even at very great head. While used also to drive fans, probably the greatest field open to steam turbines is the driving of electric generators, direct-connected or direct-geared.

De Laval Steam Turbine.

In this type the total power of the stream is devoted to the production of velocity in an expanding nozzle.

The jet so produced is driven against a set of vanes on a single wheel, ingeniously supported and run at a very high peripheral speed, the lineal velocity of teeth in this type being about 100 feet per second, and gearing ratio 10 to 1.

It is limited only by attending imperfections in gearing, and the type is not especially applicable to large sizes; they are not at present being built larger than 300 H.P.

As now designed, there is no way to reverse this machine.

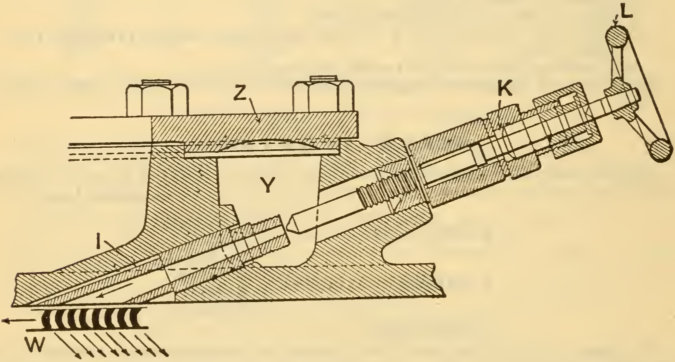


FIG. 21.

Tests of a De Laval Turbine by Dean and Main showed the saving by the use of superheated steam over that of saturated steam to be:

No. of Nozzles in Use.	Amount of Superheat.	Load with Superheated Steam.	Load with Saturated Steam.	Steam used per Brake H.P. with Sup. Steam.	Dry Steam used per Brake H.P. with Sat. Steam.	Saving by use of Superheated Steam.
	Deg. F.	H.P.	H.P.	Lbs.	Lbs.	%
Eight	84	352	333	13.94	15.17	8.8
Seven	64	298	285	14.35	15.56	8.4

Other tests by the same engineers gave with superheated steam:

De Laval Turbine.

Number of Nozzles Open, Eight (8).
Average Reading of Barometer, 30.18 in.
Average Temperature of Room, 83° F.

Date, 1902.	Hour.	Steam used per Hour. (Lbs.)	Pressure above Governor Valve. (Lbs.)	Pressure below Governor Valve. (Lbs.)	Vacuum. (In.)	Superheat above Governor Valve.	Revs. per Min. of Generators.	Brake Horse Power.	Steam used per Brake Horse Power per Hour. (Lbs.)
	A.M.								
May 22	8–9	4,833	208.3	200.6	27.2	81° F.	. . .	356.6	13.55
"	9–10	4,936	207.5	199.3	27.2	86° F.	. . .	355.7	13.88
"	10–11	5,083	207.7	202.1	27.2	91° F.	. . .	357.8	14.21
"	11–12	4,976	208.3	199.4	27.2	88° F.	. . .	354.1	14.05
"	M. P.M.								
"	12–1	4,841	207.5	194.3	27.3	82° F.	. . .	343.5	14.09
"	1–2	4,768	206.9	195.6	27.2	75° F.	. . .	344.4	13.84

Governing is accomplished by regulating the steam pressure at admission in much the same way as in reciprocating steam engines.

The Parsons Steam Turbine.

In the Parsons turbine the steam, after leaving the governor valve, enters a steam passage and turns to the right, first passing a stationary set of blades, then the blades of a revolving cylinder ; this operation is repeated a number of times, the steam moving in an axial direction until it has reached the

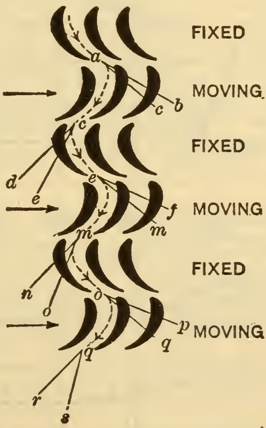


FIG. 22. Vanes, Westinghouse-Parsons Turbine.

other end of the turbine, when it is exhausted, sometimes at as low a temperature as 126° F.

The steam velocity is not as great in this type as it is in the De Laval.

Fig. 23 shows the relative floor space occupied by Westinghouse-Parsons' turbines, vertical and horizontal steam engines.

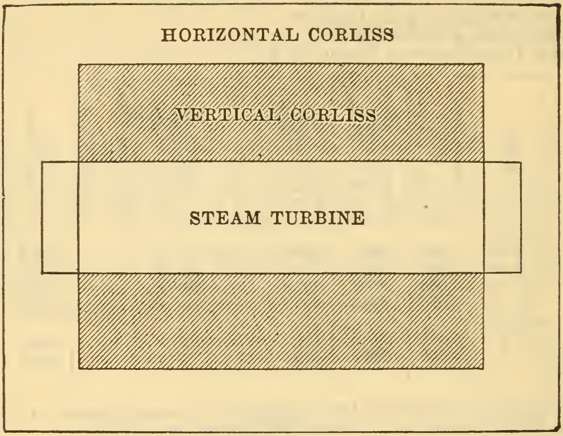

HORIZONTAL CORLISS
VERTICAL CORLISS
STEAM TURBINE

FIG. 23.

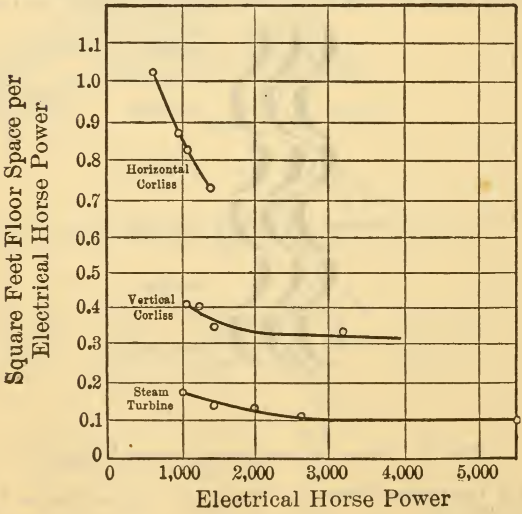

Square Feet Floor Space per Electrical Horse Power
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Horizontal Corliss
Vertical Corliss
Steam Turbine
0
1,000
2,000
3,000
4,000
5,000
Electrical Horse Power

FIG. 24.

Type.	Rows of Rotating Bucket Rings.	Steam Velocity, Feet per Second.	Revolutions per Minute.	Peripheral Speed, Feet per Second.	Buckets.
Parsons . .	35	400	3,600	200	Inserted
Rateau . .	25	800	2,400	400	Inserted
Curtis . . .	8	2,000	1,800	400	Solid
De Laval .	1	4,000	20,000	1,200	Inserted

(" Dodge.")

This type can be built so as to reverse by interchanging the steam and exhaust pipe connections. The efficiency, however, is somewhat reduced reversing.

Governing is accomplished by regulating the steam at inlet as in other types of engines.

A 400 K.W. Turbine gave a steam consumption of 14.47 full load to 16 lbs. at half rating, 19 lbs. at one-quarter rating. All per brake H.P.

The turbine at Hartford, average load, 1800 K.W., 155 lbs. steam pressure, 27 inch vacuum, 45° F. superheat, gave 19.1 lbs. of steam per K.W. hour; equal to about 11.46 per I.H.P. hour.

Curtis Steam Turbine.

In the Curtis Steam Turbine the velocity is given to the steam in an expanding nozzle, designed so as to convert nearly all of the steam's expansive force into velocity in itself.

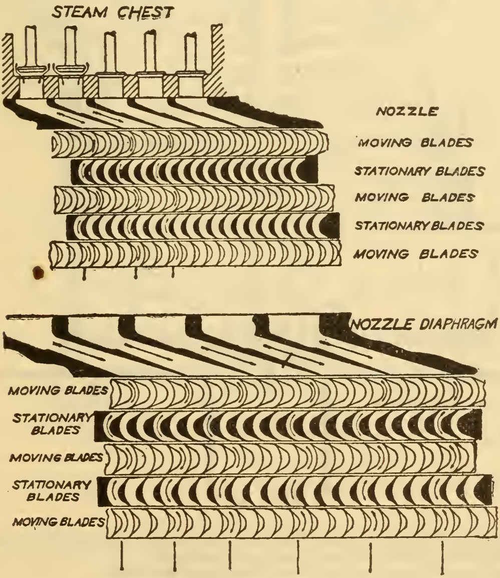


FIG. 25.

Leaving the nozzle the steam passes successively two or more lines of vanes on the moving element, placed alternately, with reversed vanes, on the fixed element.

Governing is effected by closing or opening some of the nozzle valves, thus narrowing or widening the steam belt.

Speed regulation is 2 to 4%.

Revolutions per minute of 600 K.W. machine is 1500.

Velocity of steam leaving the jet is 2000 ft. per second.

Compared with large engine outfits in Manhattan Railway Company's New York Power Plant — the weights of Curtis is to weight of Reciprocating outfit as 1 is to 8.

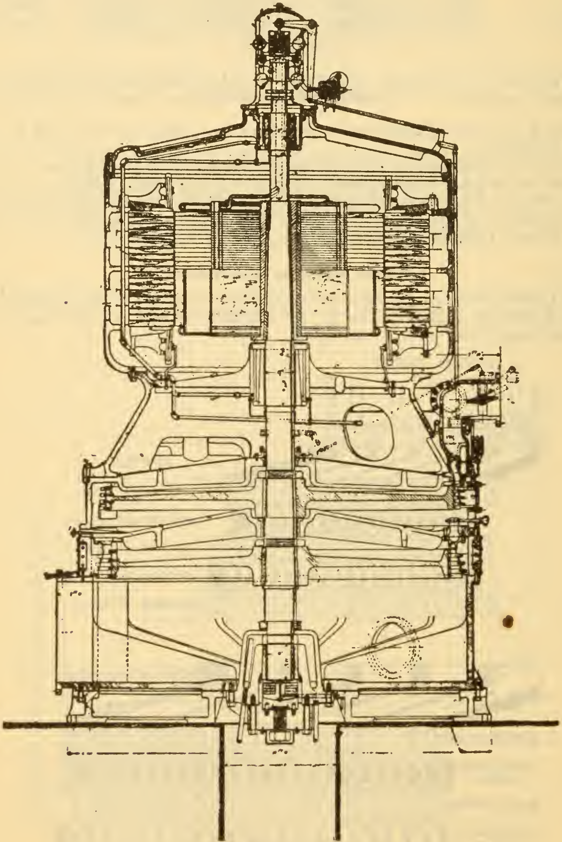


FIG. 26.

The condensing type is usually designed for 150 lbs. gauge steam pressure, and a vacuum of 28 inches of mercury at sea level.

Under these conditions normal overload may be 100%.

Nozzles are different for different pressures of steam.

This type is now being built with a condenser in its base, thereby securing fewer joints and connections and a better vacuum, resulting in a slight increase in the height of the machine.

A vertical shaft and step bearing are typical of the Curtis turbine, larger sizes, and though being lubricated with oil, experiments are now being carried out, having in view the use of water in place of the oil as a floating medium, then steam packing of stem will be avoided, and no oil be used in condenser proper.

This table gives some idea of the proportions of the Curtis Turbines, and is taken from a paper by A. H. Kruesi.

DIRECT CURRENT.

Number of Poles.	K.W.	Speed, R.P.M.	Volts.	Condensing or Non-Condensing.	Number of Stages.	Horizontal or Vertical.
2	1¼	5,000	80	Non-Condensing	1	Horizontal
2	15	4,000	80	"	1	"
2	25	3,600	125	"	1	"
4	75	2,400	125	"	2	"
4	150	2,000	125 or 250	"	2	"
4	300	1,800	250	"	4	"
4	300	2,000	550	Condensing	3	"
4	600	1,800	550	"	3	"
4	500	1,800	550	"	2	Vertical
ALTERNATING CURRENT.—60 CYCLES.						
2	100	3,600	2,300	Condensing	3	Horizontal
4	500	1,800	2,300	"	2	Vertical
8	1500	900	2,300	"	2	"
12	3000	600	2,300	"	4	"
14	5000	514	2,300	"	4	"

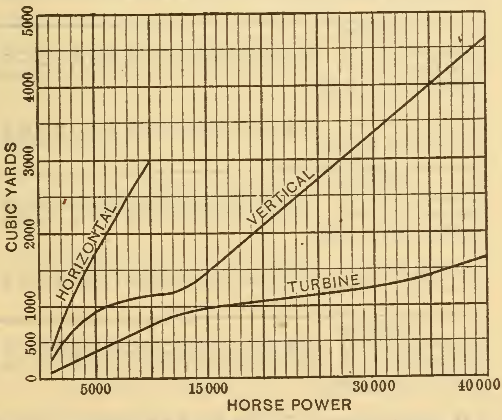


FIG. 27. Curves Showing the Relation of Foundation Material to Horse-Power.

The Rateau type is somewhat similar to the De Laval, except that the combinations of nozzles and single wheel is repeated many times, with less expansion than in the older turbines.

In making comparisons with other types of engines, it is found that for steam turbines, the average weight of the machine in lbs. per Brake H.P. is 52 lbs., against 422 for gas engines.

About the same ratio, or 1 to 8, applies to reciprocating steam engines.

STEAM TABLE.

This table is here published for the first time, and by the courtesy of the De Laval Steam Turbine Company, Trenton, N.J.

Table, giving the amount in pounds per hour, of dry saturated steam, flowing through each square inch area of the smallest section of an orifice if the pressure at the discharge end of that orifice is less than 0.577 of the pressure at the inlet of the same orifice.

Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.	Gauge Pressure, Lbs. per Sq. In.	1000 Lbs. Steam per Hr. per Sq. In. of Smallest Section.
20	1.83	43	3.01	66	4.16	89	5.32	112	6.46	135	7.59	158	8.72	181	9.83
21	1.89	44	3.06	67	4.21	90	5.37	113	6.51	136	7.64	159	8.77	182	9.88
22	1.94	45	3.11	68	4.26	91	5.42	114	6.56	137	7.69	160	8.81	183	9.93
23	1.99	46	3.16	69	4.31	92	5.47	115	6.61	138	7.74	161	8.86	184	9.98
24	2.04	47	3.21	70	4.36	93	5.52	116	6.66	139	7.79	162	8.91	185	10.03
25	2.09	48	3.26	71	4.42	94	5.57	117	6.71	140	7.84	163	8.96	186	10.08
26	2.14	49	3.31	72	4.47	95	5.62	118	6.76	141	7.89	164	9.01	187	10.12
27	2.19	50	3.36	73	4.52	96	5.67	119	6.81	142	7.94	165	9.06	188	10.17
28	2.24	51	3.41	74	4.57	97	5.71	120	6.85	143	7.99	166	9.11	189	10.22
29	2.29	52	3.46	75	4.62	98	5.76	121	6.90	144	8.03	167	9.15	190	10.27
30	2.34	53	3.51	76	4.67	99	5.81	122	6.95	145	8.08	168	9.20	191	10.32
31	2.39	54	3.56	77	4.72	100	5.86	123	7.00	146	8.13	169	9.25	192	10.36
32	2.44	55	3.61	78	4.77	101	5.91	124	7.05	147	8.18	170	9.30	193	10.41
33	2.50	56	3.66	79	4.82	102	5.96	125	7.10	148	8.23	171	9.35	194	10.46
34	2.55	57	3.71	80	4.87	103	6.01	126	7.15	149	8.28	172	9.40	195	10.51
35	2.60	58	3.76	81	4.92	104	6.06	127	7.20	150	8.33	173	9.45	196	10.56
36	2.65	59	3.81	82	4.97	105	6.11	128	7.25	151	8.38	174	9.49	197	10.60
37	2.70	60	3.86	83	5.02	106	6.16	129	7.30	152	8.42	175	9.54	198	10.65
38	2.75	61	3.91	84	5.07	107	6.21	130	7.35	153	8.47	176	9.59	199	10.70
39	2.80	62	3.96	85	5.12	108	6.26	131	7.40	154	8.52	177	9.64	200	10.75
40	2.85	63	4.01	86	5.17	109	6.31	132	7.45	155	8.57	178	9.69	201	10.80
41	2.91	64	4.06	87	5.22	110	6.36	133	7.49	156	8.62	179	9.74	202	10.85
42	2.96	65	4.11	88	5.27	111	6.41	134	7.54	157	8.67	180	9.78	203	10.90

A handy rule for approximately determining the outflow of the steam is the following:

If the absolute steam pressure at the inlet end of the orifice is p atmospheres $\frac{p}{2}$ kg. steam will flow through each mm.^{2} of the smallest section area of the orifice per hour.

The above company have in many trials demonstrated this to be true within five per cent.

WATER-POWER.

In determining the feasibility of utilizing water-power to operate electrically the industries of any particular town or city, careful consideration must be given to the following points, viz.: 1. The amount of water-power permanently available. 2. The cost of developing this power. 3. The interest on this amount. 4. The total demand for power. 5. The amounts and relative locations of the various kinds of power. 6. The cost of steam plants now in operation. 7. The interest on this amount. 8. Cost of fuel for plants now in operation. 9. Cost of operating present plants. Labor. 10. Cost of maintenance of present plants. 11. The amounts and kinds of electric power already in operation. 12. The distance of transmission. 13. The estimated cost of the hydraulic machinery. 14. The guaranteed efficiency and regulation of the hydraulic machinery. 15. Estimated cost of electric machinery. 16. Estimated cost of line construction. 17. Total cost of operating hydraulic and electric machinery. 18. Total cost of maintenance of hydraulic and electric plants. 19. The interest on the total estimated cost of proposed plant. 20. The estimated gross income.

Charles T. Main makes the following general statements as to the value of a water-power: "The value of an undeveloped variable power is usually nothing if its variation is great, unless it is to be supplemented by a steam-plant. It is of value then only when the cost per horse-power for the double-plant is less than the cost of steam-power under the same conditions as mentioned for a permanent power, and its value can be represented in the same manner as the value of a permanent power has been represented.

"The value of a developed power is as follows: If the power can be run cheaper than steam, the value is that of the power, plus the cost of plant, less depreciation. If it cannot be run as cheaply as steam, considering its cost, etc., the value of the power itself is nothing, but the value of the plant is such as could be paid for it new, which would bring the total cost of running down to the cost of steam-power, less depreciation."

Mr. Samuel Webber, *Iron Age*, Feb. and March, 1893, criticises the statements of Mr. Main and others who have made comparisons of costs of steam and of water-power unfavorable to the latter. He says: "They have based their calculations on the cost of steam, on large compound engines of 1000 or more h. p. and 120 pounds pressure of steam in their boilers, and by careful 10-hour trials succeeded in figuring down steam to a cost of about $20 per h. p., ignoring the well-known fact that its average cost in practical use, except near the coal mines, is from $40 to $50. In many instances dams, canals, and modern turbines can be all completed at a cost of $100 per h. p.; and the interest on that, and the cost of attendance and oil, will bring water-power up to but about $10 or $12 per annum; and with a man competent to attend the dynamo in attendance, it can probably be safely estimated at not over $15 per h. p.

SYNOPSIS OF REPORT REQUIRED ON WATER-POWER PROPERTY.

Location.

Geographical, etc.
Sketch of river and its tributaries.
Surrounding country and physical features.
Sources; lakes, springs, etc.
Water's head; area drained, nature of, whether forest, swamp, snow-covered mountains, etc.
Elevation of head waters and of mouth.
Length from main source to mouth.
Accessibility; how and by what routes.

Reports.

Reports of U. S. Coast or Geological Survey.
Reports of Engineers U. S. Army.
Any other reports.
Any estimate by engineers and for what purpose.
When it first attracted attention and for what reason.
History.

Rainfall.

Average for several years for the drainage area. Maximum, what month. Minimum, what month. Comparison with other similar localities.

Volume of Water.

Gauging of river if possible. Reports by other engineers.
Cubic feet per second flow.
Cubic feet per second per mile of watershed = say .2 to .3 of total rainfall and ½ available as water-power.
Comparison with other rivers.

Reservoirs.

Possibility of storing water for dry time.

Available Fall.

Location of; accessibility, by what routes.
Can power be used locally, or would it be necessary to transmit it, and if so, where to, and distances? Nature of country over which it would have to be carried.
Volume of water in cubic feet per second.

Horse-Power of River.

Calculated from available fall and volume.
Horse-power for each fall or dam.
Location of dams, dimensions, length, and height, best method of construction, estimated cost.
Backwater; volume, and how far; what interests disturbed by it; benefits, if any.
Compare power with that of similar rivers.
Probable cost of power at dams and transmitted.

Applications Possible.

Near by; at distance, stating when and for what. Note industries applicable to; comparison with other applications.

New Industries Suggested,

and old industries already going to which power is applicable.
Cost to these, and comparison with cost of other forms of power already in use.

Property of the Company.

Land, buildings, water rights, flowage rights, franchises, lines, rights of way. Character of deeds. Probable value.
Comparison with other similar properties.
Other resources.

Liabilities.

Stocks, bonds, floating debt, other.

Earning Capacity.

Probable cost of power per h. p. at power-house.
Probable cost of power per h. p. delivered or transmitted.
Price for which it can be sold at power-house, and price transmitted or delivered.

General Features.

Surrounding country, its characteristics, people, cities, and towns, industries, condition of finances.
Facilities for transportation, water and rail.
Nearness of sources of supplies and sales of products.

Horse-Power of a Waterfall.

The horse-power of a waterfall is expressed in the following formula:

Q = quantity of water in cubic feet flowing over the fall in 1 minute.
H = total head in feet, i.e., the distance between the surface of the water at the top of the fall, and that at its foot. In a water-power the head is the distance between the surface of the water in the head-race, and that of the water in the tail-race.

w = weight of water per cubic foot = 62.36 lbs. at 60° F.

$$\text{Gross horse-power of waterfall} = \frac{Q \times H \times w}{33000} \text{ or } .00189\,QH.$$

Loss of head at the entrance to and exit from a water-wheel, together with the friction of the water passing through, reduces the power that can be developed to about 70 per cent of the gross power of the fall.

Horse-Power of a Running Stream.

The power is calculated by the same formula as for a fall, but in this case H = theoretical head due to the velocity of the water in the stream = $\frac{v^2}{64.4}$ where

v = velocity of water in feet per second.
Q = the cubic feet of water actually impinging against the bucket per minute.

$$\text{Gross horse-power} = .00189\,QH.$$

Wheels for use in the current of a stream realize only about .4 of the gross theoretical power.

Current motors are often developed to operate in strong currents, such as that of the Niagara River opposite Buffalo, but are of little use excepting for small powers. Such a small fraction of the current velocity can be made use of that a current motor is extremely inefficient. In order to realize power from a current it is necessary to reduce its velocity in taking the power, and to get the full power would necessitate the backing up of the whole stream until the actual head equaled the theoretical.

Power of Water Flowing in a Pipe.

H due to velocity $= \frac{v^2}{2g} = \frac{v^2}{64.4}$ where v = velocity in feet per second.

H_1 due to pressure $= \frac{f}{w}$, where f = pressure in lbs. per square foot.

and w = 62.36 lbs. = weight 1 cubic foot of water.

H_2 distance above datum line in feet.

$$\text{Total } H = \frac{v^2}{2g} + \frac{f}{w} + H_2.$$

In hydraulic transmission the work or energy of a given quantity of water under pressure is the volume in cubic feet × lbs. pressure per square foot.

Q = cubic feet per second.
P = pressure in lbs. per square inch.

$$\text{Horse-power} = \frac{144\,PQ}{550} = .2618\,PQ.$$

Mill-Power.

It has been customary in the past to lease water-power in units larger than the horse-power, and the term *mill-power* has been used to designate the unit. The term has no uniform value, but is different in all localities.

Emerson gives the following values for the seven more important water-power.

Holyoke, Mass. — Each mill-power at the respective falls is declared to have the right during 16 hours in a day to draw 38 cubic feet of water per second at the upper fall when the head there is 20 feet, or a quantity proportionate to the height at the falls. This is equal to 86.2 horse-power as a maximum.

Lowell, Mass. — The right to draw during 15 hours in the day so much water as shall give a power equal to 25 cubic feet a second at the great fall, when the fall there is 30 feet. Equal to 85 h. p. maximum.

Lawrence, Mass. — The right to draw during 16 hours in a day so much water as shall give a horse-power equal to 30 cubic feet per second when the head is 25 feet. Equal to 85 h. p. maximum.

Minneapolis, Minn. — 30 cubic feet of water per second with head of 22 feet. Equal to 74.8 h. p.

Manchester, N. H.—Divide 725 by the number of feet of fall minus 1, and the quotient will be the number of cubic feet per second in that fall. For 20 feet fall this equals 38.1 cubic feet, equal to 86.4 h. p. maximum.

Cohoes, N. Y.—"Mill-power" equivalent to the power given by 6 cubic feet per second, when the fall is 20 feet. Equal to 13.6 h. p. maximum.

Passaic, N. J.—Mill-power: The right to draw 8½ cubic feet of water per second, fall of 22 feet, equal to 21.2 horse-power. Maximum rental, $700 per year for each mill-power = $33.00 per h. p.

The horse-power maximum above given is that due theoretically to the weight of water and the height of the fall. assuming the water-wheel to have perfect efficiency. It should be multiplied by the efficiency of the wheel, say 75 per cent for good turbines, to obtain the h.p. delivered by the wheel.

At Niagara power has in all cases been sold by the horse-power delivered to the wheels if of water, and to the building-line if electrical.

Charges for water in Manchester, Lowell, and Lawrence, are as follows:

Manchester.

About $300 per year per mill-power for original purchases.
$2 per day per mill-power for surplus.

Lowell.

About $300 per year per mill-power for original purchases.
$2 per day per mill-power during "back-water."
$4 per day per mill-power for surplus under 40 per cent.
$10 per day per mill-power for surplus over 40 per cent and under 50 per cent.
$20 per day per mill-power for surplus over 50 per cent.
$75 per day per mill-power for any excess over limitation.

Lawrence.

About $300 per year per mill-power for original purchases.
About $1200 per year per mill-power for new leases at present.
$4 per day per mill-power fur surplus up to 20 per cent.
$8 per day per mill-power for surplus over 20 and under 50 per cent.
$4 per day per mill-power for surplus under 50 per cent.

COMPARISON OF COLUMNS OF WATER IN FEET, Mercury in Inches, and Pressure in Lbs., per Square Inch.

Lbs. Press. Sq. In.	Water. Feet.	Merc'ry Inches.	Water. Feet.	Merc'ry Inches.	Lbs. Press. Sq. In.	Merc'ry Inches.	Water. Feet.	Lbs. Press. Sq. In.
1	2.311	2.046	1	0.8853	0.4327	1	1.1295	0.4887
2	4.622	4.092	2	1.7706	0.8654	2	2.2590	0.9775
3	6.933	6.138	3	2.6560	1.2981	3	3.3885	1.4662
4	9.244	8.184	4	3.5413	1.7308	4	4,5181	1.9550
5	11.555	10.230	5	4.4266	2.1635	5	5.6476	2.4437
6	13.866	12.2276	6	5.3120	2.5962	6	6.7771	2.9325
7	16.177	14.322	7	6.1973	3.0289	7	7.9066	3.4212
8	18.488	16.368	8	7.0826	3.4616	8	9.0361	3.9100
9	20.800	18.414	9	7.9680	3.8942	9	10.165	4.3987
10	23.111	20.462	10	8.8533	4.3273	10	11.295	4.8875
11	25.422	22.508	11	9.7386	4.7600	11	12.424	5.3762
12	27.733	24.554	12	10.624	5.1927	12	13.554	5.8650
13	30.044	26.600	13	11.509	5.6255	13	14.683	6.3537
14	32.355	28.646	14	12.394	6.0582	14	15.813	6.8425
15	34.666	30.692	15	13.280	6.4909	15	16.942	7.3312
16	36.977	32.738	16	14.165	6.9236	16	18.072	7.8200
17	39.288	34.784	17	15.050	7.3563	17	19.201	8.3087
18	41.599	36.830	18	15.936	7.7890	18	20.331	8.7975
19	43.910	38.876	19	16.821	8.2217	19	21.460	9.2862
20	46.221	40.922	20	17.706	8.6544	20	22.590	9.7750
21	48.532	42.968	21	18.591	9.0871	21	23.719	10.264
22	50.843	45.014	22	19.477	9.5198	22	24,849	10.752
23	53.154	47.060	23	20.362	9.9525	23	25.978	11.241
24	55.465	49.106	24	21.247	10.385	24	27.108	11.7300
25	57.776	51.152	25	22.133	10.818	25	28.237	12.219
26	60.087	53.198	26	23.018	11.251	26	29.367	12.707
27	62.398	55.244	27	23.903	11.683	27	30.496	13.196
28	64.709	57.290	28	24.789	12 116	28	31.626	13.685
39	67.020	59.336	29	25.674	12.549	29	32.755	14.174
30	69.331	61.386	30	26.560	12.981	30	33.885	14.662

The following table based on the Lowell mill-power will assist in computing cost of water-power.

SHOWING YEARLY EXPENSE OF WATER-POWER PER H. P. ON WHEEL SHAFT.

Charges for Water.		Attendance, Oil, Supplies, etc.	Fixed Charges on Cost of Plant.						Total Yearly Expense per H. P.					
			Cost of Plant.						For Plants Costing					
Per Mill-Power.	Per H. P. per Year		$50	$60	$70	$80	$90	$100	$50	$60	$70	$80	$90	$100
$300 per year *a*	$4.62	$0.72	$5.08	$6.10	$7.11	$8.12	$9.13	$10.15	$10.42	$11.44	$12.45	$13.46	$14.47	$15.49
$300 per year *b*	12.31								18.11	19.13	20.14	21.15	22.16	23.18
2 per day . .	9.48								15.28	16.30	17.31	18.32	19.33	20.35
4 " " . .	18.96								24.76	25.78	26.79	27.80	28.81	29.83
8 " " . .	37.92								43.72	44.74	45.75	46.76	47.77	48.79
10 " " . .	47.40								53.20	54.22	55.23	56.24	57.25	58.27
20 " " . .	94.80								100.60	101.62	102.63	103.64	104.65	105.67

Explanation of Table.

a, in column "Per H.P. per Year," is the cost, not including interest on the original purchase.

b, in column "Per H. P. per Year," is the cost including interest on original purchase, which amounts to about $7.49 per H.P., or 5 per cent on $10,000 per M. P. per year.

The "Fixed Charges on Cost of Plant" are depreciations at 2.5 per cent average, repairs at 1½ per cent, interest at 5 per cent, taxes at 1½ per cent in ¾ cost, and insurance at .05 per cent on exposed portion.

PRESSURE OF WATER.

The pressure of water in pounds per square inch for every foot in height to 300 feet; and then by intervals to 1000 feet head.

Feet He'd.	Press., Sq. In.	Feet He'd.	Press., Sq. In.	Feet He'd.	Press., Sq. In.	Feet Head.	Press., Sq. In.	Feet Head.	Press., Sq. In.
1	0.43	65	28.15	129	55.88	193	83.60	257	111.32
2	0.86	66	28.58	130	56.31	194	84.03	258	111.76
3	1.30	67	29.02	131	56.74	195	84.47	259	112.19
4	1.73	68	29.45	132	57.18	196	84.90	260	112.62
5	2.16	69	29.88	133	57.61	197	85.33	261	113.06
6	2.59	70	30.32	134	58.04	198	85.76	262	113.49
7	3.03	71	30.75	135	58.48	199	86.20	263	113.92
8	3.46	72	31.18	136	58.91	200	86.63	264	114.36
9	3.89	73	31.62	137	59.34	201	87.07	265	114.79
10	4.33	74	32.05	138	59.77	202	87.50	266	115.22
11	4.76	75	32.48	139	60.21	203	87.93	267	115.66
12	5.20	76	32.92	140	60.64	204	88.36	268	116.09
13	5.63	77	33.35	141	61.07	205	88.80	269	116.52
14	6.06	78	33.78	142	61.51	206	89.23	270	116.96
15	6.49	79	34.21	143	61.94	207	89.66	271	117.39
16	6.93	80	34.65	144	62.37	208	90.10	272	117.82
17	7.36	81	35.08	145	62.81	209	90.53	273	118.26
18	7.79	82	35.52	146	63.24	210	90.96	274	118.69
19	8.22	83	35.95	147	63.67	211	91.39	275	119.12
20	8.66	84	36.39	148	64.10	212	91.83	276	119.56
21	9.09	85	36.82	149	64.54	213	92.26	277	119.99
22	9.53	86	37.25	150	64.97	214	92.69	278	120.42
23	9.96	87	37.68	151	65.40	215	93.13	279	120.85
24	10.39	88	38.12	152	65.84	216	93.56	280	121.29
25	10.82	89	38.55	153	66.27	217	93.99	281	121.72
26	11.26	90	38.98	154	66.70	218	94.43	282	122.15
27	11.69	91	39.42	155	67.14	219	94.86	283	122.59
28	12.12	92	39.85	156	67.57	220	95.30	284	123.02
29	12.55	93	40.28	157	68.00	221	95.73	285	123.45
30	12.99	94	40.72	158	68.43	222	96.16	286	123.89
31	13.42	95	41.15	159	68.87	223	96.60	287	124.32
32	13.86	96	41.58	160	69.31	224	97.03	288	124.75
33	14.29	97	42.01	161	69.74	225	97.46	289	125.18
34	14.72	98	42.45	162	70.17	226	97.90	290	125.62
35	15.16	99	42.88	163	70.61	227	98.33	291	126.05
36	15.59	100	43.31	164	71.04	228	98.76	292	126.48
37	16.02	101	43.75	165	71.47	229	99.20	293	126.92
38	16.45	102	44.18	166	71.91	230	99.63	294	127.35
39	16.89	103	44.61	167	72.34	231	100.06	295	127.78
40	17.32	104	45.05	168	72.77	232	100.49	296	128.22
41	17.75	105	45.48	169	73.20	233	100.93	297	128.65
42	18.19	106	45.91	170	73.64	234	101.36	298	129.08
43	18.62	107	46.34	171	74.07	235	101.79	299	129.51
44	19.05	108	46.78	172	74.50	236	102.23	300	129.95
45	19.49	109	47.21	173	74.94	237	102.66	310	134.28
46	19.92	110	47.64	174	75.37	238	103.09	320	138.62
47	20.35	111	48.98	175	75.80	239	103.53	330	142.95
48	20.79	112	48.51	176	76.23	240	103.90	340	147.28
49	21.22	113	48.94	177	76.67	241	104.39	350	151.61
50	21.65	114	49.38	178	77.10	242	104.83	360	155.94
51	22.09	115	49.81	179	77.53	243	105.26	370	160.27
52	22.52	116	50.24	180	77.97	244	105.69	380	164.61
53	22.95	117	50.68	181	78.40	245	106.13	390	168.94
54	23.39	118	51.11	182	78.84	246	106.56	400	173.27
55	23.82	119	51.54	183	79.27	247	106.99	500	216.58
56	24.26	120	51.98	184	79.70	248	107.43	600	259.90
57	24.69	121	52.41	185	80.14	249	107.86	700	303.22
58	25.12	122	52.84	186	80.57	250	108.29	800	346.54
59	25.55	123	53.28	187	81.00	251	108.73	900	389.86
60	25.99	124	53.71	188	81.43	252	109.16	1000	433.18
61	26.42	125	54.15	189	81.87	253	109.59		
62	26.85	126	54.58	190	82.30	254	110.03		
63	27.29	127	55.01	191	82.73	255	110.46		
64	27.72	128	55.44	192	83.17	256	110.89		

RIVETED STEEL PIPES.

Riveted sheet steel pipe is much used on the Pacific Coast for conveying water for considerable distances under high heads, say as much as 1700 feet. Corrosion of iron and steel pipe has always been an argument against its use, but for about thirty years such pipe has been in use in California; and a life of twenty-five years is not considered the limit, when both inside and outside of the pipe are treated with a coating of asphalt.

The method of covering with asphalt referred to affords perfect protection against corrosion, and so long as the coating is intact, makes it practically indestructible so far as all ordinary wear is concerned. The conditions which interfere with the best service are where the coating is worn off by abrasion in transportation, or where the pipe is subject to severe shock by the presence of air, or by a sudden closing of the gates, or where the service is intermittent, causing contraction and expansion, which opens the joints and breaks the covering. With ordinary care these objections can mostly be overcome. While the primary object of coating pipe in this way is to prevent oxidization, and thus insure its durability, it is incidentally an advantage in providing a smooth surface on the inside, which reduces the friction of water in its passage.

The Coast method of laying pipe is to take the shortest practicable distance that the ground will permit, placing the pipe on the surface and connecting directly from ditch, flume, or other source of supply to the wheel. Avoid short turns or acute angles, as they lessen the head and produce shock.

The ordinary method of jointing is the *slip joint*, made up in much the same way as stove-pipe. Of course this is only adapted to comparatively low heads, special riveted-joint construction being necessary for the higher falls. In laying such pipe where the lengths come together at an angle, a lead joint should be made. This is done by putting on a sleeve, allowing a space, say three-eighths of an inch, for running in lead. With a heavy pressure, and especially on steep grades, the lengths should be wired together, lugs being put on the sections forming the joints for this purpose; and where the grade is very steep, the pipe should be securely anchored with wire cable.

In laying the pipe line it is customary to commence at the wheel, and with slip joint the lower end of each length should be wrapped with cotton drilling or burlaps to prevent leaking; care being taken in driving the joints together not to move the gate and nozzle from their position. Some temporary bracing may be necessary to provide against this.

Where several wheels are to be supplied from one pipe line, a branch from the main in the form of the letter Y is preferable to a right angle outlet. When taken from the main at a right angle, the tap-hole should be nearly as large as the main, reducing by taper joint to the size of pipe attached to the wheel gate.

It is advised where practicable to lay the pipe in a trench, covering it with earth. Even in warm climates, where this is not necessary as protection from frost, it is desirable to prevent contraction and expansion by variations of temperature, as well as to afford security against accident. When laid over a rocky surface a covering of straw or manure will protect it from the sun, and generally prevent freezing; as where kept in motion, water under pressure will stand a great degree of cold without giving trouble in this way. After connections are made, it should be tested before covering to see that the joints are tight.

Care should be taken when the pipes are first filled to see that the air is entirely expelled, the use of air valves being necessary in long lines laid over undulating surfaces. Care should also be taken before starting to see that there are no obstructions in the pipe or connections to wheel, and that there are no leaks to reduce the pressure. Pipe lines of any considerable length should be graduated as to size, being larger near the top and reduced toward the lower end, the thickness of iron for various sizes being determined by the pressure it is to carry. This is a saving in first cost, and facilitates transportation by admitting of length, being run inside of each other.

When used near railroad stations, pipe is generally made in 27 ft. lengths for purpose of economizing freight, this being the length of a car. When transported long distances by wagon, it is usually made in about 20 ft. lengths. For pipe of large diameter, or for transportation over long distances, as also for mule packing, it is made in sections or joints of 24 to 30 inches in length, rolled and punched, with rivets furnished to put together on the ground where laid. Pipe of this character, being cold riveted, is easily put together with the ordinary tools for the purpose. In such case, preparation should be made for coating with asphalt before laying.

Riveted steel pipes have also been extensively used in the East in the installation of the new water supply for Newark, Jersey City and Paterson, N.J., also at Rochester, N.Y., and were furnished by Mr. Thos. H. Millson, of East Jersey Pipe Company, Paterson, N.J.

Data of Rivet Spacings for Circular Seams of Pipe.

Pipes 48″ to 51″ Diameter.

Diameter of pipe	48″	48″	48″	51″	51″	51″	51″
Thickness	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
Diameter of rivets . . .	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Number of rivets . . .	100	84	74	108	92	80	64
Length of long plate . .	151.582	151.779	151.975	162.764	163.354	163.943	164.532
Length of short plate . .	149.895	149.717	149.538	161.007	161.203	161.399	161.595
Rivet pitch on long plate,	1.515	1.807	2.053	1.507	1.776	2.049	2.571
Rivet pitch on short plate,	1.498	1.782	2.020	1.491	1.752	2.017	2.525
Lap, center to edge . . .	1	$1\frac{3}{16}$	$1\frac{3}{8}$	1	$1\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{9}{16}$
Lap at circum., seams . .	2	$2\frac{3}{8}$	$2\frac{3}{4}$	2	$2\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{1}{8}$

Data of Rivet Spacings for Longitudinal Seams of Pipe.

Number in first row . .	35	29	25	35	29	25	22″
Number in second row .	34	28	24	34	28	24	21
Number in both rows . .	69	57	49	69	57	49	43
Rivet pitch in both rows .	2.277″	2.721″	3.125″	2.277″	2.721″	3.125″	3.542
Distance between rows .	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{4}$
Lap, center to edge . . .	$\frac{15}{16}$	$1\frac{5}{32}$	$1\frac{11}{32}$	$\frac{15}{16}$	$1\frac{5}{32}$	$1\frac{11}{32}$	$1\frac{9}{16}$
Lap at longitudinal seam,	3	$3\frac{1}{2}$	4	3	$3\frac{1}{2}$	4	$4\frac{7}{8}$

This formula for the design of riveted steel pipe is taken from Cassier's Magazine, 1902: —

$$P = \frac{Tt}{R} \div \frac{c}{f}. \qquad P = \frac{Ttf}{Rc}.$$

T = for iron, usually 48,000 lbs. per sq. in.
T = for steel, 62,000 lbs. per sq. in.
P = safe working pressure, per sq. in.
t = thickness of sheet in inches.
R = radius of pipe in inches.
c = factor of safety: 3 to 3.5 for this work.
f = proportional strength of plates after riveting:
Double riveting . . . 0.7
Single riveting . . . 0.5

The Water Power Plant at Puyallup River near Tacoma will have a steel pipe line 1700 feet long, beginning 48″ diameter, reducing to 36″ diameter at the end, built by Ridson Iron Works, San Francisco, Cal.

In many cases much expense may be saved in pipe by conveying the water in a flume or ditch along the hillside, covering in this way a large part of the distance, then piping it down to the power station by a short line. This is more especially applicable to large plants, where the cost of the pipe is an important item.

DATA FOR FLUMES AND DITCHES.

To give a general idea as to the capacity of flumes and ditches for carrying water, the following data is submitted:

The greatest safe velocity for a wooden flume is about 7 or 8 feet per second. For an earth ditch this should not exceed about 2 feet per second. In California it is the general practice to lay a flume on a grade of about ¼ inch to the rod, or often 2 inches to the 100 feet, depending on the existing conditions.

Assuming a rectangular flume 3 feet wide, running 18 inches deep, its velocity and capacity would be shown as below:

Grade.	Vel. in Ft. per Sec.	Quantity Cu. Ft. Min.
⅛ inch to rod	2.6	702
¼ " " "	3.7	999
½ " " "	5.3	1,431

As the velocity of a flume or ditch is dependent largely on its size and character of formation, no more specific data than the above can be given. It is not safe to run either ditch or flume more than about ¾ or ⅞ full.

WOODEN-STAVE PIPE.

Wooden-stave pipe has been used to some extent on the Pacific Coast for conveying water long distances under heads not much exceeding 200 feet. Although the construction of such pipe is quite simple, yet considerable skill and care are necessary to make water-tight work. The plant of the San Gabriel Los Angeles Transmission, California, uses several miles of wooden-stave pipe, 48 ins. diameter. The pipe is laid uniformly ten feet below hydraulic grade; and the wood is of such thickness as to be always water-soaked, and will thus outlast almost any other form of construction.

The staves are placed so as to break joints, the flat sides are dressed to a true circle, and the edges to radial planes. The staves are cut off square at the ends, and the ends slotted, a tight-fitting metallic tongue being used to make the joint.

The pipe depends upon steel bands for its strength, and in the case above mentioned they are of round steel rod placed ten inches apart from center to center. Where the pressures vary along the line, bands can be spaced closer or wider apart to make the necessary strength. The preference is given round bands over flat ones, on account of their embedding themselves in the wood better as it swells. They also expose less surface to rust than would flat ones of the same strength. The ends of the bands are secured together through a malleable iron shoe, having an interior shoulder for the head of the bolt, and an exterior shoulder for the nut, the whole band thus being at right angles to the line of the pipe. Where curves are not too sharp, they can easily be made in the wooden pipe; but for short turns, sections of steel-riveted pipe of somewhat larger internal diameter than that of the wooden pipe are introduced. The joints between wood and steel are made by a bell on the steel pipe that is larger than the outside diameter of the wooden pipe. After partly filling the space between bell and wood with oakum packed hard, for the remainder use neat Portland cement.

Advantages claimed for this type are that it costs less than any other form, and especially so where transportation is over the rugged country where it is most liable to be used; great length of life, and greater capacity than either cast-iron or steel-riveted. Compared with new riveted pipe, the carrying capacity of stave pipe is said to be from 10 to 40 % more, and this difference increases with age as the wooden pipe gets smoother, while the friction of the metal pipe increases to a considerable degree.

As compared with open flumes, the life is so much greater and repairs so much less as to considerably more than counterbalance the first cost. For detailed information on wooden-stave pipe, see papers by **A. L. Adams**, September, 1898, Am. Soc. C. E.

NOTE. — Mr. Arthur L. Adams writes that the pipe laid at Astoria, Ore., about which he wrote ten years ago has not proved lasting, one third of it having been renewed during the first decade of its existence.

TABLE OF RIVETED HYDRAULIC PIPE.

(Pelton Water Wheel Co.)

Showing weight, with safe head for various sizes of double-riveted pipe.

Diam. of pipe in inches.	Area of pipe in inches.	Thickness of iron by wire gauge.	Head in feet the pipe will safely stand.	Cu. ft. water pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs.
3	7	18	400	9	2
4	12	18	350	16	2¼
4	12	16	525	16	3
5	20	18	325	25	3½
5	20	16	500	25	4¼
5	20	14	675	25	5
6	28	18	296	36	4¼
6	28	16	487	36	5¾
6	28	14	743	36	7½
7	38	18	254	50	5¼
7	38	16	419	50	6¾
7	38	14	640	50	8½
8	50	16	367	63	7½
8	50	14	560	63	9½
8	50	12	854	63	13
9	63	16	327	80	8½
9	63	14	499	80	10¾
9	63	12	761	80	14¼
10	78	16	295	100	9¼
10	78	14	450	100	11¾
10	78	12	687	100	15¾
10	78	11	754	100	17½
10	78	10	900	100	19¼
11	95	16	269	120	9¾
11	95	14	412	120	13
11	95	12	626	120	17¼
11	95	11	687	120	18¾
11	95	10	820	120	21
12	113	16	246	142	11¼
12	113	14	377	142	14
12	113	12	574	142	18½
12	113	11	630	142	19¾
12	113	10	753	142	22¾
13	132	16	228	170	12
13	132	14	348	170	15
13	132	12	530	170	20
13	132	11	583	170	22
13	132	10	696	170	24½
14	153	16	211	200	13
14	153	14	324	200	16
14	153	12	494	200	21½
14	153	11	543	200	23½
14	153	10	648	200	26
15	176	16	197	225	13¾
15	176	14	302	225	17
15	176	12	460	225	23
15	176	11	507	225	24½
15	176	10	606	225	28
16	201	16	185	255	14½
16	201	14	283	255	17¼
16	201	12	432	255	24¼
16	201	11	474	255	26½
16	201	10	567	255	29½
18	254	16	165	320	16½
18	254	14	252	320	20½
18	254	12	385	320	27¼
18	254	11	424	320	30
18	254	10	505	320	34
20	314	16	148	400	18
20	314	14	227	400	22½
20	314	12	346	400	30
20	314	11	380	400	32½
20	344	10	456	400	36½
22	380	16	135	480	20
22	380	14	206	480	24¾
22	380	12	316	480	32¾
22	380	11	347	480	35¾
22	380	10	415	480	40
24	452	14	188	570	27¼
24	452	12	290	570	35½
24	452	11	318	570	39
24	452	10	379	570	43½
24	452	8	466	570	53
26	530	14	175	670	29¼
26	530	12	267	670	38½
26	530	11	294	670	42
26	530	10	352	670	47
26	530	8	432	670	57¼
28	615	14	102	775	31¼
28	615	12	247	775	41¼
28	615	11	273	775	45
28	615	10	327	775	50¼
28	615	8	400	775	61¼
30	706	12	231	890	44
30	706	11	254	890	48
30	706	10	304	890	54
30	706	8	375	890	65
30	706	7	425	890	74
36	1017	11	141	1300	58
36	1017	10	155	1300	67
36	1017	8	192	1300	78
36	1017	7	210	1300	88
40	1256	10	141	1600	71
40	1256	8	174	1600	86
40	1256	7	189	1600	97
40	1256	6	213	1600	108
40	1256	4	250	1600	126
42	1385	10	135	1760	74½
42	1385	8	165	1760	91
42	1385	7	180	1660	102
42	1385	6	210	1760	114
42	1385	4	240	1760	133
42	1385	¼	270	1760	137
42	1385	3	300	1760	145
42	1385	5/16	321	1760	177
42	1385	3/8	363	1760	216

Cubic Feet of Water per Minute Discharged Through an Orifice 1 Square Inch in Area.

For any other size of orifice, multiply by its area in square inches.

Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.	Heads in Inches.	Cubic Feet Discharged per Minute.
3	1.12	13	2.20	23	2.90	33	3.47	43	3.95	53	4.39	63	4.78
4	1.27	14	2.28	24	2.97	34	3.52	44	4.00	54	4.42	64	4.81
5	1.40	15	2.36	25	3.03	35	3.57	45	4.05	55	4.46	65	4.85
6	1.52	16	2.43	26	3.08	36	3.62	46	4.09	56	4.52	66	4.89
7	1.64	17	2.51	27	3.14	37	3.67	47	4.12	57	4.55	67	4.92
8	1.75	18	2.58	28	3.20	38	3.72	48	4.18	58	4.58	68	4.97
9	1.84	19	2.64	29	3.25	39	3.77	49	4.21	59	4.63	69	5.00
10	1.94	20	2.71	30	3.31	40	3.81	50	4.27	60	4.65	70	5.03
11	2.03	21	2.78	31	3.36	41	3.86	51	4.30	61	4.72	71	5.07
12	2.12	22	2.84	32	3.41	42	3.91	52	4.34	62	4.74	72	5.09

Table Showing the Theoretical Velocity and Discharge in Cubic Feet Through an Orifice of 1 Square Inch Issuing Under Heads Varying from 1 to 100 Feet.

Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.	Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.	Head in Feet.	Theoretical Discharge in Cu. Ft. per Min.	Theoretical Velocity in Feet per Min.
1	3.34	481.2	35	19.77	2847.6	69	27.74	3997.1
2	4.73	680.4	36	20.05	2887.2	70	27.94	4021.1
3	5.79	833.4	37	20.33	2926.8	71	28.14	4054.5
4	6.68	962.4	38	20.60	2966.4	72	28.34	4283.0
5	7.47	1075.8	39	20.87	3004.8	73	28.53	4111.3
6	8.18	1178.4	40	21.13	3043.2	74	28.73	4139.4
7	8.84	1273.2	41	21.38	3081.1	75	28.93	4165.2
8	9.45	1360.8	42	21.64	3118.5	76	29.11	4194.9
9	10.02	1443.6	43	21.90	3156.4	77	29.30	4222.4
10	10.57	1521.6	44	22.15	3191.8	78	29.49	4249.8
11	11.08	1596.0	45	22.40	3227.8	79	29.68	4265.9
12	11.57	1666.8	46	22.65	3263.6	80	29.87	4303.6
13	12.05	1734.6	47	22.89	3298.9	81	30.06	4330.8
14	12.50	1800.6	48	23.14	3333.8	82	30.24	4357.4
15	12.94	1863.6	49	23.38	3368.4	83	30.42	4383.6
16	13.37	1924.8	50	23.61	3402.5	84	30.61	4410.2
17	13.78	1984.2	51	23.85	3436.4	85	30.79	4436.4
18	14.18	2041.8	52	24.08	3469.9	86	30.97	4462.4
19	14.57	2097.6	53	24.31	3503.1	87	31.15	4488.2
20	14.95	2152.2	54	24.54	3536.0	88	31.33	4514.0
21	15.31	2205.0	55	24.76	3568.6	89	31.50	4539.5
22	15.67	2256.6	56	24.99	3600.9	90	31.68	4565.0
23	16.02	2307.6	57	25.21	3632.9	91	31.86	4590.3
24	16.37	2357.4	58	25.43	3664.6	92	32.04	4615.4
25	16.71	2406.0	59	25.65	3696.1	93	32.20	4640.5
26	17.04	2453.4	60	25.87	3727.3	94	32.38	4665.3
27	17.36	2500.2	61	26.08	3758.2	95	32.55	4690.1
28	17.68	2545.8	62	26.29	3788.9	96	32.72	4714.7
29	17.99	2590.8	63	26.51	3819.3	97	32.89	4739.2
30	18.30	2635.8	64	26.72	3849.6	98	33.06	4763.5
31	18.60	2679.0	65	26.92	3879.5	99	33.23	4787.8
32	18.90	2722.2	66	27.13	3909.2	100	33.40	4812.0
33	19.20	2764.2	67	27.33	3938.7			
34	19.49	2806.2	68	27.54	3968.4			

Flow of Water Through an Orifice.

a = area of orifice in square inches.
Q = cubic feet discharged per minute.
h = head in inches.

$$Q = .624\sqrt{h} \times a.$$

The best form of aperture for giving the greatest flow of water is a conical aperture whose greater base is the aperture, the height or length of the section of cone being half the diameter of aperture, and the area of the small opening to the area of the large opening as 10 to 16; there will be no contraction of the vein, and consequently the greatest attainable discharge will be the result.

MEASUREMENT OF FLOW OF WATER IN A STREAM.

The quantity of water flowing in a stream may be roughly estimated as follows:

Find the mean depth of the stream by taking measurements at 10 or 12 or more equal distances across. Multiply this mean depth by the width of the stream, which will give the total cross-section of the prism.

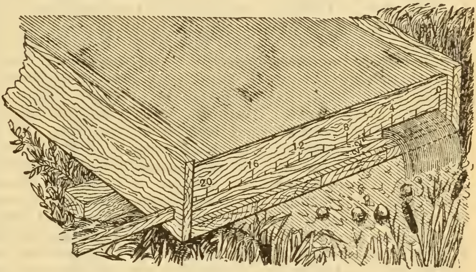


FIG. 28.

Find the velocity of the flow in feet per minute, by timing a float over a measured distance, several times to get a fair average. Use a thin float, such as a shingle, so that it may not be influenced by the wind.

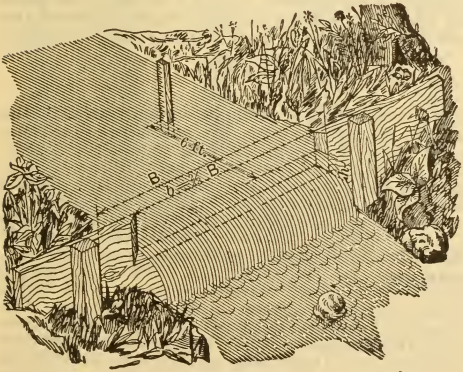


FIG. 29.

The area or cross-section of the prism multiplied by the velocity per minute will give the quantity per minute in cubic feet.

Owing to the friction of the bed and banks the actual flow is reduced to about 83 per cent of the calculated flow as above.

THEORY OF ROD FLOAT GAUGING.

(From Report on Barge Canal, 1901, Edward A. Bond, N. Y. State Engineer.)

The hydrometric rod may consist of either a plain wooden rod of uniform diameter, weighted at its lower end with iron or lead pipe of equal diameter, so as to make it sink vertically in the water to nearly its full length, or of a tin tube of uniform diameter, made either continuous or in sections fitting water-tightly into each other, and properly weighted with leaden shot, bullets, etc., at the bottom. If such a rod is placed carefully in the water, so as to prevent any vertical motion, and its projecting part is not acted upon by the wind, it may be assumed that in a short time it will move with the mean velocity of the water in the vertical plane in which it floats.

When a straight cylindrical rod of uniform diameter is immersed vertically in a moving body of water and kept from sinking, it encounters therein filaments having different velocities in the direction of the stream, and eventually acquires an intermediate velocity which is very nearly the mean of those acting upon it. Some of the fluid particles will be moving faster than the rod, while others move slower; the former will tend to accelerate the motion of the rod, both by direct pressure and by the lateral friction, while the latter tend to retard it. In the ensuing state of equilibrium and uniform motion, the accelerating and retarding forces acting on the rod must be equal, and will form a couple which causes the rod to assume a slightly inclined position in the water. Furthermore, when the channel is regular, and the rod reaches nearly to the bottom, the general law according to which the velocity of the successive filaments from the surface downwards varies, has been determined approximately by experiment, and it becomes possible to express the sums of the said accelerating and retarding forces in relatively simple mathematical terms. From the equality of these expressions, it is then found that the rod assumes the velocity of the water filament, which is located at a depth $= 0.61\,L$, where (L) denotes the immersed length of the rod. In like manner, the velocity (v_1) of the rod may also be compared with the computed or theoretical mean velocity (v_2) of all the water filaments in the vertical line or plane from the surface to the depth (L); and as it is found therefrom that (v_1) is a little less than (v_2), it may be considered that (v_1) is equal to the mean velocity (v_m) for a depth a little greater than the said length (L). Under ordinary conditions in canals and rivers with regular channels and moderate velocities, the immersed length (L) of the rod should be about 94% of the depth (T) of the water in the vertical plane of observation.

From his extensive experiments at Lowell with such rods 2 inches in diameter and of different length (L) ranging from 87 to 99 per cent of the depth (T), the latter being made to vary from 8.1 to 9.5 feet, and with mean velocities (v_m) ranging from 0.5 to 2.8 feet per second, Francis deduced the following empirical formula for finding (v_m) from the observed velocity (v_1) of the rod:

$$v_m = v_1\left(1.102 - 0.116\sqrt{\frac{T-L}{L}}\right).$$

Commenting on the results given by this formula in comparison with the simultaneous observations of discharge over his standard weir, Mr. Francis states that taking the whole of the experiments together, the average difference is about $\frac{3}{4}$ of 1 per cent, and that the largest difference is an excess of about 3.7 per cent over the weir measurement when the velocity was only 0.5 foot per second. It is also probable that the above formula will not give trustworthy values of (v_m) when the immersed length (L) of the rod is less than 75 per cent of the depth (T); hence it is desirable to make (L) as nearly equal to (T) as the character of the bed of the channel will permit.

Practical Consideration.—In order that the work of gauging a water-course with rods may be prosecuted expeditiously and with fairly accurate results, certain practical considerations should be observed. The rods should be straight cylinders of uniform diameter having the smoothest practicable surface. Their diameter should be as small as is compatible with proper strength and stiffness, and the loading at the bottom should be concentrated so as to bring the center of gravity as low down as possible in the water, at the same time being rigidly attached so as to remain in place even if the rod is inverted. They should also have ample buoyancy, in order to bring them quickly to their normal depth of immersion after accidental submergence, and the projecting portion should be as short as possible consistent with the function of serving as a marker. In their experiments, Francis and Cunningham used tin tubes about 2 inches in diameter, while Grebenau and others used varnished wooden rods, having diameters from 1.2 to 1.5 inches. Cunningham also used such rods, but gave the preference to the tubes.

Miners' Inch Measurements.

(Pelton Water Wheel Co.)

Miners' inch is a term much in use on the Pacific Coast and in the mining regions, and is described as the amount of water flowing through a hole 1 inch square in a 2-inch plank under a head of 6 inches to the top of the orifice.

Fig. 28 shows the form of measuring-box ordinarily used; and the following table gives the discharge in cubic feet per minute of a miners' inch of water, as measured under the various heads and different lengths and heights of apertures used in California.

Length of Opening in Inches.	Openings 2 Inches High.			Openings 4 Inches High.		
	Head to Center, 5 Ins.	Head to Center, 6 Inches.	Head to Center, 7 Inches.	Head to Center, 5 Inches.	Head to Center, 6 Inches.	Head to Center, 7 Inches.
	Cu.Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.	Cu. Ft.
4	1.348	1.473	1.589	1.320	1.450	1.570
6	1.355	1.480	1.596	1.336	1.470	1.595
8	1.359	1.484	1.600	1.344	1.481	1.608
10	1.361	1.485	1.602	1.349	1.487	1.615
12	1.363	1.487	1.604	1.352	1.491	1.620
14	1.364	1.488	1.604	1.354	1.494	1.623
16	1.365	1.489	1.605	1.356	1.496	1.626
18	1.365	1.489	1.606	1.357	1.498	1.628
20	1.365	1.490	1.606	1.359	1.499	1.630
22	1.366	1.490	1.607	1.359	1.500	1.631
24	1.366	1.490	1.607	1.360	1.501	1.632
26	1.366	1.490	1.607	1.361	1.502	1.633
28	1.367	1.491	1.607	1.361	1.503	1.634
30	1.367	1.491	1.608	1.362	1.503	1.635
40	1.367	1.492	1.608	1.363	1.505	1.637
50	1.368	1.493	1.609	1.364	1.507	1.639
60	1.368	1.493	1.609	1.365	1.508	1.640
70	1.368	1.493	1.609	1.365	1.508	1.641
80	1.368	1.493	1.609	1.366	1.509	1.641
90	1.369	1.493	1.610	1.366	1.509	1.641
100	1.369	1.494	1.610	1.366	1.509	1.642

NOTE. — *The apertures from which the above measurements were obtained were through material $1\frac{1}{4}$ inches thick, and the lower edge 2 inches above the bottom of the measuring-box, thus giving full contraction.*

FLOW OF WATER OVER WEIRS.

Weir Dam Measurement.

(Pelton Water Wheel Co.)

Place a board or plank in the stream, as shown in Fig. 29, at some point where a pond will form above. The length of the notch in the dam should be from two to four times its depth for small quantities, and longer for large quantities. The edges of the notch should be beveled toward the intake side as shown. The overfall below the notch should not be less than twice its depth, that is, 12 inches if the notch is 6 inches deep, and so on.

In the pond, about 6 feet above the dam, drive a stake, and then obstruct the water until it rises precisely to the bottom of the notch, and mark the stake at this level. Then complete the dam so as to cause all the water to flow through the notch, and, after time for the water to settle, mark the stake again for this new level. If preferred, the stake can be driven with its top precisely level with the bottom of the notch, and the depth of the water be measured with a rule after the water is flowing free, but the marks are preferable in most cases. The stake can then be withdrawn; and the distance between the marks is the theoretical depth of flow corresponding to the quantities in the table.

Francis's Formulæ for Weirs.

	As given by Francis.	As modified by Smith.
Weirs with both end contractions suppressed	$Q = 3.33lh^{\frac{3}{2}}$	$3.29\left(l + \frac{h}{7}\right)h^{\frac{3}{2}}$
Weirs with one end contraction suppressed	$Q = 3.33(l - .1h)\,h^{\frac{3}{2}}$	$3.29lh^{\frac{3}{2}}$
Weirs with full contraction . .	$Q = 3.33(l - .2h)h^{\frac{3}{2}}$	$3.29\left(l - \frac{h}{10}\right)h^{\frac{3}{2}}$

The greatest variation of the Francis formulæ from the value of c given by Smith amounts to 3½ per cent. The modified Francis formulæ, says Smith, will give results sufficiently exact, when great accuracy is not required, within the limits of h, from .5 feet to 2 feet, l being not less than 3 h.

$Q =$ discharge in cubic feet per second, $l =$ length of weir in feet, $h =$ effective head in feet, measured from the level of the crest to the level of still water above the weir.

If $Q' =$ discharge in cubic feet per *minute*, and l' and h' are taken in inches, the first of the above formulæ reduces to $Q' = 0.4l'h'^{\frac{3}{2}}$. The values are sufficiently accurate for ordinary computations of water-power for weirs without end contraction, that is, for a weir the full width of the channel of approach, and are approximate also for weirs with end contraction when $l =$ at least $10h$, but about 6 per cent in excess of the truth when $l = 4h$.

Weir Table.

Table Showing the Quantity of Water Passing over Weirs in Cubic Feet per Minute.

Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.	Depth of Water on Weir in In.	Cubic Ft. per Minute passed for each Ft. of Length of Weir.
1	4.85	4¾	50.20	8½	120.18	12½	214.32
1⅛	5.78	4⅞	52.18	8⅝	122.82	12¾	220.76
1¼	6.68	5	54.22	8¾	125.52	13	227.30
1⅜	7.80	5⅛	56.25	8⅞	128.14	13¼	233.92
1½	8.90	5¼	58.33	9	130.93	13½	240.54
1⅝	10.00	5⅜	60.42	9⅛	133.65	13¾	247.22
1¾	11.23	5½	62.55	9¼	136.43	14	254.03
1⅞	12.45	5⅝	64.68	9⅜	139.18	14¼	260.83
2	13.72	5¾	66.86	9½	141.99	14½	267.77
2⅛	15.02	5⅞	68.98	9⅝	144.80	14¾	274.70
2¼	16.36	6	71.27	9¾	147.64	15	281.72
2⅜	17.75	6⅛	73.45	9⅞	150.47	15¼	288.82
2½	19.17	6¼	75.77	10	153.35	15½	295.93
2⅝	20.63	6⅜	78.04	10⅛	156.20	15¾	303.10
2¾	22.11	6½	80.36	10¼	159.14	16	310.36
2⅞	23.63	6⅝	82.63	10⅜	162.07	16¼	317.69
3	25.20	6¾	85.04	10½	164.99	16½	325.03
3⅛	26.78	6⅞	87.43	10⅝	167.89	16¾	332.42
3¼	28.43	7	89.82	10¾	169.92	17	339.91
3⅜	30.06	7⅛	92.16	10⅞	173.90	17¼	347.45
3½	31.75	7¼	94.67	11	176.92	17½	355.02
3⅝	33.45	7⅜	97.11	11⅛	179.94	17¾	362.77
3¾	35.22	7½	99.50	11¼	182.99	18	370.34
3⅞	36.98	7⅝	102.10	11⅜	186.03	18¼	378.12
4	38.80	7¾	104.63	11½	189.13	18½	385.87
4⅛	40.63	7⅞	107.13	11⅝	192.20	18¾	393.66
4¼	42.49	8	109.74	11¾	195.32	19	401.63
4⅜	44.39	8⅛	112.31	11⅞	198.47	19¼	409.58
4½	46.29	8¼	114.91	12	201.59	19½	417.48
4⅝	48.22	8⅜	117.51	12¼	207.94	19¾	425.68

TABLES FOR CALCULATING THE HORSE-POWER OF WATER.

(Pelton Wheel Co.)

Miners' Inch Table.

The following table gives the horse-power of one miners' inch of water under heads from one up to eleven hundred feet. This inch equals $1\frac{1}{2}$ cubic feet per minute.

Cubic Feet Table.

The following table gives the horse-power of one cubic foot of water per minute under heads from one up to eleven hundred feet.

Heads in Feet.	Horse-Power.	Heads in Feet.	Horse-Power.	Heads in Feet.	Horse-Power.	Heads in Feet.	Horse-Power.
1	.0024147	320	.772704	1	.0016098	320	.515136
20	.0482294	330	.796851	20	.032196	330	.531234
30	.072441	340	.820998	30	.048294	340	.547332
40	.096588	350	.845145	40	.064392	350	.563430
50	.120735	360	.869292	50	.080490	360	.579528
60	.144882	370	.893439	60	.096588	370	.595626
70	.169029	380	.917586	70	.112686	380	.611724
80	.193176	390	.941733	80	.128784	390	.627822
90	.217323	400	.965880	90	.144892	400	.643920
100	.241470	410	.990027	100	.160980	410	.660018
110	.265617	420	1.014174	110	.177078	420	.676116
120	.289764	430	1.038321	120	.193176	430	.692214
130	.313911	440	1.062468	130	.209274	440	.708312
140	.338058	450	1.086615	140	.225372	450	.724410
150	.362205	460	1.110762	150	.241470	460	.740508
160	.386352	470	1.134909	160	.257568	470	.756606
170	.410499	480	1.159056	170	.273666	480	.772704
180	.434646	490	1.183206	180	.289764	490	.788802
190	.458793	500	1.207350	190	.305862	500	.804900
200	.482940	520	1.255644	200	.321960	520	.837096
210	.507087	540	1.303938	210	.338058	540	.869292
220	.531234	560	1.352232	220	.354156	560	.901488
230	.555381	580	1.400526	230	.370254	580	.933684
240	.579528	600	1.448820	240	.386352	600	.965880
250	.603675	650	1.569555	250	.402450	650	1.046370
260	.627822	700	1.690290	260	.418548	700	1.126860
270	.651969	750	1.811025	270	.434646	750	1.207350
280	.676116	800	1.931760	280	.450744	800	1.287840
290	.700263	900	2.173230	290	.466842	900	1.448820
300	.724410	1000	2.414700	300	.482940	1000	1.609800
310	.748557	1100	2.656170	310	.499038	1100	1.770780

When the Exact Head is found in Above Table.

EXAMPLE. — Have 100 foot head and 50 inches of water. How many horse-power?

By reference to above table the horse-power of 1 inch under 100 feet head is .241470. The amount multiplied by the number of inches, 50, will give 12.07 horse-power.

When Exact Head is not Found in Table.

Take the horse-power of 1 inch under 1 foot head, and multiply by the number of inches, and then by number of feet head. The product will be the required horse-power.

The above formula will answer for the cubic-feet table, by substituting the equivalents therein for those of miners' inches.

NOTE. — *The above tables are based upon an efficiency of 85 per cent.*

WATER-WHEELS.

Undershot Wheels, in which the water passes under acting by impulse, when constructed in the old-fashioned way with flat boards as floats, have a maximum theoretical efficiency of 50 per cent; but with curved floats, as in Poncelet's wheel, which are arranged so that the water enters without shock and drops from the floats into the tail-race without horizontal velocity, the maximum efficiency is as great as for overshot wheels, and the available efficiency is found to be about 60 per cent. The velocity of the periphery should be about .5 of the theoretical velocity of the water due to the head.

Breast and Overshot Wheels.

The best peripheral velocity is about 6 feet per second, and for the water supplied to it about 12 feet per second, which is the velocity due to a fall of about 2¼ feet; therefore, the point at which the water strikes the wheel should be 2¼ feet below the top-water level. The chief cause of loss in overshot wheels is the velocity which the water possesses at the moment it falls from the float or bucket; overshot wheels are good for falls of 13 feet to 20 feet; below that breast wheels are preferable. The capacity of the buckets should be three times the volume of water held in each. The distance apart of the buckets may be 12 inches in high-breast and overshot wheels, or 18 inches in low-breast wheels, while the opening of buckets may be 6 to 8 inches in high-breast, and 9 inches to 12 inches in low-breast wheels.

TURBINES.

These may be divided into two main classes, viz., pressure and impulse turbines. The former may be again divided into the following: parallel-flow, outward-flow, and inward-flow turbines, according to the direction in which the water flows through the turbine in relation to its axis.

Parallel-flow turbines, sometimes called downward-flow, are best suited for low falls, not exceeding say 30 feet. Fontaine's turbine is of this class, the wheel being placed at the bottom of the water-pipe or flume, just above the level of the tail-race. The water passes through guide blades and strikes the curved floats of the wheel. Jonval's turbine is of similar type, but is arranged to work partly by suction, and may be placed above the level of the tail-race without loss of power, which is often more convenient for working. The efficiency is from 70 to 72 per cent with well-designed wheels of this type.

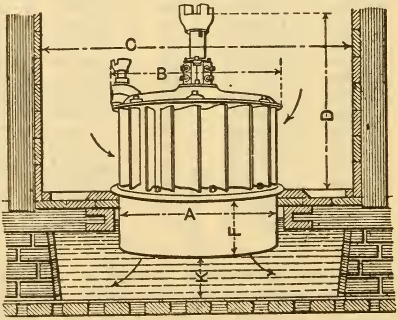


FIG. 30. Victor Wheel set in ordinary Flume.

Outward-flow Turbines have a somewhat higher efficiency than the parallel-flow — as much as 88 per cent has been realized by Boyden's turbine; Fourneyron's has given a maximum of 79 per cent.

Inward-flow Turbines have been designed by Swain and others. Tests made on a Swain turbine by J. B. Francis gave a maximum efficiency of 84 per cent with full supply, and with the gate a quarter open 61 per cent, the circumferential velocity of the wheel ranging from 80 to 60 per cent of the theoretical velocity due to the head of water. In Swain's turbine the edges of the floats are vertical and opposite the guide blades, the edges towards the bottom of the floats being bent into a quadrant form. The Victor turbine is claimed to give 88 per cent under favorable conditions. It receives the water upon the outside, and discharges it downward and outward, the lines of discharge occupying the entire diameter of the lower portion of the wheel, excepting only the space filled by the lower end of the shaft.

Impulse Turbines are suitable for very high falls. The Girard and Pelton are both of this type. It is advised that pressure turbines be used on heads of 80 feet or 100 feet, but above this an impulse turbine is best. A Girard turbine is working under a fall of 650 feet.

Installing Turbines.

Particular attention must be paid to the designing and construction of water-courses. The forebay leading to the flume should be of such size that the velocity of the water never exceeds 1 1/2 feet per second, and should be free from abrupt turns or other defects likely to cause eddies. The tail-race should have similar capacity and sufficient depth below the surface of the stream to allow at least 2 feet of dead water standing when the wheels are not in motion, and with large wheels, 3 feet to 4 feet; after extending several feet beyond the flume, this may be gradually sloped up to the level of the stream. It is not uncommon to see 2 feet or 3 feet of head lost in defective races.

When setting turbines some distance above the tail-race, the mouth of the draft-tube must be 2 inches to 4 inches below the lowest level of the standing tail-water. Theoretically draft-tubes may be 30 feet long; but 20 feet is as long as is desirable on account of the difficulty of keeping air-tight; they should be made as short as possible by placing the turbine at the bottom of the fall.

Particulars of the setting recommended for Victor turbines are given below, as an example.

Table of Dimensions of Victor Turbine.

	A.	B.	C.	D.	E.	F.	K.	
Size of Wheel.	Diameter of Cylinder passing through Floor of Flume.	Diameter of Entire Wheel-Case.	Internal Diameter of Flume.	Length of Shaft from Flange Resting on Floor of Flume to Center of Coupling.	Diameter of Bore of Upper Half of Coupling.	Length of Cylinder passing through Floor of Flume.	Depth of Pit from End of Cylinder to Bottom of Wheel-Pit.	Approximate Weight of Wheel Complete.
In.	In.	In.	Ft.	In.	In.	In.		Lbs.
6	10	13 1/2	2	12	1	5 1/2	From 2 to 8 feet deep according to size of wheel and quantity of water discharged. See special instructions on construction of flumes and tail-races.	165
8	13 1/2	17 1/8	2 1/2	19 11/16	1 7/16	6 7/8		260
10	16	20 1/4	3	22 3/4	1 11/16	7 1/2		350
12	18 3/16	23 3/16	3 1/2	28 1/2	1 15/16	9 5/8		500
15	23 3/16	28 3/16	4	33 3/4	2 7/16	11		830
17 1/2	26 1/8	31 1/8	5	35 1/2	2 11/16	12 3/4		1125
20	30 1/8	35 1/2	6	37 1/2	3 3/16	13 1/4		1475
22 1/2	33 1/8	38 1/2	6 1/2	42	3 7/16	14 1/2		1900
25	35 1/8	40 5/8	6 1/2	43 5/8	3 7/16	15 1/4		2335
27 1/2	38 1/8	43 3/4	7 1/2	48 15/16	3 15/16	16 1/4		3225
30	40 1/8	46	8	50 1/8	4 3/8	17 1/4		3540
32 1/2	43 1/8	49 1/2	9	55 5/8	4 5/8	19 1/2		4500
35	46 1/8	53	9	59	4 7/8	20		5450
40	52 1/4	60 1/4	10	64 3/4	5 3/8	22		7500
44	56 1/4	65 1/4	11	67 1/4	5 7/8	24		9380
48	60 1/4	70 1/4	12	74 5/8	6 3/8	26		11700
55	68	80	14	85 1/4	7 1/2	28		19000
60	80 1/4	92	16	96 1/2	7 7/8	32		

DIMENSIONS OF TURBINES.

Tables of sizes of turbine wheels vary so much under different makers, and are so extensive, as not to permit their insertion here, but through the kindness of Mr. Axel Ekström of the General Electric Company I am permitted to print the following sheets of curves for the McCormick type turbine and the Pelton impulse wheel. From them may be made determinations of dimensions in much shorter time than is necessary by use of tables.

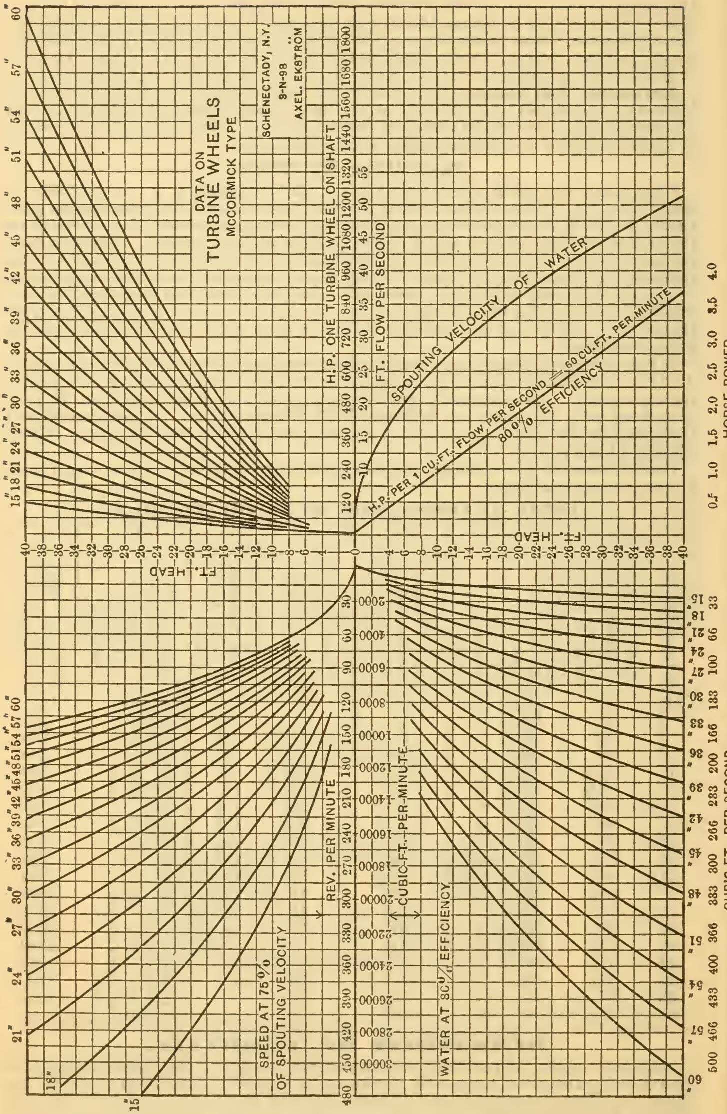

DATA ON
TURBINE WHEELS
McCORMICK TYPE
SCHENECTADY, N.Y.
9-N-98
AXEL. EKSTRÖM
H.P. ONE TURBINE WHEEL ON SHAFT
FT. FLOW PER SECOND
SPOUTING VELOCITY OF WATER
H.P. PER 1 CU.FT. FLOW PER SECOND = 60 CU.FT. PER MINUTE
80% EFFICIENCY
HORSE POWER
FT. HEAD
REV. PER MINUTE
CUBIC FT. PER MINUTE
SPEED AT 75% OF SPOUTING VELOCITY
WATER AT 80% EFFICIENCY
CUBIC FT. PER SECOND

FIG. 31.

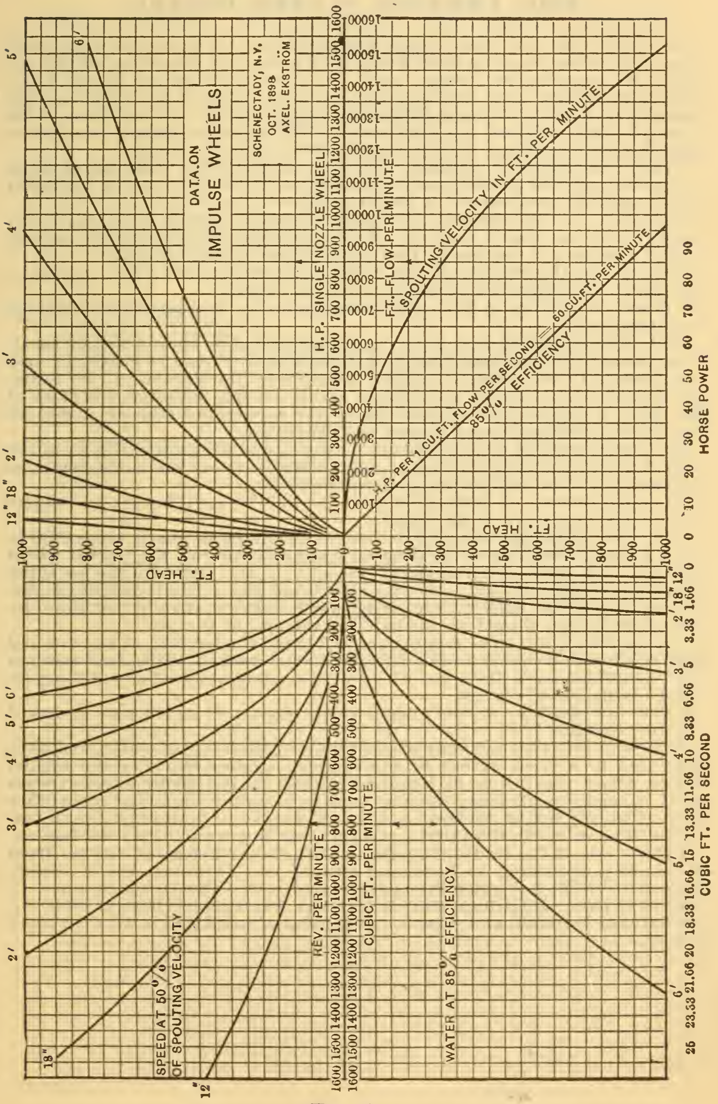

DATA ON
IMPULSE WHEELS
SCHENECTADY, N.Y.
OCT. 1898
AXEL. EKSTRÖM
H.P. SINGLE NOZZLE WHEEL
FT. FLOW PER MINUTE
SPOUTING VELOCITY IN FT. PER MINUTE
H.P. PER 1 CU.FT. FLOW PER SECOND = 60 CU.FT. PER MINUTE
85% EFFICIENCY
HORSE POWER
FT. HEAD
REV. PER MINUTE
CUBIC FT. PER MINUTE
WATER AT 85% EFFICIENCY
SPEED AT 50% OF SPOUTING VELOCITY
CUBIC FT. PER SECOND

FIG. 32.

THE IMPULSE WATER-WHEEL.

Mr. Ross E. Browne states that "The functions of a water-wheel, operated by a jet of water escaping from a nozzle, is to convert the energy of the jet, due to its velocity, into useful work. In order to utilize this energy fully, the wheel bucket, after catching the jet, must bring it to rest before discharging it, without inducing turbulence or agitation of the particles. This cannot be fully effected, and unavoidable difficulties necessitate the loss of a portion of the energy. The principal losses occur as follows:

"First: In sharp or angular diversion of the jet in entering, or in its course through the bucket, causing impact, or the conversion of a portion of the energy into heat instead of useful work.

"Second: In the so-called frictional resistance offered to the motion of the water by the wetted surfaces of the buckets, causing also the conversion of a portion of the energy into heat instead of useful work.

"Third: In the velocity of the water as it leaves the bucket, representing energy which has not been converted into work.

"Hence, in seeking a high efficiency, there are presented the following considerations:

"1st. The bucket surface at the entrance should be approximately parallel to the relative course of the jet, and the bucket should be curved in such a manner as to avoid sharp angular deflection of the stream. If, for example, a jet strikes a surface at an angle and is sharply deflected, a portion of the water is backed, the smoothness of the stream is disturbed, and there results considerable loss by impact and otherwise.

2d. The number of buckets should be small, and the path of the jet in the bucket short; in other words, the total wetted surface should be small, as the loss by friction will be proportional to this.

"A small number of buckets is made possible by applying the jet tangentially to the periphery of the wheel.

"3d. The discharge end of the bucket should be as nearly tangential to the wheel-periphery, as compatible with the clearance of the bucket which follows; and great differences of velocity in the parts of the escaping water should be avoided. In order to bring the water to rest at the discharge end of the bucket, it is easily shown mathematically that the velocity of the bucket should be one-half the velocity of the jet.

"An ordinary curved or cup bucket will cause the heaping of more or less dead or turbulent water in the bottom of the bucket. This dead water is subsequently thrown from the wheel with considerable velocity, and represents a large loss of energy.

"The introduction of the wedge in the bucket is an efficient means of avoiding this loss."

Wheels of this type are very efficient under high heads of water, and have been used to a great extent in the extreme western parts of the United States, where the fall is in hundreds of feet. It is difficult to say at what point of head the efficiency becomes such as to induce the use of some other form of wheel; but at 200 feet head the efficiencies of both impulse and turbine will be so much alike that selection must be governed by other factors.

Tests of one of the leading impulse wheels show efficiencies varying from 80 % to 86 % according to head and size of jet. However, many factors besides the efficiency enter into selection of water-wheels, which must be subject to local conditions, and as in most water-power plants, each is a special case by itself, and selection of apparatus best fitted in all ways must govern.

SHAFTING, PULLEYS, BELTING, ROPE-DRIVING.

SHAFTING.

Thurston gives the following formulæ for calculating power and size of shafting.

$H.P.$ = horse-power transmitted.

d = diameter of shaft in inches.

r = revolutions per minute.

For head shafts well supported against springing.
- For iron, $H.P. = \frac{d^3r}{125}$; $d = \sqrt[3]{\frac{125\ H.P.}{r}}$
- For cold-r'lled iron $H.P. = \frac{d^3r}{75}$; $d = \sqrt[3]{\frac{75\ H.P.}{r}}$

For line shafting hangers 8 feet apart.
- For iron, $H.P. = \frac{d^3r}{90}$; $d = \sqrt[3]{\frac{90\ H.P.}{r}}$
- For cold-r'lld iron, $H.P. = \frac{d^3r}{55}$; $d = \sqrt[3]{\frac{55\ H.P.}{r}}$

For transmission simply, no pulleys.
- For iron, $H.P. = \frac{d^3r}{62.5}$; $d = \sqrt[3]{\frac{62.5\ H.P.}{r}}$
- For cold-r'lld iron, $H.P. = \frac{d^3r}{35}$; $d = \sqrt[3]{\frac{35\ H.P.}{r}}$

Jones and Laughlin's use the same formulæ, with the following exceptions :

For line shafts, cold-rolled iron, $H.P. = \frac{d^3r}{50}$; $d = \sqrt[3]{\frac{50\ H.P.}{r}}$.

For transmission and for short-counters,

Turned iron . . . . $H.P. = \frac{d^3r}{50}$; $d = \sqrt[3]{\frac{50\ H.P.}{r}}$.

Cold-rolled iron . . . . $H.P. = \frac{d^3r}{30}$; $d = \sqrt[3]{\frac{30\ H.P.}{r}}$.

Pulleys should be placed as near to bearings as practicable, but care should be taken that oil does not drip from the box into the pulley.

The diameter of a shaft safe to carry the main pulley at the center of a bay may be found by multiplying the fourth power of the diameter obtained by the formulæ above given, by the length of the bay, and dividing the product by the distance between centers of bearings. The fourth root of the quotient will be the required diameter.

The following table is based upon the above rule, and is substantially correct :

Diameter of Shaft given by the Formulæ for Head Shafts.	Diameter of Shaft necessary to carry the Load at the Center of a Bay, which is from Center to Center of Bearings.							
	2½ ft.	3 ft.	3½ ft.	4 ft.	5 ft.	6 ft.	8 ft.	10 ft.
in.	in.	in.	in.	in.	in.	in.	in.	in.
2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
2½	2½	2⅝	2¾	2⅞	3	3⅛	3⅜	3⅝
3	3	3⅛	3¼	3⅜	3½	3¾	4	4¼
3½	. . .	3½	3⅝	3¾	4	4¼	4½	4¾
4	. . .	4	4⅛	4¼	4½	4¾	5⅛	5⅜
4½	. . .	. . .	4½	4⅝	4⅞	5⅛	5½	5⅞
5	. . .	. . .	5	5⅛	5⅜	5⅝	6	6½
5½	. . .	. . .	. . .	5½	5¾	6	6½	6⅞
6	. . .	. . .	. . .	6	6⅜	6⅝	7⅛	7½

Should the load be placed near one end of the bay, *multiply* the fourth power of the diameter of shaft necessary to safely carry the load at the center of the bay (see above table) by the product of the two ends of the shaft, and divide this product by the product of the two ends of the shaft where the pulley is placed in the center. The fourth root of this quotient will be the required diameter.

A shaft carrying both receiving and driving pulleys should be figured as a head-shaft.

Deflection of Shafting.

(Pencoyd Iron Works.)

As the deflection of steel and iron is practically alike under similar conditions of dimensions and loads, and as shafting is usually determined by its transverse stiffness rather than its ultimate strength, nearly the same dimensions should be used for steel as for iron.

For continuous line-shafting it is considered good practice to limit the deflection to a maximum of $\frac{1}{100}$ of an inch per foot of length. The weight of bare shafting in pounds $= 2.6\, d^2L = W$, or when as fully loaded with pulleys as is customary in practice, and allowing 40 lbs. per inch of width for the vertical pull of the belts, experience shows the load in pounds to be about $13\, d^2L = W$. Taking the modulus of transverse elasticity at 26,000,000 lbs., we derive from authoritative formulæ the following:

$$L = \sqrt[3]{873\, d^2},\ d = \sqrt{\frac{L^3}{873}},\ \text{for bare shafting;}$$

$$L = \sqrt[3]{175\, d^2},\ d = \sqrt{\frac{L^3}{175}},\ \text{for shafting carrying pulleys, etc.;}$$

L being the maximum distance in feet between bearings for continuous shafting subjected to bending stress alone, d = diam. in inches.

The torsional stress is inversely proportional to the velocity of rotation, while the bending stress will not be reduced in the same ratio. It is therefore impossible to write a formula covering the whole problem and sufficiently simple for practical application, but the following rules are correct within the range of velocities usual in practice.

For continuous shafting so proportioned as to deflect not more than $\frac{1}{100}$ of an inch per foot of length, allowance being made for the weakening effect of key-seats,

$$d = \sqrt[3]{\frac{50\, H.P.}{r}},\ L = \sqrt[3]{720 d^2}\ \text{for bare shafts;}$$

$$d = \sqrt[3]{\frac{70\ H.P.}{r}},\ L = \sqrt[3]{140d^2},\ \text{for shafts carrying pulleys, etc.}$$

$d =$ diam. in inches, $L =$ length in feet, $r =$ revols. per minute.

The following table (by J. B. Francis) gives the greatest admissible distances between the bearings of continuous shafts subject to no transverse strain, except from their own weight.

Diam. of Shaft, in inches	Distance between Bearings in ft. Wrought-iron Shafts.	Distance between Bearings in ft. Steel Shafts.	Diam. of Shaft, in inches.	Distance between Bearings in ft. Wrought-iron Shafts.	Distance between Bearings in ft. Steel Shafts
2	15.46	15.89	6	22.30	22.92
3	17.70	18.19	7	23.48	24.13
4	19.48	20.02	8	24.55	25.23
5	20.99	21.57	9	25.53	26.24

The writer prefers to apply a formula in all cases rather than use tables, as shafting is nearly always one-sixteenth inch less in diameter than the sizes quoted. The following tables are made up from the formulæ first given in this chapter.

Horse-Power Transmitted by Turned Iron Shafting.

As Prime Mover or Head Shaft well Supported by Bearings.

Diam.	Revolutions per Minute. 60	80	100	125	150	175	200	225	250	275	300
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¾	2.6	3.4	4.3	5.4	6.4	7.5	8.6	9.7	10.7	11.8	12.9
2	3.8	5.1	6.4	8	9.6	11.2	12.8	14.4	16	17.6	19.2
2¼	5.4	7.3	8.1	10	12	14	16	18	20	22	24
2½	7.5	10	12.5	15	18	22	25	28	31	34	37
2¾	10	13	16	20	24	28	32	36	40	44	48
3	13	17	20	25	30	35	40	45	50	55	60
3¼	16	22	27	34	40	47	54	61	67	74	81
3½	20	27	34	42	51	59	68	76	85	93	102
3¾	25	33	42	52	63	73	84	94	105	115	126
4	30	41	51	64	76	89	102	115	127	140	153
4½	43	58	72	90	108	126	144	162	180	198	216
5	60	80	100	125	150	175	200	225	250	275	300
5½	80	106	133	166	199	233	266	299	333	366	400

Approximate Centers of Bearings for Wrought Iron Line Shafts Carrying a Fair Proportion of Pulleys.

Shaft, Diameter Inches . .	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½
c. to c. Bearings — Feet . .	7	7½	8	8½	9	9½	10	11	12	13

Shaft, Diameter Inches . .	5	5½	6	6½	7	7½	8	9	10
c. to c. Bearings — Feet . .	13½	14	15	15½	16	17	18	19	20

LINE-SHAFTING, BEARINGS 8 FT. APART.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¾	6	7.4	8.9	10.4	11.9	13.4	14.9	16.4	17.9	19.4	20.9
1⅞	7.3	9.1	10.9	12.7	14.5	16.3	18.2	20	21.8	23.6	25.4
2	8.9	11.1	13.3	15.5	17.7	20	22.2	24.4	26.6	28.8	31
2⅛	10.6	13.2	15.9	18.5	21.2	23.8	26.5	29.1	31.8	34.4	37
2¼	12.6	15.8	19	22	25	28	31	35	38	41	44
2⅜	15	18	22	26	29	33	37	41	44	48	52
2½	17	21	26	30	34	39	43	47	52	56	60
2¾	23	29	34	40	46	52	58	64	69	75	81
3	30	37	45	52	60	67	75	82	90	97	105
3¼	38	47	57	66	76	85	95	104	114	123	133
3½	47	59	71	83	95	107	119	131	143	155	167
3¾	58	73	88	102	117	132	146	162	176	190	205
4	71	89	107	125	142	160	178	196	213	231	249

POWER TRANSMISSION ONLY.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	6.7	8.4	10.1	11.8	13.5	15.7	17.9	20.3	22.5	24.8	27.0
1⅝	8.6	10.7	12.8	15	17.1	20	22.8	25.8	28.6	31.5	34.3
1¾	10.7	13.4	16	18.7	21.5	25	28	32	36	39	43
1⅞	13.2	16.5	19.7	23	26.4	31	35	39	44	48	52
2	16	20	24	28	32	37	42	48	53	58	64
2⅛	19	24	29	33	38	44	51	57	63	70	76
2¼	22	28	34	39	45	52	60	68	75	83	90
2⅜	27	33	40	47	53	62	70	79	88	96	105
2½	31	39	47	54	62	73	83	93	104	114	125
2¾	41	52	62	73	83	97	111	125	139	153	167
3	54	67	81	94	108	126	144	162	180	198	216
3¼	68	86	103	120	137	160	182	205	228	250	273
3½	85	107	128	150	171	200	228	257	285	313	342

Horse-power Transmitted by Cold-rolled Iron Shafting.

AS PRIME MOVER OR HEAD SHAFT WELL SUPPORTED BY BEARINGS.

Diam.	Revolutions per Minute.										
	60	80	100	125	150	175	200	225	250	275	300
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	2.7	3.6	4.5	5.6	6.7	7.9	9.0	10	11	12	13
1¾	4.3	5.6	7.1	8.9	10.6	12.4	14.2	16	18	19	21
2	6.4	8.5	10.7	13	16	19	21	24	26	29	32
2¼	9	12	15	19	23	26	30	34	38	42	46
2½	12	17	21	26	31	36	41	47	52	57	62
2¾	16	22	27	35	41	48	55	62	70	76	82
3	21	29	36	45	54	63	72	81	90	98	108
3¼	27	36	45	57	68	80	91	103	114	126	136
3½	34	45	57	71	86	100	114	129	142	157	172
3¾	42	56	70	87	105	123	140	158	174	193	210
4	51	69	85	106	128	149	170	192	212	244	256
4½	73	97	121	151	182	212	243	273	302	333	364

LINE-SHAFTING, BEARINGS 8 FT. APART.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	225	250	275	300	325	350
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1½	6.7	8.4	10.1	11.8	13.5	15.2	16.8	18.5	20.2	21.9	23.6
1⅝	8.6	10.7	12.8	15	17.1	19.3	21.5	23.6	25.7	28.9	31
1¾	10.7	13.4	16	18.7	21.5	24.2	26.8	29.5	32.1	34.8	39
1⅞	13.2	16.5	19.7	23	26.4	29.6	32.9	36.2	39.5	42.8	46
2	16	20	24	28	32	36	40	44	48	52	56
2⅛	19	24	29	33	38	43	48	52	57	62	67
2¼	22	28	34	39	45	50	56	61	68	74	80
2⅜	27	33	40	47	53	60	67	73	80	86	94
2½	31	39	47	54	62	69	78	86	93	101	109
2¾	41	52	62	73	83	93	104	114	125	135	145
3	54	67	81	94	108	121	134	148	162	175	189
3¼	68	86	103	120	137	154	172	188	205	222	240
3½	85	107	128	150	171	192	214	235	257	278	300

POWER TRANSMISSION AND SHORT COUNTERS.

Diam.	Revolutions per Minute.										
	100	125	150	175	200	233	267	300	333	367	400
Ins.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.	H.P.
1¼	6.5	8.1	9.7	11.3	13	15.2	17.4	19.5	21.7	23.9	26
1⅜	8.5	10.7	12.8	15	17	19.8	22.7	25.5	28.4	31	34
1½	11.2	14	16.8	19.6	22.5	26	30	33	37	41	45
1⅝	14.2	17.7	21.2	24.8	28.4	33	38	42	47	52	57
1¾	18	22	27	31	35	41	47	53	59	65	71
1⅞	22	27	33	38	44	51	58	65	72	79	87
2	26	33	40	46	53	62	71	80	88	97	106
2⅛	32	40	47	55	63	73	84	95	105	116	127
2¼	38	47	57	66	76	89	101	114	127	139	152
2⅜	44	55	66	77	88	103	118	133	148	163	178
2½	52	65	78	91	104	121	138	155	172	190	207
2¾	69	84	99	113	138	161	184	207	231	254	277
3	90	112	135	157	180	210	240	270	300	330	360

Hollow Shafts.

Let d be the diameter of a solid shaft, and $d_1 d_2$ the external and internal diameters of a hollow shaft of the same material. Then the shafts will be of equal torsional strength when $d^3 = \frac{d_1^4 - d_2^4}{d_1}$. A 10-inch hollow shaft with internal diameter of 4 inches will weigh 16 % less than a solid 10-inch shaft, but its strength will be only 2.56 % less. If the hole were increased to 5 inches diameter the weight would be 25 % less than that of the solid shaft, and the strength 4.25 % less.

Table for Laying Out Shafting.

The table on the following page is used by Wm. Sellers & Co. for the laying out of shafting.

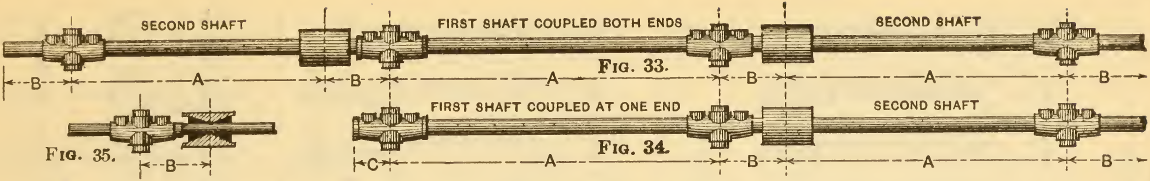


Table for Laying Out Shafting.

Length of Collared End for Fast Coll. ins.	Nominal Size of 2d Shaft. / Nominal Size of 1st Shaft, ins.	1½″	1¾″	2″	2¼″	2½″	2¾″	3″	3¼″	3½″	4″	4½″	5″	5½″	6″	6½″	7″	7½″	8″	Length of Bearing or Box, ins.	Double Cone-Vise Coupl'g. Length, Inches.	Double Cone-Vise Coupl'g. Diameter Inches.
		Distance from Center of Bearing to End of Shaft for Coupling. See *B*, Figs. 18, 19, and 20.																				
3½	1½	8½																		6	5½	3¾
4	1¾	9	9½																	7	6½	4⅝
4½	2	9½	10½	11																8	7⅝	5⅜
5	2¼		11	11½	12															9	8¼	5⅞
5⅝	2½		11½	12	12½	13														10	9½	6 9/16
6¼	2¾		12	12½	13	13½	14													11	10	7
6¾	3			13	13½	14	14½	15												12	11	7¾
7¼	3¼			13½	14	14½	15	15½	15½											13	12	8¼
7⅞	3½			14	14½	15	15½	16	16	16½										14	13	9 1/16
8 15/16	4			15	15½	16	16½	17	17	17½	18									16	14¼	10
10	4½				16½	17	17½	18	18	18½	19½	20								18	16	11⅝
11⅛	5					18½	18½	19	19½	20	20½	21½	22							20	18	12 9/16
12 3/16	5½						20	20½	21	21	22	22½	23½	24						22	19	13¼
13¼	6						21½	21½	22	22½	23	24	24½	25	26					24	21	14¼
14⅜	6½							23	23½	24	24½	25	26	26½	27½	28½				26	25	17⅜
15½	7								25	25	26	26½	27½	28	29	30	30½			28	25	17⅜
16½	7½									26½	27	28	28½	29½	30	31	31½	32		30	28⅜	19 5/16
17¾	8										28½	29½	30	31	31½	32½	33	34	32½	32	28⅜	19 5/16

USE OF TABLE.—Look for size of first shaft in left-hand column, under the head of size of first shaft, and in the top line of table marked size of second shaft, find the size of the shaft to be coupled to it. The intersection gives the length *B*; this added to the length *A*, or distance from center to center of bearing, and in cases similar to Fig. 34 to the length *C*, gives the length of the first shaft, thus: as in Fig. 33, $B + A + B =$ length; Fig. 34, $C + A + B =$ length.

Make bearings at equal distances from each other when practicable; always put 2 bearings on first, which is collared shaft. See Figs. 33 & 34.

In coupling shafts of different sizes either reduce the end of the large shaft in diameter and use a small coupling, or use a coupling to suit the larger shaft, with 1 cone bored for smaller nominal shaft.

PULLEYS.

Unwin says the number of arms is arbitrary, and gives the following values:

a = Number of arms = for a single set $= 3 + \frac{b\,d}{150}$.
d = diameter pulley.
t = thickness of edge of rim of pulley = .75 inches + $.005d$.
T = thickness of middle of rim of pulley $= 2t + c$.
b = breadth of rim of pulley $= \frac{9}{8}(B + 0.4)$.
B = breadth of belt.

$$h = \text{breadth of arm at hub} \begin{cases} \text{for single belt} = .6337\sqrt[3]{\dfrac{b\,d}{a}} \\ \text{for double belt} = .798\sqrt[3]{\dfrac{b\,d}{a}} \end{cases}$$

h_1 = breadth of arm at rim $= \frac{2}{3}h$.
e = thickness of arm at hub $= 0.4\,h$.
e_1 = thickness of arm at rim $= 0.4\,h_1$.
c = crowning $= \frac{1}{24}\,b$.
L = length of hub = about $\frac{2}{3}\,b$.

Reuleaux says pulleys of more than one set of arms may be considered as separate pulleys, except proportions of arms may be 0.8 to 0.7 that of single-arm pulleys.

To Find Size of Pulley.

D = diameter of driver, or No. teeth in gear.
d = diameter of driven, or No. teeth in pinion.
Rev = revolutions per minute of driver.
rev = revolutions per minute of driven.

$$D = \frac{d \times rev}{Rev}. \qquad Rev = \frac{d \times rev}{D}.$$

$$d = \frac{D \times Rev}{rev}. \qquad rev = \frac{D \times Rev}{d}.$$

BELTING.

The coefficient of friction of belts on pulleys varies greatly, and it is therefore customary to use some arbitrary formula that has proved safe in practice.

d = diameter pulley in inches.
πd = circumference.
v = velocity of belt (or pulley face) in feet per minute.
a = angle of arc of contact, commonly assumed as 180°.
l = length of arc of contact in feet $= \frac{\pi\,d\,a}{4320}$.
F = tractive force per square inch cross-section of belt.
w = width of belt in inches.
t = thickness of belt in inches.
S = tractive force per inch of width $= \frac{F}{t}$.
rpm = revolutions per minute.

$$v = \frac{\pi\,d}{12} \times rpm.$$

$$H.\,P. = \frac{v\,w\,S}{33000} = \frac{d\,w\,S \times rpm}{126050}.$$

A rule in common use for approximate determination of the H.P. of belts is, that a single belt 1 inch wide, traveling 1000 feet per minute, will transmit 1 horse-power. This corresponds to a strain on the belt of 33 lbs. per inch of width.

Authorities say single bells can be safely worked at 45 lbs. strain per inch of width, and on this basis

$$H.P. = \frac{v\,w}{733} = \frac{d\,w \times rpm}{2800}.$$

Double belts are said to be able to transmit power in the ratio of 10 to 7 for single belts.

$$\text{H. P. of double belts} = \frac{v\,w}{513} = \frac{d\,w \times rpm}{1960}.$$

If the double belt is twice the thickness of the single belt, then it is fair to assume that it will transmit twice the power, and

$$\text{H. P. of double belt} = \frac{v\,w}{366} = \frac{d\,w \times rpm}{1400}.$$

A. F. Nagle (Trans. A. S. M. E., vol. ii. 1881) gives the following formula

$$\text{H. P.} = CVtw\left(\frac{F - 0.012\,V^2}{550}\right).$$

Where $C = 1 - 10^{-.00758fa}$.
f = coefficient of friction.

Horse-Power of a Belt one Inch Wide, Arc of Contact 180°.

Comparison of Different Formulæ.

Velocity in Feet per Second.	Velocity in Feet per Minute.	Square Ft. of Belt per Minute.	Form. 1 H.P. = $\frac{wv}{550}$.	Form. 2 H.P. = $\frac{wv}{1100}$.	Form. 3 H.P. = $\frac{wv}{1000}$.	Form. 4 H.P. = $\frac{wv}{733}$.	Form. 5 Double. Belt H.P. = $\frac{wv}{513}$.	Nagle's Form. $\frac{7}{32}''$ single Belt. Laced.	Nagle's Form. $\frac{7}{32}''$ single Belt. Riveted.
10	600	50	1.09	.55	.60	.82	1.17	.73	1.14
20	1200	100	2.18	1.09	1.20	1.64	2.34	1.54	2.24
30	1800	150	3.27	1.64	1.80	2.46	3.51	2.25	3.31
40	2400	200	4.36	2.18	2.40	3.27	4.68	2.90	4.33
50	3000	250	5.45	2.73	3.00	4.09	5.85	3.48	5.26
60	3600	300	6.55	3.27	3.60	4.91	7.02	3.95	6.09
70	4200	350	7.63	3.82	4.20	5.73	8.19	4.29	6.78
80	4800	400	8.73	4.36	4.80	6.55	9.36	4.50	7.36
90	5400	450	9.82	4.91	5.40	7.37	10.53	4.55	7.74
100	6000	500	10.91	5.45	6.00	8.18	11.70	4.41	7.96
110	6600	550	. . .	. . .	. . .	. . .	. . .	4.05	7.97
120	7200	600	. . .	. . .	. . .	. . .	. . .	3.49	7.75

Width of Belt for a given Horse-Power.

The width of belt required for any given horse-power may be obtained by transposing the formulæ for horse-power so as to give the value of w. Thus:

From formula (1), $w = \frac{550\text{ H. P.}}{v} = \frac{9.17\text{ H. P.}}{V} = \frac{2101\text{ H. P.}}{d \times rpm} = \frac{275\text{ H. P.}}{L \times rpm}$.

From formula (2), $w = \frac{1100\text{ H. P.}}{v} = \frac{18.33\text{ H. P.}}{V} = \frac{4202\text{ H. P.}}{d \times rpm} = \frac{530\text{ H. P.}}{L \times rpm}$.

From formula (3), $w = \frac{1000\text{ H. P.}}{v} = \frac{16.67\text{ H. P.}}{V} = \frac{3820\text{ H. P.}}{d \times rpm} = \frac{500\text{ H. P.}}{L \times rpm}$.

From formula (4), $w = \frac{733\text{ H. P.}}{v} = \frac{12.22\text{ H. P.}}{V} = \frac{2800\text{ H. P.}}{d \times rpm} = \frac{360\text{ H. P.}}{L \times rpm}$.

From formula (5),* $w = \frac{513\text{ H. P.}}{v} = \frac{8.56\text{ H. P.}}{V} = \frac{1960\text{ H. P.}}{d \times rpm} = \frac{257\text{ H. P.}}{L \times rpm}$.

* *For double belts.*

Length of Belt.

Approximate rule; two pulleys $\left[\left(\frac{Dia_1 + Dia_2}{2}\right) \times 3.1416\right] + [2 \times$ distance between centers] $=$ length of belt.

Length of Belt in Roll.

Outside diameter roll in inches $+$ diameter hole $\times$ number turns $\times$ .1309 $=$ length of belt in inches for double belt.

Weight of Belt (*approximate*).

$\frac{\text{Length in feet} \times \text{width in inches}}{13} =$ weight of single belt. Divide by 8 for double belts.

Horse-Power Transmitted by Light, Double Endless Leather Belting.

(Buckley.)

Width, Inches. / Speed in feet per min.	4	6	8	10	12	14	16	18	20	22	24
2000	14	22	29	36	43	50	58	65	72	80	87
2400	17	26	35	44	52	60	70	78	88	96	105
2800	20	30	40	51	61	71	81	91	102	112	122
3000	22	33	44	54	65	76	87	98	108	120	131
3500	25	38	50	63	76	89	101	114	127	140	153
4000	29	43	58	73	87	101	116	131	145	160	174
4500	32	49	65	82	98	114	131	147	163	180	196
5000	36	55	73	91	109	127	145	163	182	200	218
5500	40	60	80	100	120	140	160	180	200	220	240
6000	44	65	87	109	130	153	175	200	218	240	260

(Speed $\times$ width $\div$ 550 $=$ horse-power, light, double.)
(Horse-power $\times$ 550 $\div$ speed $=$ width, light, double.)

Horse-Power Transmitted by Heavy, Double Endless Leather Belting.

Width, Inches. / Speed in feet per min.	4	6	8	10	12	14	16	18	20	22	24
2000	18	27	36	43	51	60	70	80	86	96	104
2400	21	31	42	53	62	72	83	94	105	115	120
2800	24	36	48	61	73	85	96	109	122	135	146
3000	27	40	53	65	78	90	104	118	129	144	157
3500	30	45	60	75	91	106	121	137	152	168	184
4000	35	52	70	88	104	121	139	157	174	192	209
4500	38	59	78	98	118	137	157	176	196	216	235
5000	43	66	87	110	130	152	174	196	218	240	262
5500	48	72	96	120	144	168	192	216	240	264	288
6000	52	78	104	122	153	183	210	240	262	288	312

(Speed $\times$ width $\div$ 460 $=$ horse-power, heavy, double.)
(Horse-power $\times$ 460 $\div$ speed $=$ width, heavy, double.)

ROPE DRIVING.

C = Circumference of rope in inches.
D = Diameter of pulley in feet.
R = Revolutions per minute.

Horse-power of Rope: $\frac{C \times D \times R}{200} = \text{H.P.}$

or, Half the diameter of rope multiplied by the hundreds of feet per minute traveled. (L. I. Seymour.)

Breaking strength of manila rope in pounds $= C^2 \times$ coefficient. The coefficient varies from 900 for ½-inch to 700 for 2-inch diameter rope. The following is a reliable table prepared by T. Spencer Miller, M.E. (See *Engineering News*, December 6, 1890.)

Diameter.	Circumference.	Ultimate Strength.	Coefficient.
½	1½	2,000	900
⅝	2	3,250	845
¾	2¼	4,000	820
⅞	2¾	6,000	790
1	3	7,000	780
1⅛	3½	9,350	765
1¼	3¾	10,000	760
1⅜	4¼	13,500	745
1½	4½	15,000	735
1⅝	5	18,200	725
1¾	5½	21,750	712
2	6	25,000	700

This table was compiled by averaging and graduating results of tests at the Watertown Arsenal and Laboratory of Riehle Brothers, in Philadelphia.

Weight of manila rope in pounds per foot = .032 (Circumference in inches)^2. (C. W. Hunt.)
or, diameter of rope in inches squared = weight in pounds per yard approximately.

The coefficient of friction on a rope working on a cast-iron pulley = 0.28; when working in an ungreased groove it is increased about three times, or from 0.57 to 0.84. If the pulleys are greased, the coefficient is reduced about one-half. It has been found by experiment that a rope 6 inches circumference in a grooved pulley possesses four times the adhesive resistance to slipping, exhibited by a half-worn, ungreased 4-inch single belt.

The length of splice should be 72 times the diameter of rope. The strength of a rope containing a properly made "long splice" was found to be 7,000 pounds per square inch of section.

A mixture of molasses and plumbago makes an excellent dope for transmitting ropes. Grease and oils of all kinds should be kept from transmission ropes, since, as a rule, they are injurious.

Following is another formula for horse-power of manila rope:

$$H.P. = \frac{(T_0 - C)V}{33000},$$

in which H.P. is the horse-power transmitted by one rope, V the velocity in feet per minute, T_0 the maximum working stress, and C the centrifugal tension, so that $(T_0 - C)$ is the *net* tension available for the transmission of power. Taking the total maximum stress at $200d^2$ and allow 20 % of this for slack side tension, we have $T_0 = 160d^2$, so that $\text{H.P.} = \frac{(160\,d^2 - C)\,V}{33{,}000}$.

A table has been calculated by this rule, giving the horse-power per rope, transmitted at various speeds.

C = Centrifugal Tension in Manila Ropes — Pounds.

Velocity of Rope in ft. per Min.	Nominal Diameter of Rope in Inches.											
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
1000	0.7	1.1	1.5	2.1	2.7	3.4	4.3	5.1	6.2	7.2	8.3	11
1500	1.5	2.4	3.4	4.7	6.2	7.6	9.7	11	13	16	18	25
2000	2.7	4.3	6.1	8.2	11	13	17	20	24	28	33	44
2500	4.3	6.7	9.6	13	17	21	27	32	38	45	52	69
3000	6.2	9.7	13	18	24	30	39	45	55	64	74	100
3500	8.4	13	19	25	34	42	53	63	75	89	102	136
4000	11	17	24	33	44	54	69	82	98	116	133	177
4500	14	22	31	42	55	69	87	103	125	146	168	223
5000	17	27	39	52	69	86	109	129	156	183	210	275
5500	21	33	47	63	83	104	132	156	189	221	254	332
6000	24	39	56	75	99	125	157	188	225	257	303	396
6500	39	45	65	88	116	145	183	217	261	307	353	462

Horse-Power of Manila Ropes.

Velocity of Rope. Ft. per Min.	Nominal Diameter of Rope in Inches.											
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
2000	2.25	3.51	5.14	6.84	9.08	11.5	14.0	17.0	20.3	23.8	27.5	36.1
2100	2.35	3.67	5.27	7.15	9.40	11.8	14.7	17.8	21.1	24.8	28.8	37.6
2200	2.45	3.82	5.48	7.45	9.80	12.3	15.3	18.5	22.0	25.9	30.0	39.2
2300	2.55	3.98	5.71	7.75	10.2	12.8	15.9	19.3	22.9	26.9	31.2	40.8
2400	2.62	4.10	5.89	7.98	10.5	13.2	16.4	19.8	23.6	27.7	32.2	42.0
2500	2.70	4.21	6.05	8.21	10.8	13.6	16.8	20.4	24.3	28.5	33.1	43.2
2600	2.78	4.33	6.21	8.43	11.1	14.0	17.3	21.0	25.0	29.3	34.0	44.4
2700	2.85	4.45	6.39	8.67	11.4	14.4	17.8	21.5	25.6	30.5	35.0	45.6
2800	2.94	4.59	6.59	8.93	11.75	14.8	18.3	22.2	26.4	31.0	36.0	47.0
2900	3.00	4.68	6.73	9.13	12.0	15.1	18.7	22.7	27.0	31.6	36.8	48.0
3000	3.06	4.78	6.87	9.32	12.3	15.4	19.1	23.2	27.6	32.3	37.6	49.1
3100	3.12	4.87	7.01	9.50	12.5	15.7	19.5	23.6	28.2	33.0	38.3	50.0
3200	3.18	4.97	7.14	9.70	12.7	16.0	19.9	24.0	28.7	33.7	39.0	51.0
3300	3.25	5.07	7.27	9.89	13.0	16.3	20.3	24.5	29.2	34.3	39.8	52.0
3400	3.30	5.15	7.39	10.0	13.2	16.6	20.6	25.0	29.7	34.8	40.4	52.8
3500	3.35	5.22	7.50	10.2	13.4	16.9	20.9	25.3	30.1	35.4	41.0	53.6
3600	3.40	5.30	7.61	10.3	13.6	17.1	21.2	25.7	30.6	35.9	41.6	54.4
3700	3.44	5.36	7.70	10.4	13.7	17.3	21.5	26.0	30.0	36.3	42.1	55.0
3800	3.46	5.40	7.76	10.5	13.8	17.4	21.6	26.2	31.1	36.6	42.4	55.4
3900	3.49	5.45	7.81	10.6	13.9	17.6	21.8	26.4	31.4	36.9	42.7	55.8
4000	3.51	5.49	7.86	10.6	14.0	17.7	21.9	26.5	31.6	37.1	43.0	56.1
4100	3.53	5.52	7.92	10.7	14.1	17.8	22.0	26.7	31.8	37.3	43.2	56.4
4200	3.55	5.54	7.95	10.8	14.2	17.9	22.1	26.8	31.9	37.5	43.4	56.8
4300	3.56	5.55	7.98	10.8	14.2	17.9	22.2	26.9	32.0	37.6	43.6	56.9
4400	3.57	5.56	7.99	10.8	14.2	18.0	22.2	27.0	32.1	37.6	43.6	57.0
4500	3.56	5.55	7.96	10.8	14.2	17.9	22.2	26.9	32.0	37.6	43.5	56.9
4600	3.55	5.54	7.95	10.8	14.2	17.9	22.1	26.8	31.9	37.5	43.4	56.8
4700	3.53	5.50	7.90	10.7	14.1	17.8	22.0	26.6	31.7	37.2	43.1	56.4
4800	3.51	5.48	7.86	10.7	14.0	17.7	21.9	26.5	31.6	37.1	43.0	56.2
4900	3.49	5.45	7.81	10.6	13.9	17.6	21.8	26.4	31.4	36.9	42.7	55.8
5000	3.45	5.38	7.73	10.5	13.8	17.4	21.5	26.1	31.0	36.4	42.2	55.2
5100	3.43	5.35	7.67	10.4	13.7	17.2	21.3	25.9	30.8	36.2	41.9	54.8
5200	3.38	5.26	7.56	10.2	13.5	17.0	21.0	25.5	30.4	35.6	41.3	54.0
5300	3.34	5.20	7.47	10.1	13.3	16.8	20.8	25.2	30.0	35.2	40.8	53.4
5400	3.28	5.11	7.34	9.95	13.1	16.5	20.4	24.8	29.4	34.6	40.1	52.5
5500	3.21	5.00	7.20	9.75	12.8	16.2	20.0	24.2	28.9	33.9	39.3	51.4
6000	2.78	4.33	6.21	8.43	11.1	14.0	17.3	21.0	25.0	29.3	34.0	44.4
6500	2.17	3.38	4.85	6.60	8.6	10.9	13.5	16.4	19.5	22.9	26.5	34.7

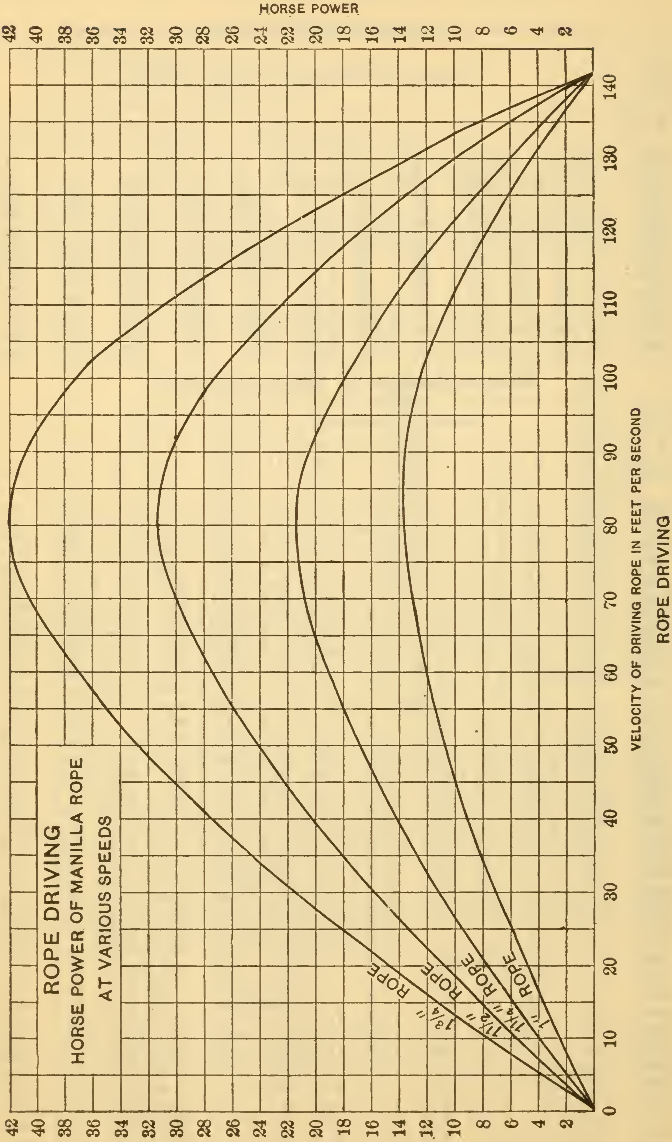

HORSE POWER
ROPE DRIVING
HORSE POWER OF MANILLA ROPE
AT VARIOUS SPEEDS
1¾" ROPE
1½" ROPE
1¼" ROPE
1" ROPE
VELOCITY OF DRIVING ROPE IN FEET PER SECOND
ROPE DRIVING

FIG. 36.

Horse-Power of "Stevedore" Transmission Rope at Various Speeds.

In this table the effect of the centrifugal force has been taken into consideration, and the strain on the fibers of the rope is the same at all speeds when transmitting the horse-power given in the table. When more than one rope is used, multiply the tabular number by the number of the ropes. At a speed of 8,400 per minute the centrifugal force absorbs all the allowable tension the rope should bear, and no power will be transmitted.

Table of the Horse-Power of Transmission Rope.

(Hunt's Formula.)

Diameter of Rope.	Speed of the Rope in Feet per Minute.											Smallest Diam. Pulleys.
	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	6,000	7,000	8,400	
½	1.45	1.9	2.3	2.7	3.	3.2	3.4	3.4	3.1	2.2	.0	.20
⅝	2.3	3.2	3.6	4.2	4.6	5.0	5.3	5.3	4.9	3.4	.0	.25
¾	3.3	4.3	5.2	5.8	6.7	7.2	7.7	7.7	7.1	4.9	.0	.30
⅞	4.5	5.9	7.0	8.2	9.1	9.8	10.8	10.7	9.3	6.9	.0	.36
1	5.8	7.7	9.2	10.7	11.9	12.8	13.6	13.7	12.5	8.8	.0	.42
1¼	9.2	12.1	14.3	16.8	18.6	20.0	21.2	21.4	19.5	13.8	.0	.54
1½	13.1	17.4	20.7	23.1	26.8	28.8	30.6	30.8	28.2	19.8	.0	.60
1¾	18.	23.7	28.2	32.8	36.4	39.2	41.5	41.8	37.4	27.6	.0	.72
2	23.2	30.8	36.8	42.8	47.6	51.2	54.4	54.8	50.	35.2	.0	.84

For a temporary installation when the rope is not to be long in use, it might be advisable to increase the work to double that given in the tables.

Slip of Ropes and Belts.

(W. W. Christie.)

Some French trials, with constant resistance, the power expended and slip in several modes of transmission was as follows:

Ropes,	158.54 gross h.p.,	Slip,	0.33 per cent.
Cotton belt,	159.67 "	"	0.78 "
Leather "	158.84 "	"	0.96 "
" "	160.23 "	"	0.78 "

Stated in percentage value, the results were:

Ropes,	100.00 gross power,	Slip,	0.100.
Cotton belt,	100.87 "	"	0.237.
Leather "	100.37 "	"	0.292.
" "	101.07 "	"	0.237.

Manila Cordage.					Tarred Hemp.
Size, Circumfer'ce. Inches.	Size, Diameter. Inches.	Weight of 100 Fathoms.	Feet in one Pound.	Breaking Strain of New Ropes. Pounds.	Weight of 100 Fathoms.
$1\frac{1}{4}$	$\frac{3}{8}$	31	20	For Ropes in use deduct $\frac{1}{3}$ from	40
$1\frac{1}{2}$	$\frac{1}{2}$	44	14	these figures, for	55
$1\frac{3}{4}$	$\frac{9}{16}$	60	10	chafing, etc.	75
2	$\frac{5}{8}$	79	$7\frac{1}{2}$	3000	100
$2\frac{1}{4}$	$\frac{3}{4}$	99	6	4000	125
$2\frac{1}{2}$	$\frac{13}{16}$	122	5	5000	155
$2\frac{3}{4}$	$\frac{7}{8}$	146	4	6000	190
3	1	176	$3\frac{3}{8}$	7000	225
$3\frac{1}{4}$	$1\frac{1}{16}$	207	3	8500	265
$3\frac{1}{2}$	$1\frac{1}{8}$	240	$2\frac{1}{2}$	9500	300
$3\frac{3}{4}$	$1\frac{1}{4}$	275	$2\frac{1}{6}$	11000	355
4	$1\frac{5}{16}$	305	2	12500	405
$4\frac{1}{4}$	$1\frac{3}{8}$	355	$1\frac{8}{12}$	14000	455
$4\frac{1}{2}$	$1\frac{1}{2}$	395	$1\frac{1}{2}$	16000	500
5	$1\frac{5}{8}$	490	$1\frac{1}{4}$	20000	630
$5\frac{1}{2}$	$1\frac{3}{4}$	595	1	24000	750
6	2	705	10 in.	27000	910
$6\frac{1}{2}$	$2\frac{1}{8}$	825	$8\frac{1}{2}$	31500	1050
7	$2\frac{1}{4}$	960	$7\frac{1}{2}$	37000	1235
$7\frac{1}{2}$	$2\frac{1}{2}$	1100	$6\frac{1}{2}$	42500	1400
8	$2\frac{5}{8}$	1255	$5\frac{1}{2}$	48500	1600
$8\frac{1}{2}$	$2\frac{7}{8}$	1415	5	54500	1820
9	3	1585	$4\frac{1}{2}$	61500	2050

Hawser laid will weigh $\frac{1}{6}$ less.

Notes on the Uses of Wire Rope.

(Roebling.)

Two kinds of wire rope are manufactured. The most pliable variety contains 19 wires in the strand, and is generally used for hoisting and running rope.

For safe working load allow $\frac{1}{5}$ or $\frac{1}{7}$ of the ultimate strength, according to speed, so as to get good wear from the rope. Wire rope is as pliable as new hemp rope of the same strength; but the greater the diameter of the sheaves the longer wire rope will last.

Experience has proved that the wear increases with the speed. It is, therefore, better to increase the load than the speed. Wire rope must not be coiled or uncoiled like hemp or manila — all untwisting or kinking must be avoided.

In no case should galvanized rope be used for running. One day's use scrapes off the zinc coating.

Table of Strains Produced by Loads on Inclined Planes.

Elevation in 100 Ft.	Strain in Lbs. on Rope from a Load of 1 Ton.	Elevation in 100 Ft.	Strain in Lbs. on Rope from a Load of 1 Ton.
Ft. Deg.		Ft. Deg.	
10 = $5\frac{1}{2}$	212	90 = 42	1347
20 = $11\frac{1}{5}$	404	100 = 45	1419
30 = $16\frac{3}{4}$	586	110 = $47\frac{3}{4}$	1487
40 = $21\frac{5}{6}$	754	120 = $50\frac{1}{4}$	1544
50 = $26\frac{1}{3}$	905	130 = $52\frac{1}{2}$	1592
60 = 31	1040	140 = $54\frac{1}{2}$	1633
70 = 35	1156	150 = $56\frac{1}{4}$	1671
80 = $38\frac{2}{3}$	1260	160 = 58	1703

Table of Transmission of Power by Wire Ropes.

Showing necessary size and speed of wheels and rope to obtain any desired amount of power.

(Roebling.)

Diam. of Wheel in Ft.	No. of Revolutions.	Diam. of Rope.	Horse-Power.	Diam. of Wheel in Ft.	No. of Revolutions.	Diam. of Rope.	Horse-Power.
4	80	3/8	3.3	10	80	11/16	58.4
	100	3/8	4.1		100	11/16	73.
	120	3/8	5.		120	11/16	87.6
	140	3/8	5.8		140	11/16	102.2
5	80	7/16	6.9	11	80	11/16	75.5
	100	7/16	8.6		100	11/16	94.4
	120	7/16	10.3		120	11/16	113.3
	140	7/16	12.1		140	11/16	132.1
6	80	1/2	10.7	12	80	3/4	99.3
	100	1/2	13.4		100	3/4	124.1
	120	1/2	16.1		120	3/4	148.9
	140	1/2	18.7		140	3/4	173.7
7	80	9/16	16.9	13	80	3/4	122.6
	100	9/16	21.1		100	3/4	153.2
	120	9/16	25.3		120	3/4	183.9
8	80	5/8	22.	14	80	7/8	148.
	100	5/8	27.5		100	7/8	185.
	120	5/8	33.		120	7/8	222.
9	80	5/8	41.5	15	80	7/8	217.
	100	5/8	51.9		100	7/8	259.
	120	5/8	62.2		120	7/8	300.

NOTE. For list of transmission ropes, see page 1325.

The drums and sheaves should be made as large as possible. The minimum size of drum is given in a column in table.

It is better to increase the load than the speed.

Wire rope is manufactured either with a wire or a hemp center. The latter is more pliable than the former, and will wear better where there is short bending. The weight of rope with wire center is about 10 per cent more than with hemp center.

CHAIN.

The size of chain is determined by the size of the stock used in making the links.

The strength of the iron always used for chains is from 41,000 to 55,000 lbs. tensile strength per square inch.

Coil Chain.

(John C. Schmidt & Co., York, Pa.)

Size of Iron in Ins.	Links per Foot.	Av. Weight per 100 Ft. in Lbs.	Proof Load in Lbs.	Size of Iron in Ins.	Links per Foot.	Av. Weight per 100 Ft. in Lbs.	Proof Load in Lbs.
3–16	13	45	600	1–2	8	225	7,000
1–4	12	75	1,400	9–16	7	320	9,000
5–16	11	120	2,500	5–8	6	400	11,000
3–8	10	150	4,000	3–4	5½	590	16,000
7–16	9	200	5,000	7–8	5	770	22,000

Short Link Chains.

Proof Tests Adopted November 11, 1896.

(Jones & Laughlins, Limited.)

Size. (Ins.)	Proof. (Lbs.)	BB Crane. (Lbs.)	BBB Crane. (Lbs.)	Average Weight per Foot. (Lbs.)
$\frac{3}{16}$	700	770	900	.5
$\frac{1}{4}$	1,200	1,320	1,500	.9
$\frac{5}{16}$	2,500	2,750	3,200	1.22
$\frac{3}{8}$	3,500	3,850	4,425	1.6
$\frac{7}{16}$	4,800	5,280	6,100	2.0
$\frac{1}{2}$	6,200	6,820	7,850	2.5
$\frac{9}{16}$	7,800	8,580	9,870	3.2
$\frac{5}{8}$	9,600	10,560	12,150	4.2
$\frac{11}{16}$	11,500	12,650	14,550	5.0
$\frac{3}{4}$	13,800	15,180	17,475	5.9
$\frac{13}{16}$	16,200	17,820	20,500	6.7
$\frac{7}{8}$	18,800	20,680	23,780	7.9
$\frac{15}{16}$	21,500	23,650	27,200	9.0
1	24,600	27,100	31,200	10.2
$1\frac{1}{16}$	26,300	28,930	33,300	11.4
$1\frac{1}{8}$	29,500	32,450	37,300	12.7
$1\frac{3}{16}$	33,000	36,300	41,750	14.2
$1\frac{1}{4}$	36,500	40,150	46,175	15.8
$1\frac{5}{16}$	40,000	44,000	50,600	17.2
$1\frac{3}{8}$	44,000	48,400	55,660	18.8
$1\frac{7}{16}$	48,200	53,000	60,950	20.4
$1\frac{1}{2}$	52,500	57,750	66,400	22.2
$1\frac{9}{16}$	57,000	62,700	72,100	24.0
$1\frac{5}{8}$	61,700	67,870	78,050	26.7
$1\frac{11}{16}$	66,500	73,150	84,120	28.5
$1\frac{3}{4}$	71,600	78,760	90,575	31.0

Safe working load should be about one-half of proof test.
The breaking strain is about double the proof test.

LUBRICATION.

When two bodies are compelled to move, one upon the other, the resistance encountered is called friction, of which we have three kinds: rolling and sliding of solids, and fluid friction of liquids and gases.

The reduction of friction and its consequent generation of heat is accomplished to a large extent by the use of lubricants.

Thurston says the characteristics of an efficient lubricant must be:

1. Enough "body," or combined capillarity and viscosity to keep the surfaces between which it is interposed from coming in contact under maximum pressure.

2. The greatest fluidity consistent with the preceding requirements.

3. The lowest possible co-efficient of friction under the conditions of actual use, i.e., the sum of the two components, solid and fluid friction, should be a minimum.

4. A maximum capacity for receiving, transmitting, storing, and carrying away heat.

5. Freedom from tendency to decompose, or to change in composition by gumming or otherwise, on exposure to the air while in use.

6. Entire absence of acid or other properties liable to produce injury of materials or metals with which they may be brought in contact.

7. A high temperature of evaporization and of decomposition and a low temperature of solidification.

8. Special adaptation to the conditions as to speed and pressure of rubbing surfaces under which the unguent is to be used.

9. It must be free from grit and all foreign matter.

All **Animal** or **Vegetable Oils** eventually decompose, and become gummy, and retard the speed of any machine to which they may be applied.

Mineral Oils—which are used in steam and electrical engineering—do not absorb oxygen, and do not take fire spontaneously, as do the animal and vegetable oils.

Greases have their proper place, as in railroad car axles, and in cups feeding journals that do not require lubrication until a certain predetermined temperature has been reached, for which the grease to be used is suited.

Vegetable Oils should not be used in any place from which there is any prospect of their being taken to the inside of a steam boiler, as they materially encourage corrosion and pitting of boiler shells.

Weight of Oil per Gallon. The Pennsylvania Railroad specifications call for these approximate weights: Lard oil, tallow oil, neatsfoot oil, bone oil, colza oil, mustard-seed oil, rape-seed oil, paraffin oil, 500 degree fire test oil, engine oil, and cylinder lubricant, 7½ pounds per gallon.

Well oil and passenger car oil	7.4 lbs. per gallon.
Navy sperm oil	7.2 " " "
Signal oil	7.1 " " "
300 degree burning oil	6.9 " " "
150 degree burning oil	6.6 " " "

In many of the large power plants the lubrication of a large proportion of the bearings is controlled by a system which pumps the oil through pipes to bearings, and after its use, it is drained to a central point there to be filtered, and foreign matter eliminated, and then used over again.

Lubrication is more apt to be overdone than to be neglected to damage of machinery.

Best Lubricants for Different Purposes.

(Thurston.)

Low temperatures, as in rock drills driven by compressed air	Light mineral lubricating oils.
Very great pressures, slow speed . .	Graphite, soapstone and other solid lubricants.
Heavy pressures, slow speed . . .	The above, lard and tallow and other greases.
Heavy pressures, high speed . . .	Sperm-oil, castor-oil, and heavy mineral oils.
Light pressures, high speed . . .	Sperm, refined, petroleum, olive, rape, cotton-seed oils.
Ordinary machinery	Lard oil, tallow oil, heavy mineral oils, and the heavier vegetable oils.
Steam cylinders	Heavy mineral oils, lard, tallow.
Watches and other delicate mechanisms	Clarified sperm, neatsfoot, porpoise, olive, and light mineral lubricating oils.

For mixture with mineral oils, sperm is best ; lard is much used ; olive and cotton-seed oils are good.

PAINTING.

After making a series of exposure tests to ascertain the efficiency of lead and zinc paints, G. R. Henderson, N. & W. Railroad, reaches the following conclusions.

Tin. — The best results were obtained with the first coat white lead, and second coat, white zinc. The second coating of zinc gave generally the best results, and the second coating of lead the most.

Galvanized Iron. — The same remarks apply to galvanized iron as given for tin.

Sheet Iron. — The mixture of one-third white zinc and two-thirds white lead, for both coats, gave the best results on this material, and, in general, the zinc paint gave better results than the lead paints.

Poplar. — The second coats of zinc showed up well on poplar, no matter whether the priming coats were white lead or white zinc, or mixed lead and zinc. The lead second coating showed up the most on this material, but in each case where the second coat was of zinc, totally or partially, the paint was in a perfect condition.

White Pine. — The same remarks apply to white pine as to poplar.

Yellow Pine. — This material seems to be difficult to properly treat with paints ; the best results were obtained with the first coat of lead, and the second coat of lead and zinc mixed. Where the first coat was of lead and zinc mixed or entirely of zinc, the results were poor throughout, which seems to indicate that as a general thing the lead is better for priming on this material.'

Conclusion. — Lead priming and zinc coating are generally good for tin, galvanized iron, poplar and white pine. Sheet iron shows up best with both coats of mixed paints. Yellow pine appeared best with the first coat of lead and the second coat of lead and zinc mixed.

Comparing the materials which were painted, we find that, generally, poplar retains the paint better than white pine; and would therefore, be preferred for siding on buildings, etc. Yellow pine seems to be the worst of all for this purpose. Black iron as a whole retains the paint better than either tin or galvanized iron.

MISCELLANEOUS TABLES.

WEIGHTS AND MEASURES.

Measure of Capacity.

Gallon.—The standard gallon measures 231 cubic inches, and contains 8.3388822 pounds avoirdupois = 58372.1757 grains Troy, of distilled water, at its maximum density 39.83° Fahrenheit, and 30 inches barometer height.

Bushel.—The standard bushel measures 2150.42 cubic inches = 77.627413 pounds avoirdupois of distilled water at 39.83° Fahrenheit, barometer 30 inches. Its dimensions are 18½ inches inside diameter, 19½ inches outside, and 8 inches deep; and when heaped, the cone must not be less than 6 inches high, equal 2747.70 cubic inches for a true cone.

Pound.—The standard pound avoirdupois is the weight of 27.7015 cubic inches of distilled water, at 39.83° Fahrenheit, barometer 30 inches, and weighed in the air.

Measure of Length.

Miles.	Furlongs.	Chains.	Rods.	Yards.	Feet.	Inches.
1	8	80	320	1760	5280	63360
0.125	1	10	40	220	660	7920
0.0125	0.1	1	4	22	66	792
0.003125	0.025	0.25	1	5.5	16.5	198
0.00056818	0.0045454	0.045454	0.181818	1	3	36
0.00018939	0.00151515	0.01515151	0.0606060	0.33333	1	12
0.000015783	0.000126262	0.001262626	0.00505050	0.0277777	0.083333	1

Measure of Surface.

Sq. Miles.	Acres.	S. Chains	Sq. Rods.	Sq. Yards	Sq. Feet.	Sq. Inches
1	640	6400	102400	3097600	27878400	4014489600
0·001562	1	10	160	4840	43560	6272640
0.0001562	0.1	1	16	484	4356	627264
0.000009764	0.00625	0.0625	1	30.25	272.25	39204
0.000000323	0.0002066	0.002066	0.0330	1	9	1296
0.0000000358	0.00002296	0.0002296	0.00367	0.1111111	1	144
0.00000000025	0.000000159	0.00000159	0.00002552	0.0007716	0.006944	1

Measure of Capacity.

Cub. Yard.	Bushel.	Cub. Feet.	Pecks.	Gallons.	Cub. Inch.
1	21.6962	27	100.987	201.974	46656
0.03961	1	1.24445	4	9.30918	2150.42
0.037037	0.803564	1	3.21425	7.4805	1728
0.009259	0.25	0.31114	1	2.32729	537.605
—	0.107421	0.133681	0.429684	1	231
—	—	0.000547	0.001860	0.004329	1

Measure of Liquids.

Gallon.	Quarts.	Pints.	Gills.	Cub. Inch.
1	4	8	32	231
0.25	1	2	8	57.75
0.125	0.5	1	4	28.875
0.03125	0.125	0.25	1	7.21875
0.004329	0.17315	0.03463	0.13858	1

Measures of Weights.

AVOIRDUPOIS.

Ton.	Cwt.	Pounds.	Ounces.	Drams.
1	20	2240	35840	573440
0.05	1	112	1792	28672
0.00044642	0.0089285	1	16	256
0.00002790	0.000558	0.0625	·1	16
0.00000174	0.0000348	0.0016	0.0625	1

TROY.

Pounds.	Ounces.	Dwt.	Grains.	Pound Avoir.
1	12	240	5760	0.822861
0.083333	1	20	480	0.068571
0.004166	0.05000	1	24	0.0034285
0.0001736	0.002083333	0.0416666	1	0.00014285
1.215275	14.58333	291.6666	7000	1

APOTHECARIES.

Pounds.	Ounces.	Drams.	Scruples.	Grains.
1	12	96	288	5760
0.08333	1	8	24	480
0.01041666	0.125	1	3	60
0.0034722	0.0416666	0.3333	1	20
0.00017361	0.0020833	0.016666	0.05	1

Equivalents of Lineal Measures—Metrical and English.

	Meters.	English Measures.			
		Inches.	Feet.	Yards.	Miles.
Millimeter . . mm	.001	.039370	.003281	.001094	. . . . .
Centimeter . cm	.01	.393701	.032809	.010936	. . . . .
Decimeter . . .	.1	3.937011	.328084	.109361	. . . . .
Meter	1.	**39.370113**	**3.280843**	**1.093614**	**.000621**
Decameter . .	10.	. . . . .	32.80843	10.93614	.006214
Hectometer . .	100.	. . . . .	328.0843	109.3614	.062137
Kilometer . . .	1,000.	. . . . .	3280.843	1093.614	.621372
Miriameter . .	10,000.	. . . . .	. . . . . .	. . . . . .	6.213718

Micron = .000,001 meter
= .001 millimeter

Equivalents of Lineal Measures — Met. and Eng. — *Continued.*

English Measures.	Meters.	Reciprocals.
1 inch	.02539954	39.37079
12 inches = 1 foot	.3047945	3.280899
3 feet = 1 yard	.9143835	1.093633
$5\frac{1}{2}$ yards = $16\frac{1}{2}$ feet = 1 rod or pole	5.029109	.1988424
4 poles = 66 feet = 22 yards = 1 chain (Gunter's)	20.11644	.0497106
80 chains = 320 poles = 5280 ft. = 1760 yds. = 1 mile	1609.3149	.00062138

A Gunter's chain has 100 links. Each link = 7.92 inches = 0.2017 meter.

Equivalents of Superficial Measures — Metrical and Eng.
(METRICAL AND ENGLISH MEASURES.)

	Square meters.	English Measures.				
		Square inches.	Square feet.	Square yards.	Acres.	Square miles.
Milliare	.1	155.01	1.076	.119	....	...
Centiare = sq. met	1.	1550.06	10.764	1.196	....	...
Deciare	10.	15500.59	107.64	11.960	....	...
Are	**100.**	**155005.9**	**1076.4**	**119.6033**	....	...
Decare (not used)	1000.	....	10764.3	1196.033	....	...
Hectare	10000.	....	107643.	11960.33	2.4711431	...
Square kilometer	1000000.	....	....	....	247.11431	.386126

English Measures.	Metrical Measures.	Reciprocals.
1 square inch	6.451367 sq. cent.	.1550059
144 square inches = 1 square foot	.09289968 sq. mt.	10.7642996
9 square feet = 1 square yard	.8360972 " "	1.196033
$30\frac{1}{4}$ sq. yds. / $272\frac{1}{4}$ sq. ft. } = 1 perch = 1 square rod or pole	25.29194 " "	.0395383
160 perches = / 10 sq. chains } = 1 acre	4046.711 " "	.00024711
640 acres = 1 square mile	2589894.5 " "	.00000038612

Equivalents of Weights — Metrical and English.

	Grammes	English Weights.				
		Oz. avoir.	Lbs. avoir.	Tons 2000 lbs.	Tons 2240 lbs.	Troy weight.
Milligramme	.001	....	....	...	...	.015 Grs.
Centigramme	.01	....	....	...	...	.15 "
Decigramme	.1	....	....	...	...	1.543 "
Gramme	**1.**	**.0353**	**.0022**	...	...	**15.43235"**
Decagramme	10.	.3527	.02205	...	...	.....
Hectogramme	100.	3.5274	.22046	...	...	.... oz.
Kilogramme	1000.	35.2739	2.2046	.001102	.000984	32.150727"
Myriagramme	10000.	352.7394	22.0462	.011023	.009842	321.507266"
Quintal	100000.	3527.3943	220.4261	.110231	.098421	3215.07266 "
Millier or Tonne	1000000	....	2204.6215	1.102311	.984206	32150.72655"

English Weights — "Avoirdupois."	Grammes.	Reciprocals.
1 grain	.06479895	15.43234875
24.34375 grains = 1 dram	1.771836	.564383
16 drams = 1 ounce = 437.5 grains	28.349375	.0352739
16 ounces = 1 pound = 7000 grains	453.592652	.00220462
100 lbs. = 1 cwt. (American)	45359.265	.000022046
112 lbs. = 1 cwt. (English)	50802.376	.00001968
20 cwt. = 1 ton (Am.) in kilos	907.18524	.001102311
20 cwt. = 1 ton (Eng.) in kilos	1016.04753	.000984206
English Weights — "Troy."		
1 grain	.06479895	15.43234875
24 grains = 1 dwt.	1.555175	.6430146
20 dwt = 1 oz.	31.103496	.3215073
12 oz. = 1 lb.	373.241954	.00267923

Equivalents of Cubic Measures — Metrical and English.

(LIQUID AND DRY MEASURES.)

Liquid.	Dry.		Metrical Measures.		English Measures.					
			Litres.	Cub. Met.	Cub. Inches.	Cub. Feet.	U.S. Gallons. 231 cub. in.	Gallons. 277.27 cu.in.	Bushels. 2150.4 cu.in.	Cub. Yds.
Millilitre	....	Cub. Cent.	.001	....	.061	....	.00026	.00022	.....	...
Centilitre	....	.....	.01	....	.61	....	.00264	.0022	.....	...
Decilitre	....	.....	.1	....	6.10	....	.02642	.022	.0027	...
Litre	**Millistere**	**Cub. Decim**	**1.**	**.001**	**61.027**	**.0353**	**.26418**	**.2201**	**.0275**	...
Decalitre	Centistere	.....	10.	.01	610.271	.3532	2.64179	2.201	.27512	...
Hectolitre	Decistere	.....	100.	.1	6102.706	3.5317	26.4179	22.00967	2.7512	.1308
Kilolitre	Stere	Cub. Met.	1000.	1.	....	35.317	264.179	220.0967	27.5121	1.308
Myriolitre	Decastere	.....	10000.	10.	....	353.1658	.....	.....	275.1209	13.0802
....	Hectostere	.....	....	100.	....	....	.....	.....	.....	130.8022

English Measures.	Metrical Measures.	Reciprocals.
1 cubic inch	16.38618 cub. cent.	.061027
1728 cubic inches = 1 cubic foot	.02831531 cub. met.	35.316582
27 cubic feet = 1 cubic yard	.7645134 " "	1.30802
1 pint (imperial or dry measure)	.56793 litres	1.760773
2 pints = 1 quart (dry measure)	1.13586 "	.880387
4 quarts = 1 gallon (imperial) = 277.274 cubic inches	4.543457 "	.220097
1 wine gallon of 231 cubic inches	3.78521 "	.264179
8 gallons (imperial) = 1 bushel (2150.4 cubic inches)	36.34766 " .036348 cub. met.	.027512 27.51209
8 bushels = 1 quarter (English)	290.7813 litres.	.003439

Metrical Measures Equivalent to English Measures.

Meters.	Inches.	Feet.
1m/m	0.039	0.0033
2	0.079	0.0066
3	0.118	0.0098
4	0.157	0.0131
5	0.197	0.0164
6	0.236	0.0197
7	0.276	0.0230
8	0.315	0.0262
9	0.354	0.0295
10m/m = 1c/m	0.394	0.033
2	0.787	0.066
3	1.181	0.098
4	1.575	0.131
5	1.969	0.164
6	2.362	0.197
7	2.756	0.230
8	3.150	0.262
9	3.543	0.295
10c/m = .1m	3.937	0.328
.2	7.874	0.656
.3	11.811	0.984
.4	15.748	1.312
.5	19.685	1.640
.6	23.622	1.969
.7	27.560	2.297
.8	31.497	2.625
.9	35.434	2.953
1m0	39.370	3.281

Table for the Conversion of Mils. (1-1000 Inches) into Centimeters.

Mils.	Centi-meters.	Mils.	Centi-meters.	Mils.	Centi-meters.	Mils.	Centi-meters.
1	.00254	18	.04571	35	.08888	52	.1321
2	.00508	19	.04825	36	.09142	53	.1346
3	.00762	20	.05079	37	.09396	54	.1372
4	.01016	21	.05333	38	.09650	55	.1397
5	.01270	22	.05587	39	.09904	56	.1422
6	.01524	23	.05841	40	.1016	57	.1448
7	.01778	24	.06095	41	.1041	58	.1473
8	.02032	25	.06348	42	.1067	59	.1499
9	.02286	26	.06602	43	.1092	60	.1524
10	.02540	27	.06856	44	.1118	61	.1549
11	.02793	28	.07110	45	.1143	62	.1575
12	.03047	29	.07364	46	.1168	63	.1600
13	.03301	30	.07618	47	.1194	64	.1626
14	.03555	31	.07872	48	.1219	65	.1651
15	.03809	32	.08126	49	.1245	66	.1676
16	.04063	33	.08380	50	.1270	67	.1702
17	.04317	34	.08634	51	.1295	68	.1727

Table for the Conversion of Mils. — *Continued.*

Mils.	Centi-meters.	Mils.	Centi-meters.	Mils.	Centi-meters.	Mils.	Centi-meters.
69	.1752	77	.1956	85	.2159	93	.2362
70	.1778	78	.1981	86	.2184	94	.2387
71	.1803	79	.2006	87	.2209	95	.2413
72	.1829	80	.2032	88	.2235	96	.2438
73	.1854	81	.2057	89	.2260	97	.2465
74	.1879	82	.2083	90	.2286	98	.2489
75	.1905	83	.2108	91	.2311	99	.2514
76	.1930	84	.2133	92	.2336	100	.2540

English Measures Equivalent to Metrical Measures.

Inches.	Milimeters.	Inches.	Meters.	Feet.	Meters.	Feet.	Meters.
$\frac{1}{32}$	0.794	1	0.0254	0.01	.003	10	3.048
$\frac{1}{16}$	1.588	2	.0508	0.02	.006	20	6.096
$\frac{3}{32}$	2.381	3	.0762	0.03	.009	30	9.144
$\frac{1}{8}$	3.175	4	.1016	0.04	.012	40	12.192
$\frac{5}{32}$	3.969	5	.1270	0.05	.015	50	15.240
$\frac{3}{16}$	4.762	6	.1524	0.06	.018	60	18.288
$\frac{7}{32}$	5.556	7	.1778	0.07	.021	70	21.336
$\frac{1}{4}$	6.350	8	.2032	0.08	.024	80	24.384
$\frac{9}{32}$	7.144	9	.2286	0.09	.027	90	27.431
$\frac{5}{16}$	7.937	10	.2540	.1	.030	100	30.479
$\frac{11}{32}$	8.731	11	.2794	.2	.061	200	60.959
$\frac{3}{8}$	9.525	12	.3048	.3	.091	300	91.438
$\frac{13}{32}$	10.319			.4	.122	400	121.918
$\frac{7}{16}$	11.112			.5	.152	500	152.397
$\frac{15}{32}$	11.906			.6	.183	600	182.877
$\frac{1}{2}$	12.700			.7	.213	700	213.356
$\frac{17}{32}$	13.494			.8	.244	800	243.836
$\frac{9}{16}$	14.287			.9	.274	900	274.315
$\frac{19}{32}$	15.081			1.0	.305	1000	304.794
$\frac{5}{8}$	15.875			2	.610		
$\frac{21}{32}$	16.668			3	.914		
$\frac{11}{16}$	17.462			4	1.219		
$\frac{23}{32}$	18.256			5	1.524		
$\frac{3}{4}$	19.050			6	1.829		
$\frac{25}{32}$	19.843			7	2.134		
$\frac{13}{16}$	20.637			8	2.438		
$\frac{27}{32}$	21.430			9	2.743		
$\frac{7}{8}$	22.224			10	3.048		
$\frac{29}{32}$	23.018						
$\frac{15}{16}$	23.812						
$\frac{31}{32}$	24.606						
1	25.400						

Conversion of Inches and Eighths into Decimals of a Foot.

Inches.	Fractions of an Inch.							
	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.01041	.02083	.03125	.04166	.05208	.0625	.07291
1	.08333	.09375	.10416	.11458	.125	.13541	.14588	.15639
2	.16666	.17707	.1875	.19792	.20832	.21873	.22914	.23965
3	.25	.26041	.270	.28125	.29166	.30208	.3125	.32291
4	.33333	.34375	.35416	.364	.375	.38541	.39588	.40639
5	.41666	.42707	.437	.44792	.45832	.46873	.47914	.48965
6	.5	.51041	.520	.53125	.54166	.55208	.5625	.57291
7	.58333	.59375	.60416	.614	.625	.63541	.64588	.65639
8	.66666	.67707	.685	.69792	.70832	.71773	.72914	.73965
9	.75	.76041	.770	.78125	.79169	.80208	.8425	.82291
10	.83333	.84375	.85416	.864	.875	.88541	.89588	.90639
11	.91666	.92707	.937	.94792	.95832	.96873	.97914	.98965
12	1 foot.	foot.	foot.	foot.	foot.	foot.	foot.	foot.

$\frac{1}{16}$ in. = 0.005208 ft ; $\frac{1}{32}$ in. = 0.00265 ft. ; $\frac{1}{64}$ in. = 0.001375 ft.

GREEK LETTERS.

Α	α	Alpha.	Ν	ν	Nu.
Β	β	Beta.	Ξ	ξ	Xi.
Γ	γ	Gamma.	Ο	ο	Omicron.
Δ	δ	Delta.	Π	π	Pi.
Ε	ε	Epsīlon.	Ρ	ρ	Rho.
Ζ	ζ	Zeta.	Σ	σ ς	Sigma.
Η	η	Eta.	Τ	τ	Tau.
Θ	θ	Theta.	Υ	υ	Upsīlon.
Ι	ι	Iota.	Φ	φ	Phi.
Κ	κ	Kappa.	Χ	χ	Chi.
Λ	λ	Lambda.	Ψ	ψ	Psi.
Μ	μ	Mu.	Ω	ω	Omĕga.

ANGULAR VELOCITY.

The number of degrees per second through which a body revolves about a center.

$$w = 2\pi\ n$$

where

n = revolutions per second
w = angular velocity.

FRICTION.

The following laws of friction are only approximate, the first not being true where pressures are very great, and the third beyond a velocity of 150 feet per minute.

1. *Friction varies directly as the pressure on the surfaces in contact.*
2. *Friction is independent of the extent of the surface in contact.*
3. *Friction is independent of the velocity, when the surfaces are in motion.*
4. *Rolling friction varies directly as the pressure, and inversely as the diameter of the rolling bodies, where the cylinders and balls are of the same substances, and are pulled or pushed, as in a car or wagon.*

   Where the road is propelled by a crank fixed on the axle, the law is reversed.

TEMPERATURE, or INTENSITY OF HEAT.

Standard Points—		Fahrenheit.	Centigrade.	Réaumur.
Boiling point of water under one atmosphere	=	212°	100°	80°
Melting point of ice		32°	0°	0°
(Absolute zero; known by theory only	=about	—461°.2	— 274°	— 219°.2)

9° Fahrenheit = 5° Centigrade = 4° Réaumur.

$$\text{Temp Fah.} = \frac{9}{5}\text{ Temp. Cent.} + 32° = \frac{9}{4}\text{ Temp. Réau.} + 32°$$

$$\text{Temp. Cent.} = \frac{5}{9}(\text{Temp. Fah.} - 32°) = \frac{5}{4}\text{ Temp. Réau.}$$

$$\text{Temp. Réau.} = \frac{4}{9}(\text{Temp. Fah.} - 32°) = \frac{4}{5}\text{ Temp. Cent.}$$

Table of Comparison of Different Thermometers.

Fah.	Réau.	Cent.	Fah.	Réau.	Cent.	Fah.	Réau.	Cent.
212	80.0	100.0	180	65.7	82.2	148	51.5	64.4
211	79.5	99.4	179	65.3	81.6	147	51.1	63.8
210	79.1	98.8	178	64.8	81.1	146	50.6	63.3
209	78.6	98.3	177	64.4	80.5	145	50.2	62.7
208	78.2	97.7	176	64.0	80.0	144	49.7	62.2
207	77.7	97.2	175	63.5	79.4	143	49.3	61.6
206	77.3	96.6	174	63.1	78.8	142	48.8	61.1
205	76.8	96.1	173	62.6	78.3	141	48.4	60.5
204	76.4	95.5	172	62.2	77.7	140	48.0	60.0
203	76.0	95.0	171	61.7	77.2	139	47.5	59.4
202	75.5	94.4	170	61.3	76.6	138	47.1	58.8
201	75.1	93.8	169	60.8	76.1	137	46.6	58.3
200	74.6	93.3	168	60.4	75.5	136	46.2	57.7
199	74.2	92.7	167	60.0	75.0	135	45.7	57.2
198	73.7	92.2	166	59.5	74.4	134	45.3	56.6
197	73.3	91.6	165	59.1	73.8	133	44.8	56.1
196	72.8	91.1	164	58.6	73.3	132	44.4	55.5
195	72.4	90.5	163	58.2	72.7	131	44.0	55.0
194	72.0	90.0	162	57.7	72.2	130	43.5	54.4
193	71.5	89.4	161	57.3	71.6	129	43.1	53.8
192	71.1	88.8	160	56.8	71.1	128	42.6	53.3
191	70.6	88.3	159	56.4	70.5	127	42.2	52.7
190	70.2	87.7	158	56.0	70.0	126	41.7	52.2
189	69.7	87.2	157	55.5	69.4	125	41.3	51.6
188	69.3	86.6	156	55.1	68.8	124	40.8	51.1
187	68.8	86.1	155	54.6	68.3	123	40.4	50.5
186	68.4	85.5	154	54.2	67.7	122	40.0	50.0
185	68.0	85.0	153	53.7	67.2	121	39.5	49.4
184	67.5	84.4	152	53.3	66.6	120	39.1	48.8
183	67.1	83.8	151	52.8	66.1	119	38.6	48.3
182	66.6	83.3	150	52.4	65.5	118	38.2	47.7
181	66.2	82.7	149	52.0	65.0	117	37.7	47.2

Table of Comparison of Different Thermometers — *Continued.*

Fah.	Réau.	Cent.	Fah.	Réau.	Cent.	Fah.	Réau.	Cent.
116	37.3	46.6	70	16.8	21.1	24	—3.5	—4.4
115	36.8	46.1	69	16.4	20.5	23	—4.0	—5.0
114	36.4	45.5	68	16.0	20.0	22	—4.4	—5.5
113	36.0	45.0	67	15.5	19.4	21	—4.8	—6.1
112	35.5	44.4	66	15.1	18.8	20	—5.3	—6.6
111	35.1	43.8	65	14.6	18.3	19	—5.7	—7.2
110	34.6	43.3	64	14.2	17.7	18	—6.2	—7.7
109	34.2	42.7	63	13.7	17.2	17	—6.6	—8.3
108	33.7	42.2	62	13.3	16.6	16	—7.1	—8.8
107	33.3	41.6	61	12.8	16.1	15	—7.5	—9.5
106	32.8	41.1	60	12.4	15.5	14	—8.0	—10.0
105	32.4	40.5	59	12.0	15.0	13	—8.4	—10.5
104	32.0	40.0	58	11.5	14.4	12	—8.8	—11.1
103	31.5	39.4	57	11.1	13.8	11	—9.3	—11.6
102	31.1	38.8	56	10.6	13.3	10	—9.7	—12.2
101	30.6	38.3	55	10.2	12.7	9	—10.2	—12.7
100	30.2	37.7	54	9.7	12.2	8	—10.6	—13.3
99	29.7	37.2	53	9.3	11.6	7	—11.1	—13.8
98	29.3	36.6	52	8.8	11.1	6	—11.5	—14.4
97	28.8	36.1	51	8.4	10.5	5	—12.0	—15.0
96	28.4	35.5	50	8.0	10.0	4	—12.4	—15.5
95	28.0	35.0	49	7.5	9.4	3	—12.8	—16.1
94	27.5	34.4	48	7.1	8.8	2	—13.3	—16.6
93	27.1	33.8	47	6.6	8.3	1	—13.7	—17.2
92	26.6	33.3	46	6.2	7.7	0	—14.2	—17.7
91	26.2	32.7	45	5.7	7.2	—1	—14.6	—18.3
90	25.7	32.2	44	5.3	6.6	—2	—15.1	—18.8
89	25.3	31.6	43	4.8	6.1	—3	—15.5	—19.4
88	24.8	31.1	42	4.4	5.5	—4	—16.0	—20.0
87	24.4	30.5	41	4.0	5.0	—5	—16.4	—20.5
86	24.0	30.0	40	3.5	4.4	—6	—16.8	—21.1
85	23.5	29.4	39	3.1	3.8	—7	—17.3	—21.6
84	23.1	28.8	38	2.6	3.3	—8	—17.7	—22.2
83	22.6	28.3	37	2.2	2.7	—9	—18.2	—22.7
82	22.2	27.7	36	1.7	2.2	—10	—18.6	—23.3
81	21.7	27.2	35	1.3	1.6	—11	—19.1	—23.8
80	21.3	26.6	34	0.8	1.1	—12	—19.5	—24.4
79	20.8	26.1	33	0.4	0.5	—13	—20.0	—25.0
78	20.4	25.5	32	0.0	0.0	—14	—20.4	—25.5
77	20.0	25.0	31	—0.4	—0.5	—15	—20.8	—26.1
76	19.5	24.4	30	—0.8	—1.1	—16	—21.3	—26.6
75	19.1	23.8	29	—1.3	—1.6	—17	—21.7	—27.2
74	18.6	23.3	28	—1.7	—2.2	—18	—22.2	—27.7
73	18.2	22.7	27	—2.2	—2.7	—19	—22.6	—28.3
72	17.7	22.2	26	—2.6	—3.3	—20	—23.1	—28.8
71	17.3	21.6	25	—3.1	—3.8			

Number of Degrees Cent. = Number of Degrees Fah.

Degrees Cent.	Tenths of a Degree — Centigrade Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.
0	0.00	0.18	0.36	0.54	0.72	0.90	1.08	1.26	1.44	1.62
1	1.80	1.98	2.16	2.34	2.55	2.70	2.88	3.06	3.24	3.42
2	3.60	3.78	3.96	4.14	4.32	4.50	4.68	4.86	5.04	5.22
3	5.40	5.58	5.76	5.94	6.12	6.30	6.48	6.66	6.84	7.02

Number of Degrees Cent. = Number of Degrees Fah. — (*Continued.*)

Degrees Cent.	Tenths of a Degree — Centigrade Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.	Fah.
4	7.20	7.38	7.56	7.74	7.92	8.10	8.28	8.46	8.64	8.82
5	9.00	9.18	9.36	9.54	9.72	9.90	10.08	10.26	10.44	10.62
6	10.80	10.98	11.16	11.34	11.52	11.70	11.88	12.06	12.24	12.42
7	12.60	12.78	12.96	13.14	13.32	13.50	13.68	13.86	14.04	14.22
8	14.40	14.58	14.76	14.94	15.12	15.30	15.48	15.66	15.84	16.02
9	16.20	16.38	16.56	16.74	16.92	17.10	17.28	17.46	17.64	17.82

Number of Degrees Fah. = Number of Degrees Cent.

Degrees Fah.	Tenths of a Degree — Fahrenheit Scale.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.	Cent.
0	0.00	0.06	0.11	0.17	0.22	0.28	0.33	0.39	0.44	0.50
1	0.56	0.61	0.67	0.72	0.78	0.83	0.89	0.94	1.00	1.06
2	1.11	1.17	1.22	1.28	1.33	1.39	1.44	1.50	1.56	1.61
3	1.67	1.72	1.78	1.83	1.89	1.94	2.00	2.06	2.11	2.17
4	2.22	2.28	2.33	2.39	2.44	2.50	2.56	2.61	2.67	2.72
5	2.78	2.83	2.89	2.94	3.00	3.06	3.11	3.17	3.22	3.28
6	3.33	3.39	3.44	3.50	3.56	3.61	3.67	3.72	3.78	3.83
7	3.89	3.94	4.00	4.06	4.11	4.17	4.22	4.28	4.33	4.39
8	4.44	4.50	4.56	4.61	4.67	4.72	4.78	4.83	4.89	4.94
9	5.00	5.06	5.11	5.17	5.22	5.28	5.33	5.39	5.44	5.50

Coefficients of Expansion at Ordinary Temperatures.
(Solids.)

Material.	Coefficient of Expansion	
	°F.	°C.
Aluminum	.0000114	.0000206
Brass	.0000104	.0000187
Brick	.00000306	.00000551
Bronze	.0000100	.0000180
Cement and Concrete from	.0000055	.000010
to	.0000078	.000014
Copper	.00000961	.0000173
Glass from	.00000399	.00000719
to	.00000521	.00000938
Gold	.00000841	.0000151
Granite	.0000046	.0000083
Iron, cast	.00000587	.0000106
Iron, wrought	.00000677	.0000122

Coefficients of Expansion—(*Continued.*)

Material.		Coefficient of Expansion. °F.	Coefficient of Expansion. °C.
Lead		.0000158	.0000284
Marble (average)		.000004	.000007
Masonry	from	.0000026	.0000047
	to	.0000049	.0000088
Platinum		.00000494	.00000890
Porcelain		.0000020	.0000036
Sandstone	from	.0000040	.0000070
	to	.0000067	.000012
Silver		.0000108	.0000194
Slate		.0000056	.0000102
Steel, untempered		.00000611	.0000110
Steel, tempered		.00000689	.0000124
Tin		.0000116	.0000209
Wood (pine)		.00000276	.00000496
Zinc		.0000163	.0000293

HEAT.

Specific Heat of Substances.

The *specific heat* of a body at any temperature is the ratio of the quantity of heat required to raise the temperature of the body one degree to the quantity of heat required to raise an equal mass of water at or near to its temperature of maximum density (4°C. or 39.2°F.) through one degree.

Specific Heats of Metals.

(Tomlinson.)

Metal.	Specific Heat at 0°C. or 32°F.	Specific Heat at 50°C. or 122°F.	Specific Heat at 100°C or 212°F
Aluminum	0.2070	0.2185	0.2300
Copper	0.0901	0.0923	0.0966
German Silver	0.0941	0.0947	0.0952
Iron	0.1060	0.1130	0.1200
Lead	0.0300	0.0315	0.0331
Platinum	0.0320	0.0326	0.0333
Platinum Silver	0.0473	0.0487	0.0501
Silver	0.0547	0.0569	0.0591
Tin	0.0523	0.0568	0.0595
Zinc	0.0901	0.0938	0.0976

Mean Specific Heat of Platinum.

(Pouillet.)

Between 0°C. (32°F.) and	100°C. (212°F.)	0.0335
" " " "	300°C. (572°F.)	0.0343
" " " "	500°C. (932°F.)	0.0352
" " " "	700°C. (1292°F.)	0.0360
" " " "	1000°C. (1832°F.)	0.0373
" " " "	1200°C. (2192°F.)	0.0382

Heat Unit Table. (A. E. Hunt.)

Name.	Molecular Symbol.	Atomic Weight.	Molecular Weight.	Products of Combustion.	Specific Gravity Hydrogen = 2.	Specific Gravity Air = 1.	Weight of 1 Liter in Grams.	Weight of 1 Cu. Ft. in Grains.	Weight of 1 Cu. Ft. in Pounds.	Calories C-K.	Heat-Value Carbon = 1.	Volume-Calorie Hydrogen = 1.
Hydrogen	H_2	1	2.	H_2O	2.0000	0.06925	0.08955	39.1263	.00559	34217.5	4.23	1.00
Marsh Gas	CH_4	...	15.97	H_2O-CO_2	15.974	0.55300	0.71506	312.445	.04464	13244.	1.63	3.09
Carbon Monoxid	CO	...	27.93	CO_2	27.937	0.96715	1.25058	546.4397	.07806	2441.7	0.302	1.00
Acetylene	C_2H_2	...	25.94	H_2O-CO_2	25.947	0.89829	1.16148	507.5338	.07255	11923.	1.48	4.53
Aethylene	C_2H_4	...	27.94	H_2O-CO_2	27.947	0.96749	1.25103	546.6318	.07809	11884.	1.47	4.86
Aethane	C_2H_6	...	29.94	H_2O-CO_2	29.947	1.03675	1.34058	585.7637	.08368	12347.	1.53	5.41
Propylene	C_3H_6	...	41.91	H_2O-CO_2	41.921	1.45124	1.87654	819.9506	.11713	11731.	1.45	7.21
Butylene	C_4H_8	...	55.89	H_2O-CO_2	55.894	1.93488	2.50190	1093.2072	.15617	11619.	1.44	9.51
Allylene	C_3H_4	...	39.92	H_2O-CO_2	39.921	1.38194	1.78692	780.7961	.11154	11690.	1.45	6.83
Benzole	C_6H_6	...	77.82	H_2O-CO_2	77.822	2.69463	3.48429	1522.4659	.21749	10102.	1.25	11.51
Naphthalene	$C_{10}H_8$	...	127.7	H_2O-CO_2	127.722	4.39880	5.68783	2485.322	.35505	9618.7	1.19	17.98
Sulphureted Hydrogen	H_2S	...	33.98	SO_2-H_2O	33.981	1.17664	1.52147	664.802	.09497	3488.	0.43	1.73
Carbon Bi-Sulphid	CS_2	...	75.93	CO_2-SO_2	75.931	2.62580	3.39980	1483.577	.21194	3404.	0.421	3.79
Water Gas		* See analysis below.			15.562	0.53883	0.69678	304.438	.04349	4839.7	0.5989	0.936
Coal Gas		* See analysis below.			11.332	0.39236	0.50739	186.620	.02666	13817.	1.710	1.924
Ammonia	NH_3	...	17.01	H_2O-N_2	17.010	0.58901	0.76163	332.790	.47543	5332.	0.659	1.33
Air	...	...	...	.....	14.444	1.00000	1.29306	565.000	.08071	...	...	...
Nitrogen	N_2	14.01	28.02	.....	28.021	0.97026	1.25461	548.197	.07831	...	...	...
Oxygen	O_2	15.96	31.92	.....	31.920	1.10531	1.42923	624.500	.08921	...	...	...
Carbon Dioxid	CO_2	...	43.89	.....	43.892	1.51980	1.96519	858.687	.12267	...	...	...
Carbon from Wood	C_2	11.97	23.94	CO_2	...	...	...	...	...	8080.	1.000	...
Anthracite — Penna.	...	...	...	CO_2-H_2O	...	...	...	...	...	7844.4	0.971	...
Bituminous Coal	...	...	...	CO_2-H_2O	...	...	...	...	...	8391.7	1.038	...
Cannel Coal	...	...	...	CO_2-H_2O	...	...	...	...	...	6365.5	0.788	...
Furnace Coke	...	...	...	CO_2-H_2O	...	...	...	...	...	7019.4	0.868	...
Gas House Coke	...	...	...	CO_2-H_2O	...	...	...	...	...	7000.	0.866	...
Coal Tar	...	...	...	CO_2-H_2O	...	...	...	...	...	8667.	1.073	...
Crude Petroleum	...	...	...	CO_2-H_2O	...	...	...	...	...	11094.1	1.373	...

* NOTE.

	Water Gas. (Uncarbureted.)	Coal Gas.
Hydrogen	49.2 %	50.28 %
Marsh gas	0.3 %	36.95 %
Illuminants	Trace.	6.34 %
Carbon monoxid	43.8 %	4.37 %
Carbon dioxid	2.7 %	None.
Nitrogen	4.0 %	Trace.

Mean Specific Heat of Water.

(Regnault.)

Between 0°C. (32°F.) and 40°C. (104°F.)	1.0013
" " " " 80°C. (176°F.)	1.0035
" " " " 120°C. (248°F.)	1.0067
" " " " 160°C. (320°F.)	1.0109
" " " " 200°C. (392°F.)	1.0160
" " " " 230°C. (446°F.)	1.0204

Mean Specific Heat of Glass (Kohlrausch) 0.19

Specific Heat of Gases and Vapors at Constant Pressure.

Substance.	Specific Heat for Equal.		Observer.
	Volumes.	Weights.	
Air	0.2375	0.2375	Regnault
Carbon monoxide	0.2370	0.2450	Regnault
Carbon dioxide	0.2985	0.1952	Wiedermann
Hydrogen	0.2359	3.4090	Regnault
Nitrogen	0.2368	0.2438	Regnault
Oxygen	0.2405	0.2175	Regnault
Steam	0.2989	0.4805	Regnault

Total Heat of Steam.

British Thermal Unit: (B. T. U.) is the quantity of heat which will raise the temperature of one pound of water one degree Fah. at or near its temperature of maximum density 39.1°.

French Calorie: is the quantity of heat that will raise the temperature of one kilogramme of pure water 1°C. at or near 4°C.

Pound Calorie: is the quantity of heat that will raise the temperature of one pound of water 1°C.

1 B. T. U. = .252 Calories.
1 Calorie = 3.968 B. T. U.
1 lb. Calorie = 1.8 B. T. U.
1 pound Calorie = 0.4536 Calorie.

The Mechanical Equivalent of Heat.

Joule gives 1 B. T. U. = 772 ft. lbs.
Professor Rowland, 1 B. T. U. = 778 ft. lbs.

$$1 \text{ ft. lb.} = \frac{1}{778} = .001285 \text{ B. T. U. per minute.}$$

1 H. P. = 42.416 B. T. U.

(See Table of Energy Equivalents on p 1258.)

Specific Gravity.

Names of Substances.	Specific gravity	Weight per Cub. in.
Woods.		
Cedar, Indian .	1.315	.0476
" American	.561	.0203
Citron	.726	.0263
Cocoa-wood . .	1.040	.0376
Cherry-tree . .	.715	.0259
Cork	.240	.0087
Cypress, Spanish	.644	.0233
Ebony, American	1.331	.0481
" Indian .	1.209	.0437
Elder-tree . . .	.695	.0252
Elm, trunk of .	.671	.0243
Filbert-tree . .	.600	.0217
Fir, male . . .	.550	.0199
" female . .	.498	.0180
Hazel	.600	.0217
Jasmine, Spanish	.770	.0279
Juniper-tree . .	.556	.0201
Lemon-tree . .	.703	.0254
Lignum-vitæ . .	1.333	.0482
Linden-tree . .	.604	.0219
Logwood . . .	.913	.0331
Mastic-tree . .	.849	.0307
Mahogany . . .	1.063	.0385
Maple	.750	.0271
Medlar	.944	.0342
Mulberry . . .	.897	.0324
Oak, heart of, 60 old	1.170	.0423
Orange-tree . .	.705	.0255
Pear-tree . . .	.661	.0239
Pomegranate-tree	1.354	.0490
Poplar	.383	.0138
" white Spanish	.529	.0191
Plum-tree . . .	.785	.0284
Quince-tree . .	.705	.0255
Sassafras . . .	.482	.0174
Spruce	.500	.0181
" old . . .	.460	.0166
Pine, yellow . .	.660	.0239
" white . .	.554	.0200
Vine	1.327	.0480
Walnut	.671	.0243
Yew, Dutch . .	.788	.0285
" Spanish .	.807	.0292
Liquids.		
Acid, Acetic . .	1.062	.0384
" Nitric . .	1.217	.0440
" Sulphuric .	1.841	.0666
" Muriatic .	1.200	.0434
" Fluoric . .	1.500	.0542
" Phosphoric	1.558	.0563
Alcohol, commer.	.833	.0301
" pure .	.792	.0287
Ammoniac, liquid	.897	.0324
Beer, lager . . .	1.034	.0374
Champagne . .	.997	.0360
Cider	1.018	.0361
Ether, sulphuric	.739	.0267
Naptha	.848	
Egg	1.090	.0394
Honey	1·450	.0524
Human blood .	1.054	.0381
Milk	1.032	.0373

Names of Substances.	Specific gravity	Weight per cu. Inch.
Oil, Linseed	.940	.0340
" Olive	.915	.0331
" Turpentine	.870	.0314
" Whale	.932	.0337
Proof Spirit	.925	.0334
Vinegar	1.080	.0390
Water, distilled	1.000	.0361
" sea	1.030	.0371
" Dead Sea	1.240	.0448
Wine.	.992	.0359
" Port	.997	.0361
Miscellaneous.		
Ebonite	1.8	
Pitch	1.6	
Asphaltum	.905 1.650	.0327 .0597
Beeswax	.965	.0349
Butter	.942	.0341
Camphor	.988	.0357
India rubber	.933	.0338
Fat of Beef	.923	.0334
" Hogs	.936	.0338
" Mutton	.923	.0334
Gamboge	1.222	.0442
Gunpowder, loose	.900	.0325
" shaken . . .	1.000	.0361
" solid . . .	1.550 1.800	.0561 .0650
Gum Arabic	1.452	.0525
Indigo	1.009	.0365
Lard	.947	.0343
Mastic	1.074	.0388
Spermaceti	.943	.0341
Sugar	1.605	.0580
Tallow, sheep	.924	.0334
" calf	.934	.0338
" ox	.923	.0334
Atmospheric air	.0012	.000043
Gases. Vapors.		W'g't cu.ft. gr'ns.
Atmospheric air	1.000	527.0
Ammoniacal gas	.500	263.7
Carbonic acid	1.527	805.3
Carbonic oxid	.972	512.7
Carbureted hydrogen . .	.972	512.7
Chlorine	2.500	1316
Chlorocarbonous acid . .	3.472	1828
Chloroprussic acid . . .	2.152	1134
Fluoboric acid	2 371	1250
Hydriodic acid	4.346	2290
Hydrogen	.069	36.33
Oxygen	1.104	581.8
Sulphuretted hydrogen .	1.777	9370
Nitrogen	.972	512.0
Vapor of alcohol	1.613	851.0
" turpentine spirits	5.013	2642
" water	.623	328.0
Smoke of bituminous coal	.102	53.80
" wood	.90	474.0
Steam at 212°	.488	257.3

TABLE OF SPECIFIC GRAVITY AND UNIT WEIGHTS.

Water at 39.1° Fahrenheit = 4° Centigrade ; 62.425 pounds to the cubic foot (authority, Kent, Haswell, and D. K. Clark).

	Specific Gravity.	Authority.	Lbs. per Cubic Foot.	Lbs. per Cubic Inch.	Kilos per Cubic Decm.
Aluminum, pure cast	2.56	P. R. C.	159.63	.0924	2.56
" " rolled	2.68	"	167.11	.0967	2.68
" " anne'ld	2.66	"	165.86	.0960	2.66
" nickel alloy, cast	2.85	"	178.10	.1031	2.85
" " " rolled	2.76	"	172.10	.0996	2.76
" " " ann'ld	2.74	"	170.85	.0989	2.74
Aluminum Bronze, 10%	7.70	Riche.	480.13	.2779	7.70
" " 5%	8.26	"	515.63	.2984	8.26
Brass, cu. 67, zn. 33 cast	8.32	Haswell.	519.36	.3006	8.32
" cu. 60, zn. 40 "	8.405	Thurston.	524.68	.3036	8.405
Cobalt	8.50	R.-A.	530.61	.3071	8.50
Brass, plates . . .	....	.....	....	....	....
high yellow .	8.586	P. R. C.	535.38	.3098	8.586
Bronze composition .	....	.....	....	....	....
cu. 90, tin 10 .	8.669	Thurston.	541.17	.3132	8.669
Bronze composition .	....	.....	....	....	....
cu. 84, tin 16 .	8.832	Haswell.	551.34	.3191	8.832
Lithium	0.57	R.-A.	36.83	.0213	.57
Potassium	0.87	"	54.31	.0314	.87
Sodium	0.97	"	60.55	.0350	.97
Rubidium	1.52	"	94.89	.0549	1.52
Calcium	1.57	"	98.01	.0567	1.57
Magnesium	1.74	"	108.62	.0629	1.74
Caesium	1.88	"	117.36	.0679	1.88
Boron	2.00	Haswell.	124.85	.0723	2.00
Glucinum	2.07	R.-A.	129.22	.0748	2.07
Strontium	2.54	"	158.56	.0918	2.54
Barium	3.75	"	234.09	.1355	3.75
Zirconium	4.15	"	259.06	.1499	4.15
Selenium	4.50	Haswell.	280.91	.1626	4.50
Titanium	5.30	"	330.85	.1915	5.30
Vanadium	5.50	R.-A.	343.34	.1987	5.50
Arsenic	5.67	"	353.95	.2048	5.67
Columbium	6.00	Haswell.	374.55	.2168	6.00
Lanthanum	6.20	"	387.03	.2240	6.20
Niobium	6.27	R.-A.	391.40	.2265	6.27
Didymium	6.54	"	408.26	.2363	6.54
Cerium	6.68	"	417.00	.2413	6.68
Antimony	6.71	"	418.86	.2424	6.71
Chromium	6.80	"	429.49	.2457	6.80
Zinc, cast	6.861	Haswell.	428.30	.2479	6.861
" pure	7.15	R.-A.	446.43	.2583	7.15
" rolled	7.191	Haswell.	448.90	.2598	7.191
Wolfram	7.119	"	444.40	.2572	7.119
Tin, pure	7.29	R.-A.	455.08	.2634	7.29
Indium	7.42	"	463.19	.2681	7.42
Iron, cast	7.218	Kent.	450.08	.2605	7.218
" wrought . . .	7.70	"	480.13	.2779	7.70
" wire	7.774	Haswell.	485.29	.2808	7.774
Steel, Bessemer . .	7.852	"	479.00	.2837	7.852
" soft	7.854	Kent.	489.74	.2834	7.854
Iron, pure	7.86	R.-A.	490.66	.2840	7.86

TABLE OF SPECIFIC GRAVITY.—*Continued.*

	Specific Gravity.	Authority.	Lbs. per Cubic Foot.	Lbs. per Cubic Inch.	Kilos per Cubic Decm.
Manganese	8.00	R.-A.	499.40	.2890	8.00
Cinnabar	8.809	Haswell.	505.52	.2925	8.098
Cadmium	8.60	R.-A.	536.85	.3107	8.60
Molybdenum	8.60	"	536.85	.3107	8.60
Gun Bronze	8.750	Haswell.	546.22	.3161	8.750
Tobin Bronze	8.379	A. C. Co.	523.06	.3021	8.379
Nickel	8.80	R.-A.	549.34	.3179	8.80
Copper, pure	8.82	"	550.59	.3186	8.82
Copperplates and sheet	8.93	A. of C. M.	556.83	.3222	8.93
Bismuth	9.80	R.-A.	611.76	.3540	9.80
Silver	10.53	"	657.33	.3805	10.53
Tantalum	10.80	"	674.19	.3902	10.80
Thorium	11.10	"	692.93	.4010	11.10
Lead	11.37	"	709.77	.4108	11.37
Palladium	11.50	"	717.88	.4154	11.50
Thalium	11.85	"	739.73	.4281	11.85
Rhodium	12.10	"	755.34	.4371	12.10
Ruthenium	12.26	"	765.33	.4429	12.26
Mercury	13.59	"	848.35	.4909	13.59
Uranium	18.70	"	1167.45	.6755	18.70
Tungsten	19.10	"	1192.31	.6900	19.10
Gold	19.32	"	1206.05	.6979	19.32
Platinum	21.50	"	1342.13	.7767	21.50
Iridium	22.42	"	1399.57	.8099	22.42
Osmium	22.48	"	1403.31	.8121	22.48

Anthorities — R.-A. — Professor Roberts-Austen.
Haswell — Haswell's Engineer's Pocket Book.
P. R. C. — Pittsburg Reduction Co.'s tests.
Kent — Kent's Mechanical Engineer's Pocket Book.
Thurston — Report of Committee on Metallic Alloys of U. S. Board appointed to test iron, steel, and other metals. Thurston's Materials of Engineering.
Riche — Quoted by Thurston.
A. C. Co. — Ansonia Brass and Copper Co.
A. of C. M. — Association of Copper Manufacturers.

SPECIFIC GRAVITY AT 62° FAHRENHEIT OF ALUMINUM AND ALUMINUM ALLOYS.

Aluminum Commercially Pure, Cast	2.56
Nickel Aluminum Alloy Ingots for rolling	2.72
" " Casting Alloy	2.85
Special Casting Alloy, Cast	3.00
Aluminum Commercially Pure, as rolled, sheets and wire	2.68
" " " Annealed	2.66
Nickel Aluminum Alloy, as rolled, sheets and wire	2.76
" " " Sheets Annealed	2.74

Weight.

Using these specific gravities, assuming water at 62 degrees Fahrenheit, and at Standard Barometric Height, as 62.355 lbs. per cubic foot (authority, Kent and D. K. Clark).

Sheet of cast aluminum, 12 inches square and 1 inch thick, weighs	13.3024 lbs.
Sheet of rolled aluminum, 12 inches square and 1 inch thick, weighs	13.9259 lbs.
Bar of cast aluminum, 1 inch square and 12 inches long, weighs	1.1085 lbs.
Bar of rolled aluminum, 1 inch square and 12 inches long, weighs	1.1605 lbs.
Bar of aluminum, cast, 1 inch round and 12 inches long, weighs	.8706 lbs.
Bar of rolled aluminum, 1 inch round and 12 inches long, weighs	.9114 lbs.

POWER REQUIRED TO DRIVE MACHINERY SHOPS, AND TO DO VARIOUS KINDS OF WORK.

PRONY BRAKE.

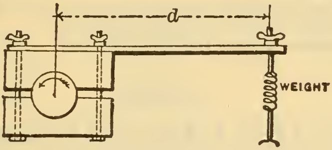


FIG. 1.

Constant $= \frac{2\pi}{33000} = .0001904.$

Then

Horse-power = .0001904 $\times\ d \times w \times$ revolutions per minute.

Horse-Power Formulas.

In an article by C. H. Benjamin in March, 1899, *Machinery* are the following formulas for computing the horse-power required to operate tools, where W = weight metal removed per hour.

Experiments with several lathes give:

H.P. = .035 W for cast iron.
H.P. = .067 W for machinery steel.
Experiments with a Gray planer give:
H.P. = .032 W for cast iron.
Experiments with a Hendey shaper give
H.P. = .030 W for cast iron.
For milling machines we have:
H.P. = .14 W. for cast iron.
H.P. = .10 W for bronze.
H.P. = .30 W for tool steel.

In each case, the power required to run the tool, light, should be added.

Power Used by Machine-Tools.

(R. E. Dinsmore, from the *Electrical World*.)

1. Shop shafting $2\frac{3}{16}$ in. $\times$ 180 ft. at 160 revs., carrying 26 pulleys from 6 in. diam. to 36 in., and running 20 idle machine belts . 1.32 H. P.
2. Lodge-Davis upright back-geared drill-press with table, 28 in. swing, drilling $\frac{3}{8}$ in. hole in cast iron, with a feed of 1 in. per minute . . . . 0.78 H. P.
3. Morse twist-drill grinder No. 2, carrying 26 in. wheels at 3200 revs . . . . 0.29 H. P.
4. Pease planer 30 in. $\times$ 36 in., table 6 ft., planing cast iron, cut $\frac{1}{4}$ in. deep, planing 6 sq. in. per minute, at 9 reversals . . . . 1.06 H. P.
5. Shaping-machine 22 in. stroke, cutting steel die, 6 in. stroke, $\frac{1}{8}$ in. deep, shaping at rate of 1.7 square inch per minute . . . 0.37 H. P.
6. Engine-lathe 17 in. swing, turning steel shaft $2\frac{3}{8}$ in. diam., cut $\frac{3}{16}$ deep, feeding 7.92 in. per minute . . . . 0.43 H. P.
7. Engine lathe 21 in. swing, boring cast-iron hole 5 in. diam., cut $\frac{3}{16}$ diam., feeding 0.3 in. per minute . . . . 0.23 H. P.
8. Sturtevant No. 2, monogram blower at 1800 revs. per minute, no piping . . . . 0.8 H. P.
9. Heavy planer 28 in. $\times$ 28 in. $\times$ 14 ft. bed, stroke 8 in., cutting steel, 22 reversals per minute . . . . 3.2 H. P.

Power Required for Machine Tools—Results of Tests. Tests of Various Machine Tools.

(From a paper read by F. B. Duncan before the Engineers' Society of Western Pennsylvania.)

Engine Lathes.

16 in.; motor power required, approximate, 2 H.P. at maximum.
18 in. × 6 ft.; motor power required, 2.1 H.P.
36 in. × 10 ft.; motor power required, 10 H.P.

Planers.

10 × 10 × 20 ft.; 3 tools, $\frac{3}{4}$ × $\frac{1}{8}$ in. cut; cutting speed, 18 ft.; planing 40-ton iron casting. H.P. required for cut, 26.5; for return, 23.6; for reverse, 42.9. Ratio return, 3 to 1. Motor, 30 H.P., belted to countershaft.

8 × 8 × 20 ft.; 3 tools, $\frac{5}{8}$ × $\frac{1}{8}$ in. cut; cutting speed, 18 ft.; planing 32-ton iron casting; H.P. for cut, 16; for return, 14-8; for reverse, 28.2. Ratio return, 3 to 1. Motor, 25 H.P., belted to countershaft.

66 × 60 in. × 12 ft.; 2 tools $\frac{1}{2}$ × 1-16 in. cut; cutting speed, 21 ft.; planing 4 ton open hearth casting. H.P. required for cut, 10; for return, 14; for reverse, 16. Ratio return, $3\frac{1}{2}$ to 1. Motor mounted on planer housing with 42-inch 1,500-pound flywheel, running at 400 revolutions, mounted on motor shaft; flywheel used as driving pulley for return of platen.

28 × 52 in. × 6 ft.; 1 cutting tool, $\frac{3}{4}$ × $\frac{1}{8}$ in. cut; cutting speed, 22 ft.; planing 3-ton iron casting. H.P. required for cut, 3.1; for return, 3.8; for reverse, 4.4. Ratio return, 4 to 1. Motor, 3 H.P., 800 revolutions. Average load on motor, 2.48. Flywheel, 30 in. diameter, 496 pounds, 800 revolutions, mounted on motor shaft and used as pulley for return of platen.

Miscellaneous.

28 in. Gisholt turret lathe: machining Tropenas cast steel weight, 400 pound; size cut, one tool, $\frac{3}{4}$ × 5-16 in.; 4 tools, $\frac{1}{2}$ × 5-64 in.; weight casting. 400 pounds; power for cut, 3.9 H.P

21 in. drill press; power required, 1 H.P.

5 ft. radial drill; maximum power required, 2.03 H.P. Motor used, 2 H.P. 600 revolutions.

Double and emery wheel stand; two 18 × 2 in. wheels, 950 rev.; 2 laborers grinding castings; maximum H.P., momentarily, 6; average, 3.5. Motor, 5 H.P., mounted on grinder shaft.

10 ft. boring and turning mill; cutting tools, 2; cut, $\frac{3}{4}$ × 1-16 in.; cutting speed, 20 ft.; machining 3.5-ton casting; H.P. required for cut, 8.6. Motor used, 12 H.P.

Slotter; cut, $\frac{3}{8}$ × 1-16 in.; speed of tool, 20 ft.; machining open hearth steel castings; power required, 6.98 H.P.

Flat turret lathe; $1\frac{1}{2}$ H.P. motor required.

Gisholt tool grinder; speed, 1,600 to 1,800 rev.; power required, 7 for short periods, 4 on average. Motor used, 5 H.P.

The figures given in the following table for the power required to run the planing machines empty, do not include the maximum horse-power at the instant of reversal, but represent the average forward and return of the empty table.

Results of tests at the Baldwin Locomotive Works, Philadelphia :

Kind of Machines.	Size.	Material Cut.	No. of Tools.	Horse-Power.				
				Motor and Shaft.	Empty Machine.	Total Cutting.		
						Min.	Max.	Ave.
Wheel lathe	84 in.	Cast iron	2	....	....	2.9	7.9	6.1
Wheel lathe .	84 in.	Cast iron	2	....	....	4.2	5.8	5.1
Wheel lathe .	84 in.	Cast iron	2	....	1.5	5.3	6.2	5.8
Boring mill .	78 in.	Cast iron	1	....	....	4.3	4.7	4.5
Boring mill .	78 in.	Cast iron	1	....	....	5.5	7.1	6.5
Slotter . . .	36 in. × 12 in.	Wrought iron	1	1.5	1.5	4.4	6.7	5.3
Planer . . .	62 in. × 35 ft.	Wrought iron	2	4.4	11.4	20.6	21.6	21.1
Planer . . .	62 in. × 35 ft.	Wrought iron	2	....	5.8	23.0	26.0	24.5
Planer . . .	36 in. × 12 ft.	Wrought iron	2	2.7	3.0	11.3	13.8	12.5
Planer . . .	24 in. × 13 ft.	Steel	2	1.95	4.3	....	....	8.0
Planer . . .	36 in. × 18 ft.	Wrought iron	2	3.2	4.3	....	....	16.7
Planer . . .	56 in. × 35 ft.	Wrought iron	2	4.6	9.9	13.0	13.7	13.3
Planer . . .	56 in. × 24 ft.	Wrought iron	2	4.56	6.0	16.0	17.7	16.8
Wheel lathe	90 in.	Cast steel	2	1.43	2.1	....	....	6.38
Radial drill .	42 in.	Cast steel	1	0.96	1.1	....	....	2.1
Boring mill .	4 ft. 6 in.	Cast steel	1	2.1	2.4	....	....	4.6
Boring mill .	5 ft. 6 in.	Cast iron	1	1.6	2.4	4.2	4.8	4.4
Slotter . . .	40 in. × 15 in.	Wrought iron	1	1.8	2.2	....	....	7.3
Shaper . . .	19 in. str.	Wrought iron	1	1.3	1.8	4.8	9.7	7.3

Results of tests, in ten different plants by C. H. Benjamin, to determine the proportion of power absorbed by the counters, belting, line shaft, etc.

Nature of Work.	Friction Horse-Power.						Useful Horse-Power.	
	Per 100 ft. of Shafting.	Per 100 lbs. of Shafting.	Per 100 sq. ft. of Shafting per minute.	Per Bearing.	Per Counter.	Per Belt.	Per Machine.	Per Man.
Boiler shop	4.77	.205	.04	.550	.538	.477	.310	.877
Bridge work	3.28	.137	.04	.337	.606	.521	.164	.142
Heavy machinery. . .	5.70	.233	.038	.581	.665	.453	.707	.160
Heavy machinery. . .	8.55	.306	.06	.799	.600	.475	.627	.342
Average	5.57	.220	.044	.567	.602	.481	.452	.380
Light machinery . . .	2.75	.276	.034	.204	.155	.095	.790	.099
Small tools	8.00	.400	.09	.689	.127	.119	.109	.152
Small tools	2.49	.233	.03	.240	.121	.113	.881	.227
Sewing machines . . .	4.36	.430	.05	.397	.269	.208	.180	.204
Sewing machines . . .	5.08	.134	.034	.406	.172	.154	.181	.093
Screw machines. . . .	6.33	.381	.05	.633	.291	.235	.296	.396
Average	4.83	.309	.048	.428	.189	.154	.406	.195

For group driving determine average horse-power for each tool, add these together and use a motor with a capacity of from 40 to 70 per cent of the total thus obtained. The size of motor will depend upon the way the machines are worked — i.e., cutting speed, feed, material cut, and whether modern air-hardened tools are used; also to what extent machines are to operate simultaneously. The larger the group the smaller the motor relative to total power.

Motor Power for Machine Tools. Actual Installations.

William R. Trigg Works.

Horse-power of motors used at the Wm. R. Trigg Works, Richmond, Va. (See article by Wm. Burlingham, in September, 1902, *Machinery.*)

Machine.	Horse-Power of Motor.
18 in. Cincinnati D. H. shaper	3
10 ft. Pond boring mill	20
18 in. Newton slotter	7½
No. 6 Baush radial drill	5
5 ft. radial drill	5
14 in. Newton slotter	5
36 in. × 12 ft. Woodward & Powell planer	15
56 in. × 56 in. × 12 ft. Gray planer	20
30 in. × 30 in. × 8 ft. Woodward & Powell planer	10
No. 5 Mitts & Merrill keyseater	3
No. 1 Newton floor boring machine	7.5
38 in. × 44 ft. shaft lathe	7.5
Niles hor. boring machine	15
No. 4 duplex milling machine, Newton	10
7 ft. Betts boring mill	15
10-in. Betts slotter	3
51-in. Baush boring mill	7.5
No. 1 Acme bolt cutter	7.5
42 in. × 42 in. × 20 ft. planer	15
Dallett & Co. portable deck planer	5
62 in. × 30 ft. Putnam lathe	10
36 in. × 25 ft. Putnam lathe	7.5
22 ft. Bending rolls	
Driving	35
Lifting	10
12 in. straightening rolls	15
No. 3 double punch	10
Duplex planer	15
Double angle shear	10
No. 4 punch	10
No. 4 punch	10
No. 2 punch	5
No. 3 hor. punch	7.5
No. 6 Sturtevant blower	12

Hannibal Shops.

Horse-power of motors used at the Hannibal shops of the St. Joseph and Hannibal Ry. (*Railroad Gazette.*)

MACHINE SHOP.

Machine.	Horse-Power of Motor.
54 in. planer	15
42 in. planer	10
32 in. planer	7.5
Emery grinder	
Grindstone	
Double centering machine	3
90 in. driving wheel lathe	6
2 quartering ends of same	3
48 in. lathe	5
18 in. slotter	
22 in. shaft lathe	5
Car wheel borer	5
Car wheel press	10

Machine.	Horse-Power of Motor.
Journal lathe	
Grindstone	10
32 in. lathe	4
18 in. shaper	5
40 in. vertical drill	2
4-spindle gang drill	7.5
Milling machine	3
Grinding machine	3
32 in. lathe	
Flat turret lathe	4
18 in. lathe	
18 in. brass turret lathe	
16 in. lathe	4
16 in. lathe	
16 in. lathe	
Drill	5
No. 5 radial drill	
Acme triple bolt cutter	
2 in. double bolt cutter	5
No. 6 radial drill	5
No. 5 oscillating grinder	25
24 in. lathe	
24 in. lathe	5
Acme nut tapper	3
16 in. tool room lathe	2
No. 2 oscillating grinder	
Twist drill grinder	5
Boiler Shop.	
No. 6 Niles power bending rolls	35
Double punch and shears	6
Flue tumblers	15
Flue cutter	
Flue scarfer	3.5
Small punch	2
Blacksmith Shop.	
Bolt header	
Grindstone	5
Bolt shears	5
Punch and shears	7.5
Bradley hammer	5
Forge blower	15
Forge fan	10
Wood Mill.	
Automatic cut-off saw	10
38 in. band resaw	8
Vertical borer	7.5
Automatic car gainer	15
Mortiser	15
Buzz planer	7.5
Single surfacer	13
Planer and matcher	25
Self-feed large rip saw	25
Small rip saw	15
Four-sided timber planer	45
Power feed railroad cutoff saw	10
Rip saw	15
Outside moulder	22.5
Double surfacer	17.5
Upright moulder	9.5
Large tenoner	7.5
Scroll saw	2

Machines.	Horse-Power of Motor.
Sharpener and gummer	
Band saw, setter and filer	
Emery wheels	
Grindstone	5
Shavings exhauster	50
Elevator	7.5
Cabinet Shop.	
Patternmaker's lathes	5
Scroll saw	3
Tenoning machine	5
Hollow chisel mortiser	4
Universal saw bench	5

Central Railroad of New Jersey Shops.

Horse-power of motors used at the Central Ry. of New Jersey Shops. (*Railroad Gazette.*)

Lathes.	Horse-Power of Motor.
88 in. wheel	7½
72 in. driving wheel	5
Single head axle	2
Double head axle	5
36 in. × 16 ft.	4
33 in. × 18 ft.	3
30 in. × 12 ft.	3
24 in. × 16 ft.	3
42 in. × 14 ft.	3
28 in. × 12 ft.	2
Planers, Slotters, Shapers.	
60 in. × 60 in. × 25 ft. Pond planer	15
36 in. × 36 in. × 10 ft. Pond planer	5
36 in. × 36 in. × 10 ft. planer	7½
24 in. × 24 in. × 6 ft. Pond planer	5
48 in. × 54 in. × 14 ft. planer	7½
24 in. crank planer	4
16 in. traveling head shaper	3
8 in. slotter	3
14 in. slotter	4
24 in. slotter	4
Boring and Turning Mills — Boring Machines.	
80 in. boring mill	5
39 in. boring mill	5
39 inch vertical boring machine	3
36 in. car wheel boring machine	5
8 ft. boring mill with slotter	7½
Driving wheel quartering machine	5
Rod borer	3
Drill Presses.	
No. 3 Bickford radial drill	3
30 in. drill press	2
30 in. drill press	2
40 in. drill press (floating)	3
40 in. drill press	3
40 in. drill press (floating)	3
8-spindle arch-bar drill	5
Grinders.	
B. & S. surface grinder	3
Water tool grinder	5
Angle cock grinder	3

Miscellaneous.	Horse-Power of Motor.
54 in. throat single end punch	10
No. 6 bulldozer complete	7½
3 in. heading and forging machine	10
Newton cold-saw	10
½ in. bolt heading machine	5
½ in. Acme single head bolt cutter	2
Bolt shears	4
10 ft. boiler rolls	5
84 in. driving wheel press	5
42 in. car wheel press	5
36 in. car wheel press	3

An Ideal Railway Shop.

Estimated motor power for various tools for a railway shop. (From a paper read before the Master Mechanics' Convention, June, 1902, by L. R. Pomeroy.)

Lathes.	Horse-Power of Motor.
90 in. driving wheel	7.5
80 in. driving wheel	7.5
42 in. truck wheel tire turning, heavy	5
Axle, single, heavy, for driving axles	5
Axle, double head	5
48 in. × 14 ft. engine, heavy	5
36 in. × 16 ft. engine, heavy	3
30 in. × 12 ft. engine, heavy	3
28 in. × 12 ft. engine, heavy	2
26 in. × 8 ft. engine, very heavy	2.5
20 in. × 10 ft. engine, medium	2
18 in. × 10 ft. engine, medium	2
16 in. × 8 ft. engine, medium	2
2 × 24 flat turret	3
21 in. heavy screw machine	3
20 in. universal monitor, for brass	1
18 in. universal monitor, for brass	2
16 in. Fox lathe, with turret	2
12 in. speed lathe	2
Drill Presses.	
72 in. radial, heavy	5
60 in. radial, heavy	3
48 in. radial, medium	2
40 in. upright heavy	3
36 in. upright heavy	2½
30 in. upright, heavy	2
20 in. upright, light	2
Cotter drilling machine	2
Sensitive drill	.5
Grinding Machines.	
Landis grinder for piston rods, etc.	3
Surface grinder	3
Universal grinding machine (same as No. 2 B. & S.)	2
Twist drill grinder	2
Sellers or Disholt tool grinder	3
Two 20 in. wet tool grinders	5
Small tool grinder (B. & S. No. 1)	1
Flexible swinging, grinding, and polishing machine	3
Large buffing and polishing wheel	2½
Planers.	
72 in. × 72 in. × 14 ft.	15
60 in. × 60 in. × 28 ft.	15
54 in. × 52 in. × 14 ft.	15
42 in × 42 in. × 16 ft.	10
38 in. × 38 in. × 10 ft.	7.5
36 in. × 36 in. × 10 ft.	7.5
30 in. × 30 in. × 8 ft.	5

	Horse-Power of Motor.
Shapers.	
16 in traveling head shaper	2
16 in. shaper	2
14 in. shaper	2
12 in. shaper	2
Richards side planer, 20 in. × 6 in.	5
Slotting Machines.	
18 in. slotting machine	7.5
14 in. slotting machine	5
10 in. slotting machine	3
Colburn keyseating machine	5
Boring Mills.	
84 in. boring and turning mill, two heads	7.5
62 in. boring and turning mill, two heads	5
37 in. boring and turning mill, two heads	5
30 in. horizontal boring and drilling machine	5
Cylinder boring machine	7.5
Milling Machines.	
Heavy vertical milling machine	10
Vertical milling machine (No. 6 Becker-Brainard)	7.5
Heavy slab milling machine	15
Universal milling machine (heavy)	5
Plain horizontal milling machine (same as Becker-Brainard No. 7)	4
Small, plain milling machine for brass work	2.5
Universal milling machine (same as B. & S. No. 3)	1
Bolt and Nut Machinery.	
2½ in. single head bolt cutter	2
1½ in. double head bolt cutter	4
5-spindle nut-tapping machine	3
Bolt-pointing machine	3
Nut-facing machine	3
Heavy power hacksaw	2
Small power hacksaw	1
Blacksmiths' Tools.	
Quick-acting belt hammer	5
3 in. bolt heading and upsetting machine	3
1½ bolt heading and upsetting machine	3
Heavy shear to cut 4 × 4 bar	7½
Shear to cut up to 5 × 1 in.	5
Shear to cut up to 1¼ in. round iron	5
No. 3 Newton cold saw cutting-off machine	5
Boiler Tools.	
16 ft. gap hyd. fixed riveter, pump, accumulator, and crane, complete	100
Heavy boiler plate punch or shear, 48 in. throat depth	10
Heavy boiler plate punch or shear, 30 in. throat depth	7.5
Tank plate punch, 30 in. throat depth	5
Tank plate shear, 24 in. throat depth	5
Boiler plate shear, 30 in. throat depth, ¾ in. plate	7.5
Flange punch	5
12 ft. boiler rolls for ¾ in. plate	
Light 6 ft. rolls	35
Plate planer, 20 ft.	3
Woodworking Tools.	
Patternmaker's lathe	5
Band saw	3
Medium-sized saw bench, crosscut and rip saw	5
Medium-sized hand planing and jointing machine	5

Horse-power in Machine-shops; Friction; Men Employed.

(Flather.)

Name of Firm.	Kind of Work.	Horse-power. Total.	Required to drive Shafting.	Required to drive Machinery.	Per Cent to drive Shafting.	Number of Men.	No. of Men per Total H. P.	No. of Men per Effective H.P.
Lane & Bodley	E. & W.W.	58				132	2.27	
J. A. Fay & Co.	W. W.	100	15	85	15	300	3.00	3.53
Union Iron Works . .	E., M. M.	400	95	305	23	1600	4.00	5.24
Frontier Iron & Brass W'ks	M. E., etc.	25	8	17	32	150	6.00	8.82
Taylor Mfg. Co.	E.	95				230	2.42	
Baldwin Loco. Works .	L.	2500	2000	500	80	4100	1.64	8.20
W. Sellers & Co. (one department)	H. M.	102	41	61	40	300	2.93	4.87
Pond Machine Tool Co. .	M. T.	180	75	105	41	432	2.40	4.11
Pratt & Whitney Co. . .	"	120				725	6.04	
Brown & Sharpe Co. . .	"	230				900	3.91	
Yale & Towne Co. . . .	C. & L.	135	67	68	49	700	5.11	10.25
Ferracute Machine Co. .	P. & D.	35	11	24	31	90	2.57	3.75
T. B. Wood's Sons . . .	P. & S.	12				30	2.50	
Bridgeport Forge Co. .	H. F.	150	75	75	50	130	.86	1.73
Singer Mfg. Co.	S. M.	1300				3500	2.69	
Howe Mfg. Co.	"	350				1500	4.28	
Worcester Mach. Screw Co.	M. S.	40				80	2.00	
Hartford " " "	"	400	100	300	25	250	0.62	0.83
Nicholson File Co. . .	F.	350				400	1.14	
Averages	. . . . .	346.4			38.6%	818.3	2.96	5.13

Abbreviations: E., engine; W.W., wood-working machinery; M. M., mining machinery; M. E., marine engines; L., locomotives; H. M., heavy machinery; M. T., machine-tools; C. & L., cranes and locks; P. & D., presses and dies; P. & S., pulleys and shafting; H. F., heavy forgings; S. M., sewing-machines; M. S., machine-screws; F., files.

Tests at the Wm. R. Trigg Works.

(See September, 1902, *Machinery*.)

62 in. × 30 ft. lathe, turning hard cast iron. Tool of Sanderson self-hardening steel. About 6 H.P. required to run the lathe light. Experiments: (1) Cut, ⅛ in. deep, 1-16 in. feed; 21 ft. cutting speed; 33.8 lbs. metal removed per hour; 1.15 H.P. = .034 lb. wt. metal removed per hour. (2) Cut, ⅛ in. deep, 1-16 in. feed; 33 ft. cutting speed; 54.8 lbs. metal removed per hour; 1.52 H.P. = .028 lb. wt. metal removed per hour.

36 in. × 12 ft. Woodward & Powell planer, two tools cutting on cast steel. Cuts were ⅛ in. deep by 1-16 in. feed. First experiment, cutting speed, 17.15 ft. per minute; reverse speed, 60 ft. per minute. H.P. cutting, 2.15; returning, 2.22; reverse to cut, 4.77; reverse to return, 11. Second experiment, cutting speed, 21.83 ft. per minute; reverse speed, 68.6 ft. per minute. H.P. cutting, 2.85; returning, 3.06; reverse to cut, 6.52; reverse to return, 11. In these experiments the reverse to cut consumed (of course for an instant only) from 2.22 to 2 29 times the power required to cut; and the reverse to return

from 4.95 to 3.59 the power required to return; or from 5.11 to 3.86 the power required for cutting.

36 in. × 25 ft. Putnam lathe, cutting shaft nickel steel, oil tempered and annealed, with Sanderson self-hardening tool steel. Diameter work, 9¾ in. Experiments: (1) Cut ⅛ in. deep × ⅛ in. feed, 5.76 revolutions. H.P. = 1.5. (2) Cut 3-16 × ⅛, 4.65 revolutions, H.P. = 1.76. (3) Cut ¼ × ⅛, 3.28 revolutions, H.P. = 1.9. (4) Cut ¼ × ⅛, 2.71 revolutions, H.P. = 1.26.

Another line of experiments was conducted with the same lathe cutting nickel steel shaft 9¾ in. diameter, cut constant at ¼ in. deep and feed ⅛ in. per revolution. The speed of motor was gradually increased from No. 3 notch to No. 11 notch of the controller, representing an increase of motor revolutions from 220 to 700 per minute, or an increase in the revolutions of the lathe from 3.03 per minute to 9.64 per minute. The H.P. required increased from 1.068 to 4.26.

Cotton Machinery.

Wm. O. Webber.

Looms.

Make.	Width.	Picks per Min.	Picks per Inch.	Warp. Weft.	Horse-power.
Amoskeag, Whitin	49 in.	142 ft.	68 × 80	24 × 31	.254
Amoskeag, Whitin	45 in.	142 ft.	68 × 80	24 × 31	.214
Lowell Shop	40 in.	160 ft.	72 × 80	24 × 31	.273
Lowell Shop	36 in.	160 ft.	64 × 90	24 × 38	.286
Lowell Shop	32 in.	170 ft.	64 × 88	27½ × 38	.311
Whitin	40 in.	144 ft.	80 × 84	28 × 33	.2315
Amoskeag	48 in.	144 ft.	80 × 84	28 × 33	.257
Whitin	40 in.	147 ft.	84 × 92	28 × 33	.256

Slashers. — 2,872 ends

Cut in 84 seconds = 3.93 horse-power.
Cut in 64 seconds = 4.574 horse-power.
Cut in 52 seconds = 5.53 horse-power.

Warpers. — 359 ends, 50 yds. per min. = .313 H.P.

Shears, 4 blades and fans, 1,800 R.P.M.
100 yards per min. 42 inch cloth = 6.07 H.P.

Cards.

			Horse-power.
Finisher, Lowell	36 inch cylinder	128 R.	.187
Finisher, Amoskeag	36 inch cylinder	140 R.	.247
Finisher, Whitin	36 inch cylinder	140 R.	.19
Lowell breaker	36 inch cylinder	128 R.	.225
Amoskeag breaker	36 inch cylinder	140 R.	.247
Whitin breaker	36 inch cylinder	140 R.	.173
Revolving top flat card . . .	40 inch cylinder	162 R.	.921

Printing Machinery, Power Required.

WM. O. WEBBER.

	Horse-Power.
30 in. × 52 in. 2 rev. No. 8 Cottrell press, 19 impressions per minute	1.189
27 in. × 41 in. No. 20 Adams press, 16 impressions per minute	.68
32 in. × 54 in. Huber perfecting press	2.44
43 in. × 64 in. Huber perfecting press, automatic feed	5.55
27 in. × 41 in. No. 4 Adams job press	.43
26 in. × 40 in. No. 2 Adams job press	.337
32 in. × 54 in. No. 1 Potter cylinder roller press	.50
26 in. No. 1 Hoe perfecting press	5.41
Web paper-wetting machine	.52

NEWSPAPER PRINTING MACHINERY.

	Horse-power.
One 10 page web perfecting press, 12,000 per hour	15.39
One 10 page web perfecting press, 24,000 per hour	31.
One 12 page web perfecting press, 12,000 per hour	20.45
One 12 page web perfecting press, 24,000 per hour	29.56
One 32 page web perfecting press, 12 000 per hour	28.73

CALICO PRINTING MACHINERY — Capacity 100 yds. print goods per min.

	Rev. per min.	Foot-pounds.	Horse-power.
One 19 cylinder, soaper and dryer, full	110	2,182	3.97
One cutting machine, full	65	1,525	2.77
One set drying cans to cutting machine, full	110	1,282	2.33
One back starcher, 3 wide machines, full	115	2,330	4.24
One indigo skying machine, 5 vats, all working full	64	2,635	4.78
One 40 in. 5 roll calender, working full	234	5,390	9.80
One single color printing machine	...	.....	10.6

Power Required For Sewing-Machines.

Light-running	20	machines to 1 h.p.
Heavy work on same	15	" " "
Leather-sewing	12	" " "
Button-hole machines	8 to 12	" " "

POWER CONSUMPTION.

Character of Installations.	Average K.W. Hours per Month.	Average Connected Motor Load, H.P.	Individual or Group Drive.*	Ave. No. of Motors.	Connected Motor Load Times Average Load.	Total No. of Installations
Bakeries	1,582	32.8	G	2.7	27.8	17
Bakeries	705.3	22.5	I	3.1	19.5	8
Boiler shops	326.7	51.4	G	2.8	33.3	11
Boiler shops	1,172	32.2	I	5.2	20.7	5
Boots and shoes	3,050	39.7	G	5.8	42.8	13
Box making	1,555	18.1	G	4.3	45.4	20
Blacksmiths	586	9.4	G	2.2	34.2	12
Brass finishing	5,736	40.5	G	7.4	45.0	9
Butchers and packers	1,990	24.8	G	2.0	36.4	13
Butchers and packers	1,049	36.9	I	6.7	18.8	10
Breweries	12,310	94.0	G	4.6	33.0	8
Carpet cleaning	644	14.5	G	1.6	30.1	12
Cement mixing	2,009	37.5	G	1.0	24.9	4
Candy manufactory	1,893	26.6	G	3.5	33.6	10
Candy manufactory	796	29.9	I	7.5	16.3	8
Cotton mills	11,829	99.0	G	3.0	60.1	3
Carriage works	2,091	24.8	G	3.5	35.5	22
Chemical works	4,802	109.	G	5.5	23.5	6
Clothing manufacturing	1,181	23.	G	4.0	44.5	33
Grain elevators	3,842	114.4	G & I	3.8	32.6	19
Feather cleaners	2,447	54.4	G & I	5.5	25.7	2
General manufacturing	6,133	67.5	G & I	6.4	33.9	181
Engrv. and electrotyping	863	12.4	G	2.5	46.9	8
Engrv. and electrotyping	2,369	46.3	I	26.7	22.5	7
Glass grinding	2,760	33.5	G	3.0	36.6	6
Foundries	2,057	27.7	G	2.3	43.7	15
Foundries	2,419	81.1	I	7.0	21.3	18
Furniture manufacturing	1,750	35.7	G	3 6	35.6	9
Flour mills	41,276	148.5	G	3.1	48.1	13
Hoisting and conveying	2,905	70.5	G	6.4	28.3	5
Hoisting and conveying	6,562	253.	I	20.0	13.0	9
Ice cream	596	31.	G & I	5.4	35.9	7
Refrigeration	4,645	36.7	G & I	2.5	53.4	17
Jewelry manufacturing	2,526	31.7	G	4.6	31.6	5
Laundries	676	10.8	G	2.1	34.0	19
Marble finishing	1,464	19.8	G & I	1.3	51.3	12
Machine shops	4,006	57.6	G	4.5	34.5	51
Newspapers	3,150	47.4	G	4.8	38.0	24
Newspapers	4,975	137.0	I	17.3	15.1	21
Ornamental iron works	2,771	38.4	G	3.6	41.6	9
Paint manufacturing	2,814	60.4	G & I	4.6	26.5	11
Printers and bookbinders	1,147	20.4	G	2.6	39.5	54
Printers and bookbinders	6,215	76.8	I	24.0	26.0	39
Plumbing manufacturing	3,020	42.4	G	4.8	21.5	15
Rubber manufacturing	1,051	26.0	G & I	15.	24.7	2
Sheet metal mfg.	1,321	38.8	G	3.7	27.3	17
Soap manufacturing	3,434	73.0	G	10.0	27.6	2
Seeds	2,917	55.1	G & I	5.8	24.4	5
Structural steel	6,514	176.0	I	16.1	18.5	6
Structural steel	77,704	552.1	G	35.6	31.1	6
Stone cutting	7,425	76.5	G & I	3.8	34.4	20
Tanners	2,466	28.6	G	2.6	54.6	5
Tobacco working	3,441	62.3	G	7.0	37.5	4
Wholesale groceries	2,005	47.0	G & I	4.5	26.0	17
Wood working	2 306	39.5	G & I	3.6	33.3	64
Woolen mills	20,985	150.	G	3.0	71.0	1
Averages	3,500	.....	.....	6.08	33.9	951

* G. stands for Group. I. for Individual.

Power for Electric Cranes.

Journal Society of Western Engineers.

The following data on the power required for electric traveling cranes were given by Mr. S. S. Wales at a meeting of the Engineers' Society of Western Pennsylvania.

An electric crane is divided into three general parts — bridge, trolley, and hoist, each of which has its own motor and controlling system, and each subjected to different conditions of work.

For the bridge, where the ratio of axle bearings to diameter of wheel is between one to five and one to six, the following table will answer our purpose for weights and traction for different spans:

Let L = working load of crane in tons.
W = weight of bridge alone in tons.
w = weight of trolley alone in tons.
S = speed in feet per minute.
P = pounds per ton required.

Span.	W.	P.
25 ft.	$.3L$	30 lbs.
50 ft.	$.6L$	35 lbs.
75 ft.	$1.\ L$	40 lbs.
100 ft.	$1.5L$	45 lbs.

For the trolley we would assume the weight and traction as shown in the following table:

L.	W.	P.
1 to 25 tons.	$.3L$	30 lbs.
25 to 75 tons.	$.4L$	35 lbs.
75 to 150 tons.	$.5L$	40 lbs.

Now the power required for bridge will be:

$$\frac{(L + W + w) \times P \times S}{33{,}000} = \text{H.P.}$$

which result will be used in connection with the motor characteristic to determine the gear reduction from motor to track wheel. As the nominal H.P. rating of a series motor is based on an hour's run with a rise of 75° C. above the surrounding air and as conditions of bad track, bad bearings, or poor alignment of track wheels may be met with, $1\frac{1}{2}$ times the above result should be taken as the proper size motor for the bridge.

For the trolley the power required would be:

$$\frac{(L + w) \times P \times S}{33{,}000} = \text{H.P.}$$

which will be used for speed and gear reductions, but $1\frac{1}{4}$ times this should be used for size of motor.

For hoist work we cannot have so large margin of power, as the variation from full load to no load may imply a possible dangerous increase of speed, and unless the crane is to be subjected to its maximum load continuously or is to be worked where the temperature of the surrounding air will be high, it is safe to use the size found by assuming 1 H.P. per 10 ft. ton per minute of hoisting. This is nearly equal to assuming the useful work done as 60 per cent of the power consumed.

As an illustration, let us take a crane of 50-ton capacity, lifting speed of hoist 15 feet per minute. Bridge to be 70 feet span and to run 200 feet per minute with load. Trolley to travel 100 feet per minute with full load. On the foregoing assumption the bridge would weigh 50 tons and require 40 pounds per ton for traction, and the trolley would weigh 20 tons, and require 35 pounds per ton for traction.

The power for the bridge would be:

$$\frac{120 \times 40 \times 200}{33{,}000} = 29 \text{ H.P.}$$

and the size motor 1½ times this would give 43½ H.P. or 50 H.P., this being the nearest standard size, and the specification should read not less than 50 H.P. motor to be used for bridge travel.

Similarly the trolley will require

$$\frac{70 \times 35 \times 100}{33{,}000} = 7.43 \text{ H.P.}$$

and the size motor required will be 1¼ times this, or 8.28 H.P.

The hoist would require

$$\frac{50 \times 15}{10} = 75 \text{ H.P.}$$

and would be specified not less than 75 H.P. motor to be used as hoists.

Operating Cost of Electric Elevators.

From Circular of Cincinnati Gas and Electric Co.

SIX MONTHS' AVERAGE.

Freight Elevators.*			Passenger Elevators.†		
No.	H.P.	Average Monthly Cost.	No.	H.P.	Average Monthly Cost.
1	10	$11.92	1	15	$39.54
1	10	10.00	2	20½	19.05
5	20	33.01	1	18	65.83
1	5	5.00	2	17½	17.30
1	5	4.00	1	22½	23.57
1	5	5.00	1	15	14.22
1	5	4.00	5	73	59.40
1	5	7.37	2	32	38.16
1	5	4.00	3	38½	34.55
1	5	11.86	2	10½	19.80
1	10	9.50	1	8	9.73
1	10	9.50	1	8	14.87
1	8½	9.49	1	11	18.42
2	25	23.75	1	15	9.15
1	5	3.50	1	15	22.01
1	10	9.50	1	15	4.75
1	5	4.75	2	16½	17.62
1	10	11.30	1	12½	14.66
1	8	7.60	2	12½	12.33
1	20	28.06	2	11	17.74
1	7½	7.12	3	41	37.95
1	5	4.75	1	10	23.49
1	5	4.60	1	16	18.24
1	5	5.25	1	10	19.05
1	7½	7.12	1	10	19.50
			1	13	13.30
30	221½	$241.95	1	10	18.98
			1	26	35.31
			45	523	$658.58

* Average cost per elevator per month $8. Average cost per month per horse-power, $1.09.

† Average cost per elevator per month, $14.64. Average cost per month per horse-power, $1.26.

Saving by Electric Drive. — Fig. Nos. 2 and 3 show graphically the saving made in power by the use of electric drive over the use of shafting and belting.

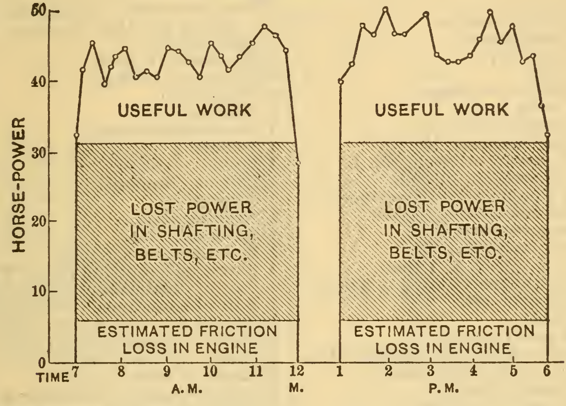


FIG. 2. 1895, Diagram of Losses in Power Transmission, Factory of Central Stamping Co., Brooklyn, N.Y. Crocker-Wheeler Electric Company.

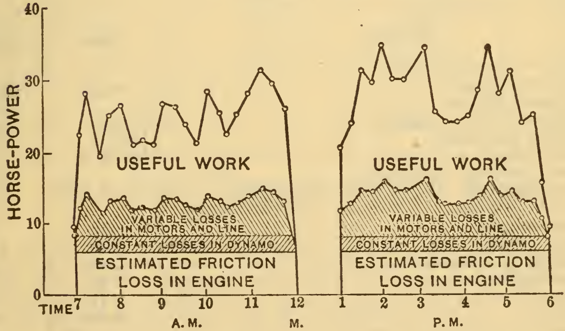


FIG. 3. 1895, Diagram of Losses in Power Transmission, Factory of Central Stamping Co., Newark, N.J. Crocker-Wheeler Electric Company.

LIST OF TOOLS AND SUPPLIES USEFUL IN INSTALLING ELECTRIC LIGHTS AND DYNAMOS.

1 Tool chest.
1 Magneto and cable.
1 Speed indicator.
1 Tape line, 75 ft.
1 Rule, 2 ft.
1 Scraper, for bearings.
1 Blow lamp.
1 Clawhammer, No. 13.
1 Ball pein hammer, No. 24.
1 B. & S. pocket wrench, No. 4.
1 Monkey wrench, 10 inch.
1 Set (2) Champion screw-drivers.
1 Large screw-driver, 12-inch.
1 Off-set screw-driver.
1 Ratchet brace, No. 33.
Bits, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1 inch.
1 Clarke Expansive bit, $\frac{7}{8}$ to 3 inch.
1 Screw-driver bit.
1 Gimlet bit.
1 Wood countersink.
1 Extension drill, $\frac{3}{8}$ in. length, 24 in.
1 Long or extension gimlet.
1 Cold chisel, $\frac{3}{4}$ inch.
1 Half round cold chisel.
1 Cape chisel.
1 Wood chisel, firmer paring, $\frac{5}{8}$ inch.
1 Brick drill.
Files, one each: round, flat, half-round and three-square.
1 Saw, 20 inch.
1 Hack-saw, 10 inch.
10 Extra saw blades.
1 Plumb bob.
1 Brad awl.
1 Pair carbon tongs.
1 Soldering copper, No. 3.
1 Pound of solder.
1 Pair of climbers.
1 Come-along.
1 Splicing-clamp.
1 Strap and vise.
1 Pair line pliers, 8 inch.
1 Pair of side-cutting pliers, 5 inch.
1 Pair of diagonal-cutting pliers, 5 in
1 Pair of round-nose pliers, 5 inch.
1 Pair of flat-nose pliers, 5 inch.
1 Pair of burner pliers, 7 inch.
6 Sheets of emery cloth.
6 Sheets of crocus cloth.
2 Gross of assorted machine screws.
2 Gross of assorted wood screws.
150 Special screws.
Taps, 6–30, 10–24, 12–24, 18–18.
Drills, 34, 21, 9, 15–64.
Tap wrench.

The following-named tools will probably be required in constructing lines for city or commercial lighting:

(Davis.)

Article.	Size.	Cost about
Stubs' pliers, plain	8 in.	$2.00
Climbers and straps	.....	3.00
Pulley-block and ecc. clamp	To No. 3 B. & S.	8.00
Come-along and strap		2.25
Splicing-clamps		2.50
Linemen's tool-bag and strap	.....	4.80
Soldering-furnace	.....	6.00
Gasoline blow-pipes	.....	6.00
Soldering coppers	2 lb.	.95
Pole-hole shovels	8 ft.	1.50
Pole-hole spoon, regular	7 ft.	1.25
Octagon digging-bars	8 ft.	3.50
Tamping-bars	7 ft.	2.60
Crowbar	10 lb.	.90
Pick-axe	.....	.75
Carrying-hook, heavy	.....	6.00
Cant-hook	4 ft.	2.00
Pike-poles	16 ft.	2.40
Pole-supporter	6 ft.	12.00
Comb, pay-out reel and straps	.....	20.00
Nail-hammer	1 lb.	1.00
Linemen's broad hatchets	6 in.	1.50
Drawing-knives	12 in.	2.10
Hand-saw	26 in.	1.50
Ratchet-brace, bits	10 in.	3.00
Screw-drivers	8 in.	.80
Wrench	12 in.	1.25
Bastard file	12 in.	.30

APPROXIMATE LIST OF SUPPLIES

REQUIRED IN INSTALLING 15 CITY LAMPS AND 20 COMMERCIAL LAMPS ON A FIVE-MILE CIRCUIT, SETTING POLES 132 FEET APART.

(Davis.)

Articles.	Size or Diameter.	Price about	Quantity.
Electric-light poles . . .	30 ft., 6 in.	$2.40 each	180
Electric-light poles . .	35 ft., 7 in.	4.15 "	. . .
Electric-light poles . . .	40 ft., 7 in.	5.50 "	40
Cross-arms, 4-pin	4 ft.	.30 "	200
Painted oak pins	1½ in.	.02 "	800
Oak pins and bolts . . .	1½ in.	.07 "	24
Iron break-arms	. . . . . .	.75 "	25
Lag-screws and washers .	½ × 7 in.	.04 "	400
Glass insulators, D. G. . .	. . . . . .	.07½ "	850
Pole steps	⅝ × 8 in.	.05 "	2500
Guy stranded cable . . .	⅜ in.	.07 lb.	500 lbs.
Cross-arm brace and bolts	. . . . . .	.20 each	40
Line wire	6 BS	125.00 mi.	6 miles

MATERIAL REQUIRED FOR CONNECTING IN LAMPS.

(Davis.)

Sleet-proof pulleys . . .	. . . . . .	$0.75 each.	30
Street-lamp cleats, iron .	. . . . . .	.25 "	15
Arc-lamp cordage	⅜ in.	1.25 hd. ft.	25
Suspension cable	¼ in.	.02½ ft.	3000 ft.
Hard-rubber tube	⅜ × ⅝ in.	1.50 lb.	5 lbs.
Soft-rubber tubing . . .	⅜ in.	.20 ft.	200 ft.
Arc cut-out	. . . . . .	3.50 each	20
Porcelain insulators and screws	. . . . .	2.40 hd.	400
Oak brackets and spikes .	. . . . . .	2.50 "	150

THAWING FROZEN WATER PIPES ELECTRICALLY.

The use of electricity for thawing out frozen underground water pipes requires a transformer say of 10 or 20 kilowatts capacity, which can be taken to the locality required, connecting the primary with the high tension circuit passing the place, and then connecting the secondary through an ampere meter and rheostat to the service in trouble. Where services from the street mains to two adjacent houses are both frozen, it is only necessary to connect the secondary circuit to the kitchen faucet of both houses and thus the circuit is complete through the service of one house to the street main and back through the service of the second house.

Where the service of but one house is to be thawed, one end of the secondary circuit is connected to the kitchen faucet and the other end to the nearest street hydrant or other street connection. Currents varying from 20 to 500 amperes are used, obviously, varying according to the conditions; and the time taken to thaw the ice sufficiently to start the water running will be from 10 to 45 minutes or perhaps 3 to 8 hours, according to circumstances.

The average time for the ordinary house service will seldom exceed 45 minutes, while for a five or six inch pipe that has been frozen solid the highest amount of current and time mentioned will be required.

It is very seldom necessary to melt the entire plug of ice, as the thawing of a thin sheet nearest the metal will start the water running and that will consume the ice in a short time.

The following table is compiled from data that have appeared in various periodicals. It represents average conditions for last year, and shows what may be expected in the future:

Size Pipe.	Length.	Volts.	Amps.	Time Required to Thaw.
¾″	40 ft.	50	300	8 min.
¾″	100 ft.	55	135	10 min.
¾″	250 ft.	50	400	20 min.
1″	250 ft.	50	500	20 min.
1″	700 ft.	55	175	5 hrs.
4″	1300 ft.	55	260	3 hrs.
10″	800 ft.	70	400	2 hrs.

The following notes on melting points of various substances may be of assistance in checking thermometers and showing the safe limits on electrical apparatus that operates in heated conditions.

	C.	F.
Pure cane sugar (granulated) melts at	160	320
Tin melts at	235	455
Bismuth melts at	269	518
Lead melts at	327	618
Zinc melts at	419	788

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