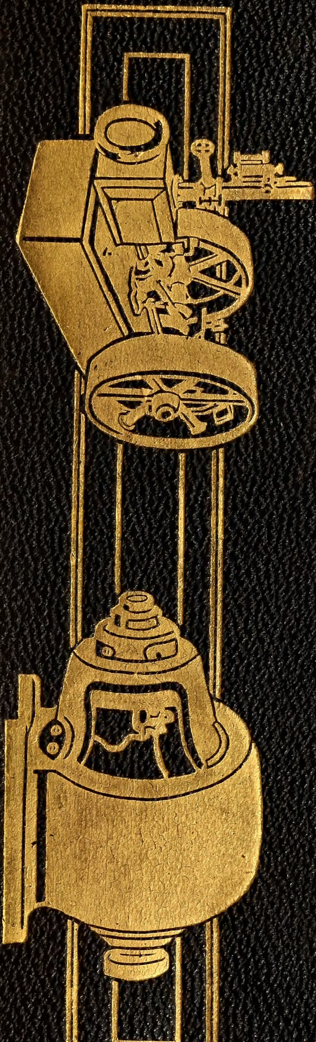

STANDARD

AMERICAN CYCLOPEDIA OF STEAM ENGINEERING

A Treatise on the Care and Management of Steam Engines, Boilers and Dynamos

Including Instructions for an Efficient Management of all Classes of Steam Engines, Boiler Operation, Care of the Boiler, including Washing Out, How to Fire a Boiler, Etc. Valves and Valve Setting, including Correct Adjustment of Single Valve and Corliss Engines. Mechanical Stokers and the Principle Involved in the Action of Automatic Stokers. Steam Turbine Engines, their Construction and Operations, the Fundamental Principles of the Steam Turbine, Types of Steam Turbine, Speed Regulation and Efficiency. Refrigeration, Pumps and Ai mpressors. Electricity for Engineers, including Construction and Operation of Dynamos, Motors, Lamps, Storage Batteries, Etc. A Complete Engineers' Catechism, Embodying Questions and Answers Necessary to Pass Successful Examinations for Licenses for Stationary and Marine Engineer. Mechanical and Machine Drawing, with Plain and Simple Instructions.

FULLY ILLUSTRATED

BY CALVIN F. SWINGLE AND OTHERS

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1915

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STEAM ENGINEERING

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INTRODUCTION

ENGINEERING DIVISION

In the following pages the author proposes to deal mainly with the *operation* of steam engines, boilers, feed pumps, and all the necessary adjuncts of a steam plant, rather than with the *construction* and *erection* of the same, although the designing and construction of steam machinery will receive some attention.

In order to successfully operate a steam plant the engineer in charge should, in addition to his other accomplishments, have at least sufficient technical knowledge to enable him to ascertain, by measurements and calculations, such very important points as the safe working pressure of his boiler, the most economical point of cut off for his engine, whether engine and boiler are properly proportioned for the work to be performed, and many other details which will be treated upon in their proper place.

Without a doubt the most successful operating engineers are those who combine practice with theory, and in order to obtain a practical working knowledge of steam engineering it is absolutely necessary that the young man who desires to become a successful engineer should start in the boiler-room, that he should thoroughly familiarize himself with all of the details of boiler management, and while his hands and eyes are thus gradually being trained to the practical part of the work he should at the same time be training his mind in the theoretical part by reading and studying technical books and journals relative to steam engineering. In order to facilitate this work series of practical questions will follow the close of each chapter, the answers to which may be found in the matter contained in the chapter. And now with the hope that a study of the following pages may prove to be a help to all into whose hands this book may come, the author respectfully dedicates it to his fellow craftsmen, the engineers of America.

C. F. S.

Engineering

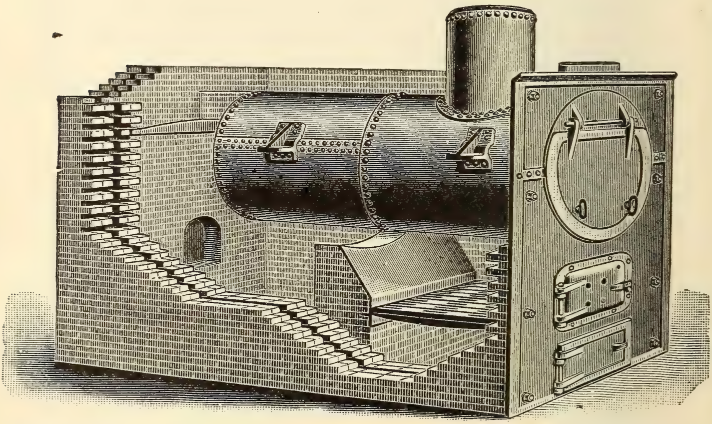
CHAPTER I

THE BOILER

Description of various types—Construction—Rules for ascertaining strength of sheet before and after punching—Strength of rivets—Single and double riveted seams—Triple riveted butt joints, strength of—Force tending to rupture a boiler—Rules for finding the safe working pressure of boilers—Bracing—Rules for bracing—Bracing domes.

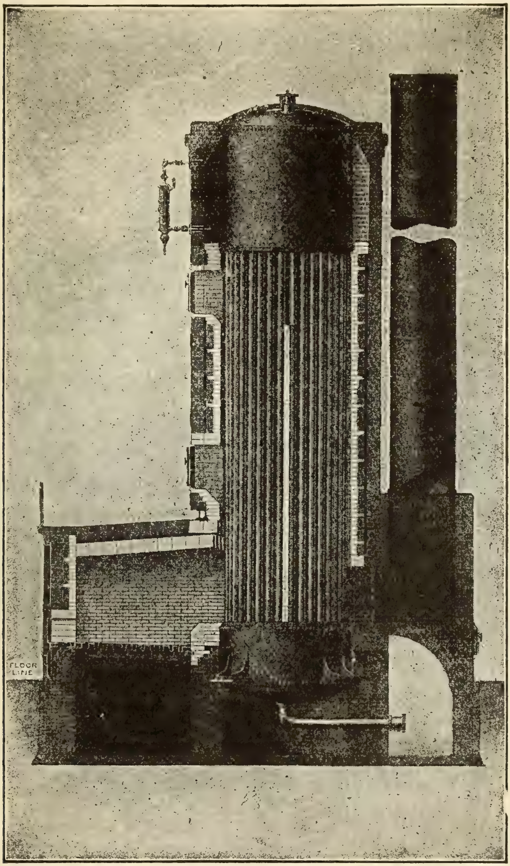
It is hardly within the scope of this book to describe the many and varied types of metallic vessels known as steam boilers in use to-day for the generation of steam for power and other purposes. The author will deal mainly with those types most commonly used in this country for stationary service.

Description. These may be divided into four different classes. The first and most simple type, and the one from which the others have gradually evolved, is the plain cylinder boiler in which the heated gases merely pass under the boiler, coming in contact only with the lower half of the shell and then pass to the stack. These boilers are generally of small diameter (about 30 in.) and great length (30 ft.). Next comes the flue cylindrical boiler, which is somewhat larger in diameter than the former, generally 40 in. diameter and 20 to 30 ft. long, with two large flues 12 to 14 in. diameter extending through it. The return tubular boiler, consisting of a shell with tubes of small diameter (2 to 4 in.) extending from head to head through which the hot gases from the furnace pass on their way to the stack. This boiler, which comes in the third class, is probably more extensively used in the United States for stationary service than any other type. The fourth class comprises the water tube boilers, in which the water is carried in tubes 3 to 4 in. in diameter, sometimes vertical and sometimes inclined, and connected at the top to one end of a steam drum,



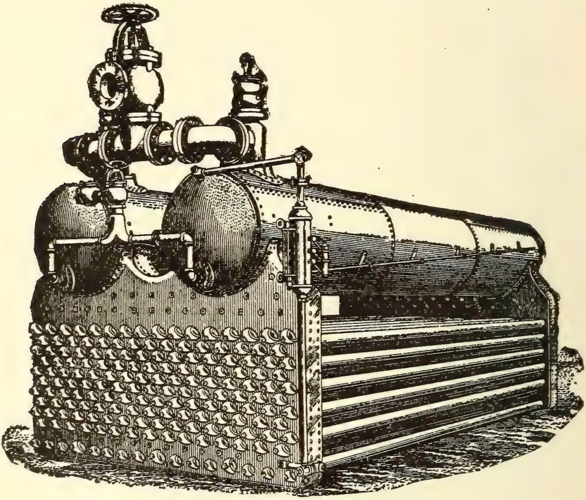
STANDARD HORIZONTAL BOILER WITH FULL-ARCH FRONT SETTING.

and having the lower ends of the tubes connected to a mud drum, which is also connected to the opposite end of the steam drum, thus providing for a free circulation of the water. Of the latter type there have been many different kinds evolved during the last one hundred years, the majority of them having had but a brief existence, being compelled to obey the inexorable law of the survival of the fittest, and to-day there are a few excellent types of water tube boilers which have become standard and are being extensively used. The margin of safety as regards disastrous



WICKES VERTICAL WATER TUBE BOILER.

explosions appears to be in favor of the water tube boiler. It is not contended that they are entirely exempt from the danger of explosion. On the contrary, the percentage of explosions of water tube boilers in proportion to the number in use is probably as large, if not larger, than it is with boilers of the shell or return tubular type, but the results are seldom so destructive of life or property, for the reason that if one or more of the tubes give way the pressure is released and the danger is past.



500 HORSE POWER HEINE WATER TUBE BOILER.

Construction. As the four classes of boilers above referred to are constructed of similar material, although assembled in different ways, the standard rules for calculating strength of joints, bracing, etc., may be applied to all.

The shell should be made of homogeneous steel of about 60,000 lbs. tensile strength. The thickness depending upon the pressure to be carried. The term tensile strength means that it would take a pull of 60,000 lbs. in the direction of its length to break a bar of the material one inch square, or two inches wide by one-half inch thick, or three-eighths of an inch thick by 2.67 in. wide.

The heads are generally made one-eighth of an inch thicker than the shell.

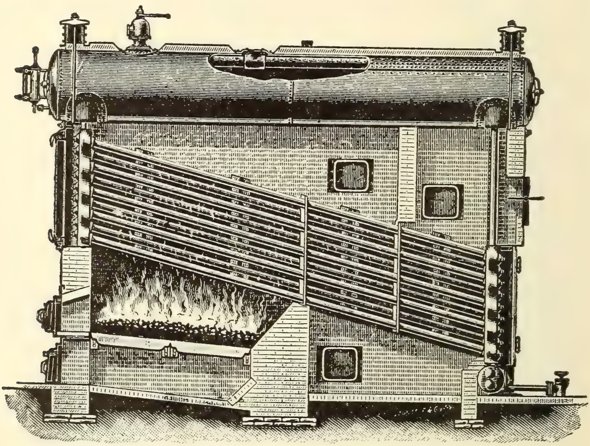
Riveting. Boiler rivets should be of good charcoal iron, or a soft, mild steel of 38,000 lbs. to 40,000 lbs. T. S. No boiler is stronger than its weakest part, and it is evident that a riveted joint has not the full strength of the solid plate. In order to ascertain the safe working pressure of a boiler it is necessary to first determine the strength of the riveted seams, and the method of doing this is as follows: Assume the boiler to be of the horizontal tubular type, 60 in. in diameter by 16 ft. in length. The plates to be of steel $\frac{3}{8}$ in. thick, having a tensile strength of 60,000 lbs. per square inch, the longitudinal seams to be double riveted and the girth seams to be single riveted. The pitch of the rivets, that is the distance from the center of one rivet hole to the center of the next one in the same row, to be for the double riveted seams $3\frac{1}{4}$ in. and for the single riveted seams $2\frac{3}{8}$ in. The diameter of the rivets to be $\frac{7}{8}$ in. and diameter of holes to be $\frac{15}{16}$ in. Assume the rivets to have a T. S. of 38,000 lbs. per square inch of sectional area. First, find strength of a section of solid plate $3\frac{1}{4}$ in. wide, which is the width between centers of rivet holes before punching.

Rule 1. Pitch × thickness × T. S. Thus, $3.25 \times .375 \times 60{,}000 = 73{,}125$ lbs., strength of solid plate.

Second, find strength of net section of plate, meaning that portion of plate left after deducting the diameter of one hole $\frac{15}{16}$ in., which expressed in decimals = .9375 in. from the width of plate before punching.

Rule 2. Pitch − diameter of hole × thickness × T. S. Thus, 3.25 − .9375 × .375 × 60,000 = 52,031 lbs., strength of net section of plate.

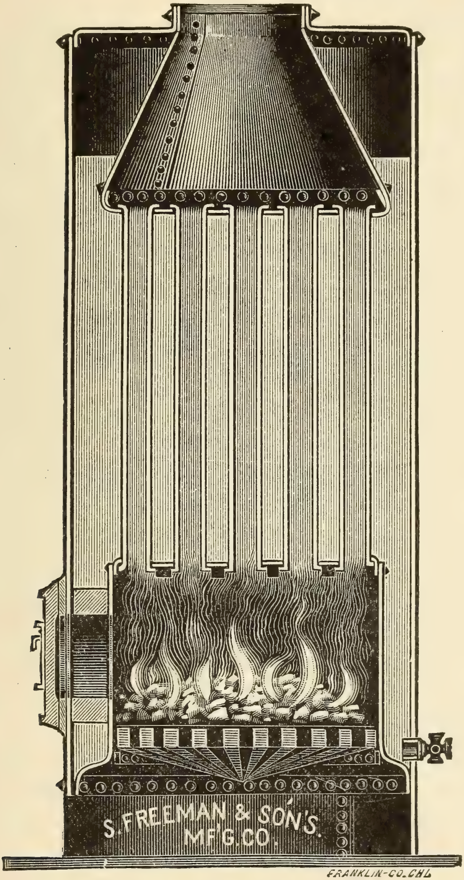
Third, find strength of rivets. In calculating the strength of rivets in a double riveted seam, the sectional area of two rivets must be considered, taking



BABCOCK AND WILCOX BOILER.

one-half the area of two rivets in the first row, and the area of another rivet in the second row. The area of a ⅞-in. rivet is .6013 in., but when in position it is assumed to fill the hole $\frac{15}{16}$ in. Consequently, its area would then be .69 in. and its strength is found by Rule 3.

Rule 3. Sectional area × T. S. Thus, .69 × 38,000 = 26,220 lbs., strength of one rivet, and multiplying by 2, as there are two rivets, the result is 26,220 × 2 = 52,440 lbs., strength of rivets in the seam under consideration. It thus appears that the plate is the weakest por-



VERTICAL FIRE BOX BOILER.

tion and the percentage of strength retained is found by multiplying 52,031 by 100 and dividing by 73,125.

the strength of solid plate. Thus, $\frac{52,031 \times 100}{73,125} = 71.1$ per cent.

The query might arise, why is the diameter of one rivet hole deducted from the pitch when figuring the strength of net plate? The answer is, that in punching the holes one-half the diameter of each hole is cut from the section designated, thereby reducing its width by just that amount.

The 71.1 per cent. obtained by the calculation represents the strength of the boiler as compared to the strength of the sheet before punching, and should enter into all calculations for the safe working pressure.

It is usual in practice to figure the strength of a double-riveted seam at 70 per cent. of the strength of the solid plate. The strength of triple-riveted butt joints may be calculated by taking a section of plate along the first row of rivets and estimate it as a single-riveted joint, then add to this result the strength of rivets in the second and third rows for a section of the same width. In properly designed triple-riveted butt joints the percentage of strength retained is 88, and some recent achievements in designing have shown the remarkable result of quadruple-riveted butt joints retaining as high as 92 to 94 per cent. of the strength of the solid plate.

Bursting Pressure. The query might arise, why should the longitudinal or side seams require to be stronger than the girth or round about seams? The answer is, that the force tending to rupture the boiler along the line of the longitudinal seams is proportional to the diameter divided by two, while the stress tending to pull it apart endwise is only one-half that, or proportional to the diameter divided by four.

To illustrate, let Fig. 1 represent the shell of the boiler heretofore referred to, ignoring for the time being the tubes and braces, and consider the boiler simply as a hollow cylinder. Now the total force tending to rupture the boiler along the line of the girth seams or in the direction of the horizontal arrows = area of one head in square inches × pressure in pounds per square inch. It is true that the pressure is exerted against both heads, but the area of one head can only be considered for the reason that the two stresses are exerted against each other just as in the case of two horses pulling against each other, or in opposite direction on the same chain. The stress on the chain will

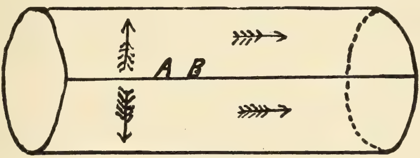


FIGURE 1.

be what each horse (not both) pulls. To further illustrate, suppose one of the horses to be replaced by a permanent post or wall and let one end of the chain be attached thereto. One head or one side of the boiler pulls against the other, and the stress on the seams is the force with which each (not both) pulls. Referring again to Fig. 1, area of one head = $60^2 \times .7854 = 2827.4$ sq. in. Suppose there is a pressure of 10 lbs. per square inch in the boiler. Then total stress on the girth seams = $2827.4 \times 10 = 28{,}274$ lbs. Opposed to this pull is the entire circumference of the boiler, which is $60 \times 3.1416 = 188.5$ in. Therefore, dividing total pressure (28,274 lbs.) by the circumference in inches (188.5) will give 150 lbs. as the stress on each inch of the girth seams. While the stress on each inch of the longitudinal seams or along the line A B, Fig. 1, and which is exerted in the direction of the vertical arrows, is pressure (10 lbs.) × one-half the diameter (30 in.) = 300 lbs. One-half the diameter is used because the pressure in any direction is effective only on the surface at right angles to that direction.

The formula for finding the bursting pressure of a boiler may be expressed as follows:

$B = \frac{T.S. \times T}{R}$ in which B = bursting pressure.
T.S. = tensile strength.
T = thickness of sheet.
R = radius or one-half the diam.

Example. T. S. = 55,000 lbs. per square inch.
T = ⅜ in. (expressed decimally = .375 in.).
R = 30 in.

Then $55{,}000 \times .375 \div 30 = 687.5$ lbs. per square inch, which is the pressure at which rupture would take place provided there were no seams in the boiler and the original strength of the sheet was retained, but, as has been seen, a certain percentage of strength is lost through punching or drilling the necessary rivet holes, and this must be taken into account.

The formula now becomes, for double riveting, $B = \frac{T.S. \times T \times .70}{R}$, in which the letters preserve the same value as in the original formula, but the result is reduced by multiplying by the decimal .70, which represents the percentage of strength retained by double-riveted seams. Consequently B will now =

$$\frac{55{,}000 \times .375 \times .70}{30} = 481 \text{ lbs.}$$

In case the seams are all single riveted .56 must be substituted for .70, and with triple-riveted butt joints .88 can safely be used.

Safe Working Pressure. In order to ascertain the safe working pressure of a boiler it is necessary first to calculate the bursting pressure and divide this by another factor called the factor of safety. The one most commonly used for boilers is 5, or in other words the safe working pressure = one-fifth the bursting pressure. In the case of the boiler under consideration, the safe pressure would be $481 \div 5 = 96$ lbs., at which point the safety valve should blow off.

Bracing. Every engineer can easily ascertain for himself whether the boilers under his charge are properly braced or not. The parts that require bracing are: all flat surfaces, such as the sides and top of the fire-box in boilers of the locomotive type, and those portions of the heads above and below the tubes in horizontal tubular boilers, also the top of the dome.

The stress per square inch of sectional area on braces and stays should not exceed 6,000 lbs. It is customary to consider the flange of the head and the top row of tubes as sufficient bracing for a space two inches wide above the tubes and the same distance around the flange. Therefore the part of the head to be braced will be the segment contained within a line drawn two inches above the top row of tubes and two inches inside the flange.

In order to ascertain the number of braces required for a given boiler head, three factors are necessary: first, the area of the segment in square inches; second, the diameter and T. S. of the braces, and third, the pressure to be carried. By the use of Table No. 1 the areas of segments of boiler heads ranging from 42 to 72 in. in diameter can easily be obtained. Assume the boiler to be 60 in. in diameter, distance from top of tubes to top of shell 24 in. Deduct 4 in. for surface braced by top row of tubes and flange, leaving the height of segment to be braced 20 in.

TABLE I

Diameter of Boiler.	Ditsance from Tubes to Shell.	Height of Segment.	Constant.
42 in.	15 in.	11 in.	.16314
44 in.	17 in.	13 in.	.1936
48 in.	19 in.	15 in.	.20923
54 in.	21 in.	17 in.	.21201
60 in.	24 in.	20 in.	.22886
66 in.	25 in.	21 in.	.214
72 in.	29 in.	25 in.	.24212

Rule. Multiply the square of the diameter of the boiler by the constant number found in right hand column opposite column headed diameter.

Example. 60 × 60 × .22886 = 823.89 sq. in., area of segment to be braced. Find number of braces required. Assume the braces to be 1⅛ in. in diameter and of a T. S. of 38,000 lbs. per square inch of section. The area of one brace will be .994 sq. in., which × 6,000 lbs. gives 5,964 lbs. as the stress allowable on each brace. Suppose the pressure to be carried is 100 lbs. per square inch. There will be area of segment (823.89 sq. in.) × pressure (100 lbs.) = 82,389 lbs., total stress. Dividing this result by 5,964 lbs. (the capacity of each brace) gives 13.8 braces as the number needed. In practice there should be fourteen.

Having a T. S. of 38,000 lbs. and using 6 as the factor of safety, each brace could safely sustain a pull of 6,295 lbs. Therefore it is evident that the above mentioned load for each brace is well within the limit. For convenience in calculating the areas of segments of circles, other than those mentioned in Table 1, the following rule is given:

Referring to Figure 2 it is desired to find the area of the segment contained within the lines A B C E. It will be necessary first to find the area of the sector bounded by the lines A B C D. This is done by multiplying one-half the length of the arc, A B C, by the radius, D B. Having obtained the area of the sector, the next step is to find the area of the triangle bounded by the lines A E C D and subtract it from the area of the sector. The remainder will be the area of the segment. Having found the area of the surface to be braced, and the number of braces required, it now becomes necessary to consider the spacing of the same.

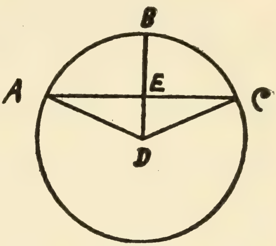


FIGURE 2.

Rule. Divide area to be braced by the number of braces, and extract the square root of quotient.

Example. 823.89÷14=58.8 sq. in. to be allotted to each brace. Extract square root of 58.8 and the result is 7.68 inches, which is the length of one side of the square which each brace will be required to sustain.

For internally fired boilers the same rules can be applied except that the surfaces to be braced are generally of rectangular shape and consequently the area is more easily figured than in the case of segments. That part of the head below the tubes also requires to be braced, and two braces are generally sufficient, as at A and B, Fig. 3. In the case of domes it is safe to consider the portion of the head within three inches of the flange as sufficiently braced. Then suppose the dome to be 36 in. in diameter, there will remain a circle 30 in. in diameter to be braced. The circumference of this circle is 94.2 in. and the pitch, or distance from center to center of the braces, being 7.6 in., the number of braces required is found by dividing 94.2 by 7.6, giving 12 braces. These braces should be located along a line which is one-half the pitch, or 3.8 in., within the circumference of the 30-in. circle. The space immediately surrounding the hole cut for the steam outlet will be sufficiently reënforced by the flange riveted on for the reception of the steam pipe. All holes cut in boilers, such as man holes, hand holes, and those for pipe connections, above two inches should be properly reënforced by riveting either inside or outside a wrought-iron or steel ring or flange of such thickness and width as to contain at least as much material as has been cut from the hole.

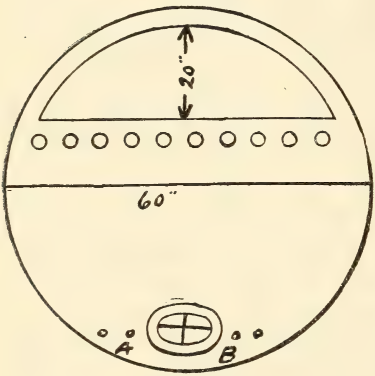


FIGURE 3.

Questions

1. How many types of steam boilers are there?
2. What kind of boilers are included in type one?
3. Describe a boiler belonging to type two.
4. Describe a boiler of the third type.

5. How is a boiler of the fourth type constructed?

6. In what respect do water tube boilers have the advantage over other types as regards explosions?

7. What kind of material should be used in the construction of boilers?

8. What does the term tensile strength (T. S.) mean?

9. What is the usual T. S. of steel boiler plates?

10. How much thicker than the shell plates should the heads be?

11. Of what material and of what T. S. should the rivets be?

12. Is a riveted joint as strong as the solid plate?

13. What is meant by the pitch of the rivets?

14. What is the usual pitch for a double riveted seam?

15. Give the rule for finding the strength of the solid plate before punching.

16. What is meant by net section of plate?

17. What is the rule for finding strength of net section of plate?

18. How is the strength of rivets in a double riveted seam calculated?

19. What percentage of the strength of solid plate is usually retained in a double riveted seam?

20. How is the strength of a triple riveted butt strap joint calculated?

21. What per cent. of the original strength of the sheet is retained in a properly designed triple riveted butt strap joint?

22. Why should the side seams be stronger than the girth seams?

23. What is the rule for finding the bursting pressure of a boiler?

24. How is the safe working pressure of a boiler calculated?

25. What parts of a boiler require bracing internally?

26. What stress per square inch of sectional area may be allowed on braces?

27. How is the number of braces required for any part of the boiler obtained?

28. How should domes be braced?

CHAPTER II

BOILER SETTINGS AND APPURTENANCES

Foundations—Brick work, etc.—Grate surface—Insulation—Water columns—Steam gages—Safety valves—Rules for finding areas of—Fusible plugs and where to place them—Domes and mud drums—Feed pipes—A good arch for the back connection—Blow off pipes and cocks—Surface blow off and circulating system—Feed pumps and feed water heaters—Injectors—Saving effected by heating the feed water with exhaust steam—Apparatus for making coal tests—Heating surface—Rules for figuring the same.

Settings. In the case of internally fired boilers the matter of setting resolves itself into the simple point of securing a sufficiently solid foundation, either of stone or brick laid in cement, for the boiler to rest upon.

But with horizontal tubular or water tube boilers the matter of brick work becomes important, and particular attention should be paid to securing a good foundation for the walls and great care exercised in building them in such manner that the expansion of the inner wall or lining will not seriously affect the outer walls. This can be done be leaving an air space of two inches in the rear and side walls, beginning at or near the level of the grate-bars and extending as high as the fire line, or about the center line of the boiler. Above this height the wall should be solid. Fig. 4 shows a plan and an end elevation illustrating this idea. The ends of some of the bricks should be allowed to project at intervals from the outer walls across the air space, so as to come in touch with the inner walls.

Where boilers are set in batteries of two or more the middle or party walls should be built up solid from the foundation. All parts of the walls with which the

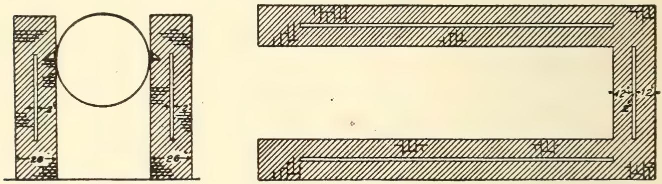


FIGURE 4.

fire comes in contact should be lined with fire brick, every fifth course being a header to tie the lining to the main wall.

Bridge walls should be built straight across from wall to wall of the setting, and should not be curved to conform to the circle of the boiler shell. The proper

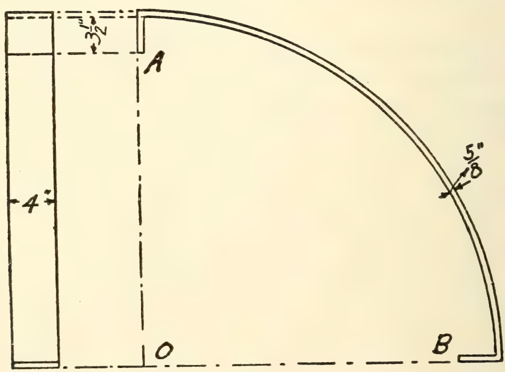


FIGURE 5.

distance from the top of the bridge wall to the bottom of the boiler varies from eight to ten inches, depending upon the size of the boiler. The space back of the bridge wall, called the combustion chamber, can be filled in with earth or sand, and should slope gradually downward from the back of the bridge wall to the floor level at the rear wall, and should be paved with hard burned brick. The ashes and soot can then be easily cleaned out by means of a long-handled hoe or scraper inserted through the cleaning out door, which should always be placed in the back wall of every boiler setting.

Back Arches. A good and durable arch can be made

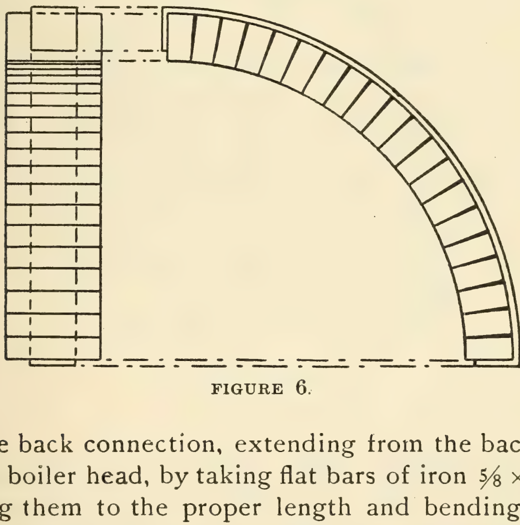


FIGURE 6.

for the back connection, extending from the back wall to the boiler head, by taking flat bars of iron $5/8 \times 4$ in., cutting them to the proper length and bending them in the shape of an arch, turning four inches of each end back at right angles, as shown in Fig. 5. The distance O-B should equal that from the rear wall to the boiler head, and the height, O-A, should be about equal to O-B, and should bring the point A about two inches above the top row of tubes. The clamp thus formed is filled with a course of side arch fire brick,

Fig. 6, and will form a complete and self-sustaining arch, the bottom, B, resting on the back wall, and the top, A, supported by an angle iron riveted across the boiler head about three inches above the top row of tubes. See Figs. 7 and 8.

Enough of these arches should be made so that when laid side by side they will cover the distance from one side wall to the other across the rear end of the boiler. A fifty-four-inch boiler would thus require six clamps,

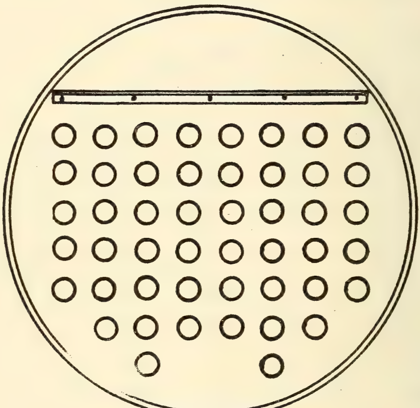


FIGURE 7.

a sixty-inch boiler seven clamps, and a seventy-two-inch boiler would require eight clamps; the length of a fire brick being about nine inches. In case of needed repairs to the back end of the boiler the sections can be lifted off, thus giving free access to all parts, and when the repairs are completed the arches can be reset with very little trouble and much less expense than the building of a solid arch would necessitate. This form of segmental arch allows ample freedom for expansion of the boiler, in the direction of its length, without leaving an opening when the boiler contracts.

The crosswise construction of arch bars, while affording equal facility in repair work, is necessarily more expensive than the form here described, and is also open to the objection that it cannot follow the contracting boiler and maintain a tight joint or connection

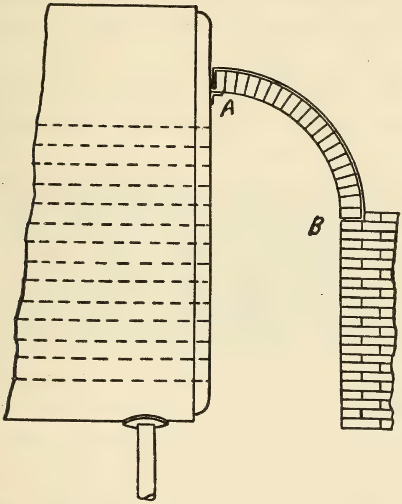


FIGURE 8.

between the back arch and the rear head above the tubes.

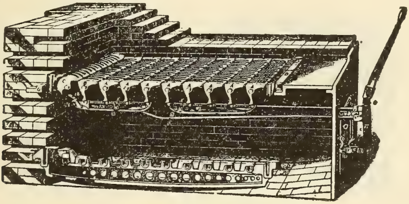
Boiler walls should always be well secured in both directions by tie rods extending throughout the entire length and breadth of the setting, whether there be one boiler or a battery of several. The bottom rods should be laid in place at the floor level when starting the brick work, and the top rods extending transversely across the boilers can be laid on top of the boilers.

The top rods extending from front to back can be laid in the side walls or rest on top of them. All tie rods should be at least one inch in diameter, and for batteries of several boilers they should be larger. The rods should extend three or four inches beyond the brick work, with good threads and nuts on each end to receive the buck stays. In laying down the transverse tie rods they should be located so as to allow the buck stays to bind the brick work where the greatest concentration of heat occurs.

Horizontal boilers should always be set at least one inch lower at the back end than at the front, to make sure that the rear ends of the tubes will be covered with water so long as any appears in the gauge glass, provided of course that the lower end of the glass is properly located with reference to the top row of tubes, which will be discussed later on. Upon the brick work and immediately under each lug of the boiler there should be laid in mortar a wrought or cast iron plate several inches larger in dimension than the bearing surface of the lug and not less than one inch in thickness. Upon each of these plates there should be placed two rollers made of round iron 1 or 1⅛ in. in diameter, and as long as the width of the lug. These rollers should be placed at right angles to the length of the boiler, in such a position that the lug will bear equally upon them. The object of the rollers is to prevent disturbance of the brick work by the endwise expansion and contraction of the boiler.

Grate Surface. The number of square feet of grate surface required depends upon the size of the boiler. A good rule and one easy to remember is to make the length of the grates equal to the diameter of the boiler. The width, of course, will depend upon the construction of the furnace. If the fire brick lining is built perpendicular, the width of grate will be about equal to the diameter of the boiler. On the other hand, if the lining is given a batter of three inches, starting at the level of the grate, then the width will be reduced six inches. It is customary to allow one square foot of grate surface to every 36 sq. ft. of heating surface. The distance of the grate-bars from the shell of the boiler varies from 24 to 28 in., according to the dimensions of the boiler.

Insulation. All boilers should be well protected from the cooling influence of outside air, if economy



M'CLAVE'S GRATES.

of fuel is any object. The tops of horizontal boilers should be covered with some kind of heat insulating material, or arched over with common brick, leaving a space of two inches between the boiler and the arch. The resulting saving in fuel will far more than compensate for the extra expense in a very short time. All cracks in the side and rear walls should be carefully pointed up with mortar or fire clay. One source of heat loss in return flue boilers is short circuiting from the furnace to the breeching, caused by the arches over the fire doors becoming loose and shaky, and allowing considerable of the heat to escape directly to the stack instead of passing under the boiler and through the tubes. Another bad air leak often occurs at the back connection when the arch rests wholly upon iron bars imbedded in the side walls. This leak, as has already been noted, is caused by the expansion of the boiler, which gradually pushes the arch away from the back head until, in the course of time, there will be a space of ⅝ in. and sometimes ¾ in. between the head and the arch. The obvious remedy for this is an arch that will go and come with the movement of the boiler, and such an arch can be secured by building it in sections, as illustrated by Fig. 3, and then riveting a piece of angle iron to the boiler head, above

M'CLAVE'S GRATES.

the top row of tubes for the upper ends of the sections to rest upon, as already described. It will be seen that within all possible range of boiler movement in either direction the arch will, with this construction, always remain close to the head.

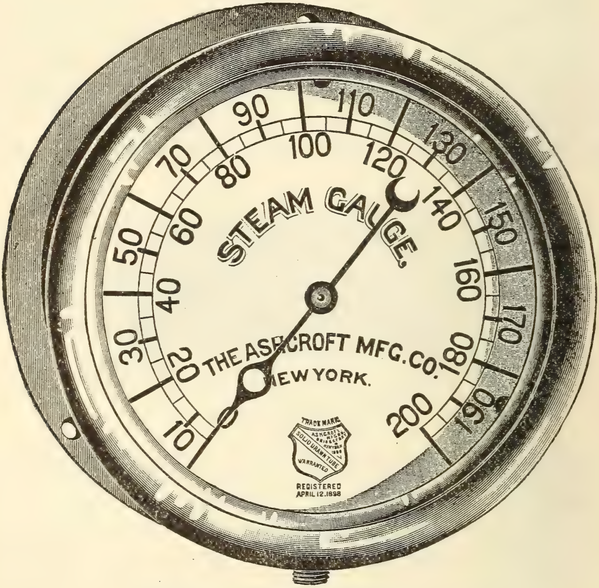
Water Columns. Water columns should be so located as to bring the lower end of the gauge glass exactly on a level with the top of the upper row of tubes, thus always affording a perfect guide as to the depth of water over the tubes. Many gauge glasses are placed too low, and water tenders and firemen are often deceived by them unless their positions with relation to the tubes are carefullv noted.

The only safe plan for an engineer to pursue in taking charge of a steam plant is to seize the first opportunity for noting this relation. When he has washed out his boilers he may leave the top man-hole plates out while refilling them, and when the water stands at about four inches over the top row of tubes, the depth of water in the glass should be measured. He should do this with every boiler in the plant, and make a memorandum for each boiler. He will then know his bearings with regard to the safe height of water to be carried in the several gauge glasses. If he finds any of them are too low, he should lose no time

M'CLAVE'S GRATES.

in having them altered to comform to the requirements of safety. The position of the lower gauge cock should be three inches above the top row of tubes.

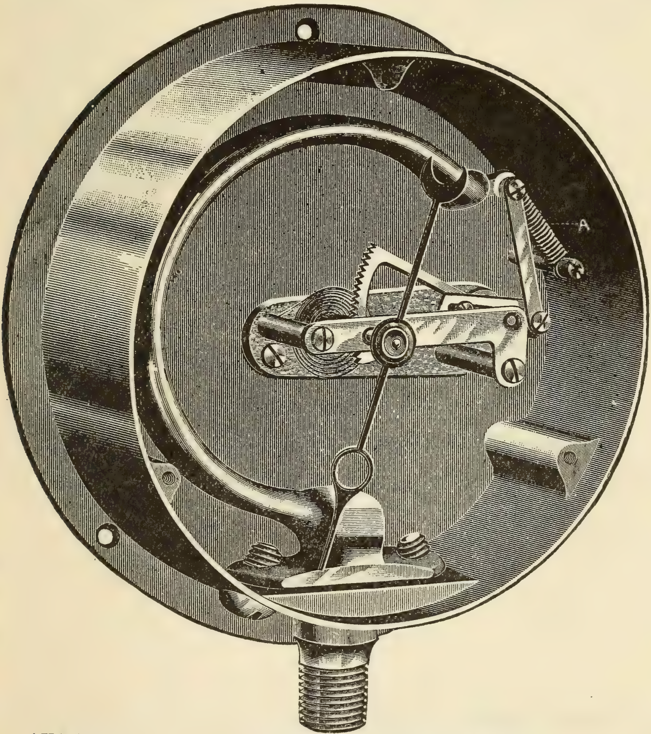
In making connections for the water column plugged crosses should always be used in place of ells. Brass plugs are to be preferred if they can be obtained; but whether of brass or iron, they should always be well coated with a paste made of graphite and cylinder oil before they are screwed in. They can then be easily removed when washing out the boiler, so as to allow the scale, which is sure to form in the lower connection, to be cleaned out. The best point at which to connect the lower pipe with the boiler is in the lower part of the head just below the bottom row of tubes, and near the side of the boiler on which the water column is to stand; 1¼ or 1½ in. pipe should be used in all cases. The top connection can be made either in the head near the top, or in the shell. A ¾ or 1 in. drain pipe should be led into the ash pit, fitted with a good reli-



AUXILIARY SPRING PRESSURE GAUGE.

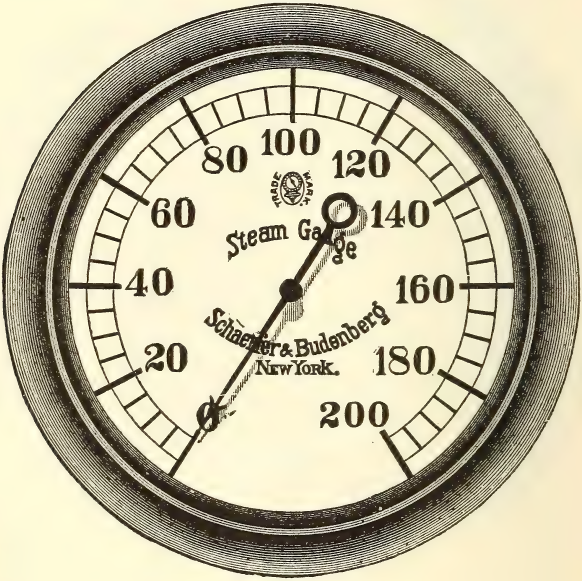
able valve which should be opened at frequent intervals to allow the mud and dirt to blow out of the water column and its connections. This is a very important point, and great care should be taken to keep the water column and all its connections thoroughly clean at all times.

One of the best indications that some portion of the connections between the water glass and the boiler is choked or plugged with scale, is when there is no perceptible movement of the water in the glass. When the connections are free and the boiler is being fired,



AUXILIARY SPRING PRESSURE GAUGE, SECTIONAL VIEW.

there is always a slight movement of the water up and down in the glass, and when there is no perceptible movement it is time to look for the cause at once. Many instances of burned tubes have occurred, and even explosions caused by low water in boilers while the gauge glass showed the water to be at a safe height. But owing to the connections having become plugged with scale, the water in the glass had no connection whatever with that in the boiler, and the water column was therefore worse than useless.



Steam Gauges. As water columns are made at present the steam gauge is usually connected at the top of the column. This makes a handsome and convenient connection, although theoretically the proper method would be to connect the steam gauge directly with the dome or the steam space of the shell. There should always be a trap or siphon in the gauge pipe in order to retain the water of condensation, so as to prevent the hot steam from coming in contact with the spring.

If at any time the water is drained from the siphon, care should be exercised in turning on the steam again by allowing it to flow in very slowly at first until the siphon is again filled with water.

The steam gauge and the safety valve should be compared frequently by raising the steam pressure high enough to cause the valve to open at the point for which it is set to blow.

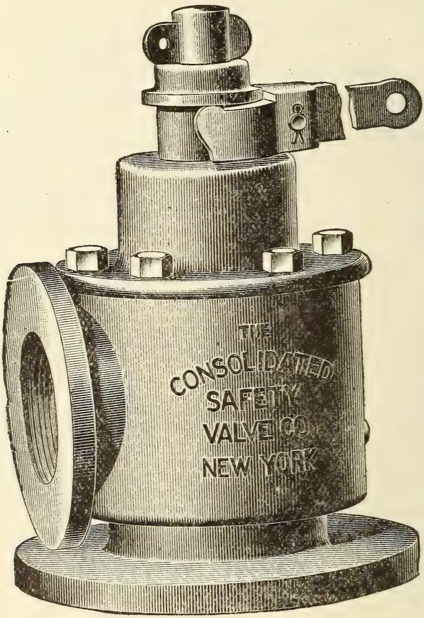
Safety Valves. The modern pop valve is generally reliable, but, like everything else, if it is allowed to stand idle too long it is likely to become rusty and stick. Therefore it should be allowed to blow off at least once or twice a week in order to keep it in good condition.

Most pop valves for stationary boilers are provided with a short lever, and if at any time the valve does not pop when the steam gauge shows the pressure to be high enough, it can generally be started by a light blow on the lever with a hammer.

The ratio of safety valve area to that of grate surface is, for the old style lever and weight valve, 1 sq. in. of valve area for each 2 sq. ft. of grate surface, and for pop valves 1 sq. in. of valve area for each 3 sq. ft. of grate surface.

Each boiler in a battery should have its own safety valve, and, in fact, be entirely independent of its mates as regards safety appliances.

One example of safety valve computation will be given. Suppose the grate surface of a boiler is $5 \times 6 = 30$ sq. ft, what should be the diameter of the lever safety valve? The required area of the valve is $30 \div 2 = 15$ sq. in. Then $15 \div .7854 = 19$, which is the square of the diameter of the valve. Extracting the square root of 19 gives 4.35 in. diameter of valve. In actual practice one 5 in. or two 3 in. lever safety valves would be required. If a pop valve is to be used the required area is 30 ÷ 3 = 10 sq. in. Then 10 ÷ .7854 = 12.73 = square of diameter of valve. Extract the

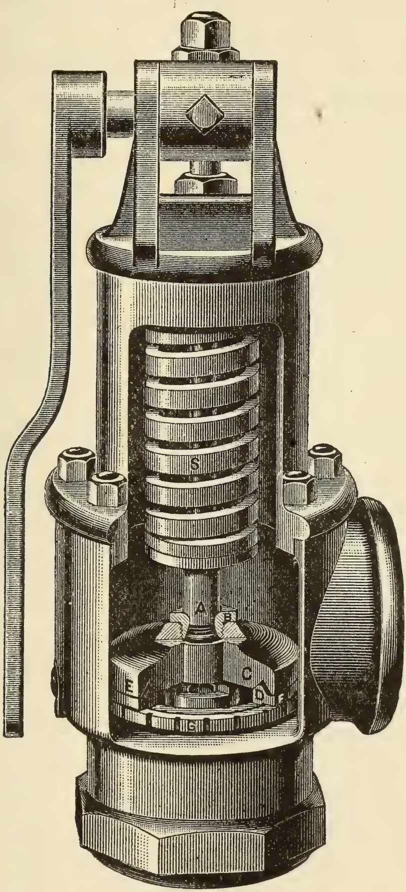


POP VALVE.

square root of 12.73 and the result is 3.6 in. = diameter of valve. In practice a 4 in. valve would be required.

Fusible Plugs. A fusible plug should be inserted in that part of the heating surface of a boiler which is first liable to be overheated from lack of water.

In a horizontal tubular or return flue boiler the proper location for the fusible plug is in the back head



INSIDE VIEW OF A POP SAFETY VALVE.

about 1½ or 2 in. above the top row of tubes. In fire-box boilers the plug can be put into the crown sheet directly over the fire. These plugs should be made of brass with hexagon heads and standard pipe threads, in sizes ½, ¾, 1 in., or even larger if desired. A hole drilled axially through the center and counter sunk in the end that enters the boiler is filled with an alloy of such composition that it will melt and run out at the temperature of the dry steam at the pressure carried in the boiler. Thus, if the water should get below the plug the dry steam, coming in contact with the fusible alloy, melts it and, escaping through the hole in the plug, gives the alarm, and in case of fire-box or internally fired boilers the steam will generally extinguish the fire also. The hole is counter sunk on the inner end of the plug so as to retain the fusible metal against the boiler pressure. These plugs should be looked after each time the boilers are washed out, and all dirt and scale should be cleaned off in order that the fusible metal may be exposed to the heat.

Another type of fusible plug consists of a small brass cylinder into one end of which is screwed a plug filled with a metal which will fuse at the temperature of dry steam at the pressure which is to be carried in the boiler. The other end of the cylinder is reduced and fitted with a small stop valve and threaded to screw into a brass bushing inserted into the top of the boiler shell. This bushing also receives at its lower end a piece of ½ or ¾ in. pipe which extends downwards to within 2 in. of the top row of tubes, or the crown sheet if the boiler is internally fired. The principle of the device is that in case the water falls below the lower end of the pipe, steam will enter, fuse the metal in the plug, and be free to blow and give warning of danger. Some of these appliances are fitted with whistles which are sounded in case the steam gets access to them. But even with such devices no engineer can afford to relax his own vigilance and depend entirely upon the safety appliances to prevent accidents from low water.

Domes and Mud-Drums. As a general proposition, both mud drums and domes are useless appendages to steam boilers. There are, no doubt, instances where they may serve a purpose, but as a rule their use is of no advantage to a boiler. Neither are the so-called circulating systems, sometimes attached to return tubular boilers, of any real value. These consist of one or more 4 to 6 in. pipes extending under the boiler from front to back through the furnace and the combustion chamber and connected to each end of the boiler.

Feed Pipes. Authorities differ in regard to the proper location of the inlet for the feed pipe, but upon one point all are agreed, namely, that the feed water, which is always at a lower temperature than the water in the boiler, should not be allowed to come directly in contact with the hot boiler sheets until its temperature has been raised to within a few degrees of the temperature of the water in the boiler. Certainly one of the most fruitful sources of leaks in the seams and around the rivets is the practice of introducing the feed water into the bottom either at the back or front ends of boilers, as is too often the case. The cool water coming directly in contact with the hot sheets causes alternate contraction and expansion, and results in leaks, and very often in small cracks in the sheet, the cracks extending radially from the rivet holes. It would appear that the proper method is to connect the feed pipe either into the front head just above the tubes, or into the top of the shell. The nipple entering the boiler should have a long thread cut on the end which screws into the sheet, and to this end inside the boiler there should be connected another pipe which shall extend horizontally at least two-thirds of the length of the boiler, resting on top of the tubes, and then discharge. Or, what is still better, allow the internal pipe to extend from the entering nipple at the front end to within a few inches of the back head, then at right angles across the top of the tubes to the other side, and from there discharge downward. By this method the feed water is heated to nearly, if not quite, the temperature of the water in the boiler before it is discharged. One of the objections to this system is the liability of the pipe inside the boiler to become filled with scale and finally plugged entirely. In such cases the only remedy is to replace it with new pipe. But the great advantage of having the water thoroughly heated before being discharged into the boiler will much more than compensate for the extra expense of piping, and the general idea of introducing the feed water at the top instead of at the bottom of the boiler is therefore recommended as being the best.

The diameter of feed pipes ranges from 1 in. for small sized boilers, up to 1½ and 2 in. for boilers of 54 to 72 in. in diameter. It is not good policy to have the feed pipe larger than necessary for the capacity of the boiler; because it then acts as a sort of cooling reservoir for the feed water, and may cause considerable loss of heat.

For batteries of two or more boilers it is necessary to run a main feed header, with branch pipes leading to each boiler. The header should be large enough to supply all the boilers at the same time, should it ever become necessary to do so. The header can be run along the front of the boilers just above the fire doors with the branch pipes running up on either side, clear of the flue doors and entering the front connection, or smoke arch, and the boiler head at a point two inches above the tubes. There should always be a valve in each branch pipe between the check valve and the header for the purpose of regulating the supply of water to each boiler, and also for shutting off the pump pressure in case of needed repairs to the check valve. Another valve should be placed between the check valve and the boiler. By this arrangement it is always possible to get at the check valve when it is out of order.

Blow off Pipes. Blow off pipes should always be connected with the lowest part of the water space of a boiler. If there is a mud-drum, then of course the blow off should be connected with it; but if there is no mud-drum, the blow off should connect with the bottom of the shell, near the back head, extend downwards to the floor of the combustion chamber, and thence horizontally out through the back wall, where the blow off cock can be located.

The best blow off cocks are the asbestos packed iron-body plug cocks, which are durable and safe. A globe valve should never be used in a blow off pipe, because the scale and dirt will lodge in it and prevent its being closed tightly. A straight way or gate valve is not so bad, but an asbestos packed plug cock is undoubtedly the best and safest.

In order to protect the blow off pipe from the intense heat, a shield consisting of a piece of larger pipe can be slipped over the vertical part before it is connected.

Blow off cocks should be opened for a few seconds once or twice a day, to allow the scale and mud to be blown out. If neglected too long they are liable to become filled with scale and burn out. A plan which is said to give good results is to connect a tee in the horizontal part of the pipe, and from this tee run a 1 in.

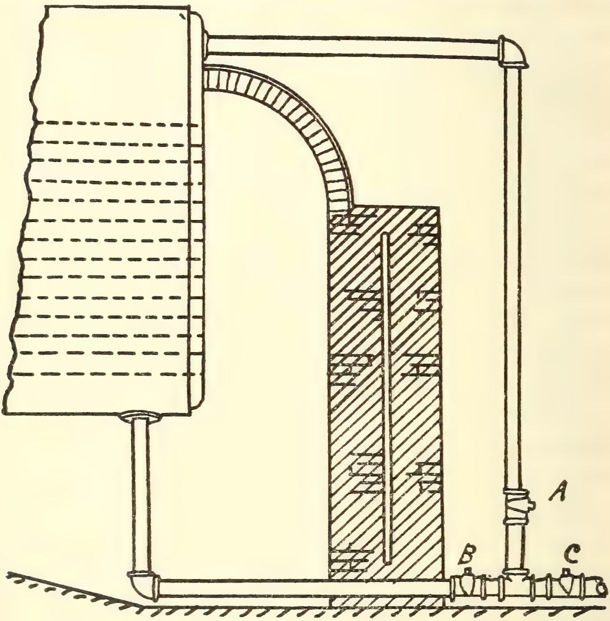


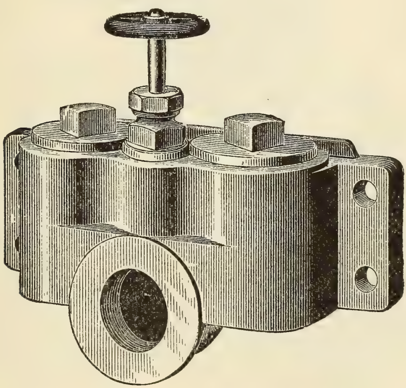
FIGURE 9.

pipe to a point in the back head at the water level. It is claimed that this will cause a circulation of water in the pipe and prevent the formation of scale.

A surface blow off is a great advantage, especially if the water is muddy or liable to foam. By having the surface blow off connected on a level with the water line a large amount of mud and other matter which is kept on the surface by the constant ebullition can be blown out.

A combination surface blow off, bottom blow off, and circulating system can be arranged by a connection such as illustrated in Fig. 9. By closing cock A and opening cocks B and C the bottom blow off is put in operation; by closing B and opening A and C the surface blow off is started, and by closing C and leaving A and B open the device will act as a circulating system. The pipe should be of the same size throughout. Blow off pipes should be of ample size, never less than 1¼ in., and from that to 2½ in., depending upon the size of the boiler.

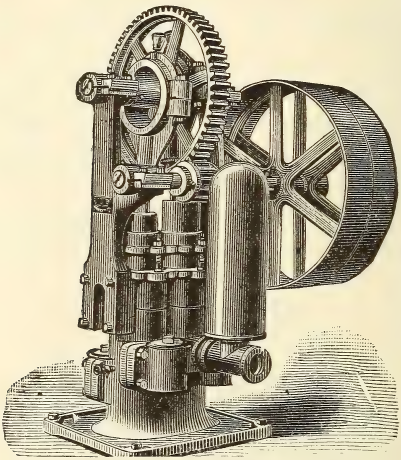
Feed Pumps and Injectors. The belt driven power pump is the most economical boiler feeder, but is not



DIFFERENTIAL VALVE, DAVIS PUMP.

the most convenient nor the safest. When the engine stops, the pump stops also, and sometimes it happens that the belt gives way and the pump stops at just the time when the boiler is being worked the hardest.

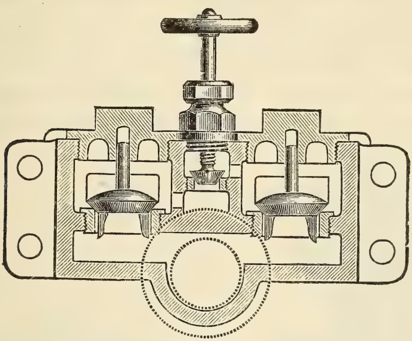
The modern double acting steam pump, of which there are many different makes to choose from, is without doubt the most reliable boiler feeding appliance and the one best adapted to all circumstances and conditions, although it is not economical in the



DAVIS BELT DRIVEN FEED PUMP.

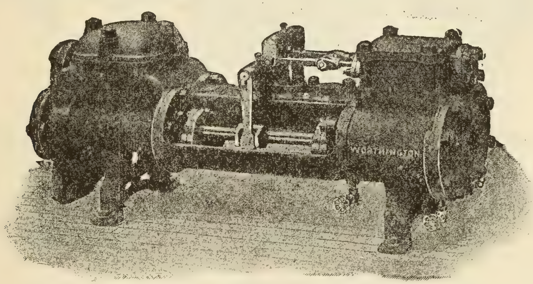
use of steam, since the principle of expansion cannot be carried out with the pump as with the engine.

In selecting a feed pump care should be exercised to see that it is of the proper size and capacity to supply the maximum quantity of water that the boiler can evaporate. This may be ascertained by taking into consideration the amount of heating surface and the required consumption of coal per square foot of grate surface per hour. First, take the coal consumption. Assume the boiler to have 30 sq. ft. of grate surface, and that it is desired to burn 15 lbs. of coal per square foot of grate per hour, which is a good average with the ordinary hand fired furnace using bituminous coal.



SECTIONAL VIEW OF DIFFERENTIAL VALVE.

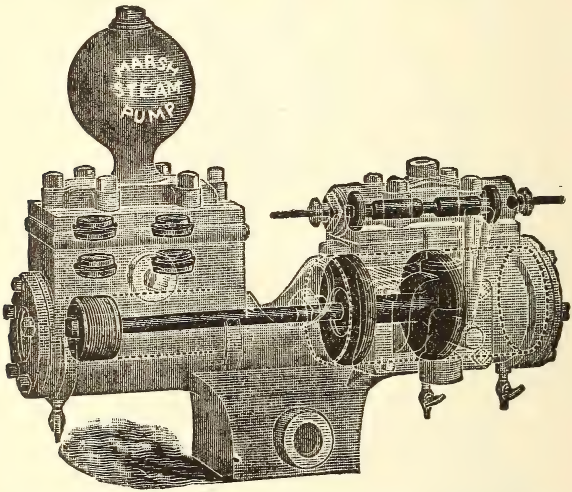
Suppose the boiler is capable of evaporating 8 lbs. of water per pound of coal consumed. Then $30 \times 15 \times 8 =$ 3,600 lbs. of water evaporated per hour. Dividing



WORTHINGTON DUPLEX BOILER FEED PUMP.

3,600 by 62.4 (the weight of a cubic foot of water in pounds) gives 57.6 cu. ft. per hour, which, divided by 60, gives 0.96 cu. ft. per minute. This multiplied by

1,728 (number of cubic inches in a cubic foot) gives 1,659 cu. in. per minute which the pump is required to supply. Suppose the pump is to make forty strokes per minute, and the length of stroke is five inches. Then 1659 ÷ 40 = 41.47 cu. in. per stroke, which, divided by 5 (length of stroke in inches) gives 8.294 sq. in. as the required area of water piston. 8.294 ÷ .7854 = 10.56, which is the square of the corresponding diam-

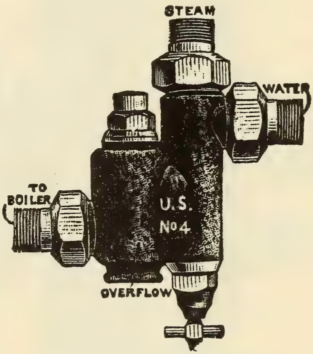


PHANTOM VIEW OF MARSH INDEPENDENT STEAM PUMP.

eter, and the square root of 10.56 = 3.25. So, theoretically, the size of the water end of the pump would be 3¼ in. in diameter by 5 in. stroke; but as it is always safer to have a reserve of pumping capacity, the proper size of the pump would be 3½ in. in diameter by 5 in. stroke, with a steam cylinder of 6 or 7 in. in diameter.

There is another rule for ascertaining the size of the feed pump, by taking the number of square feet of heating surface in the boiler and allow a pump capacity of 1 cu. ft. per hour for each 15 sq. ft. of heating surface. Thus, let the total heating surface of the boiler be 786 sq. ft. Dividing this by 15 gives 52.4 as the number of cubic feet of water required per hour, from which the pump dimensions may be found in the same way as in the preceding case.

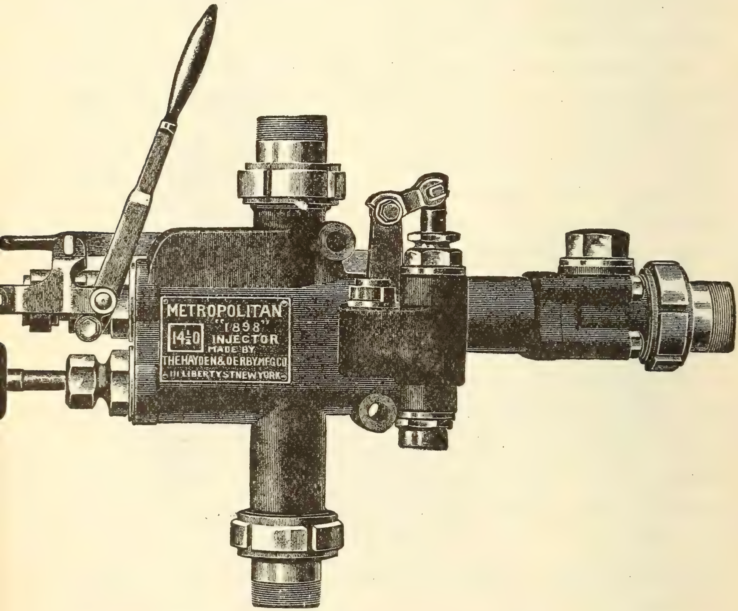
In figuring on the capacity of a feed pump for a battery of two or more boilers, the total quantity of water required by all the boilers must be taken into consideration. All boiler-rooms should be supplied with at least two feed pumps, so that if one breaks down there may always be another one available.



U. S. AUTOMATIC INJECTOR.

The injector is a reliable boiler feeder, and is in fact more economical than the steam pump, because the heat in the steam used is all returned to the boiler, excepting the losses by radiation. But the disadvantage attending the use of the injector is that it will not work well with the feed water at a temperature very much in excess of 100° F., while a good steam pump, fitted with hard rubber valves, will handle water at a temperature as high as 200° or 208° F., when the water flows to the pump by gravity from a heater, or it will raise water from a receiving tank on a short suction lift at a temperature of 150° or 160° F.

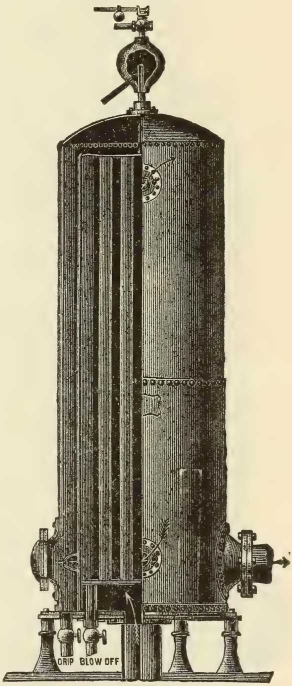
Feed Water Heaters. One great source of economy in fuel is the utilization of all the available exhaust steam for heating the feed water before it enters the boiler. Of course if the main engine is a condensing engine, the exhaust from that source is not directly available, except by interposing a closed heater between the cylinder and the condenser, or by using



METROPOLITAN INJECTOR, MODEL O.

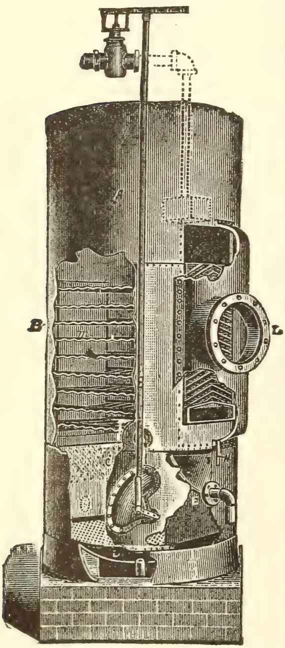
the water of condensation for feeding the boilers. This can be done with safety, provided a surface condenser is used, but with a jet condenser or an open heater in which the exhaust mingles with the water, it is advisable to have an oil separator to prevent the oil from getting into the boilers.

Exhaust heaters are of two kinds, open and closed. In the open heater the exhaust steam mingles directly with the water and a portion of it is condensed. A well-designed open exhaust heater will raise the temperature of the water to very nearly the boiling point, 212° F. These heaters should be set so that the water will flow by gravity from them to the feed pump In the closed type of exhaust heaters, the exhaust steam and the water are kept separate. In some styles the steam passes through tubes, which are surrounded by water, while in others the water fills the tubes, which are in turn surrounded by the steam. In either case the water in the closed heater is under the full boiler pressure while the feed pump is in operation, because the heater is between the pump and the boiler, while with the open heater the pump is between the heater and the boiler.



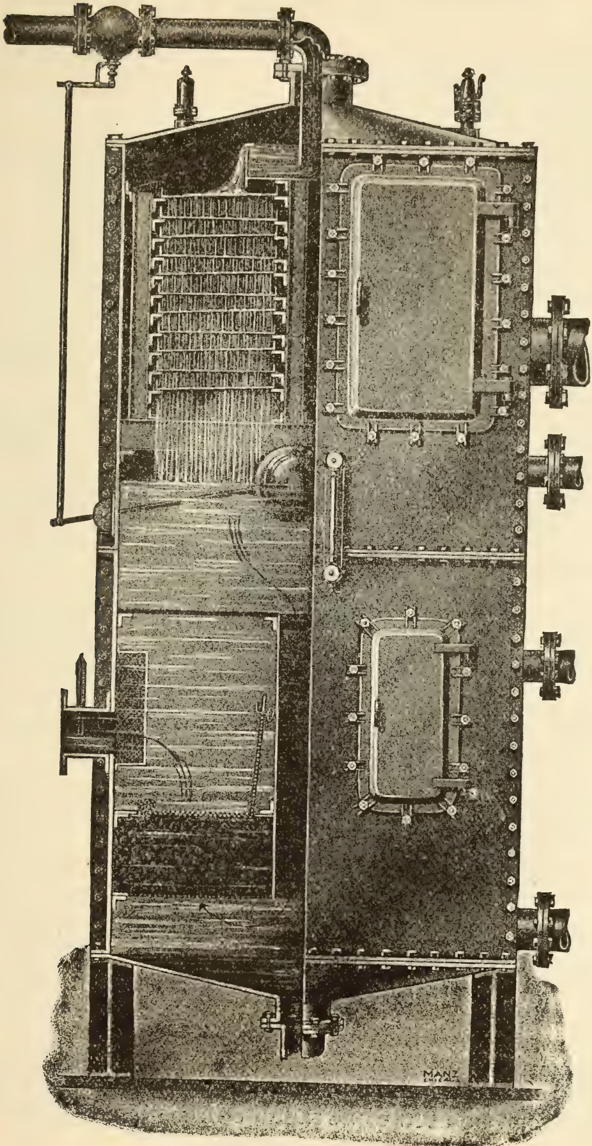
BARAGWANATH STEAM JACKET FEED WATER HEATER.

The saving effected by heating the feed water with exhaust steam can be easily ascertained by the use of a thermometer, a steam table, and a simple arithmetical calculation. First, find by thermometer the temperature of the water before entering the heater; find its temperature as it leaves the heater. Next ascertain by the steam table the number of heat units above 32° F. in the water at each of the two temperatures. Subtract the less from the greater, and the remainder will be the number of heat units added to the water by the heater. Next find by the table the number of heat units above 32° F. in the steam at the pressure ordinarily carried in the boiler, and subtract from this the number of heat units in the water before it enters the heater. The result will be the number of heat units that would be required to convert the water into steam of the required pressure, provided no heater were used. Then to find the percentage of saving effected by the heater, multiply the number of heat units added to the water by the heater by 100, and divide by the number of heat units required to convert the unheated water into steam, from the initial temperature at which it enters the heater.



INTERIOR VIEW OF OPEN HEATER.

Example. Assume the boiler to be carrying 100 lbs. gauge pressure. Suppose the temperature of the water before entering the heater is 60° F., and that after leaving the heater its temperature is 202° F., what is the percentage of saving due to the heater? The solution of the problem is as follows:



SQUARE OPEN HEATER.

Boiler pressure by gauge = 100 lbs.

Initial temperature of feed water = 60° F.

Heated temperature of feed water = 202° F.

From the steam table (see Chapter IV., Table 5) it is found that

Heat units in water at 202° F. = 170.7.

Heat units in water at 60° F. = 28.01.

Heat units added to water by heater = 170.7 − 28.01 = 142.69.

Heat units in steam at 100 lbs. gauge pressure = 1185.0.

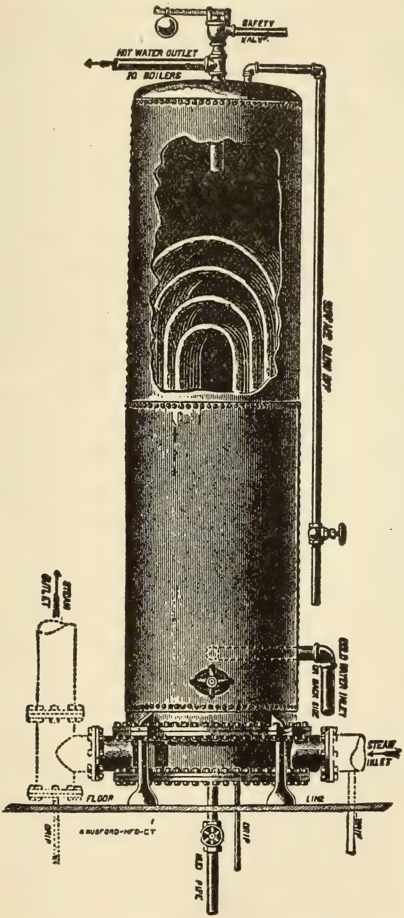
Heat units to be added to water at 60° F. to make steam of 100 lbs. gauge pressure = 1185.0 − 28.01 = 1156.99.

Percentage of saving effected by the use of the heater $= \frac{142.69 \times 100}{1156.99} = 12.33$ per cent.

Suppose the coal consumed under this boiler amounts to two tons per day at a cost of $3.00 per ton, or a fuel cost of $6.00 per day. Then the saving in dollars and cents due to the heater in the foregoing example would be 12.33 per cent of $6.00, or $0.7398 (74 cents) per day.

Heaters, especially those of the closed type, should have capacity sufficient to supply the boiler for fifteen or twenty minutes. There would then be a body of water continually in the heater in direct contact with the heating surface, and as it passes slowly through it will receive much more heat than if rushed through a heater that is too small. All heaters and feed pipes should be well protected by some good insulating covering to prevent loss of heat by radiation. In some cases the exhaust steam, or a portion of it at least, can be used to advantage in an exhaust injector.

This device, where it can be used at all, is economical in that it not only feeds the boiler, but also heats the



CLOSED FEED WATER HEATER.

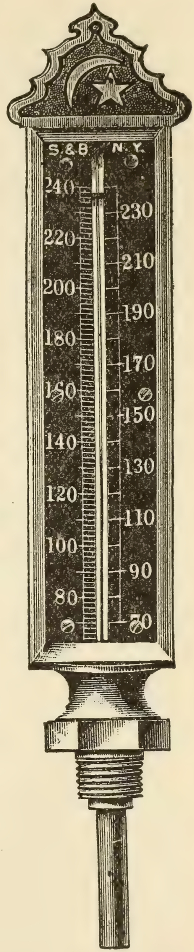
water without the use of live steam. But it will not force the water against a pressure much above 75 lbs.

to the square inch, and if the initial temperature of the water is much above 75° F. the exhaust injector will not handle it. Heaters which use live steam direct from the boilers heat the feed water to a much higher temperature, so that they act as purifiers by removing a large portion of the scale-forming impurities before the water enters the boiler. Live steam heaters, however, are not to be considered as economizers of heat.

Provisions for Testing. While considering feed pipes and other apparatus necessarily appertaining to the feeding of boilers, it is well to devote a short space also to the fittings and other devices required for successfully conducting tests of the boiler and furnace. This subject is mentioned here for the reason that the author considers that the necessary fittings and appliances for making evaporative tests properly belong to, and in fact are a part of, the feed piping, and can be put in while the plant is being erected at much less cost and trouble than if the matter is postponed until after the plant is in operation.

Beginning then at the check valve, there should be a tee located in the horizontal section of the feed pipe, as near to the check valve as practicable, and between it and the feed pump; or a tee can be used in place of an ell to connect the vertical and horizontal sections of the branch pipe where it rises in front of the boiler. One opening of this tee is reduced to ⅜ or ½ in. to permit the attachment of a hot water thermometer. These thermometers are also made angle-shaped at the shank, so that if desired they can be screwed into a tee placed in vertical pipe and still allow the scale to stand vertical. The thermometer is for the purpose of showing at what temperature the feed water enters the boiler during the test, and therefore should be as near the boiler as possible. After the test is completed the thermometer may be taken out and a plug inserted in its place.

The next requirement will be a device of some kind for ascertaining the weight of water pumped into the boiler during the test. In some well ordered plants each boiler is fitted with a hot water meter in the feed pipe, but as this arrangement is hardly within the reach of all, a substitute equally as accurate can be made by placing two small water tanks, each having a capacity of eight or ten cubic feet, in the vicinity of the feed pump. These tanks can be made of light tank iron, and each should be fitted with a nipple and valve near the bottom for connection with the suction side of the pump. The tops of the tanks may be left open. If an open heater is used, and it is possible to place the tanks low enough to allow a portion of the water from the heater to be led into them by gravity, it will be desirable to do so. A pipe leading from the main water supply, with a branch to each tank, is also needed for filling them. One of the feed pumps, of which there should always be at least two, as already stated, is fitted with a tee in the suction pipe near the pump to receive the pipe



HOT WATER THERMOMETER.

leading from the tanks. During the test the main suction leading to this pump from the general supply should be kept closed, so that only the water that passes through the tanks is used for feeding the boiler. If the plant be a small one, with but one or two boilers and only a single feed pump, the latter can be made to do duty as a testing pump, because during the test there will be no other boilers to feed besides the ones under test.

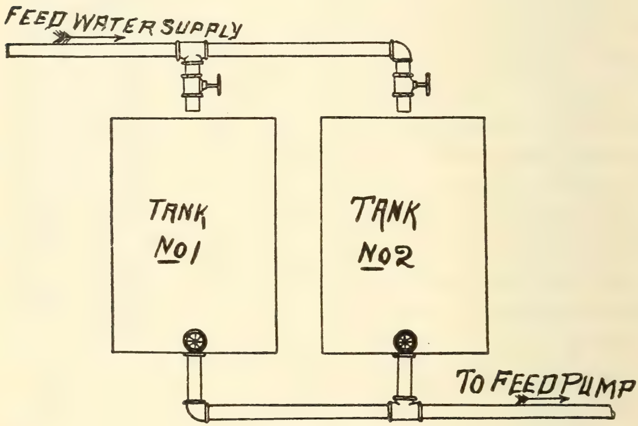


FIGURE 10.

If metal tanks are considered too expensive, two good water-tight barrels can be substituted. Fig. 10 will give the reader a general idea of what is needed for obtaining the weight of the water by the method just described. If a closed heater is used and no other boilers are in service during the test, the cold water can be measured in the tanks and pumped directly through the heater, but if it is necessary to feed other boilers besides those under test, then either a separate feed pipe must be run to the test boilers, or else hot water meters will have to be put into the branch pipes.

In cases where a separate feed pipe must be put in for the test boiler and the water which is used for testing cannot be passed through a heater, there should be a ¾ or 1 in. pipe connected to the feed main or header and leading to the testing tanks, in order to allow a portion of the hot feed water to run into and mix with the cold water in the tanks as they are being filled, thus partially warming the water before it goes to the boiler.

Heating Surface. The heating surface of a boiler consists of that portion of the boiler which is exposed to the heat on one side and water on the other. In a horizontal boiler of either the flue or tubular type, the available heating surface is, first, the lower half of the shell; second, the area of the back head below the water line minus the combined cross sectional area of all the tubes or flues; third, the inside area of the flues; fourth, the area of the front head minus the sectional area of the flues.

For a fire-box boiler of the vertical type, the area of the flue sheets minus the sectional area of the flues, plus the area of the fire-box plus the inside area of the flues constitutes the heating surface. If the boiler is a horizontal internally fired boiler, the heating surface will consist of, first, area of three sides of the fire-box; second, area of the crown sheet; third, area of flue sheets minus sectional area of flues; fourth, inside area of the flues.

In estimating the area of the fire-box, the area of the fire door should be subtracted therefrom. If the fire-box be circular, as in the case of a vertical boiler, the area may be obtained by first finding by measurements the diameter, which multiplied by 3.1416 will give the circumference. Then multiply this result by the height or the distance between the grate bars and the flue sheet. In the case of water tube boilers the outside area of the tubes must be taken. Two examples will be given illustrating methods of calculating heating surface:

First, take a horizontal tubular boiler, diameter 72 in., length 18 ft., having sixty-two 4½ in. flues; find area of lower half of shell.

Circumference = diameter × 3.1416 = 18.8496 ft.

One-half of the circumference multiplied by the length = required area. Thus, 18.8496 ÷ 2 × 18 = 169.64 sq. ft.

Next find heating surface of back head below the water line. Total area = $72^2 \times .7854 = 4071.5$ sq. in. Assume two-thirds of this area to be exposed to the heat. ⅔ of 4071.5 = 2714.3 sq. in. From this must be deducted the sectional area of the tubes. In giving the size of boiler tubes the outside diameter is taken. The tubes being 4½ in.; the area of a circle 4½ in. in diameter is 15.9 sq. in. Number of flues, 62 × 15.9 = 985.8 sq. in. = sectional area of tubes. The heating surface of the back head therefore = 2714.3 − 985.8 = 1728.5 sq. in. Dividing this by 144, to reduce to feet, we have 12 sq. ft.

Next find inside area of tubes. The standard thickness of a 4½ in. tube = .134 in. The inside diameter therefore will be 4.5 − (2 × .134) = 4.23 in., and the circumference will be 4.23 × 3.1416 = 13.29 in., and the inside area will be 13.29 × length, 18 ft., = 216 in. Thus 216 × 13.29 ÷ 144 = 19.93 sq. ft., inside area of one flue. There being 62 flues, the total heating surface of tubes is 19.93 × 62 = 1235.66 sq. ft. The heating surface of the front head is found in the same manner as that of the back head, with the exception that the whole area should be figured instead of two-thirds, for the reason that the entire surface is exposed to the heat, although that portion above the water line may be considered as superheating surface. The heating surface of front head would be: area 4071.5 – sectional area of tubes 985.8 = 3085.7 sq. in. = 21.43 sq. ft.

The total heating surface of the boiler is thus found to be 1438.73 sq. ft, divided up as follows:

Lower half of shell,	169.64	sq. ft.
Back head,	12.00	"
Tubes,	1235.66	"
Front head,	21.43	"
	1438.73	"

Next taking a vertical fire-box boiler of the following dimensions: diameter of flue sheet, and also of fire-box, 50 in.; height of fire-box above grate bars, 30 in.; number of flues, 200; size of flues, 2 in.; length of flues, 7 ft.

First, find heating surface in flue sheet.

Area of circle, 50 in. in diameter = 1,963.5 sq. in.

Sectional area of 2 in. flue = 3.14 sq. in., which multiplied by 200 = 628 sq. in., total sectional area of tubes. The heating surface of one flue sheet therefore will be $1{,}963.5 - 628 \div 144 = 9$ sq. ft.

Assuming that the tops of the flues are submerged, the area of the top flue sheet will also be 9 sq. ft. Then heating surface of flue sheets $= 9 \times 2 = 18$ sq. ft.

Second, find heating surface of tubes. The standard thickness of a 2 in. flue is .095 in. The inside diameter will consequently be $2 - (.095 \times 2) = 1.8$ in., and the circumference will be $1.8 \times 3.1416 = 5.66$ in. The length of the flue being 7 ft., or 84 in., the inside area will be 5.66 × 84 ÷ 144 = 3.3 sq. ft., and multiplying this result by 200 we have 200 × 3.3 = 660 sq. ft. as the heating surface of the flues.

Third, find heating surface of the fire-box. Diameter of fire-box = 50 in., which multiplied by 3.1416 = 157.08, which is the circumference. The height being 30 in., the total area will be 157.08 × 30 ÷ 144 = 32.7 sq. ft. Allowing 1 sq. ft. as the area of the fire door, will leave 31.7 sq. ft. heating surface of fire-box. The heating surface of the boiler will be:

For the flue sheets,	18	sq. ft.
For the flues,	660	"
For the fire-box,	31.7	"
Total,	709.7	"

The above methods may be applied in estimating the heating surface of any boiler, provided in the case of water tube boilers that the outside in place of the inside area of the tubes be figured.

Questions

1. How should the bridge wall of a horizontal boiler be built?

2. How should the brick work of a boiler be secured in order to prevent damage by expansion and contraction?

3. Which end of a horizontal boiler should be the lowest, and why?

4. How should the water column be located?

5. How high above the top row of tubes should the lower gauge cock be?

6. What is the proper ratio of safety valve area to grate surface?

7. Where should the fusible plug be located?

8. Where should the feed pipe enter the boiler?

9. Where should the blow off pipe be connected?

10. What is the most economical device for feeding a boiler?

11. In selecting a feed pump, how may the required size of pump be ascertained?

12. What is the disadvantage in the use of the injector for feeding a boiler?

13. What is gained by using a feed water heater?

14. How many kinds of exhaust heaters are there?

15. How may the saving effected by using the exhaust steam for heating the feed water be estimated?

16. What should the capacity of the heater be?

17. What provision should be made for testing coal and other fuel?

18. What is the heating surface of a boiler?

CHAPTER III

BOILER OPERATION

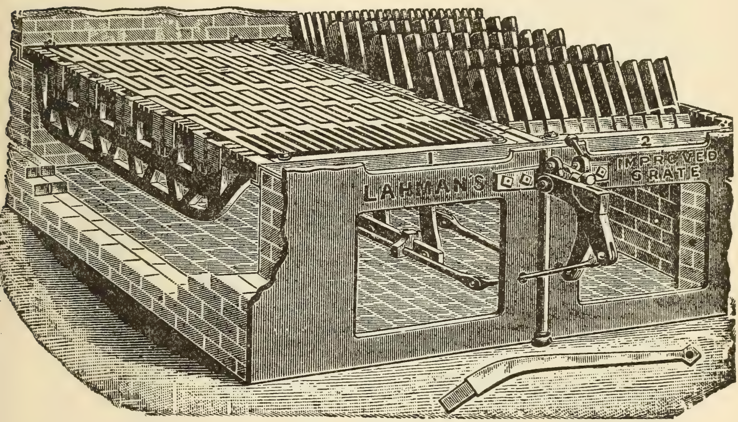
First care of the engineer on entering his boiler-room—Cleaning fires—Fire tools, etc.—Firing—Suggestions as to best method of firing—Quantity of air required per pound of coal—Cleaning tubes—Washing out, etc.—Why it is dangerous to cool a boiler too quickly—Repairing tubes—Cleaning inside of boiler—Pitting—How to feed a boiler—What to do in cases of emergency—Connecting with main—Foaming, priming, etc.—Safety valve calculations—Rules for safety valve calculations—Feed pumps—Care of feed pumps—Directions for setting steam valves of duplex pumps—Hydraulics for engineers.

Operation. Having considered in the previous chapters the principal details in the construction and erection of boilers with which the working engineer is interested, it is now in order to devote a space to their operation.

Duties. The first act of the careful engineer on entering his boiler-room when he goes on duty should be to ascertain the exact height of the water in his boilers. This he can do by opening the valve in the drain pipe of the water column, allowing it to blow out freely for a few seconds, then close it tight and allow the water to settle back in the glass. This should be done with each boiler under steam, not only once, but several times during the day. No engineer should be satisfied with a general squint along the line of gauge glasses, but he should either go himself or else instruct his fireman or water tender to make the rounds of each boiler and be sure that the water is all right.

The next thing to be looked after is the fire. If the plant is run continuously day and night it is the duty of the firemen coming off watch to have the fires clean, the ash pits all cleaned out, a good supply of coal on the floor, and everything in good order for the on coming force. A good fireman will take pride in always leaving things in neat shape for the man who is to relieve him.

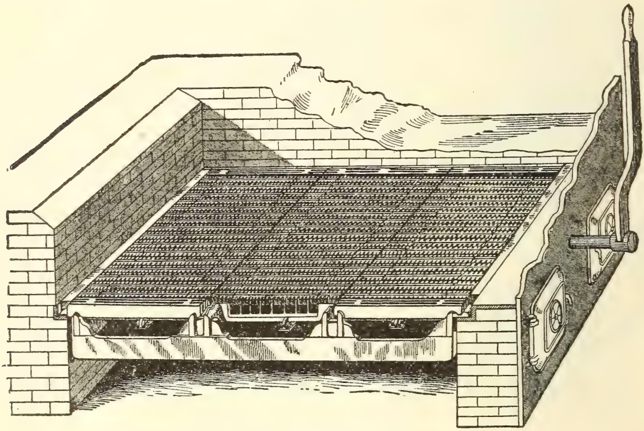
Cleaning Fires. With some varieties of coal this is



LAHMAN'S GRATE.

comparatively easy task, especially if the boilers are fitted with shaking grates. With a coal that does not form a clinker on the grate bars, the fires can be kept in good condition by cleaning them twice or three times in twenty-four hours, as the larger part of the loose ashes and noncombustible can be gotten rid of by shaking the grates and using the slice bar at intervals more or less frequent; but such coals are generally considered too expensive to use in the ordinary manufacturing plant, and cheaper grades are substituted.

Fire Tools. For cleaning fires successfully and quickly the following tools should be provided: a slice bar, a fire hook, a heavy iron or steel hoe, and a light hoe for cleaning the ash-pit. It is unnecessary to describe these tools, as they are familiar to all engineers. A suggestion as to the kind of handles with which they should be fitted may be of benefit. The working ends of the aforesaid tools having been made and each welded to a bar of 1 or 1⅛ in. round



MARTIN ANTI-FRICTION ROCKING GRATES.

iron and 10 or 12 in. long, take pieces of 1 or 1¼ in. iron pipe cut to the length desired for the handles and weld the shanks of the tools to them. To the other end of the pipe weld a handle made of round iron somewhat smaller than the shank. By using pipe handles the weight of the tools is considerably lessened, and they will still be sufficiently strong. The labor of cleaning the fire will thus be greatly lightened. When a fire shows signs of being foul and choked with clinker, preparations should be made at once for cleaning it by allowing one side to burn down as low as possible, putting fresh coal on the other side alone. When the first side has burned as low as it can without danger of letting the steam pressure fall too much, take the slice bar and run it in along the side of the furnace on top of the clinker and back to near the bridge wall, then using the door jamb as a fulcrum, give it a quick strong sweep across the fire and the greater part of the live coals will be pushed over to the other side. What remains of the coal not yet consumed can be pulled out upon the floor with the light hoe and shoveled to one side, to be thrown back into the furnace after the clinker is taken out. Having now disposed of the live coal, take the slice bar and run it along on top of the grates, loosening and breaking up the clinker thoroughly, after which take the heavy hoe and pull it all out on the floor. A helper should be ready with a pail of water, or, what is still better, a small rubber hose connected to a cold water pipe running along the boiler fronts for this purpose, and put on just enough water to quench the intense heat of the red hot clinker as it lies on the floor. When the grates are cleaned, close the door, and with the slice bar in the other side push all the live coal over to the side just cleaned, where it should be leveled off and fresh coal added. After this has become ignited, treat the other side in the same way. An expert fireman will thus clean a fire with very little loss in steam pressure, and practically no waste of coal.

Firing. No definite set of rules for hand firing can be laid down that will be suitable for all steam plants, or for the many different kinds of coal used. Some kinds of coal need very little stirring or slicing, while others that have a tendency to coke and form a crust on top of the fire need to be sliced quite often.

Every engineer, if he is at all observant, should be able to judge for himself as to the best method of treating the coal he is using, so as to get the most economical results. A few general maxims may be laid down. First, keep a clean fire; second, see that every square inch of grate surface is covered with a good live fire; third, keep a level fire, don't allow hills and valleys and yawning chasms to form in the furnace, but keep the fire level; fourth, when cleaning the fire always be sure to clean all the clinkers and dead ashes away from the back end of the grates at the bridge wall, in order that the air may have a free passage through the grate bars, because this is one of the best points in the furnace for securing good combustion provided the bridge wall is kept clean from the grates up. By keeping the back ends of the grate bars and the face of the bridge wall clean, the air is permitted to come in contact with the hot fire brick, and thus one of the greatest aids to good combustion is utilized. Don't allow the fire to become so deep and heavy that the air cannot pass up through it, because without a good supply of air good combustion is impossible. When the chimney draft is good the quantity of cold air admitted underneath the grate bars may be easily regulated by leaving the ash-pit doors partly open. The amount of opening required can be ascertained by a little experimenting and depends upon the intensity of the draft and the condition of the fire. With a clean, light fire and the air spaces in the grates free from dead ashes, a slight opening of the ash-pit doors will suffice to admit all the air required beneath the grates. But if the fire is heavy and the grates are clogged, a larger opening will be necessary. In firing bituminous coal containing a large percentage of volatile (light or gaseous matter) the best results can be obtained by leaving the fire doors slightly open for a few seconds immediately after throwing in a fresh fire. The reason for doing this is that the volatile matter in the coal flashes into flame the instant it comes in contact with the heat of the furnace, and if a sufficient supply of oxygen is not present just at this particular time the combustion will be imperfect and the result will be the formation of carbon mon-oxide or carbonic oxide gas, and the loss of about two-thirds of the heat units contained in the coal. This loss can be guarded against in a great measure by a sufficient volume of air, either through the fire doors directly after putting in a fresh fire, or, what is still better, providing air ducts through the bridge wall or side walls which will bring the air in on top of the fire. Each pound of coal requires for its complete combustion 12 lbs. or about 150 cu. ft. of air, and the largest volume of air is needed just after fresh coal has been added to the fire.

Cleanliness. In order to get the best results great care should be taken that the tubes be kept clean and free from soot. Especially does this apply to horizontal return tubular boilers, for the reason that when the tubes become clogged with soot the efficiency of the draft is destroyed and the steaming capacity of the boiler is greatly reduced. Soot not only stops the draft, but it is a non-conductor of heat. In some batteries of boilers where an inferior grade of coal is used and the draft is poor, it is absolutely necessary to scrape or blow the tubes at least once a day in order to enable the boilers to generate sufficient steam.

As to the process of cleaning there are various devices on the market, both for blowing the soot out by means of a steam jet and also for scraping the inside of the tubes. The steam jet, if properly made and used with a high pressure and dry steam, does very satisfactory work, but it should not be depended upon exclusively to keep the tubes clean, because in process of time a scale will form inside the tubes that nothing but a good scraper will remove. For that reason it is good practice to use the scraper two or three times a week at least. When the boiler is cooled down for washing out, the bottom of the shell should be cleaned of all accumulations of dust and ashes, the combustion chamber back of the bridge wall cleaned out, and the back flue sheet or head swept off and examined, and if there is a fusible plug in the back head the scale should be scraped from it, both inside and outside the boiler, because if it is covered with scale neither the water nor the heat can come in contact with it, and it will be non-effective.

Washing Out. The length of time that a boiler can be run safely and economically after having been washed out depends upon the nature of the feed water. If the water is impregnated to a considerable extent with scale forming matter, the boiler should be washed out every two weeks at the least, and in some cases of particularly bad water it becomes necessary to shorten the time to one week. To prepare a boiler for washing the fire should be allowed to burn as low as possible and then be pulled out of the furnace, the furnace doors left slightly ajar and the damper left wide open in order that the walls may gradually cool. It is as bad a practice to cool a boiler off too suddenly as it is to fire it up too quick, because the sudden change of temperature either way has an injurious effect on the seams, contracting or expanding the plates, according as it is cooled or warmed, and thus creating leaks and very often small cracks radiating from the rivet holes, and becoming larger with each change of temperature, until finally the strength of the seam is destroyed and rupture takes place. After the boiler has become comparatively cool and there is no pressure indicated by the steam gauge the blow off cock may be opened and the water allowed to run out. The gauge cocks and also the drip to the water column should be left open to allow the air to enter and displace the water. Otherwise there will be a partial vacuum formed in the boiler and the water will not run out freely.

A boiler should not be blown out, that is, emptied of water while under pressure. The sudden change of temperature is sure to have a bad effect upon the sheets and seams. Suppose for instance that all the water is blown out of a boiler under a pressure of 20 lbs. by the steam gauge. The temperature of steam at 20 lbs. is 260° F., and it may be assumed that the metal of the boiler is at or near that temperature also. Assume the temperature of the atmosphere in the boiler-room to be 60° F. There will then be a range of $260° - 60° = 200°$ temperature for the boiler to pass through within a short time, which will certainly have a bad effect, and besides this the boiler shell will be so hot that the loose mud and sediment left after the water has run out is liable to be baked upon the sheets, making it much harder to remove.

While inside the boiler the boiler washer should closely examine all the braces and stays, and if any are found loose or broken they should be repaired at once before the boiler is used again. The soundness of braces, rivets, etc., can be ascertained by tapping them with a light hammer.

Renewing Tubes. As it is practically impossible to prevent scale from forming on the outside of the tubes of horizontal tubular boilers unless the feed water is exceptionally good, and as the tubes will in course of time become leaky where they are expanded into the heads, the engineer if he has a battery of two or more, should take advantage of the first opportunity that presents itself to take out of service the boiler that shows the most signs of deterioration and take out the tubes, and after cleaning them of scale by scraping and hammering or rolling in a tumbling cylinder, he should select those that are still in good condition and have them pieced out at the ends, making them almost as good as new.

The flues being out of the boiler will give the boiler washer a good opportunity to thoroughly clean the inside also, and if there are any loose rivets they should be replaced and leaky or suspicious looking seams chipped and caulked. If there are indications of corrosion or pitting, a stiff paste or putty made of plumbago mixed with a small proportion of cylinder oil may be applied to the affected parts with good results.

Feed Water. There is no steam plant of any consequence that does not have more or less exhaust steam or returns from a steam heating system which can be utilized for heating the feed water before it enters the boiler. Cold water should never be pumped into a boiler that is under steam when it is possible to prevent it.

In feeding a boiler the speed of the feed pump should be so gauged as to supply the water just as fast as it is evaporated. The firing can then be even and regular.

If the supply of feed water should suddenly be cut off, owing to breakage of the pump or bursting of a water main, and no other source of supply was available, the dampers should be immediately closed, or if there should be no damper in the breeching, the draft may be stopped by opening the flue doors. The fires should then be deadened by shoveling wet or damp ashes in on top of them, or if the ashes cannot be readily procured, bank the fires over with green coal broken into fine bits. This, with the draft all shut off, will deaden the fires, while the engine still running will gradually use up the extra steam. If the water should get dangerously low in the boilers the fires may be pulled, provided they have become deadened sufficiently, but they should never be pulled while they are burning lively, because the stirring will only serve to increase the heat and the danger will be aggravated.

Connecting a Recently Fired Up Boiler. After a boiler has been washed out, filled with water, and fired up, the next move is to connect it with the main battery. The steam in the boiler to be connected having been raised to the same pressure as that in the battery, the connecting valve should be opened slightly, just enough to permit a small jet of steam to pass through, which can be heard by placing the ear near the body of the valve. This jet of steam may be passing from the battery into the newly connected boiler or *vice versa.* Whichever way it passes, the valve should not be opened any farther until the flow of steam stops, which will indicate that the pressure has been equalized. It will then be found that the valve will move much easier and it may be gradually opened until it is wide open.

Foaming. Water carried with the steam from the boiler to the engine, even if in small quantities, is very detrimental to the successful operation of the engine, as it washes the oil from the walls of the cylinder, thereby increasing the friction, and unless a plentiful supply of oil is entering the cylinder cutting of the piston rings will take place. There is also danger of breaking a cylinder head or of bending the piston rod if the water comes in too large quantities.

There are certain kinds of water which have a natural tendency to foam, especially such as contain considerable organic matter, and the more severe the service to which the boiler is put the more will the water foam, until it is practically impossible to locate the true level of the water in the boilers, and the only recourse the water tender has is to keep his feed pump running at such a speed as will in his judgment supply the water as fast as it goes out of the boilers. It is a dangerous condition to say the least, and the only remedy for it is either a change to a different kind of water, or if this is not possible, then an increase in the number of boilers, which would make it possible to supply sufficient steam for the engine without being compelled to fire the boilers so hard.

Priming. By which is meant the carrying over of water in the form of fine spray mingled with the steam, is not so dangerous as foaming and yet it causes much loss in the efficiency of a boiler or engine. It can be prevented to a large extent by placing a baffle plate in the steam space of the boiler directly under the dome or outlet to the connection with the steam main.

Safety Valves. Rules are given in Chapter II. for guidance in making calculations relating to spring pop valves, which are now almost universally used on boilers, and which, without doubt, are the most reliable appliance for relieving a boiler of surplus steam.

A short space will be devoted to the consideration of the lever safety valve also, as it may be of interest to some students.

The U. S. marine rule for lever valves is here repeated: "Lever safety valves to be attached to marine boilers shall have an area of not less than one square inch to every two square feet of 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 axis."

In order to arrive at accurate results in lever safety valve calculations it is necessary to know first the number of pounds pressure exerted upon the stem of the valve by the lever itself, irrespective of the weight, also the weight of the valve and stem, as all these weights together with the weight of the ball suspended upon the lever tend to hold the valve down against the pressure of the steam. The effective weight of the lever can be ascertained by leaving it in its position attached to the fulcrum and connecting a spring balance scale to it at the point where it rests on the valve stem. The weight of the valve and stem can also be found by means of the scale. When the above weights are known, together with the weight at the end of the lever and its distance from the fulcrum, also the area of the valve and its distance from the fulcrum, the pressure at which the valve will blow can be found by the following rules:

Rule 1. Multiply the weight by its distance from the fulcrum. Multiply the weight of the valve and lever by the distance of the stem from the fulcrum and add this to the former product. Divide the sum of the two products by the product of the area of the valve multiplied by the distance of its stem from the fulcrum. The result will be pressure in pounds per square inch required to lift the valve.

Example. Diameter of value, 3 in.

Distance of stem from fulcrum, 3 in.

Effective weight of lever, valve and stem, 20 lbs.

Weight of ball, 50 lbs.

Distance of ball from fulcrum, 30 in.

Required pressure at which the valve will blow off, $50 \times 30 + 20 \times 3 = 1560$.

Area of valve, $7.0686 \times 3 = 21.2058$.

$1560 \div 21.2058 = 73.57$ lbs. pressure.

When the pressure at which it is desired the valve should blow off is known, together with the weights of all the parts, the proper distance from the fulcrum at which to place the weight is ascertained by Rule 2.

Rule 2. Multiply the area of the valve by the pressure and from the product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of the stem from the fulcrum and divide by the weight of the ball. The quotient will be the required distance.

Example. Area of valve, 7.07 sq. in.

To blow off at 75 lbs.

Effective weight of lever and valve, 20 lbs.

Weight of ball, 50 lbs.

Distance of valve stem from fulcrum, 3 in.

$7.07 \times 75 - 20 = 510.25$.

$510.25 \times 3 \div 50 = 30.6$ in., distance from fulcrum at which to place the ball.

When the pressure is known, together with the distance of the weight from the fulcrum, the weight of the ball is obtained by Rule 3.

Rule 3. Multiply the area of the valve by the pressure and from the product subtract the effective weight of the lever and valve. Multiply the remainder by the distance of the stem from the fulcrum and divide by the distance of the ball from the fulcrum. The quotient will be the required weight.

Example. Area of valve, ... 7.07 sq. in.
Pressure in pounds per square inch, . . 80 lbs.
Effective weight of lever and valve, . . 20 lbs.
Distance of stem from fulcrum, ... 3 in.
Distance of weight from fulcrum, . . . 30 in.

$7.07 \times 80 - 20 = 545.6$.

$545.6 \times 3 \div 30 = 54.56$ lbs., weight of ball.

Safety valves, especially those of the lever type, are liable to become corroded and stick to their seats if allowed to go any great length of time without blowing. Therefore it is good practice to raise the steam pressure to the blowing off point at least two or three times a week, or oftener, for the purpose of testing the valve. If it opens and releases the steam at the proper point all is well, but if it does not, it should be looked after forthwith. Generally the mere raising of the lever by hand, or a few taps with a hammer if it be a pop valve, will free it and cause it to work all right again; but if this treatment has to be resorted to very often the valve should be taken down and overhauled. In too many steam plants not enough importance is attached to the safety valve. The fact is, it is one of the most useful and important adjuncts of a boiler, and if neglected serious results are sure to follow.

Feed Pumps. A good engineer will always take a pride in keeping his feed pump in good condition, and if he has two or more of them, which every steam plant of any consequence should have, he will have an opportunity to keep his pumps in good shape. The water pistons of most boiler feed pumps are fitted to receive rings of fibrous packing. The best packing for this purpose and one that will stand both hot and cold water service is made of pure canvas cut in strips of the required width, ½, ⅝, ¾ in., etc., and laid together with a water proof cement having the edges for the wearing surface. This packing is called square canvas packing, and can be purchased in any size required for the pump. The size is easily ascertained by placing the water piston, minus the follower plate, centrally in the water cylinder and measuring the space between the piston and cylinder walls. This packing should not be allowed to run for too long a time before renewing, for the reason that pieces of it are liable to become loose and be forced along with the feed water on its way to the boiler and lodge under the check valve, holding it open and causing no end of trouble. If the feed pump has to handle hot water, or has to lift the water several feet by suction, the packing rings should be looked after at least once a month.

Hard rubber valves are, all things considered, the best for a boiler feed pump, as they are not affected by hot water and do not hammer the seats like metallic composition valves do. Every boiler feed pump should be fitted with a good sight-feed lubricator for cylinder oil. The steam valve mechanism of a steam pump is very sensitive and delicate and requires good lubrication in order to do good work. In too many cases feed pumps are fitted with an old style cylinder oil cup and there is generally more oil on the outside of the valve chest than there is inside, while the valve is bulldozed into working by frequent blows from a convenient club.

The steam valves of all steam pumps are adjusted before they are sent out from the factory, and most of them are arranged so that the stroke may be shortened or lengthened as the engineer desires. It is best as a rule to allow a pump to make as long a stroke as it will without striking the heads, because then the parts are worn evenly.

Sometimes an engineer is called upon to set the valves of a duplex pump which have become disarranged. In such a case he should proceed as follows: Place both pistons exactly at mid-stroke. This may be done in two ways. First, by dropping a plummet line alongside the levers connecting the rock shafts with the spools on the piston rods. Then bring the rods to the position where the centers of the spools will be in a vertical line with the centers of the rock shafts.

The second method is to move the piston to the extreme end of the stroke until it comes in contact with the cylinder head. Then mark the rod at the face of the stuffing box gland. Next move the piston to the other end of the stroke and mark the rod at the opposite gland. Now make a mark on the rod exactly half way between the two outside marks and move the piston back until the middle mark is at the face of the gland and the piston will be at mid-stroke. Having placed both pistons at mid-strike, remove the valve chest covers and adjust the valves in their central position, viz., so that they cover the steam ports. The valve rod being in position and connected to the rocker arm by means of the short link, the nut or nuts securing the valve to the rod should be so adjusted as to be equidistant from the lugs on the valve, say $\frac{3}{32}$ or $\frac{1}{8}$ of an inch according to the amount of lost motion desired, which latter factor governs the length of stroke in some makes of duplex pumps, while in others it is controlled by tappets on the valve rod outside of the valve chest. Care should be taken while making these adjustments that the valve be retained exactly in its central position.

Having set the valves correctly, move one of the pistons far enough from mid-stroke to get a small opening of the steam port on the opposite side, then replace the valve chest covers and the pump will be ready to run. As these valves are generally made without any outside lap, a slight movement of one of the pistons in either direction from its central position will suffice to uncover one of the ports on the other cylinder sufficiently to start the pump.

Sometimes duplex pumps "work lame," that is, one piston will make a quick full stroke while the other piston will move very slowly and just far enough to work the steam valve of the opposite side. In the majority of cases this irregular action is due to unequal friction in the packing of the rods, or the packing rings on one of the pistons may be worn out.

If one side of a duplex pump becomes disabled from any cause, as breaking of piston rod in the water cylinder, for instance, which is liable to happen, the pump may still be operated in the following manner until duplicate parts to replace the broken ones have been secured. Loosen the nuts or tappets on the valve stem of the broken side and place them far enough apart so that the steam valve will be moved through only a small portion of its stroke, thereby admitting only steam enough to move the empty steam piston and rod, and thus work the steam valve of the remaining side. The packing on the broken rod should be screwed up tight, so as to create as much friction as possible; there being no resistance in the water end. In this way the pump may be operated for several days or weeks and thus prevent a shut down.

Hydraulics for Engineers. Among the many difficult problems that are continually coming up for engineers to solve, there is none more perplexing than the correct calculation of the quantity of water which will be discharged in a given time from pipes of various sizes and under the many different heads or pressures. Problems in hydraulics, as given by the majority of writers on engineering, are usually in elaborate algebraical equations, which, to the ordinary working engineer, are very perplexing, at least the author has found them to be so in his experience. Therefore with a view of assisting his brother engineers in the solution of problems along this line which they may be called upon to solve, the author has spent considerable time and labor in searching for and compiling a few rules and examples for hydraulic calculations in plain arithmetic which he hopes may be of benefit.

First, to find velocity of flow in the pump, or in other words, piston speed.

Rule. Multiply number of strokes per minute by length of stroke in feet, or fractions thereof.

Second, the velocity of flow in the discharge pipe is in inverse ratio to the squares of the diameters of the pipe and the water cylinder of pump.

Thus, a pump cylinder is 6 in. in diameter, and the piston speed is 100 ft. per minute; the discharge pipe being 3 in. in diameter. What is the velocity of flow in the pipe?

Example. $\frac{6 \times 6}{3 \times 3} = 4$. In this case the velocity in the pipe is four times that in the pump, and $100 \times 4 = 400$ ft. per minute, velocity for water in the discharge pipe.

Third, to find velocity in feet per minute necessary to discharge a given quantity of water in a given time.

Rule. Multiply the number of cubic feet to be discharged by 144 and divide by area of pipe in inches.

Fourth, to find area of pipe when the volume and velocity of water to be discharged are known.

Rule. Multiply volume in cubic feet by 144 and divide by the velocity in feet per minute.

Fifth, one of the first requisites in making correct calculations of the quantity of water discharged from any sized pipe is to obtain the velocity of flow per second. There are several rules for doing this, among which the following appear to be the plainest and most simple:

Rule 1. Multiply the square root of the head in inches by the constant 27.8. For instance, assume the head to be 100 ft. = 1200 in. The square root of 1200 is 35 nearly, then $35 \times 27.8 = 973$ in. = 81 ft. per second velocity.

Rule 2. Multiply the square root of the head in feet by the constant 8, as follows: The square of $100 = 10$ and $10 \times 8 = 80$ ft. velocity per second.

Rule 3. Multiply twice the acceleration of gravity by the head in feet and extract the square root of product. The acceleration of gravity may be considered the constant number 32, neglecting decimals.

$32 \times 2 \times 100 = 6400$. Square root of $6400 = 80$ ft. per second.

In many instances it is more convenient to use the pressure in pounds per square inch as shown by gauge instead of the height or head, and we can then apply Rule 4.

Rule 4. Multiply the square root of the pressure in pounds per square inch by the constant number 12.16 as follows: Pressure due to 100 ft. head = 44 lbs., nearly. Square root of $44 = 6.6$, which multiplied by $12.16 = 80.2$ ft. velocity per second.

Having ascertained the velocity of flow, we may now proceed to calculate the weight of water in pounds per second discharged from any size of pipe, neglecting for the time being the loss in pressure caused by friction from elbows and bends in the pipe and also the peculiar shape assumed by a stream of water flowing through pipes or conduits when there is no resistance except the pressure of the atmosphere and friction caused by long distance transmission.

We will take for our calculation a four-inch pipe from which the water has a free flow under a head of 100 ft., which gives a velocity of 80 ft. per second.

Rule 5. Divide the velocity in feet per second by the constant 2.3, and multiply the quotient by the area of discharge pipe in square inches. $80 \div 2.3 = 34.7$. Now the area of a four-inch pipe is 12.57 sq. in., and $34.7 \times 12.57 = 436$ lbs. discharged per second.

In order to get the matter clearly before us, let us assume that we have a section of four-inch pipe just 80 ft. in length and that it lies in a horizontal position and is filled solidly full of water. It will contain area, 12.57 sq. in. $\times$ length, 960 in. = 12,067.2 cu. in. of water, and as one pound of water occupies a space of

27.7 cu. in., we therefore have 1,2067.2 ÷ 27.7 = 436 lbs. of water, and at a velocity of 80 ft. per second our pipe will be emptied and refilled continuously each second. We have also Rule 6 to find the number of cubic feet discharged per minute when the velocity per minute is known.

Rule 6. Multiply the area of pipe in square inches by the velocity in feet per minute and divide by the constant 144.

Example. Area of 4 in. pipe = 12.57 sq. in. Velocity of flow = 80 ft. per second = 4,800 ft. per minute. Then $\frac{12.57 \times 4,800}{144} = 419$ cu. ft. per minute = 6.99 cu. ft. per second, which multiplied by 62.3 lbs. (weight of 1 cu. ft.) = 435.4 lbs. per second.

As stated before, no allowance is made by the above rules for friction or other retarding influences, but for ordinary purposes in connection with a steam plant a deduction of 25 per cent. is probably sufficient. Of course if the water is being discharged into an elevated tank or against direct pressure of any kind, the resistance in pounds per square inch or the height in feet must be deducted from the impelling pressure or head. Let us assume, for instance, that our 4 in. pipe is discharging water into a tank at an elevation of 75 ft. above the level of the pump, and that to reach the tank requires 100 ft. of pipe with two 90° ells and one straight-way valve. We wish to discharge 500 gal. per minute into the tank and will therefore require a velocity of about 13 ft. per second, which will necessitate a pressure of a little more than 1 lb. per square inch to be maintained at the pump over and above all resistance. Now the resistance to be overcome in this case will be:

Pressure per square inch due to 75 ft. head,	32.5 lbs.
Friction loss due to length of pipe and velocity,	7.43 "
Friction loss due to two 90° ells,	2.16 "
Friction loss due to straight way valve,	.2 "
Total,	42.29 lbs.

Requiring a pressure of say 43 lbs. per square inch, or about the equivalent of 100 ft. head at the pump.

Again, suppose that in place of the elevated tank we have 1,000 ft. of 8 in. horizontal pipe with a 4 in. delivery at the end farthest from the pump, and three branch pipes each 100 ft. long and 4 in. in diameter with one 90° ell and one straight-way valve, connected at intervals to the 8 in. main, and it is required to discharge in all 1,000 gals. per minute, or at the rate of 250 gals. per minute for each 4 in. delivery. The friction loss for each 100 ft. in length of 8 in. pipe at a velocity of 13 ft. per second is .94 lbs., and for each 100 ft. of 4 in. pipe it is 1.89 lbs. Likewise the friction loss for each 90° ell is 1.08 lbs., and for a straight way valve .2 lbs., at the above velocity. The total resistance therefore to be overcome is as follows:

For 1,000 ft. of 8 in. pipe,	.94 lbs. × 10 = 9.4 lbs.
For 300 ft. of 4 in. pipe,	1.89 lbs. × 3 = 5.67 "
For four 90° ells,	1.08 lbs. × 4 = 4.32 "
For four straight-way valves,	.2 lbs. × 4 = .8 "
Total,	20.19 lbs.

Consequently the pressure required at the pump will be about 22 lbs. per square inch, equal to a head of 50 ft.

Questions

1. What should be the first care of an engineer on entering his boiler room when he goes on watch?

2. What is one of the duties of the fireman before coming off watch?

3. Name the various tools necessary for cleaning fires properly.

4. Describe the operation of cleaning fires.

5. What general rules should be observed in firing?

6. How may the best results be obtained in firing bituminous coal?

7. What will be the result if a sufficient supply of oxygen is not admitted to the furnace?

8. What quantity of air (cubic feet or pounds weight) is required for the complete combustion of one pound of coal?

9. Suppose there is a fusible plug in the boiler and it becomes covered with scale, what will be the result?

10. How long may a boiler be run safely after washing it out?

11. What should be done with a boiler in order to prepare it for washing out?

12. What effect does the too sudden cooling off or firing up of a boiler have upon the seams?

13. What other bad result takes place within the boiler when it is emptied of water while hot?

14. What should be done with tubes that have become badly scaled?

15. How fast should the feed water be supplied?

16. What should be done in case the supply of feed water be cut off suddenly?

17. What is the proper method of connecting a recently fired up boiler to the main header?

18. What are some of the dangerous results of foaming?

19. What can be done to prevent or at least to modify foaming in boilers?

20. Which are the most reliable pop valves or lever safety valves?

21. What is the rule regulating the area of lever safety valves?

22. What two factors must first be known before correct calculations can be made as to the weight and position of the ball on a lever safety valve?

23. How may the effective weight of the lever and that of the valve and stem be found?

24. When the area in square inches of the valve, the weight of the valve and stem, the effective weight of the lever, the weight of the ball and its distance from the fulcrum are known, how is the pressure at which the valve will blow off ascertained?

25. When the pressure at which the valve should blow off is known, together with the weights of all the parts, how may the distance the ball should be from the fulcrum be ascertained?

26. When the pressure is known, together with the distance of the ball from the fulcrum, how is the weight of the ball found?

27. What should be done with a safety valve in order to keep it in good working condition?

28. Describe the process of setting the steam valves of a duplex pump.

29. How may a duplex pump be operated in case one of the water pistons becomes disabled?

30. How is the velocity of flow or piston speed per minute of a pump ascertained?

31. The piston speed being known, how is the velocity of flow in the discharge pipe found?

32. When it is required to discharge a certain quantity of water from a given size of pipe in a given time, how may the velocity of flow in feet per minute be found?

33. When the volume of water to be discharged and the velocity of flow are known, how is the area of the pipe obtained?

34. What is meant by "acceleration of gravity," and what constant number represents it in connection with hydraulics?

35. What per cent. of allowance is ordinarily made for friction in water pipes?

CHAPTER IV

COMBUSTION—WATER—STEAM

Combustion—Composition of air—Carbon—The principal constituent of fuels—Hydrogen, its nature and heating value—Table, giving analysis of various coals—Process of combustion described—Quantity of air required—Furnace temperature—How to utilize the heat in the escaping gases—Heat, what it is and how produced—Joule's researches—The heat unit—Specific heat—Sensible heat and latent heat—Experiments of Professor Black—Total heat of evaporation—Water, its composition, nature, etc.—Steam, its expansive nature, temperature, etc.—Saturated steam, etc.—Total heat of steam—Density of steam.

Combustion. The subject of the combustion of fuels being one in which every engineer is vitally interested, it is proper that its leading features and principles be discussed. One of the main factors in the combustion of coal is the proper supply of air. Air is composed of two gases, oxygen and nitrogen, in the proportion, by volume, of 21 per cent. of oxygen and 79 per cent. of nitrogen, or by weight, 23 per cent. of oxygen and 77 per cent. of nitrogen.

The composition of pure dry air, as given by Kent in *Steam Boiler Economy*, is as follows:

By volume, 20.91 parts O. and 79.09 parts N.

By weight, 23.15 parts O. and 76.85 parts N.

Air is a mixture and not a chemical combination of these two elements. The principal constituent of coal and most other fuels, whether solid, liquid or gaseous, is carbon. Hydrogen is a light combustible gas and combined either with carbon or with carbon and oxygen, in various proportions, is also a valuable constituent of fuels, notably of bituminous coal. The heating value of one pound of pure carbon is rated at 14,500 heat units, while one pound of hydrogen gas contains 62,000 heat units.

Analysis of coal shows that it contains moisture, fixed carbon, volatile matter, ash and sulphur in various proportions according to the quality of the coal. The following table deduced from a few of the many valuable tables of analysis of the coals of the United States, as given by Mr. Kent, will show the composition of the principal bituminous coals in use in this country for steam purposes. Two samples are selected from each of the great coal producing states, with the exception of Illinois, from which four were taken.

TABLE 2

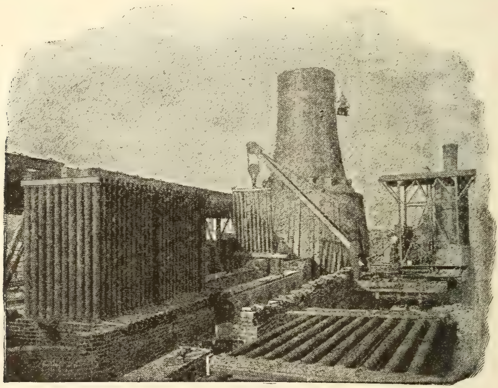
State	Kind of Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Pennsylvania	Youghiogheny	1.03	36.49	59.05	2.61	0.81
"	Connellsville	1.26	30.10	59.61	8.23	0.78
West Virginia	Quinimont	0.76	18.65	79.26	1.11	0.23
"	Fire Creek	0.61	22.34	75.02	1.47	0.56
E. Kentucky	Peach Orchard	4.60	35.70	53.28	6.42	1.08
"	Pike County	1.80	26.80	67.60	3.80	0.97
Alabama	Cahaba	1.66	33.28	63.04	2.02	0.53
"	Pratt Co.'s	1.47	32.29	59.50	6.73	1.22
Ohio	Hocking Valley	6.59	35.77	49.64	8.00	1.59
"	Muskingum "	3.47	37.88	53.30	5.35	2.24
Indiana	Block	8.50	31.00	57.50	3.00	
"	"	2.50	44.75	51.25	1.50	
W. Kentucky	Nolin River	4.70	33.24	54.94	11.70	2.54
"	Ohio County	3.70	30.70	45.00	3.16	1.24
Illinois	Big Muddy	6.40	30.60	54.60	8.30	1.50
"	Wilmington	15.50	32.80	39.90	11.80	
"	" screenings	14.00	28.00	34.20	23.80	
"	Duquoin	8.90	23.50	60.60	7.00	

The process of combustion consists in the union of the carbon and hydrogen of the fuel with the oxygen of the air. Each atom of carbon combines with two atoms of oxygen, and the energetic vibration set up by their combination is heat. Bituminous coal contains a large percentage of volatile matter which is released and flashes into flame when the coal is thrown into the furnace, and unless air is supplied in large amounts at this stage of the combustion there will be an excess of smoke and consequent loss of carbon. On the other hand there is a loss in admitting too much air because the surplus is heated to the temperature of the furnace without aiding the combustion and will carry off to the chimney just as many heat units as were required to raise it from the temperature at which it entered the furnace to that at which it enters the uptake. It will therefore be seen that a great advantage will be gained by first allowing the air that is needed above the fire to pass over or through heated bridge walls or side walls. Some kinds of coal need more air for their combustion than do others, and good judgment and close observation are needed on the part of the fireman to properly regulate the supply.

Some boilers will make steam more economically by partly closing the ash-pit doors, while others require the same doors to be kept wide open. The quantity of air required for the combustion of one pound of coal is, by volume, about 150 cu. ft.; by weight, about 12 lbs.

The temperature of the furnace is usually about 2500°, in some cases reaching as high as 3000°. The temperature of the escaping gases should not be much above nor below 400° F. for bituminous coal. The waste heat in the escaping gases can be utilized to great advantage by passing them through what are called economizers before they escape into the chimney. These economizers consist of coils or stacks of cast iron pipe placed within the flue or breeching leading from the boilers to the chimney and are enveloped in the hot gases, while the feed water is passed through the pipes on its way to the boilers, the result being that considerable heat is thus imparted to the feed water that would otherwise go to waste.

In order to attain the highest economy in the burning of coal in boiler furnaces two factors are indispen-



GREEN'S FUEL ECONOMIZER UNDER CONSTRUCTION.

sable, viz., a constant high furnace temperature and quick combustion, and these factors can only be secured by supplying the fresh coal constantly just as fast as it is burned, and also by preventing as much as possible the admission of cold air to the furnace. This is why the automatic or mechanical stoker, if it be of the proper design, is more economical and causes less smoke than hand firing. The fireman when he puts in a fire is prone to shovel in a good supply all at once, and this has the tendency to greatly reduce the temperature of the furnace, while at the same time it retards combustion. On the other hand the mechanical stoker supplies the coal continuously only as fast as it is required and no faster, and the furnace doors do not need to be opened at all, by which a large volume of cold air is prevented from entering the furnace and reducing the temperature. The author does not wish to be understood as recommending the adoption and use of mechanical stokers to replace hand firing, but he draws this contrast between the two methods of firing in order that it may be of some benefit to the thousands of honest toilers who earn a livelihood by shoveling coal into boiler furnaces.

The problem of the economical use of coal and the abatement of the smoke nuisance, especially in our large cities, has of late years become so serious that it is to the interest of every engineer, and especially every fireman, to use the utmost diligence, care and good judgment in the use of coal, and to emulate as much as possible the methods of the mechanical stoker.

Heat. All matter, whether solid, liquid or gaseous, consists of molecules or atoms, which are in a state of continual vibration, and the result of this vibration is heat. The intensity of the heat evolved depends upon the degree of agitation to which the molecules are subject.

Until as late as the beginning of the nineteenth century two rival theories in regard to the nature of heat had been advocated by scientists. The older of these theories was that heat was a material substance, a subtle elastic fluid termed caloric, and that this fluid penetrated matter something like water penetrates a sponge. But this theory was shown to be false by the wonderful researches and experiments of Count Rumford at Munich, Bavaria, in 1798.

By means of the friction between two heavy metallic bodies placed in a wooden trough filled with water, one of the pieces of metal being rotated by machinery driven by horses, Count Rumford succeeded in raising the temperature of the water in two and one-half hours from its original temperature of 60° to 212° F., the boiling point, thus demonstrating that heat is not a material substance, but that it is due to vibration or motion, an internal commotion among the molecules of matter. This theory, known as the Kinetic theory of heat, has since been generally accepted, although it was nearly fifty years after Rumford advocated it in a paper read before the Royal Society of Great Britain in 1798, before scientists generally became converted to this idea of the nature of heat and the science of Thermo Dynamics placed on a firm basis.

During the period from 1840 to 1849 Dr. Joule made a series of experiments which not only confirmed the truth of Count Rumford's theory that heat was not a material substance but a form of energy which may be applied to or taken away from bodies, but Joule's experiments also established a method of estimating in mechanical units or foot pounds the amount of that energy. This latter was a most important discovery because by means of it the exact relation between heat and work can be accurately measured.

The first law of thermo dynamics is this: Heat and mechanical energy or work are mutually convertible. That is, a certain amount of work will produce a certain amount of heat, and the heat thus produced is capable of producing by its disappearance a fixed amount of mechanical energy if rightly applied. The mechanical energy in the form of heat which, through the medium of the steam engine, has revolutionized the world, was first stored up by the sun's heat millions of years ago in the coal which in turn, by

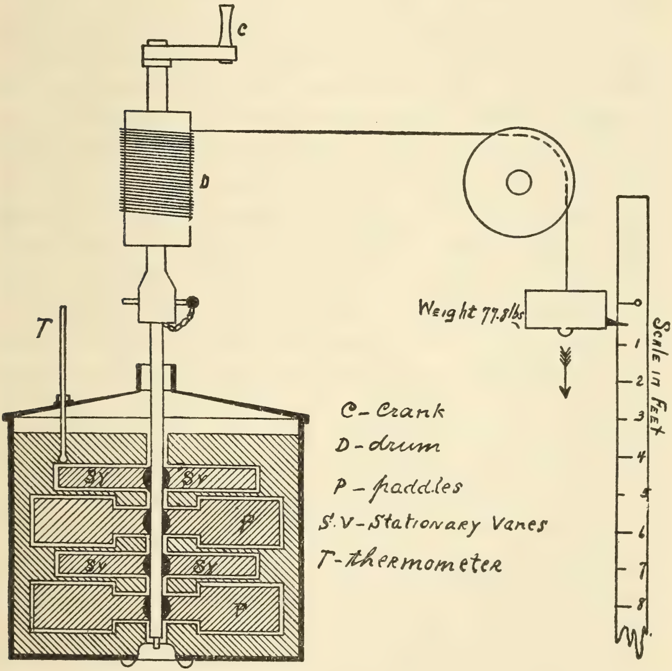


FIGURE 11

combustion, is made to release it for purposes of mechanical work.

The general principles of Dr. Joule's device for measuring the amount of work in heat are illustrated in Fig. 11. It consisted of a small copper cylinder containing a known quantity of water at a known temperature. Inside the cylinder and extending through the top was a vertical shaft to which were fixed paddles for stirring the water. Stationary vanes were also placed inside the cylinder. Motion was imparted to the shaft through the medium of a cord or small rope coiled around a drum near the top of the shaft and running over a grooved pulley or sheave. To the free end of the cord a known weight was attached. This weight was allowed to fall through a certain distance, and in falling it turned the shaft with its paddles, which in turn agitated the water, thus producing a certain amount of heat. To illustrate, suppose the weight to be 77.8 lbs., and that by means of the crank at the top end of the shaft it has been raised to the zero mark at the top of the scale. (See Fig. 11.) One pound of water at 39.1° F. is poured into the copper cylinder, which is then closed and the weight released. At the moment the weight passes the 10 ft. mark on the scale, the thermometer attached to the cylinder will indicate that the temperature of the water has been raised one degree. Then multiplying the number of pounds in the weight by the distance in feet through which it fell will give the number of foot pounds of work done. Thus, 77.8 lbs. × 10 ft. = 778 foot pounds.

The heat unit or British thermal unit (B. T. U.) is the quantity of heat required to raise the temperature of one pound of water one degree, or from 39° to 40° F., and the amount of mechanical work required to produce a unit of heat is 778 foot pounds. Therefore the mechanical equivalent of heat is the energy required to raise 778 lbs. one foot high, or 77.8 lbs. 10 ft. high, or 1 lb. 778 feet high. Or again, suppose a one-pound weight falls through a space of 778 ft. or a weight of 778 lbs. falls one foot, enough mechanical energy would thus be developed to raise a pound of water one degree in temperature, provided all the energy so developed could be utilized in churning or stirring the water, as in Joule's machine. Hence the mechanical equivalent of heat is 778 foot pounds.

Specific Heat. The specific heat of any substance is the ratio of the quantity of heat required to raise a given weight of that substance one degree in temperature to the quantity of heat required to raise an equal weight of water one degree in temperature when the water is at its maximum density, 39.1° F. To illustrate, take the specific heat of lead, for instance, which is .031, while the specific heat of water is 1. That means that it would require 31 times as much heat to raise one pound of water one degree in temperature as it would to raise the temperature of a pound of lead one degree.

The following table gives the specific heat of different substances in which engineers are most generally interested.

TABLE 3.

Water at 39.1° F.	1.000
Ice at 32° F.	.504
Steam at 212° F.	.480
Mercury	.033
Cast iron	.130
Wrought iron	.113
Soft steel	.116
Copper	.095
Lead	.031
Coal	.240
Air	.238
Hydrogen	3.404
Oxygen	.218
Nitrogen	.244

Sensible Heat and Latent Heat. The plainest and most simple definition of these two terms is that given by Sir Wm. Thomson. He says: "Heat given to a body and warming it is sensible heat. Heat given to a body and not warming it is latent heat." Sensible heat in a substance is the heat that can be measured in degrees of a thermometer, while latent heat is the heat in any substance that is not shown by the thermometer.

To illustrate this more fully a brief reference to some experiments made by Professor Black in 1762 will no doubt make the matter plain. It will be remembered that at that early date comparatively little was known of the true nature of heat, hence Professor Black's investigations and discoveries along this line appear all the more wonderful. He procured equal weights of ice at 32° F. and water at the same temperature, that is, just at the freezing point, and placing them in separate glass vessels suspended the vessels in a room in which the uniform temperature was 47° F. He noticed that in one-half hour the water had increased 7° F. in temperature, but that twenty half hours elapsed before all of the ice was melted. Therefore he reasoned that twenty times more heat had entered the ice than had entered the water, because at the end of the twenty half hours when the ice was all melted the water in both vessels was of the same temperature. The water having absorbed 7° of heat during the first half hour must have continued to absorb heat at the same rate during the whole of the twenty half hours, although the thermometer did not indicate it. From this he calculated that $7^\circ \times 20 = 140^\circ$ of heat had become latent or hidden in the water.

In another experiment Professor Black placed a lump of melting ice which he estimated to be at a temperature of 33° F. on the surface, in a vessel containing the same weight of water at 176° F., and he observed that when the whole of the ice had been melted the temperature of the water was 33° F., thus proving that 143° of heat (176° – 33°) had been absorbed in melting the ice and was at that moment latent in the water By these two experiments Professor Black established the theory of the latent heat of water, and his estimate was very near the truth because the results obtained since that time by the greatest experimenters show that the latent heat of water is 142 heat units, or B. T. U.

Black's experiment for ascertaining the latent heat in steam at atmospheric pressure was made in the following simple manner: He placed a flat, open tin dish on a hot plate over a fire and into the dish he put a small quantity of water at 50° F. In four minutes the water began to boil, and in twenty minutes more it had all evaporated. In the first four minutes the temperature had increased 212° – 50° = 162°, and the temperature remained at 212° throughout the twenty minutes that it required to evaporate all the water, despite the fact that the water had been receiving heat during this period at the same rate as during the first four minutes. He therefore reasoned that in the twenty minutes the water had absorbed five times as much heat as it had in the four minutes, or 162° × 5 = 810°, without any sensible rise in temperature. Therefore the 810° became latent in the steam. Owing to the crude nature of the experiment Professor Black's estimate of the number of degrees of latent heat in steam was incorrect, as it has been proven by many famous experimenters since then that the latent heat of steam at atmospheric pressure is 965.7 B. T. U.

It will thus be perceived that what is meant by the term latent heat is that quantity of heat which becomes hidden or latent when the state of a body is changed from a solid to a liquid, as in the case of melting ice, or from a liquid to a gaseous state, as with water evaporated into steam. But the heat so disappearing has not been lost, on the contrary it has, while becoming latent, been doing an immense amount of work, as can easily be ascertained by means of a few simple figures. It has been seen that a heat unit is the quantity of heat required to raise one pound of water one degree in temperature and also that the mechanical equivalent of heat, or, in other words, the mechanical energy stored in one heat unit is equal to 778 foot pounds of work.

A horse power equals 33,000 ft. lbs. of energy in one minute of time, and a heat unit = 778 ÷ 33,000 = .0236, or about $\frac{1}{43}$ of a horse power. The work done by the heat which becomes latent in converting one pound of ice at 32° F. into water at the same temperature = 142 heat units × 778 ft. lbs. = 110,476 ft. lbs., which divided by 33,000 equals 3.34 horse power. Again, by the evaporation of one pound of water from 32° F. into steam at atmospheric pressure, 965.7 units of heat become latent in the steam and the work done = 965.7 × 778 = 751,314 ft. lbs. = 22.7 horse power. It will thus be seen what tremendous energy lies stored in one pound of coal, which contains from 12,000 to 14,500 heat units, provided all the heat could be utilized in an engine.

Total Heat of Evaporation. In order to raise the temperature of one pound of water from the freezing point, 32° F., to the boiling point, 212° F., there must be added to the temperature of the water 212° − 32° =

180°. This represents the sensible heat Then to make the water boil at atmospheric pressure, or, in other words, to evaporate it, there must still be added 965.7 B. T. U., thus 180 + 965.7 = 1,145.7, or in round numbers 1,146 heat units. This represents what is termed the total heat of evaporation at atmospheric pressure and is the sum of the sensible and latent heat in steam at that pressure. But if a thermometer were held in steam evaporating into the open air, as, for instance, in front of the spout of a tea-kettle, it would indicate but 212° F.

When steam is generated at a higher pressure than 212°, the sensible heat increases and the latent heat decreases slowly, while at the same time the total heat of evaporation slowly increases as the pressure increases, but not in the same ratio. As, for instance, the total heat in steam at atmospheric pressure is 1,146 B. T. U., while the total heat in steam at 100 lbs. gauge pressure is 1,185 B. T. U., and the sensible temperature of steam at atmospheric pressure is 212°, while at 100 lbs. gauge pressure the temperature is 338 and the latent heat is 876 B. T. U. See table.

Water. The elements that enter into the composition of pure water are the two gases, hydrogen and oxygen, in the following proportions:

By volume,	hydrogen	2,	oxygen	1.
By weight,	"	11.1,	"	88.9.

Perfectly pure water is not attainable, neither is it desirable nor necessary to the welfare of the human race, because the presence of certain proportions of air and ammonia add greatly to its value as an agent for manufacturing purposes and for generating steam. The nearest approach to pure water is rain water, but even this contains 2.5 volumes of air to each 100 volumes of water. Pure distilled water, such for instance as the return water from steam heating systems, is not desirable for use alone in a boiler as it will cause corrosion and pitting of the sheets, but if it is mixed with other water before going into the boiler its use is highly beneficial, as it will prevent to a certain degree the formation of scale and incrustation. Nearly all water used for the generation of steam in boilers contains more or less scale-forming matter, such as the carbonates of lime and magnesia, the sulphates of lime and magnesia, oxide of iron, silica and organic matter which latter tends to cause foaming in boilers.

The carbonates of lime and magnesia are the chief causes of incrustation. The sulphate of lime forms a hard crystalline scale which is extremely difficult to remove when once formed on the sheets and tubes of boilers. Of late years the intelligent application of chemistry to the analyzing of feed waters has been of great benefit to engineers and steam users, in that it has enabled them to properly treat the water with solvents either before it is pumped into the boiler, or by the introduction into the boiler of certain scale preventing compounds made especially for treating the particular kind of water used. Where it is necessary to treat water in this manner great care and watchfulness should be exercised by the engineer in the selection and use of a boiler compound.

From ten to forty grains of mineral matter per gallon are held in solution by the waters of the different rivers, streams and lakes; well and mine water contain still more.

Water contracts and becomes denser in cooling until it reaches a temperature of 39.1° F., its point of greatest density. Below this temperature it expands and at 32° F. it becomes solid or freezes, and in the act of freezing it expands considerably, as every engineer who has had to deal with frozen water pipes can testify.

Water is 815 times heavier than atmospheric air. The weight of a cubic foot of water at 39.1° is approximately 62.5 lbs., although authorities differ on this matter, some of them placing it at 62.379 lbs., and others at 62.425 lbs. per cubic foot. As its temperature increases its weight per cubic foot decreases until at 212° F. one cubic foot weighs 59.76 lbs.

The table which follows is compiled from various sources and gives the weight of a cubic foot of water at different temperatures.

TABLE 4

Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot
32° F.	62.42 lbs.	132° F.	61.52 lbs.	230° F.	59.37 lbs.
42°	62.42	142°	61.34	240°	59.10
52°	62.40	152°	61.14	250°	58.85
62°	62.36	162°	60.94	260°	58.52
72°	62.30	172°	60.73	270°	58.21
82°	62.21	182°	60.50	300°	57.26
92°	62.11	192°	60.27	330°	56.24
102°	62.00	202°	60.02	360°	55.16
112°	61.86	212°	59.76	390°	54.03
122°	61.70	220°	59.64	420°	52.86

The boiling point of water varies according to the pressure to which it is subject. In the open air at sea level the boiling point is 212° F. When confined in a boiler under steam pressure the boiling point of water depends upon the pressure and temperature of the steam, as, for instance, at 100 lbs. gauge pressure the temperature of the steam is 338° F., to which temperature the water must be raised before its molecules will separate and be converted into steam. In the absence of any pressure, as in a perfect vacuum, water boils at 32° F. temperature. In a vacuum of 28 in., corresponding to an absolute pressure of .943 lbs., water will boil at 100°, and in a vacuum of 26 in., at which the absolute pressure is 2 lbs., the boiling point of water is 127° F. On the tops of high mountains in a rarefied atmosphere water will boil at a much lower temperature than at sea level, for instance at an altitude of 15,000 ft. above sea level water boils at 184° F.

Steam. Having discussed to some extent the physical properties of water, it is now in order to devote some time to the study of the nature of steam, which is simply water in its gaseous form made so by the application of heat.

As has been stated in another portion of this book, matter consists of molecules or atoms inconceivably small in size, yet each having an individuality, and in the case of solids or liquids, each having a mutual cohesion or attraction for the other, and all being in a state of continual vibration more or less violent according to the temperature of the body.

The law of gravitation which holds the universe together, also exerts its wonderful influence on these atoms and causes them to hold together with more or less tenacity according to the nature of the substance. Thus it is much more difficult to chip off pieces of iron or granite than it is of wood. But in the case of water and other liquids the atoms, while they adhere to each other to a certain extent, still they are not so hard to separate, in fact, they are to some extent repulsive to each other, and unless confined within certain bounds the atoms will gradually scatter and spread out, and finally either be evaporated or sink out of sight in the earth's surface. Heat applied to any substance tends to accelerate the vibrations of the molecules, and if enough heat is applied it will reduce the hardest substances to a liquid or gaseous state.

The process of the generation of steam from water is simply an increase of the natural vibrations of the molecules of the water, caused by the application of heat until they lose all attraction for each other and become instead entirely repulsive, and unless confined will fly off into space. But being confined they continually strike against the sides of the containing vessel, thus causing the pressure which steam or any other gas exerts when under confinement.

Of course steam, like other gases, when under pressure is invisible, but the laws governing its action are well known. These laws, especially those relating to the expansion of steam, will be more fully discussed in the chapters on the Indicator. The temperature of steam in contact with the water from which it is generated, as for instance in the ordinary steam boiler, depends upon the pressure under which it is generated. Thus at atmospheric pressure its temperature is 212° F. If the vessel is closed and the pressure increased the temperature of the steam and also that of the water rises.

Saturated Steam. When steam is taken directly from the boiler to the engine without being superheated, it is termed saturated steam. This does not necessarily imply that it is wet and mixed with spray and moisture.

Superheated Steam. When steam is conducted into or through a vessel or coils of pipe separate from the boiler in which it was generated and is there heated to a higher temperature than that due to its pressure, it is said to be superheated.

Dry Steam. When steam contains no moisture it is said to be dry. Dry steam may be either saturated or superheated.

Wet Steam. When steam contains mist or spray intermingled it is termed wet steam, although it may have the same temperature as dry saturated steam of the same pressure.

During the further consideration of steam in this book, saturated steam will be mainly under discussion for the reason that this is the normal condition of steam as used most generally in steam engines.

Total Heat of Steam. The total heat in steam includes the heat required to raise the temperature of the water from 32° F. to the temperature of the steam plus the heat required to evaporate the water at that temperature. This latter heat becomes latent in the steam, and is therefore called the latent heat of steam.

The work done by the heat acting within the mass of water and causing the molecules to rise to the surface is termed by scientists internal work, and the work done in compressing the steam already formed in the boiler or in pushing it against the superincumbent atmosphere, if the vessel be open, is termed external work. There are, therefore, in reality three elements to be taken into consideration in estimating the total heat of steam, but as the heat expended in doing external work is done within the mass itself it may, for practical purposes, be included in the general term latent heat of steam.

Density of Steam. The expression density of steam means the actual weight in pounds or fractions of a pound avoirdupois of a given volume of steam, as one cubic foot. This is a very important point for young engineers especially to remember, so as not to get the two terms, pounds pressure and pounds weight, mixed, as some are prone to do.

Volume of Steam. By this term is meant the volume as expressed by the number of cubic feet in one pound weight of steam.

Relative Volume of Steam. This expression has reference to the number of volumes of steam produced from one volume of water. Thus the steam produced by the evaporation of one cubic foot of water from 39° F. into steam at atmospheric pressure will occupy a space of 1646 cu. ft., but, as the steam is compressed and the pressure allowed to rise, the relative volume of the steam becomes smaller, as for instance at 100 lbs. gauge pressure the steam produced from one cubic foot of water will occupy but 237.6 cu. ft., and if the same steam was compressed to 1,000 lbs. absolute or 985.3 lbs. gauge pressure it would then occupy only 30 cu. ft.

The condition of steam as regards its dryness may be approximately estimated by observing its appearance as it issues from a pet cock or other small opening into the atmosphere. Dry or nearly dry steam containing about 1 per cent. of moisture will be transparent close to the orifice through which it issues, and even if it is of a grayish white color it may be estimated to contain not over 2 per cent. of moisture.

Steam in its relation to the engine should be considered in the character of a vehicle for transferring the energy, created by the heat, from the boiler to the engine. For this reason all steam drums, headers and pipes should be thoroughly insulated in order to prevent, as much as possible, the loss of heat or energy by radiation.

Table 5, showing the properties of saturated steam, is compiled mainly from Kent's *Steam Boiler Economy.* The decimals have not been carried out in the columns headed Relative Volume and Weight of 1 cu. ft. of steam, as their absence will affect the results very little.

TABLE 5

Properties of Saturated Steam

Vacuum Inches of Mercury	Absolute Pressure Lbs. per Sq. Inch	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
29.74	.089	32.	0.	1091.7	1091.7	208,080	3333.3	.0003
29.67	.122	40.	8.	1094.1	1086.1	154,330	2472.2	.0004
29.56	.176	50.	18.	1097.2	1079.2	107,630	1724.1	.0006
29.40	.254	60.	28.01	1100.2	1072.2	76,370	1223.4	.0008
29.19	.359	70.	38.02	1103.3	1065.3	54,660	875.61	.0011
28.90	.502	80.	48.04	1106.3	1058.3	39,690	635.80	.0016
28.51	.692	90.	58.06	1109.4	1051.3	29,290	469.20	.0021
28.00	.943	100.	68.08	1112.4	1044.4	21,830	349.70	.0028
27.88	1.	102.1	70.09	1113.1	1043.0	20,623	334.23	.0030
25.85	2.	126.3	94.44	1120.5	1026.0	10,730	173.23	.0058
23.83	3.	141.6	109.9	1125.1	1015.3	7,325	118.00	.0085
21.78	4.	153.1	121.4	1128.6	1007.2	5,588	89.80	.0111
19.74	5.	162.3	130.7	1131.4	1000.7	4,530	72.50	.0137
17.70	6.	170.1	138.6	1133.8	995.2	3,816	61.10	.0163
15.67	7.	176.9	145.4	1135.9	990.5	3,302	53.00	.0189
13.63	8.	182.9	151.5	1137.7	986.2	2,912	46.60	.0214
11.60	9.	188.3	156.9	1139.4	982.4	2,607	41.82	.0239
9.56	10.	193.2	161.9	1140.9	979.0	2,361	37.80	.0264
7.52	11.	197.8	166.5	1142.3	975.8	2,159	34.61	.0289
5.49	12.	202.0	170.7	1143.5	972.8	1,990	31.90	.0314
3.45	13.	205.9	174.7	1144.7	970.0	1,846	29.60	.0338
1.41	14.	209.6	178.4	1145.9	967.4	1,721	27.50	.0363
0.00	14.7	212.0	180.9	1146.6	965.7	1,646	26.36	.0379

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
0.3	15	213.3	181.9	1146.9	965.0	1,614	25.90	.0387
1.3	16	216.3	185.3	1147.9	962.7	1,519	24.33	.0411
2.3	17	219.4	188.4	1148.9	960.5	1,434	23.00	.0435
3.3	18	222.4	191.4	1149.8	958.3	1,359	21.80	.0459
4.3	19	225.2	194.3	1150.6	956.3	1,292	20.70	.0483
5.3	20	227.9	197.0	1151.5	954.4	1,231	19.72	.0507
6.3	21	230.5	199.7	1152.2	952.6	1,176	18.84	.0531
7.3	22	233.0	202.2	1153.0	950.8	1,126	18.03	.0555
8.3	23	235.4	204.7	1153.7	949.1	1,080	17.30	.0578
9.3	24	237.8	207.0	1154.5	947.4	1,038	16.62	.0602
10.3	25	240.0	209.3	1155.1	945.8	998	16.00	.0625
11.3	26	242.2	211.5	1155.8	944.3	962	15.42	.0649
12.3	27	244.3	213.7	1156.4	942.8	929	14.90	.0672
13.3	28	246.3	215.7	1157.1	941.3	898	14.40	.0696
14.3	29	248.3	217.8	1157.7	939.9	869	13.91	.0719
15.3	30	250.2	219.7	1158.3	938.9	841	13.50	.0742
16.3	31	252.1	221.6	1158.8	937.2	816	13.07	.0765
17.3	32	254.0	223.5	1159.4	935.9	792	12.68	.0788
18.3	33	255.7	225.3	1159.9	934.6	769	12.32	.0812
19.3	34	257.5	227.1	1160.5	933.4	748	12.00	.0835
20.3	35	259.2	228.8	1161.0	932.2	728	11.66	.0858
21.3	36	260.8	230.5	1161.5	931.0	709	11.36	.0880
22.3	37	262.5	232.1	1162.0	929.8	691	11.07	.0903
23.3	38	264.0	233.8	1162.5	928.7	674	10.80	.0926
24.3	39	265.6	235.4	1162.9	927.6	658	10.53	.0949
25.3	40	267.1	236.9	1163.4	926.5	642	10.28	.0972
26.3	41	268.6	238.5	1163.9	925.4	627	10.05	.0995
27.3	42	270.1	240.0	1164.3	924.4	613	9.83	.1018
28.3	43	271.5	241.4	1164.7	923.3	600	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587	9.41	.1063
30.3	45	274.3	244.3	1165.6	921.3	575	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563	9.02	.1108
32.3	47	277.0	247.0	1166.4	919.4	552	8.84	.1131
33.3	48	278.3	248.4	1166.8	918.5	541	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	531	8.50	.1176
35.3	50	280.9	251.0	1167.6	916.6	520	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	511	8.19	.1221
37.3	52	283.3	253.5	1168.4	914.9	502	8.04	.1243

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F. In the Water h Heat-units	Total Heat above 32° F. In the Steam H Heat-units	Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
38.3	53	284.5	254.7	1168.7	914.0	492	7.90	.1266
39.3	54	285.7	256.0	1169.1	913.1	484	7.76	.1288
40.3	55	286.9	257.2	1169.4	912.3	476	7.63	.1311
41.3	56	288.1	258.3	1169.8	911.5	468	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460	7.38	.1355
43.3	58	290.3	260.7	1170.5	909.8	453	7.26	.1377
44.3	59	291.4	261.8	1170.8	909.0	446	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	439	7.03	.1422
46.3	61	293.6	264.0	1171.5	907.5	432	6.92	.1444
47.3	62	294.7	265.1	1171.8	906.7	425	6.82	.1466
48.3	63	295.7	266.2	1172.1	905.9	419	6.72	.1488
49.3	64	296.8	267.2	1172.4	905.2	413	6.62	.1511
50.3	65	297.8	268.3	1172.8	904.5	407	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	401	6.43	.1555
52.3	67	299.8	270.4	1173.4	903.0	395	6.34	.1577
53 3	68	300.8	271.4	1173.7	902.3	390	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384	6.17	.1621
55.3	70	302.7	273.4	1174.3	900.9	379	6.09	.1643
56.3	71	303.7	274.4	1174.6	900.2	374	6.01	.1665
57.3	72	304.6	275.3	1174.8	899.5	369	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	365	5.85	.1709
59.3	74	306.5	277.2	1175.4	898.2	360	5.78	.1731
60.3	75	307.4	278.2	1175.7	897.5	356	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351	5.63	.1775
62.3	77	309.2	280.0	1176.2	896.2	347	5.57	.1797
63.3	78	310.1	280.9	1176.5	895.6	343	5.50	.1819
64.3	79	310.9	281.8	1176.8	895.0	339	5.43	.1840
65.3	80	311.8	282.7	1177.0	894.3	334	5.37	.1862
66.3	81	312.7	283.6	1177.3	893.7	331	5.31	.1884
67.3	82	313.5	284.5	1177.6	893.1	327	5.25	.1906
68.3	83	314.4	285.3	1177.8	892.5	323	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	320	5.13	.1950
70.3	85	316.0	287.0	1178.3	891.3	316	5.07	.1971
71.3	86	316.8	287.9	1178.6	890.7	313	5.02	.1993
72.3	87	317.7	288.7	1178.8	890.1	309	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	306	4.91	.2036
74.3	89	319.3	290.4	1179.3	888.9	303	4.86	.2058
75.3	90	320.0	291.2	1179.6	888.4	299	4.81	.2080

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
76.3	91	320.8	292.0	1179.8	887.8	296	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293	4.71	.2123
78.3	93	322.4	293.6	1180.3	886.7	290	4.66	.2145
79.3	94	323.1	294.4	1180.5	886.1	287	4.62	.2166
80.3	95	323.9	295.1	1180 7	885.6	285	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	282	4.53	.2210
82.3	97	325.4	296.7	1181.2	884.5	279	4.48	.2231
83.3	98	326.1	297.4	1181.4	884.0	276	4.44	.2253
84.3	99	326.8	298.2	1181.6	883.4	274	4.40	.2274
85.3	100	327.6	298.9	1181.8	882.9	271	4.36	.2296
86.3	101	328.3	299.7	1182.1	882.4	268	4.32	.2317
87.3	102	329.0	300.4	1182.3	881.9	266	4.28	.2339
88.3	103	329.7	301.1	1182.5	881.4	264	4.24	.2360
89.3	104	330.4	301.9	1182.7	880.8	261	4.20	.2382
90.3	105	331.1	302.6	1182.9	880.3	259	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	257	4.12	.2425
92.3	107	332.5	304.0	1183.4	879.3	254	4.09	.2446
93.3	108	333.2	304.7	1183.6	878.8	252	4.05	.2467
94.3	109	333.9	305.4	1183.8	878.3	250	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	248	3.98	.2510
96.3	111	335.2	306.8	1184.2	877.4	246	3.95	.2531
97.3	112	335.9	307.5	1184.4	876.9	244	3.92	.2553
98.3	113	336.5	308.2	1184.6	876.4	242	3.88	.2574
99.3	114	337.2	308.8	1184.8	875.9	240	3.85	.2596
100.3	115	337.8	309.5	1185.0	875.5	238	3.82	.2617
101.3	116	338.5	310.2	1185.2	875.0	236	3.79	.2638
102.3	117	339.1	310.8	1185.4	874.5	234	3.76	.2660
103.3	118	339.7	311.5	1185.6	874.1	232	3.73	.2681
104.3	119	340.4	312.1	1185.8	873.6	230	3.70	.2703
105.3	120	341.0	312.8	1185.9	873.2	228	3.67	.2764
106.3	121	341.6	313.4	1186.1	872.7	227	3.64	.2745
107.3	122	342.2	314.1	1186.3	872.3	225	3.62	.2766
108.3	123	342.9	314.7	1186.5	871.8	223	3.59	.2788
109.3	124	343.5	315.3	1186.7	871.4	221	3.56	.2809
110.3	125	344.1	316.0	1186.9	870.9	220	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218	3.51	2851
112.3	127	345.3	317.2	1187.3	870.0	216	3.48	.2872
113.3	128	345.9	317.8	1187.4	869.6	215	3.46	.2894

TABLE 5—*Contiuued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
114.3	129	346.5	318.4	1187.6	869.2	213	3.43	.2915
115.3	130	347.1	319.1	1187.8	868.7	212	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210	3.38	.2957
117.3	132	348.2	320.3	1188.2	867.9	209	3.36	.2978
118.3	133	348.8	320.8	1188.3	867.5	207	3.33	.3000
119.3	134	349.4	321.5	1188.5	867.0	206	3.31	.3021
120.3	135	350.0	322.1	1188.7	866.6	204	3.29	.3042
121.3	136	350.5	322.6	1188.9	866.2	203	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201	3.24	.3084
123.3	138	351.8	323.8	1189.2	865.4	200	3.22	.3105
124.3	139	352.2	324.4	1189.4	865.0	199	3.20	.3126
125.3	140	352.8	325.0	1189.5	864.6	197	3.18	.3147
126.3	141	353.3	325.5	1189.7	864.2	196	3.16	.3169
127.3	142	353.9	326.1	1189.9	863.8	195	3.14	.3190
128.3	143	354.4	326.7	1190.0	863.4	193	3.11	.3211
129.3	144	355.0	327.2	1190.2	863.0	192	3.09	.3232
130.3	145	355.5	327.8	1190.4	862.6	191	3.07	.3253
131.3	146	356.0	328.4	1190.5	862.2	190	3.05	.3274
133.3	148	357.1	329.5	1190.9	861.4	187	3.02	.3316
135.3	150	358.2	330.6	1191.2	860.6	185	2.98	.3358
140.3	155	360.7	333.2	1192.0	858.7	179	2.89	.3463
145.3	160	363.3	335.9	1192.7	856.9	174	2.80	.3567
150.3	165	365.7	338.4	1193.5	855.1	169	2.72	.3671
155.3	170	368.2	340.9	1194.2	853.3	164	2.65	.3775
160.3	175	370.5	343.4	1194.9	851.6	160	2.58	.3879
165.3	180	372.8	345.8	1195.7	849.9	156	2.51	.3983
170.3	185	375.1	348.1	1196.3	848.2	152	2.45	.4087
175.3	190	377.3	350.4	1197.0	846.6	148	2.39	.4191
180.3	195	379.5	352.7	1197.7	845.0	144	2.33	.4296
185.3	200	381.6	354.9	1198.3	843.4	141	2.27	.4400
190.3	205	383.7	357.1	1199.0	841.9	138	2.22	.4503
195.3	210	385.7	359.2	1199.6	840.4	135	2.17	.4605
200.3	215	387.7	361.3	1200.2	838.9	132	2.12	.4707
205.3	220	389.7	362.2	1200.8	838.6	129	2.06	.4852
245.3	260	404.4	377.4	1205.3	827.9	110	1.76	.5686
285.3	300	417.4	390.9	1209.2	818.3	96	1.53	.6515
485.3	500	467.4	443.5	1224.5	781.0	59	.94	1.062
685.3	700	504.1	482.4	1235.7	753.3	42	.68	1.470
985.3	1000	546.8	528.3	1248.7	720.3	30	.48	2.082

Questions

1. What is combustion?

2. What is one of the main factors in combustion?

3. Of what is air composed?

4. In what proportion are these two gases combined?

5. What is the principal constituent of coal and other fuels?

6. What other valuable constituent is contained in bituminous coal?

7. What is the usual temperature of a boiler furnace when in active operation?

8. About what should be the temperature of the escaping gases?

9. What two factors are indispensable in the economical use of coal?

10. What is heat?

11. What is the heat unit?

12. What is the mechanical equivalent of heat?

13. How many heat units are there in one pound of carbon?

14. How many heat units are there in one pound of hydrogen gas?

15. What is specific heat?

16. What is sensible heat?

17. What is latent heat?

18. Is the latent heat imparted to a body lost?

19. What is meant by the total heat of evaporation?

20. How much heat expressed in heat units is required to evaporate one pound of water from a temperature of 32° into steam at atmospheric pressure?

21. Name the two elements composing pure water.

22 In what proportion are these two gases combined in the formation of water?

23. Is perfectly pure water desirable for use in steam boilers?

24. What causes scale to form in boilers?

25. What proportion of mineral matter is usually found in water?

26. What is steam?

27. Of what does matter consist?

28. How does the application of heat to any substance affect its molecules?

29. In what particular manner does heat affect the molecules of water?

30. Is steam under pressure visible?

31. What is saturated steam?

32. What is dry steam?

33. What is superheated steam?

34. What is meant by the term total heat in steam?

35. What is meant by the density of steam?

36. What is meant by the volume of steam?

37. What is the weight of a cubic foot of water at 39.1° temperature?

38. What is the weight of a cubic foot of water at a temperature of 212°?

39. What is the boiling point of water in the open air at sea level?

40. At what temperature will water boil in a perfect vacuum?

41. What is meant by the relative volume of steam?

CHAPTER V

EVAPORATION TESTS

Evaporation tests, object of—Preparing for a test—Suggestions as to apparatus needed—Taking the temperature of the feed water—Precautions necessary to obtain accurate results—Duration of test—Feeding a boiler during a test—How to proceed if the boiler is fed by an injector—Determining the percentage of moisture in the steam—Moisture in the coal—Chimney draft—Draft gauge—Rules for determining the results of a test—"Equivalent evaporation," how to compute—Factors of evaporation—Boiler horse power.

Evaporation Tests. The object of making evaporation tests of steam boilers is primarily to ascertain how many pounds of water the boilers are evaporating per pound of coal burned; but these tests can and should be made to determine several other important points with reference to the operation of the boilers, as for instance: 1. The efficiency of the boiler and furnace as an apparatus for the consumption of fuel and the evaporation of water; whether this apparatus is performing its guaranteed duty in this respect, and how it compares with a known standard. 2. To determine the relative economy of different varieties of coal, also to determine the relative value of fuels other than coal, such as oil, gas, etc. 3. To ascertain whether or not the boilers as they are operated under ordinary every day conditions are being run as economically as they should be. 4. In case the boilers, owing to an increased demand for steam, fail to supply a sufficient quantity without forcing the fires, whether or not additional boilers are needed, or whether the trouble could be overcome by a change of conditions in operating them.

As was stated in the chapter on boiler setting, every steam plant can and should be equipped with the necessary apparatus for making evaporation tests, and every engineer should take pride in making a good showing in the economical use of coal, and, be it said to their credit, the majority of engineers do this, although many of them are working under conditions that prevent them from doing all that they might desire along this line. Too many engineers are compelled to look after work entirely outside of and foreign to their vocation as engineers, often having to go to some distant part of the building to make repairs to some part of the machinery, leaving their boiler and engine to care for themselves for the time being, thus not only endangering the safety of property, but of life as well. But conditions are gradually changing for the better in this respect, and employers and owners of steam plants are coming more and more to recognize the fact that the engineer is something more than a mere handy man about a factory, in fact, that he has a distinct and responsible vocation to be fulfilled, viz., the safe and economical operation of the plant where the power comes from.

The author proposes to present in as brief a manner as possible a few simple suggestions and rules for the benefit of engineers who desire to make evaporation tests with a view of determining one or more of the points mentioned at the beginning of this chapter.

Tests for the last three purposes named can be made by the regular engineering force of the plant, but in case a controversy should arise between the maker of the boiler and the purchaser regarding the first mentioned point, viz., the guaranteed efficiency of the boiler or the furnace, the services of experts in boiler testing may be resorted to.

Preparing for a Test. All testing apparatus should be kept in such shape that it will not take three or four days to get it ready for making a test. On the contrary, it can be and should be always kept in condition ready for use, so that the preparations for making a test will occupy but a short time. A small platform scale sufficiently large for weighing a wheel-barrow load of coal should also be provided in addition to the apparatus referred to in Chapter II.

The capacity of each of the two tanks therein mentioned, and which are illustrated in Fig. 10, can be determined in two ways, either by measuring the cubical contents of each or by placing them one at a time on the scales, filling them with water to within a few inches of the top, and note the weight. Also make a permanent mark on the inside at the water level. The water should then be permitted to run out until within an inch or so of the outlet pipe near the bottom, where another plain mark should be made, after which the empty tank should be again weighed, then by subtracting the last weight from the first the exact number of pounds of water that the tank will contain between the top and bottom marks can be determined and a note made of it.

It is much more convenient to have each tank contain the same quantity of water, although not absolutely necessary. The tanks should also be numbered 1 and 2 respectively in order to prevent confusion in keeping a record of the number of tanks full of water used during the test. Care should be exercised to have the water with which the tanks are filled while on the scale, at or near the same temperature as that at which it is to be fed into the boiler during the test. Otherwise there is liability of error owing to the variation in the weight of water at different temperatures. In order to guard against this, the capacity in cubic feet of each tank between the top and bottom marks should be ascertained by measuring the distance between the marks, also the diameter, or, if the tanks be square, the length of one side, after which the cubical contents can be easily figured and noted down. By knowing the capacity in cubic feet of each tank all possibility of error in the weight of feed water will be eliminated.

The scales for weighing the coal can be fitted with a temporary wooden platform large enough to accommodate a wheel-barrow, and after it has been balanced with the empty barrow on it, the record of weight of coal burned during the test can be easily kept.

The same barrow should be used throughout the test, and to save complications in estimating the weight, the same number of pounds of coal should be filled in the barrow each load. The coal passer will learn in a short time to fill the barrow to within a few pounds of the same weight each load by counting the shovelsful and the difference can easily be adjusted by having a small box of coal near the scale from which to take a few lumps to balance the load, or if there is too much coal in the barrow some of it can be thrown into the box.

At least two separate tally sheets should be provided, marked respectively coal and water, and the one for coal placed near the scale, and care should be taken that each load is tallied as soon as it is weighed. The tally sheet for water should be near the measuring tanks and as soon as a tank is emptied it should be tallied. The temperature of the feed water should be taken at least every thirty minutes, or oftener if possible, from a thermometer placed in the feed pipe near the check valve, as described in Chapter II. The readings should be noted and, at the expiration of the test, the average taken.

If the object of the test is to ascertain the efficiency of the boiler and furnace it is absolutely necessary that the boiler and all its appurtenances be put in good condition, by cleaning the heating surface both inside the boiler and outside, scraping and blowing the soot out of the tubes if it be a return tubular boiler, and blowing the soot and ashes from between the tubes if it is a water tube boiler. All dust, soot and ashes should be removed from the outside of the shell and also from the combustion chamber and smoke connections. The grate bars and sides of the furnace should be cleared of all clinker, and all air leaks made as close as possible. The boiler and all its water connections should be free from leaks, especially the blow-off valve or cock. If any doubt exists as to the latter it should be plugged or a blind flange put on it. It is very essential that there should be no way for the water to leak out of the boiler, neither should any water be allowed to get into the boiler during the test except that which is measured by passing through the tanks.

The engineer making the test should know the number of square feet of grate surface and also the area of the heating surface in square feet. Rules for computing the latter are given in Chapter II. If the boiler is a water tube boiler the outside diameter of the tubes must be used in estimating the heating surface. A correct knowledge of the above points is essential in making a test for determining any one of the four objects mentioned at the commencement of this chapter, but especially is it needed in conducting a test of the efficiency of the boiler and furnace.

In making an efficiency test it is essential that the boiler should be run at its fullest capacity from the beginning to the end of the test. Therefore arrangements should be made to dispose of the steam as fast as it is generated. If the boiler is in a battery connected with a common header, its mates can be fired lighter during the test, but if there is but the one boiler in use a waste steam pipe should be temporarily connected through which the surplus steam, if there is any, can be discharged into the open air through a valve regulated as required. Before starting the test the boiler should be thoroughly heated by having been run several hours at the ordinary rate. The fire should then be cleaned and put in good condition to receive fresh coal.

At the time of beginning the test the water level should be at or near the height ordinarily carried and its position marked by tying a cord around one of the guard rods of the gauge glass, and, to prevent all possibility of error, the height of the water in the glass should be measured and a note made of it. Note also the time that the first lot of weighed coal is fed to the furnace and record it as the starting time. The steam pressure should be noted at the beginning of the test and at regular intervals during the progress of the test in order that the average pressure may be obtained.

At the close of the test all of the above conditions should be as nearly as possible the same as at the beginning; the quantity and condition of the fire should be the same, also the steam pressure and water level. This can be accomplished only by careful work towards the close of the test.

During the progress of the test care should be exercised to prevent any waste of coal, especially in cleaning the fire. The ash made during the test must not be wet down until after it is weighed, as in all calculations for combustible and non-combustible matter in the coal the ash should be dry.

The duration of the test should be at least ten hours if it is possible to continue it for that length of time. The feed pump should be kept running at such speed as will supply the water to the boiler as fast as it is evaporated, and no faster. If at the close of the test a portion of water is left in the last tank tallied it can be measured and deducted from the total. And if any weighed coal is left on the floor it should be weighed back and deducted from the total weight. If the boiler is fed by an injector instead of a pump during the test, the injector should receive steam directly from the boiler under test through a well protected pipe. Also, the temperature of the feed water should be taken from the measuring tanks, or at least from the suction side of the injector, for the reason that the water in passing through the injector receives a large quantity of heat imparted to it by live steam directly from the boiler. Therefore the temperature of the water after it leaves the injector would not be a true factor for figuring the evaporation.

Determination of the Percentage of Moisture in the Steam. This is an important point in estimating the results of an evaporation test for the reason that each pound weight of moisture in the steam as it leaves the boiler represents a pound of water that has not been evaporated into steam, and should therefore be deducted from the total weight of water fed into the boiler during the test.

The steam should be tested for moisture by taking samples of it from the steam pipe or header as near the boiler as possible in order to guard against additional moisture caused by condensation. For making expert boiler tests for scientific and other purposes, an instrument called a calorimeter is used for ascertaining the quantity of moisture in the steam. But most engineers are not so fortunate as to possess one of these instruments, nor even to induce their employers to purchase one, therefore space will not be taken up in describing it here. A method of testing the quality of the steam by noting the appearance of a small jet blowing into the atmosphere is mentioned near the close of Chapter IV, which in the absence of a calorimeter would answer very well for ordinary purposes.

Moisture in the Coal. This can generally be obtained from the reports of the geologist of the state in which the coal is mined or from the dealer, although the former is the most reliable. The percentage of moisture must be deducted from the total weight of coal in figuring the weight of combustible.

Measuring the Chimney Draft. A good draft is indispensable for obtaining economical results in an evaporation test. The draft can be easily regulated by a damper to suit the conditions. Chimney draft is ordinarily measured by a draft gauge connected with the smoke flue near the chimney. The usual form of draft gauge is a glass tube bent in the shape of the letter U. (See Fig. 12.) One leg is connected to the flue by a small rubber hose, while the other is open to the atmosphere. The tube is partly filled with water, which will, when there is no draft, stand at the same height in both legs. When connected to the chimney or flue the suction will cause the water in the leg to which the hose is attached to rise, while the level of the water in the other leg will be equally depressed, and the extent of the variation in fractions of an inch is the measure of the draft. Thus the draft is referred to as being .5, .7 or .75 inches. The draft should not be less than .5 inches in any case to insure good results.

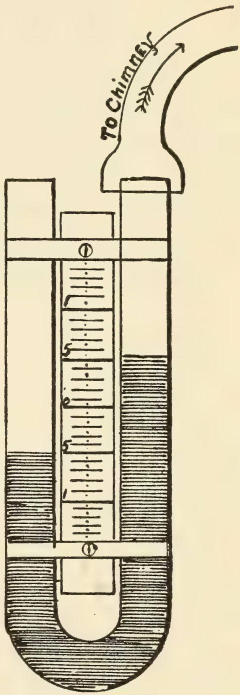


FIGURE 12.

Having thus successfully conducted the test to its close, and being armed with all the data heretofore noted, the engineer is now ready to compute the results.

If the test is made for the purpose of determining the efficiency of the boiler and setting as a whole, including grate, chimney draft, etc., then the result must be based upon the number of pounds of water evaporated per pound of coal. This latter phrase includes not only the purely combustible matter in the coal, but the non-combustible also, as ash, moisture, etc. Some varieties of western coal contain as high as 12 to 14 per cent. of moisture, and the ability of the furnace to extract heat from the mass is to be tested, as well as the ability of the boiler to absorb and transmit that heat to the water. Therefore the efficiency of the boiler and furnace =

$$\frac{\text{Heat absorbed per pound of coal.}}{\text{Heating value of one pound of coal.}}$$

If the test is to determine the efficiency of the boiler itself as an absorber of heat, then the combustible alone must be considered in working out the final result. Thus,

Efficiency of boiler =

$$\frac{\text{Heat absorbed per pound of combustible.}}{\text{Heating value of one pound of combustible.}}$$

When making a series of tests for the purpose of comparing the economical value of different varieties of coal the conditions should be as nearly uniform as possible; that is, let the tests be made under ordinary working conditions and with the same boiler or boilers, and if possible with the same fireman.

The following is a record of one of many evaporation tests made by the author, and is introduced here for the purpose of illustrating methods of computing the results to be obtained from the various data. The rather large quantity of coal burned per square foot of grate surface per hour (25 lbs.) is owing to the fact that the boiler was run to its full capacity, the coal burning clean and forming no clinker. The chimney draft also was exceptionally good, giving a large unit of evaporation per square foot of heating surface per hour. The low temperature of the escaping gases is due to the fact that they were returned over the top of the boiler before passing to the chimney.

Date of test..................
Duration of test, 12 hours.

Boiler, return tubular, 72 in. diameter, 18 ft. long, 62-4½ in. tubes.

Kind of coal, Pocahontas; average steam pressure..	85	lbs.
Weight of coal consumed	11,100	"
Weight of water apparently evaporated.............	107,187	"
Weight of dry ash returned ....8.1 per cent.=	900	"
Moisture in the coal...................2.0 " =	222	"
Moisture in the steam.................1.0 " =	1,071	"
Dry coal corrected for moisture	10,878	"
Weight of combustible.............................	9,978	"
Water corrected for moisture in the steam	106,116	"
Water evaporated into dry steam, from and at 212°..	117,788	"
Water evaporated per lb. of coal, actual conditions..	9.65	"
Water evaporated per lb. of coal, from and at 212°..	10.61	"
Water evaporated per lb. of combustible, from and at 212°..	11.81	"
Water evaporated per lb. of dry coal, from and at 212°	10.82	"
Water evaporated per hr. per sq. ft. of heating surface	6.22	"
Coal burned per sq. ft. of grate surface per hour	25	"
Horse power developed by boiler during test........	284.5	
Temperature of feed water, average................	141°	
Temperature of chimney gases, average............	400°	
Square feet of grate surface.......................	36	
Square feet of heating surface......................	1576	
Ratio of grate surface to heating surface............	43.7	

The results obtained will be taken up in their regular order beginning with, first, water evaporated into dry steam from and at 212°. As it may be of benefit to some, a short definition of the meaning of the above expression is here given.

The term "equivalent evaporation," or the evaporation from and at 212°, assumes that the feed water enters the boiler at a temperature of 212° and is evaporated into steam at 212° temperature and at atmospheric pressure. As for instance, if the top man hole plate were left out or some other large opening in the steam space allowed the steam to escape into the atmosphere as fast as it was generated. Owing to the variation in the temperatures of the feed water used in different tests, and also the variation in the steam pressure, it is absolutely necessary that the results of all tests be brought by computation to the common basis of 212° in order to obtain a just comparison.

The process by which this is done is as follows: Referring to the record of the test it is seen that the steam pressure average was 85 lbs. gauge pressure, or 100 lbs. absolute, and that the temperature of the feed water was 141°. Referring again to Table No. 5, physical properties of steam, it will be seen that in a pound of steam at 100 lbs. absolute pressure there are 1,181.8 heat units, and in a pound of water at 141° temperature there are 109.9 heat units. It therefore took 1181.8 − 109.9 = 1071.9 heat units to convert one pound of feed water at 141° into steam at 85 lbs. pressure. To convert a pound of water at 212° into steam at atmospheric pressure, and 212° temperature requires 965.7 heat units, and the 1,071.9 heat units would evaporate 1,071.9 ÷ 965.7 = 1.11 lbs. water from and at 212°. The 1.11 is the factor of evaporation for 85 lbs. gauge pressure and 141° temperature of feed water, and by multiplying "water corrected for moisture in the steam" (see record of test), 106,116 lbs., by 1.11, the weight of water which could have been evaporated into steam from and at 212°, is obtained, which is 117,788 lbs. The factor of evaporation is based upon the steam pressure and the temperature of the feed water in any test and the formula for ascertaining it is as follows: $\text{Factor} = \frac{H - h}{965.7}$, in which H = total heat in the steam, and h = total heat in the feed water. It is used in shortening the process of finding the evaporation from and at 212°, and Table No. 6 gives the factor of evaporation for various pressures and temperatures.

Table 6

Factors of Evaporation

Feed Water Temperature	Gauge Press. 50 lbs.	Gauge Press. 60 lbs.	Gauge Press. 70 lbs.	Gauge Press. 80 lbs.	Gauge Press. 90 lbs.	Gauge Press. 100 lbs.	Gauge Press. 110 lbs.	Gauge Press. 120 lbs.	Gauge Press. 140 lbs.
212°	1.027	1.030	1.032	1.035	1.037	1.039	1.041	1.043	1.047
200°	1.039	1.042	1.045	1.047	1.050	1.052	1.054	1.056	1.059
191°	1.049	1.052	1.054	1.057	1.059	1.061	1.063	1.065	1.069
182°	1.058	1.061	1.064	1.066	1.069	1.071	1.073	1.075	1.078
173°	1.067	1.070	1.073	1.076	1.078	1.080	1.082	1.084	1.087
164°	1.077	1.080	1.083	1.085	1.087	1.090	1.091	1.093	1.097
152°	1.089	1.092	1.095	1.098	1.100	1.102	1.104	1.106	1.109
143°	1.099	1.102	1.105	1.107	1.109	1.111	1.113	1.115	1.119
134°	1.108	1.111	1.114	1.116	1.119	1.121	1.123	1.125	1.128
125°	1.118	1.121	1.123	1.126	1.128	1.130	1.132	1.134	1.137
113°	1.130	1.133	1.136	1.138	1.140	1.143	1.145	1.146	1.150
104°	1.138	1.142	1.145	1.148	1.150	1.152	1.154	1.156	1.159
95°	1.149	1.152	1.154	1.157	1.159	1.161	1.163	1.165	1.169
86°	1.158	1.161	1.164	1.166	1.169	1.171	1.173	1.174	1.178
77°	1.167	1.170	1.173	1.176	1.178	1.180	1.182	1.184	1.187
65°	1.180	1.183	1.186	1.188	1.190	1.192	1.194	1.196	1.200
56°	1.189	1.192	1.195	1.197	1.200	1.202	1.204	1.206	1.209
47°	1.199	1.201	1.204	1.207	1.209	1.211	1.213	1.215	1.218
38°	1.208	1.211	1.214	1.216	1.218	1.220	1.222	1.224	1.228

Second, water evaporated per pound of coal actual conditions = water apparently evaporated divided by coal consumed = 9.65 lbs. No accurate estimate regarding the quality of the coal or the efficiency of the boiler can be made from this figure (9.65 lbs.). It can be used, however, in estimating the cost of fuel for generating the steam; as, for instance, if the boiler is supplying steam to an engine that uses 30 lbs. of steam per horse power per hour, it will require 30 ÷ 9.65 = 3.1 lbs. of coal per horse power per hour; the "actual conditions" under which the boiler is being operated being the pressure of steam required by the engine and the temperature of the feed water.

Third, water evaporated per pound of coal from and at 212° = water evaporated into dry steam from and at 212° divided by coal consumed = 10.61 lbs. This figure is the proper one to use in comparing the relative economic values of different varieties of coal tested with the same boiler or boilers.

Fourth, water evaporated per pound of combustible from and at 212° = water evaporated into dry steam from and at 212° divided by weight of combustible = 11.81 lbs. This result is the one to be used for ascertaining the efficiency of the boiler, and the percentage of efficiency is found by dividing the heat absorbed by the boiler per pound of combustible by the heat value of one pound of combustible. The average heat value of bituminous and semi-bituminous coals is not far from 15,000 heat units per pound of combustible. In the evaporation of 11.81 pounds of water from and at 212° the heat absorbed was $11.81 \times 965.7 = 11,404.9$ heat units. The efficiency of the boiler therefore was $\frac{11,404.9 \times 100}{15,000} = 76$ per cent.

In like manner to ascertain the efficiency of the boiler and furnace as a whole, the water evaporated from and at 212° per pound of coal is taken. Thus, $10.61 \times 965.7 = 10,246$ heat units absorbed from each pound of coal. Now assuming that there were 13,500 heat units in each pound of the coal used in the test, the per cent of efficiency of boiler and furnace was

$$\frac{10,246 \times 100}{13,500} = 75.9.$$

Fifth, water evaporated per pound of dry coal from and at 212° = water evaporated into dry steam from and at 212° divided by coal corrected for moisture. Thus, $117,788 \div 10,878 = 10.82$ lbs. This result is useful for calculating the results of tests of the same grade of coal, but differing in the degree of moisture in each.

Sixth. Boiler horse power. The latest decision of the American Society of Mechanical Engineers (than whom there is no better authority) regarding the horse power of a boiler is 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 lbs. of water evaporated per hour from a feed temperature of 212° into steam of the same temperature. This standard is equivalent to 33,317 B. T. U. per hour. It is also practically equivalent to an evaporation of 30 lbs. of water from a feed water temperature of 100° F. into steam of 70 lbs. gauge pressure."

According to this rule the horse power developed by the boiler during the test under consideration = water evaporated into dry steam from and at 212°, 117,788 lbs ÷ 12 hrs. ÷ 34.5 = 284.5 horse power.

Questions

1. What is the primary object of an evaporation test?

2. Name four other important points which can be determined by evaporation tests.

3. In making a test of the efficiency of the boiler and furnace, what precautions should be observed?

4. How is the heating surface of water tube boilers estimated?

5. What length of time should a test be conducted?

6. In case the boiler is fed by an injector, what precautions are necessary?

7. If the steam contains any moisture, what should be done?

8. How is the weight of combustible determined?

9. What is a calorimeter, and for what purpose is it used?

10. By what other method may the moisture in the steam be estimated approximately?

11. What should be done with the percentage of moisture in the coal?

12. How is the chimney draft measured?

13. Describe a draft gauge.

14. Give the formula for ascertaining the efficiency of the boiler and setting.

15. If the test is to determine the efficiency of the boiler alone, what factors are used?

16. If a series of tests is made for comparing different varieties of coal, what should be done?

17. What is meant by equivalent evaporation?

18. Why should the results of all tests be computed from and at 212°?

19. What is a factor of evaporation?

20. How is it determined?

21. What is a boiler horse power?

22. How many heat units per hour is this equivalent to?

CHAPTER VI

VALVES AND VALVE SETTING

Valves and valve setting—Importance of correct adjustment—The D slide valve—Single valve engines—Four valve engines—Various positions of the slide valve during one revolution—Relative positions of the crank pin and eccentric during the stroke—Valve diagrams—Placing the engine on the center—Adjusting the length of eccentric rod—Measuring the inside and outside lap—Setting the valve—Fixed cut off engines—Variable automatic cut off—Factors affecting the distribution of the steam—Why the four valve engine is the most economical—Description of corliss valves and valve gear and directions for adjusting the same.

Valves and Valve Setting. It goes without saying that every man who aspires to be an engineer should endeavor to thoroughly acquaint himself with the principles governing the action of valves as well as the details of valve setting. But it must be remembered that this knowledge can not be acquired in a day or a week, or even months. True, a man may be able to learn some of the alphabet of valve lore in a comparatively short time, but the more practical experience he has in the work the more will he realize the supreme need of mastering all the details of the process.

The common D slide valve, simple as it appears, is capable of furnishing problems over which savants have puzzled themselves.

The development of the full amount of power of which the engine is capable, its efficiency and economical use of steam, and its regular and quiet action are, in the largest degree, dependent upon the correct adjustment of its valve or valves.

There are many different types of valves for controlling the admission and release of steam to and from the cylinders of engines, but the basic principles governing the adjustment of all, whether slide, poppet, rotative, piston, etc., are exemplified in the action of the common D slide valve, viz., the admission of the steam to the cylinder, its cut off and release, and the closure of the exhaust, each and all of which events are to take place at the proper moment during one stroke of the piston.

In order to properly perform these important functions the valve must have lead and lap. The various terms relating to valve action are plainly defined in Chapter VIII on "Definitions," and it is unnecessary to repeat them here. If the outside lap is increased admission will be later and cut off earlier, and if it be desired to keep the lead the same it will be necessary to move the eccentric forward, which will make the other events, cut off, release, and compression, earlier also. If the inside lap is increased the result will be an earlier closing of the exhaust and increased compression.

These propositions refer mainly to engines of the single valve variety in which one valve controls the admission and distribution of the steam for both ends of the cylinder. In engines of the four valve type, having a separate steam and exhaust valve for each end of the cylinder, each individual valve may be adjusted independently of the others, as will be explained later on, and in the case of engines having separate eccentrics, one for the steam and one for the exhaust valves, the adjustment becomes still more perfect.

We will first study the action of the D slide valve by referring to Fig. 13, which is a sectional view of a valve, valve seat and ports. The valve is represented at mid travel or in its central position. S P, S P are the steam ports, and E P is the exhaust port. The projections marked X at each foot of the arch inside

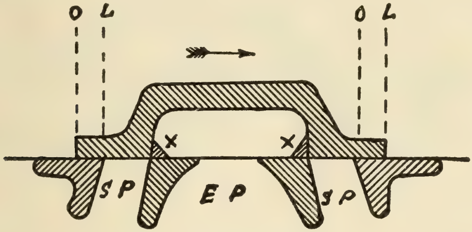


FIGURE 13.

the valve, represent inside lap and may be added to or taken from the inside edges of the valve, according as more or less compression is desired. The dotted lines, O L, O L represent outside lap.

Motion is imparted to the valve through the medium

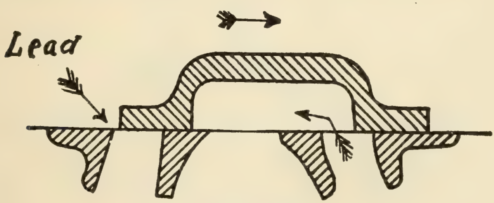


FIGURE 14.

of the eccentric. If the valve had neither lap nor lead the position of the eccentric on the crank shaft would be just 90° or one-quarter of a circle ahead of the crank, but as more or less lap as well as lead is required, it becomes necessary to move the eccentric still farther ahead of the crank, and this farther advance is termed angular advance, lap angle for lap and lead angle for lead.

Assuming the piston to be at the end of the stroke towards the crank, in other words, the engine to be

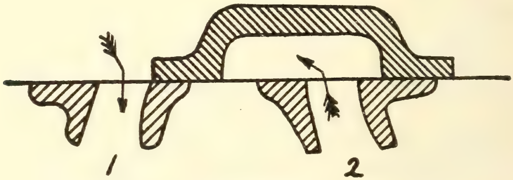


FIGURE 15.

on the dead center, the first function of the valve is lead or admission, illustrated by Fig. 14. Owing to the valve having both lap and lead, the position of the highest point of the eccentric will be assumed in this case to be 120° ahead of the crank, the position of the latter being at 0°.

Exhaust opening has also occurred at the opposite

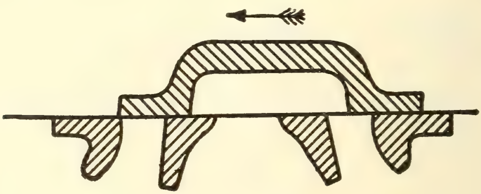


FIGURE 16.

end of the cylinder. The second function is full port opening, Fig. 15, the crank having moved through 60° and the eccentric is now at 180°, the farthest point of its throw in that direction, the valve being at the end of its travel. At this point it might be well to note a matter about which some persons are liable to become confused, simple as it is, viz., that the travel of a slide valve equals twice the port opening plus twice the outside lap. For instance, suppose the width of each steam port to be 1¼ in. and the outside lap to be 1 in. In Fig. 15 the valve is at the extreme end of its travel

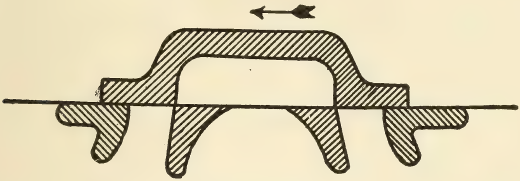


FIGURE 17.

towards the right and is about to return. It first covers port number one = 1¼ in. Next it moves to mid travel lap number one = 2¼ in. Its next move is lap number two = 3¼ in., and lastly it uncovers port number two = 4½ in., which is its travel.

To return to the third function of the valve or cut

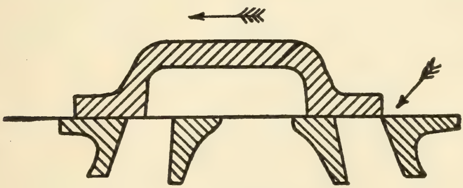


FIGURE 18.

off, Fig. 16. The crank has now traversed 120° and the highest point of the eccentric is at 60° on the return circle, a point equivalent to 240° of the circle described by the crank.

The fourth function is when compression begins at the head end of the cylinder, Fig. 17. The crank is now at 150°, the piston being near the end of the stroke and the eccentric has reached 90° of the return circle or three-quarters of the crank circle, while the crank has still to travel 30° in order to complete the first one-half of its circle. At this point we can study the effect of inside lap, because if the valve has no inside lap, release on the crank end will begin almost at the same moment that compression takes place at the head end,

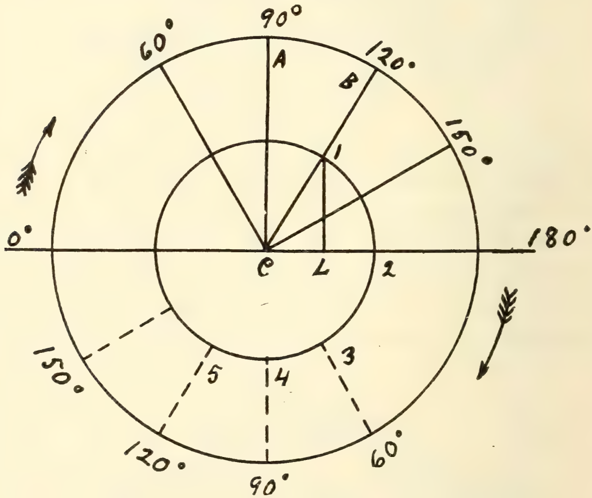


FIGURE 19.

but by adding inside lap, compression can be caused to take place earlier and release later.

The next event is admission at the head end of the cylinder, Fig. 18. The crank has now arrived at 180°, having completed one-half of a revolution; the piston is at the end of the stroke, and the eccentric is at 120° on the return path. Fig. 19 serves to better illustrate the relative positions of the crank pin and eccentric during the stroke. The inner circle represents the path described by the high point of the eccentric, and the large circle that of the crank pin. The radius C 2 of the small circle represents the throw of the eccentric, and the distance C L is the lap of the valve plus the lead. The point of intersection of the vertical line, L 1, with the eccentric circle locates the position of the highest point of the eccentric, and the line C B, drawn from the center of the crank shaft through this point, indicates the angular advance, which in this case is 30° represented by the angle A B C. The figures 1, 2, 3, 4, 5 indicate the position of the high point of the eccentric at the moment of each function of the valve. The action of the valve can be more graphically illustrated by means of valve diagrams, of which there are several different kinds, notably the Bilgram and Zeuner. The Zeuner diagram will be made use of in this instance.

Fig. 20 shows the total movement of the valve, regardless of lap and lead. First draw line C 1 to represent the center line of the engine. Next draw line C 4 perpendicular to the line of centers, with C as the center of the crank shaft. The radius of the semicircle D, 1, 2, 3, 4, 5, 6 equals the radius of eccentricity. Line C D represents the position of the crank when the valve is at mid travel or in its central position, D being the location of the crank pin. Referring back to Fig. 13 the valve is there shown in its central position and supposed to be moving in the direction of the arrow in order to admit steam to the crank end of the cylinder. Again referring to Fig. 20, draw line C A in such a position that the angle A B C will equal the angular advance of the eccentric, which we will assume in this case to be 30°. This will bring the high point of the eccentric at B while the crank, as before stated, is at D. Next using line C A as the diameter draw a circle about it called the valve circle.

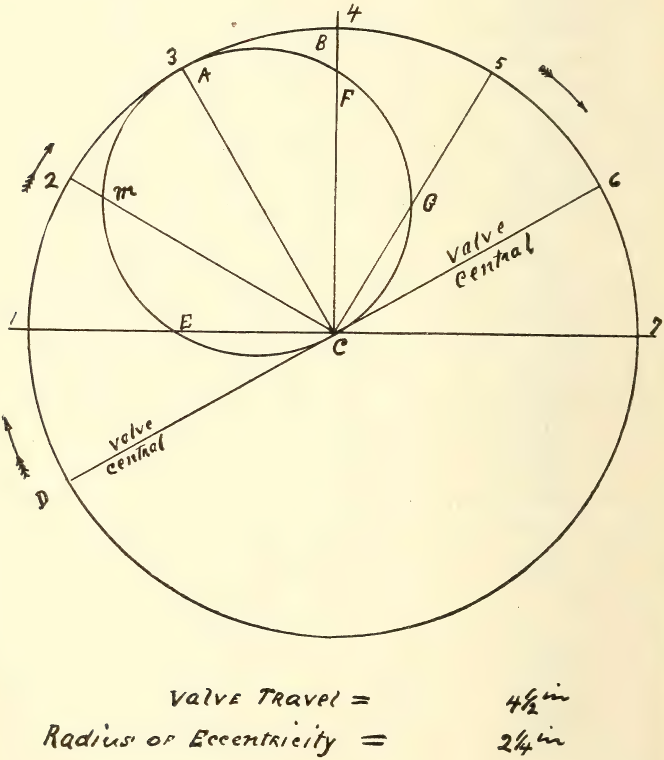


FIGURE 20.

Now suppose the crank to be turning in the direction of the arrows. At position D the crank line is just about to cut into the valve circle, the valve being central. When the crank gets to position 1 the valve has moved the distance C E. When the crank is at 2 the valve has moved the distance C M, and when the crank arrives at 3 the valve has moved to the limit of its travel from its central position and it now begins the return movement. The motion of the valve is comparatively slow at this point for the reason that the high point of the eccentric is now passing the center at 7. The distance the valve has moved backward while the crank has moved from 3 to 4 is the distance B F, while F C represents its distance from the central position, and G C the same when the crank is at 5. When the crank arrives at 6 and its line has left the valve circle, the valve is again central. Fig. 20 merely shows the movement of the valve through one-half of its travel without giving any details regarding port openings, cut off, etc.

In Fig. 21 the influence of outside lap is delineated. According to the dimensions of the valve under consideration the outside lap is one inch. The diagram is drawn precisely as in Fig. 20, and in addition strike an arc representing the outside lap, using C as the center with a radius equal to the outside lap. As before, the crank is at D and the valve central. When the crank has moved to E and its line cuts the intersection of the outside lap and valve circles, the valve has moved the distance C H, just equal to the outside lap, and the port begins to uncover at this point. Then by the time the crank gets to the center, 1, the port is open the distance L O, which is the lead, in this case ⅛ in. This position of the valve is shown in Fig. 14.

The position of the crank when cut-off takes place is ascertained by drawing a line, C G 5, through the intersection of the outside lap and valve circles, where the valve is on its return movement (see Fig. 16). Thus far no account has been taken of release and compression, and in order to determine the position of the crank when these events occur it will be necessary to

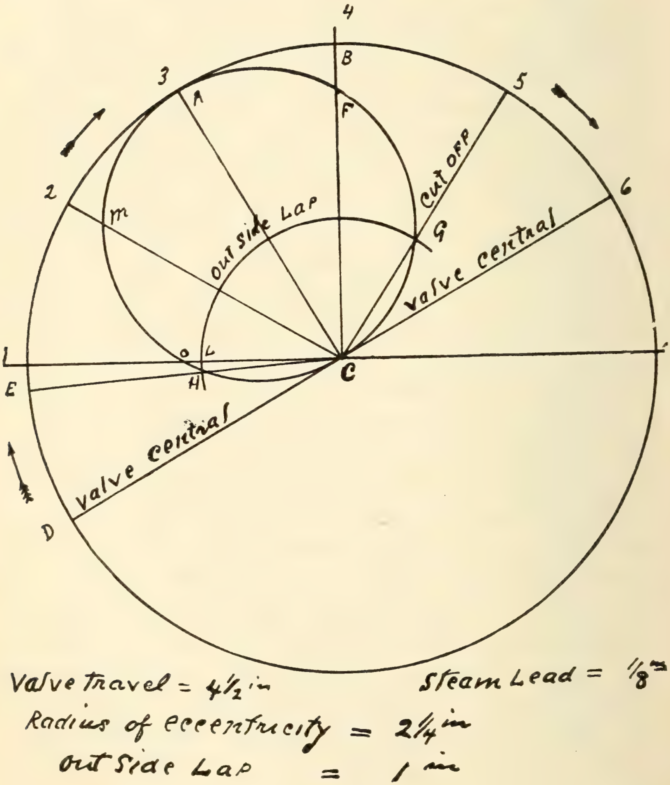


FIGURE 21.

draw the valve circle for the opposite movement of the valve, for be it remembered that the movement of the valve so far considered has been only one-half of its

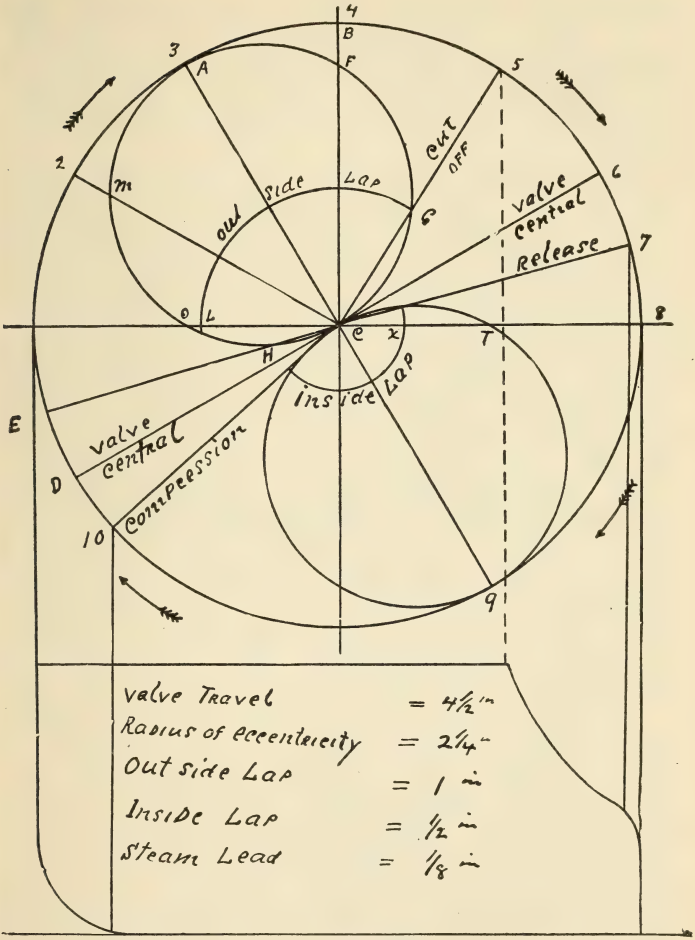


FIGURE 22.

travel; that is, it has moved from its central position towards the head end of the cylinder and back again. We have seen how it has thus performed the functions of admission, full port opening and cut off for the crank end of the cylinder, and now by referring to Fig. 22 it will be seen at what point of the stroke the remaining events, viz., release and compression occur.

Draw a second valve circle, Fig. 22, diametrically opposite the first. Also draw an arc with a radius equal to the inside lap, which in this case is assumed to be one-half inch. When the crank gets to the position 7 its center line cuts the intersection of the inside lap and valve circles and release begins. When the crank arrives on the center 8, the valve has moved the distance C T from central position; but C X of this distance has been occupied by the inside lap, therefore the lead on the exhaust is represented by the distance X T. When the crank on its return stroke arrives at the position marked 10, its line again cuts the intersection of the inside lap and valve circles and compression takes place, as in Fig. 17. By dropping perpendiculars from the positions of the crank at 1, 5, 7 and 10 an indicator diagram may be drawn showing the performance of an engine with this style of valve.

Fig. 23 shows the effect of decreasing the angular advance, that is, setting the eccentric back towards the crank. In this instance the eccentric is set back 10°, thus making the angle of advance 20° instead of 30° as before. The full lines represent the new angle, while the dotted circles and lines indicate the valve and its movements as drawn at first. A shows the original point of admission and A′ the position of the crank when admission takes place with the lesser angle of advance. Similarly R and R′ show the old and new points of release, and C and C′ the compression. The two different points of cut off are also indicated. If will be observed that all of these events occur later and the lead also is diminished.

In locomotives, and also in some types of adjustable cut off engines, the travel of the valve may be varied at will, and the effect of decreasing the valve's travel

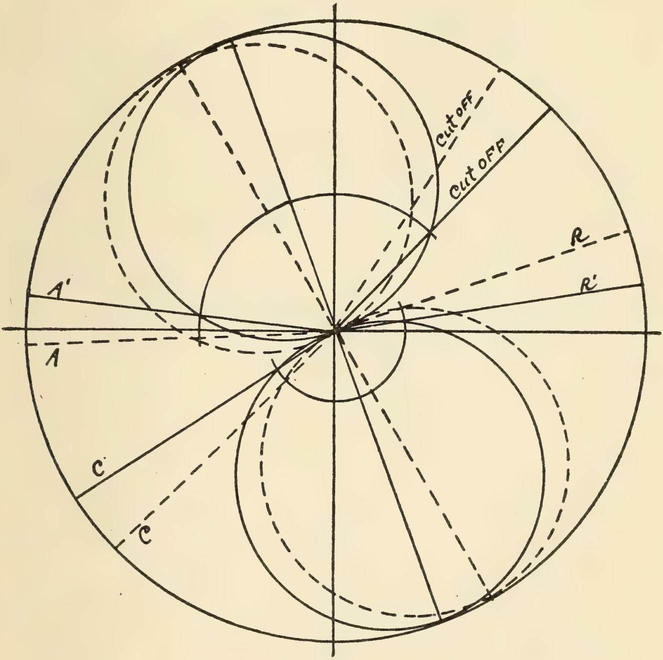


FIGURE 23.

is illustrated by Fig. 24, the full lines showing the decreased travel and its influence, and the dotted lines showing the original. Admission and release occur later, while cut off and compression take place earlier, and the lead is less. The travel of the valve as indicated in Fig. 24 has been decreased one inch, making it 3½ in. in place of 4½ in. as before.

Fig. 25 shows the result of increasing the outside lap. The lap has been increased in this case from 1 in., as originally drawn, to 1¼ in. as indicated by the

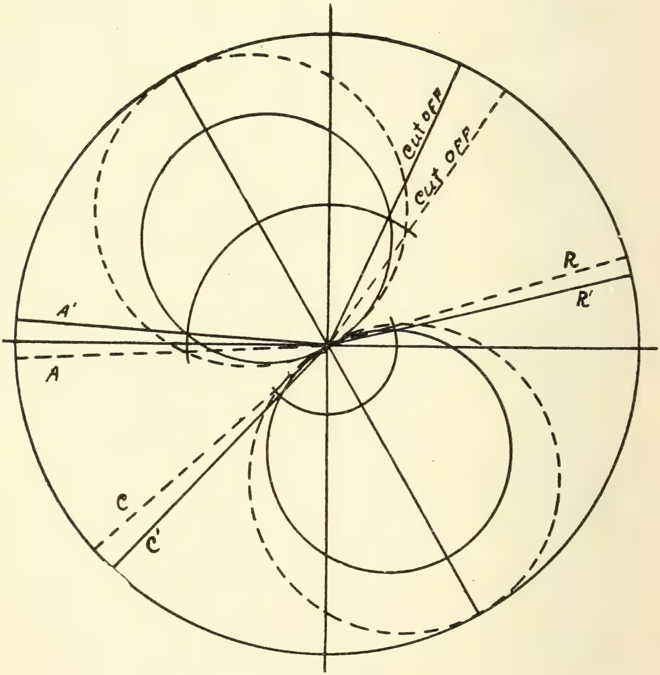


FIGURE 24

full lines, while the dotted lines show the lap as it was before being changed. The effect of this change is to cause less lead, a later admission and an earlier cut off, but compression and release are not affected for the reason that these latter events are controlled by the inside lap, which has not been changed.

In Fig. 22 the valve is shown as cutting off the steam when the crank has completed 120° or two-thirds of the half revolution, but the point of cut off on the indicator diagram shows that the piston has traveled $\frac{7}{9}$ of the stroke. This discrepancy is due to the obliquity

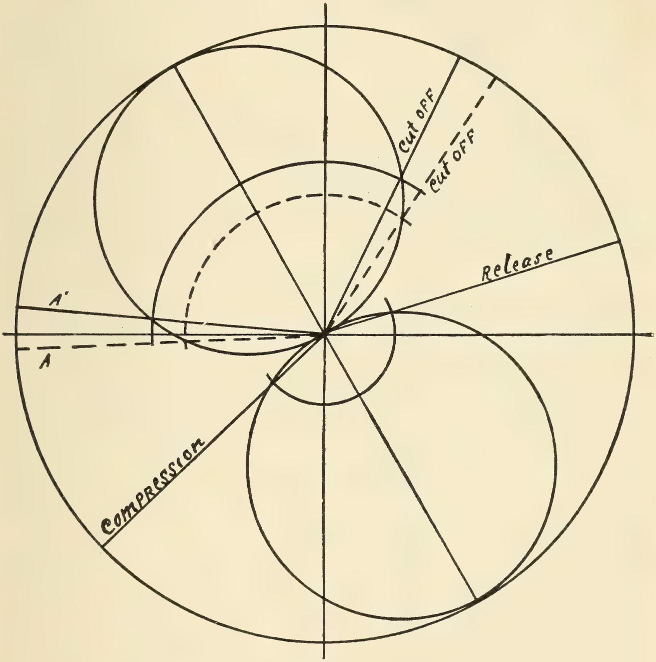


FIGURE 25.

of the connecting rod, as it will be seen by looking at the valve diagram, Fig. 22, that the crank must travel farther to complete the stroke from this point than the piston does. In order to cause the valve to cut off earlier, say at one-half stroke, it will be necessary to do one of two things, either to increase the outside

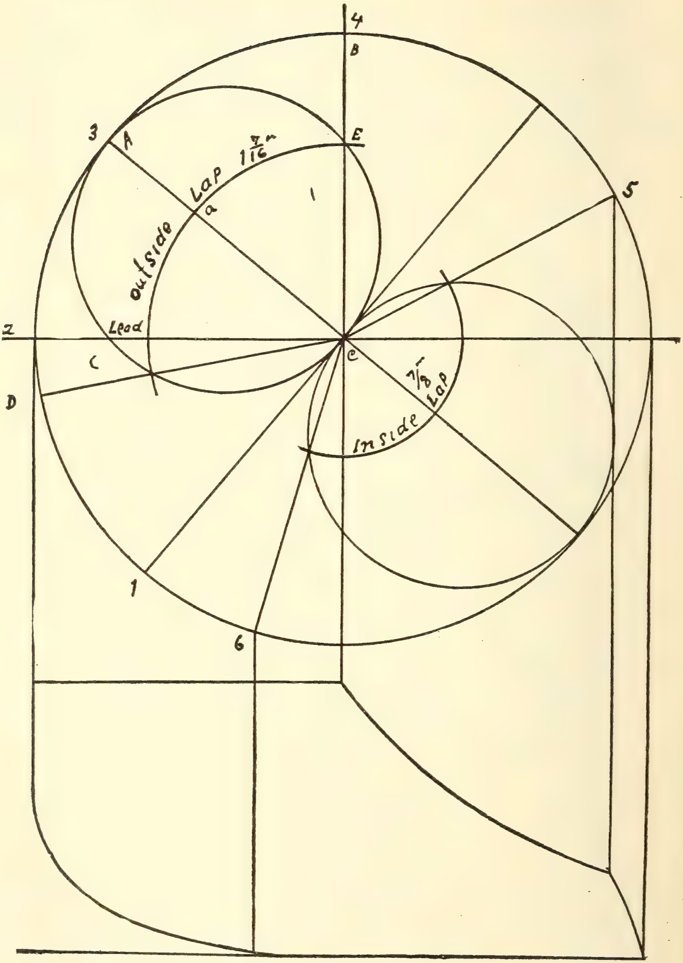


FIGURE 26.

lap, which would have a tendency to cause admission to occur too late, or the angle of advance may be increased sufficient to cause cut off to take place at half stroke, but to do this alone would cause admission to occur too early. Therefore the proper thing to do is to increase both the angle of advance and the outside lap. Fig. 26 shows how this can be done without decreasing the travel of the valve. The angle of advance, A B C, is now 50°, where before it was 30°, as in Fig. 22.

The valve is central when the crank is at position 1; the high point of the eccentric being at point 4. The outside lap which before was 1 in. has had $\frac{7}{16}$ in. added to it, making it $1\frac{7}{16}$ in. When the crank gets to D the port is just commencing to open, and with the crank on the center at 2, the lead is ¼ in.

It will readily be seen at this point that by increasing the outside lap still more the lead can be diminished, and the point of cut off made still earlier, but this would result in a still further reduction of the power of the engine, which has already been considerably reduced, as shown by the diminished area of the indicator diagram as compared with the one in Fig. 22. When the crank gets to position 3 the valve has reached the limit of its travel, and the port is open the distance A a, which is as far as the outside lap will permit. With the crank at point 4 cut off occurs. But with the increased angular advance and the inside lap remaining as it was before, viz., ½ in., release would occur too early. Therefore it will be necessary to increase the inside lap sufficient to cause release and compression to take place at as near the proper points as possible. In this instance ⅜ in. has been added, making the inside lap ⅞ in., and release takes place with the crank at position 5, while compression begins at 6. These points may also be changed by simply adding to or decreasing the inside lap.

It should be noted that in the foregoing discussion of valve gear it is understood that the valve stem moves in the same direction as the eccentric rod, that is, the direction of motion is not reversed by a rocker arm interposed between the eccentric and the valve.

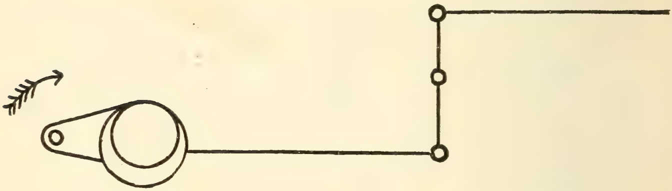


FIGURE 27.

In case there should be a rocker arm connected so as to reverse the motion and thereby cause the valve to move opposite to the eccentric rod, it will be necessary to set the eccentric behind the crank, as in Fig. 27.

Most engines are fitted with a rocker arm for transmitting the motion of the eccentric to the valve stem,

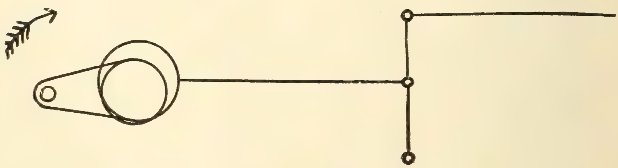


FIGURE 28.

but the usual practice is to attach them so that the direction of motion is not reversed, as in Fig. 28

The first step in the operation of valve setting is to place the engine on the dead center, which means that the piston is at the end of the stroke, and the centers of the main shaft, crank pin and crosshead pin, or wrist pin as it is sometimes called, are in line (see Fig. 31). When moving the engine to place it on the center it should always be turned in the direction in which it is to run. This is to guard against any errors which might result from lost motion or looseness in the reciprocating parts. Turn the fly wheel around until the crosshead is almost to the end of the stroke, say within a half inch of it, as at A, Fig. 29. Then with a

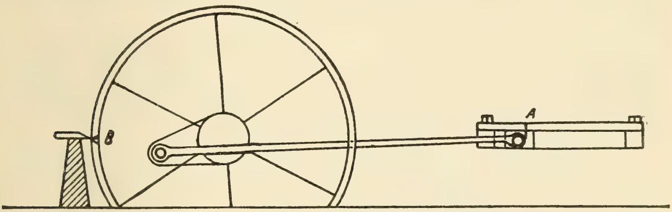


FIGURE 29.

steel scriber or penknife mark the location of the crosshead on the guides A, also provide a secure resting place upon the floor of the engine-room for a marker to be placed against the rim of the wheel. This rest should be firmly fastened to the floor in order that its position may not be changed during the operation of valve setting. Place the marker against the wheel as at B and mark the point with a center punch or cold chisel. Next turn the engine carefully until the crosshead completes the stroke and moves back on the return stroke until the mark A is in line again. Make another mark on the rim of the wheel opposite the marker at C. This position of the engine is shown in Fig. 30, and it will be seen that the crank is now as much above the center as it was below in Fig.

29. Now with a pair of large dividers ascertain the middle or half distance between marks B and C and put another mark, D, at this point. Then turn the

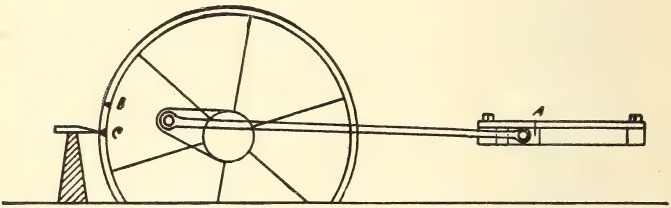


FIGURE 30.

engine a complete revolution until mark D comes opposite the pointer, Fig. 31, and the engine will be on the true center.

At this point the question may arise, why not simply reverse the motion and back the wheel up until the mark D is in line with the marker? The answer is,

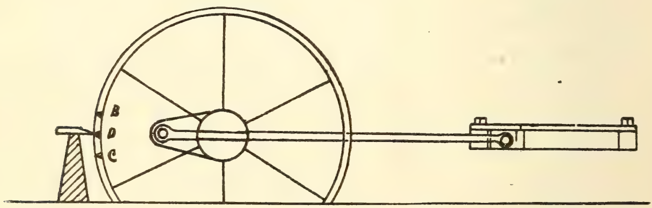


FIGURE 31.

that while this would undoubtedly save considerable labor, yet it would almost certainly result in an error, on account of the lost motion of the moving parts which would permit of considerable movement of the wheel before any movement of the crosshead would take place if the wheel was turned back. The result would be that when mark D came to be opposite to the pointer, the crank would not be on the true center. The next move is to see that the eccentric rod is adjusted to the proper length. If there is a rocker arm, connect the eccentric rod in its proper place, leaving the valve rod disconnected for the time being.

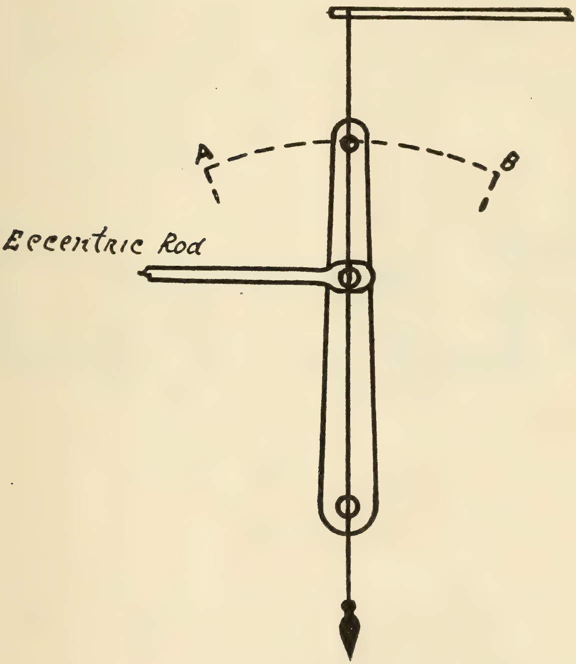


FIGURE 32.

Then adjust the length of the rod so that when the eccentric is turned around on the shaft the rocker arm will vibrate equal distances on each side of a plummet line suspended through the center of the pin upon which the arm turns, as in Fig. 32. Before connecting the valve rod the valve should be put in its central position and marked. To do this it will be necessary to first ascertain the outside lap.

The most accurate method of doing this is to take the valve out and measure the distances between the outside edges of the steam ports as at B, Fig. 33. Then measure the width of the valve from edge to edge as at A. Then $A - B \div 2 =$ the outside lap. For instance, $A = 8.5$ in., $B = 6.5$ in. Then $8.5 - 6.5 = 2$, and 2

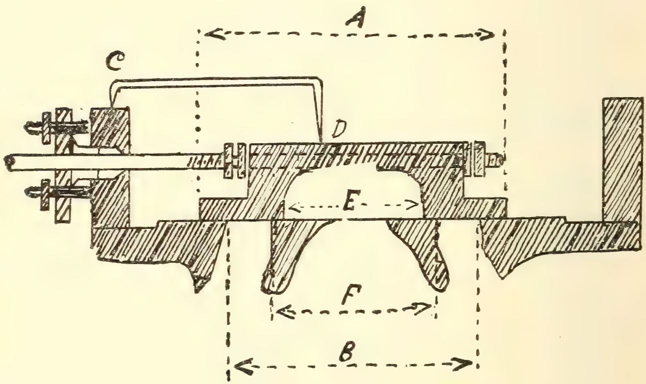


FIGURE 33.

divided by $2 = 1$ in., which is the lap. The inside lap should also be measured at this point for convenience, and the measurements preserved for future reference. The inside lap is ascertained by measuring the distance between the inside edges of the ports and the distance across the arch of the valve from one inside edge to the other (see Fig. 33) and dividing the difference by 2. For instance, the distance F is 4 in., and E is 3 in.; then $\frac{4-3}{2} = .5$ in., making the inside lap ½ in.

To place the valve central, measure the width of the outside lap each way from the outside edges of the steam ports and mark the points on the valve seat with a sharp lead pencil. Then place the valve with edges on the marks and it will be central. To insure accuracy measurements should also be taken from the outside edges of the steam ports to the ends of the seats. Having fixed the valve in its central position, replace the stem and if it is secured in the valve by nuts, as in Fig. 33, care should be taken to leave a little play for the valve between the nuts, otherwise it is liable to become stuck and held off the seat when it gets hot and expands. Make a center punch mark C, on the edge of the valve chest directly over the valve stem, and placing one leg of a tram or pair of dividers in the mark, with the other leg describe a mark on the top of the valve as at D, thus marking the valve in its central position.

Now with the rocker arm perpendicular, the eccentric rod having been previously adjusted, connect the valve rod to the rocker, and turn the eccentric to the limit of its throw in one direction, and measure the distance the valve has traveled from its central position. Then turn the eccentric around to its extreme throw in the other direction, and if the valve travels the same distance from its central position in the opposite direction the lengths of the rods are correct, but if not correct the necessary change can usually be made by shifting the nuts on the valve stem, or if the valve is secured to the stem by a yoke the change can be made in the rod.

Having succeeded in getting the correct travel for the valve, the next step is to set the eccentric. With the engine on the dead center, turn the eccentric around on the shaft in the direction in which the engine is to run, so as to take up all the play in the valve stem and other moving parts, and with the tram or dividers watch the valve until it has moved away from its central position by the amount of its outside lap, plus the lead it is desired to give the valve. For instance, if the valve has one inch outside lap and the lead is to be ⅛ in., the valve should be moved away from its central position 1⅛ in., and also away from the end of the cylinder at which the piston is. The steam port for that end should now be open ⅛ in., and the eccentric should be ahead of the crank one-quarter turn plus the angular advance required for the outside lap and lead, or if as previously explained, the motion of the eccentric is reversed by a rocker arm the eccentric should be behind the crank by the same amount. Tighten the set screws holding the eccentric on to the shaft and turn the engine around until it is on the opposite center. Then if the lead is the same on each center the valve is set correctly. If the lead is not the same, move the valve on the stem toward the end having the most lead, a distance equal to one-half the difference between the two leads. If the lead as equalized is more than is desired, move the eccentric back on the shaft until the correct lead opening is secured, then tighten the set screws permanently, and with a sharp cold chisel make a plain mark on the shaft and opposite to this another mark on the eccentric. This will save considerable trouble in case the eccentric should slip or be accidentally moved from its true position at any time.

Although the common D slide valve as applied to stationary engines usually has its point of cut off fixed, yet there are many types of variable automatic cut off engines with single slide valves of various patterns, such as box valves in which the steam passes through the valve, piston valves in which the steam either passes through or around the ends of the valve, so-called gridiron valves and various other types. Such valves are generally applied to high speed engines and are actuated by eccentrics which are under the control of shaft governors which vary the position of the eccentric with relation to the crank according to the load that is on the engine, thus regulating the point of cut off so as to maintain a constant speed, while the throttle is kept wide open. While the details of setting all the various styles of valves, including the corliss or four valve type, differ considerably from those required in setting the D valve, yet the same principles govern the operation, no matter what kind of a valve is to be adjusted

In all types of reciprocating engines the same factors affecting the distribution of the steam are present, viz., the outside or steam lap affecting admission and cut off, and the inside or exhaust lap affecting release and compression. While the D valve (and other types of single valves) combines these four principal factors within itself (that is, two steam laps and two exhaust laps), it should be noted that in the four valve type of engine the same factors are distributed among four valves, each valve performing its own particular function in controlling the distribution of the steam for the end of the cylinder to which it is attached. Also each valve may be adjusted to a certain degree independently of the others, and this fact goes far towards explaining why engines of this type, with the disengaging valve gear, are so much more economical in the use of steam than are those with the ordinary fixed cut off. Thus, for instance, the steam valves of a corliss engine may be adjusted to cut off the steam at any point, from the very beginning up to one-half of the stroke, without in the least affecting the release or compression because these events are controlled by the exhaust valves.

As the corliss engine is a prominent and familiar type of the four valve detaching cut off engine, and embodies the main features of nearly all engines belonging to that class, it will be used to illustrate the method of setting the valves on a four valve engine.

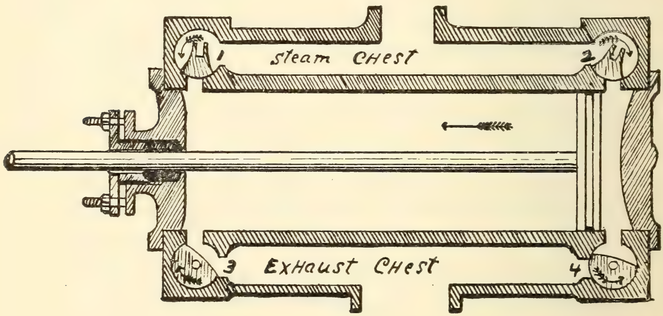


FIGURE 34.

Fig. 34 is a sectional view of the cylinder, steam and exhaust chests, and the valve chambers of a corliss engine. 1 and 2 are the steam valves and 3 and 4 the exhaust valves. The valves work in cylindrical chambers accurately bored out, the face of the valve being turned off to fit steam tight. They are what is termed rotative valves, that is, they receive a semi-rotary motion from the wrist plate, which in turn is actuated by the eccentric.

In some of the modern improved makes of four valve engines there are two eccentrics, one for the steam and the other for the exhaust valves. This arrangement permits of still greater latitude in adjustments for the economical use of steam.

In Fig. 34 the piston is shown as just ready to begin the stroke towards the left. Admission is taking place at valve 2 and release at valve 3, valves 1 and 4 being closed. The arrows show the direction in which the valves move. Motion is transmitted from the wrist plate to the valves by means of short connecting rods and cranks attached to the valve stems. These rods

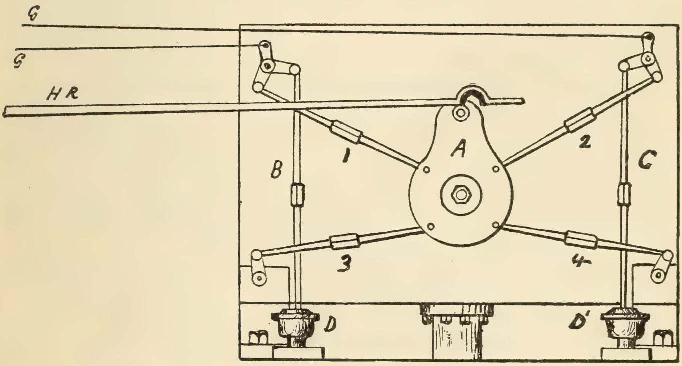


FIGURE 35.

are, or at least should be, fitted with right and left hand threads or turn buckles for the purpose of lengthening or shortening the rods while setting the valves.

The valve gear of a corliss engine with a single eccentric is shown in Fig. 35. The connections of the exhaust valves with the wrist plate are positive, and the travel of these valves is fixed, being a constant quantity, but the connections of the steam valves with the wrist plate are detachable, being under the control of the governor. Various designs of releasing mechanism are in use by different builders, but the same general principles govern the operation of all, viz., that the valve is quickly opened at the commencement of the stroke when the wrist plate has its fastest motion, and that the governor trips the releasing meehanism at that point in the stroke at which it is desired that cut off should take place, and that the valve is then quickly closed by means of a vacuum dash pot or, as in some types of engines, by a spring. Connection is made between the wrist plate and rocker arm by means of the hook rod, so-called because it hooks over the wrist plate pin, and can easily be disconnected in case it is desired to work the valves by hand, as in warming up the engine preparatory to starting up.

Referring to Fig. 35, A is the wrist plate, B and C are the dash pot rods, D, D′ the dash pots and H R the hook rod. G and G′ represent the governor rods, and the figures 1, 2, 3 and 4 indicate the valve rods with turn buckles for changing their lengths.

As in setting the slide valve, the first requisite in setting corliss valves is to put the engine on the center, the method of doing which has been fully described. Next adjust the length of the hook rod, if it is adjustable, if not, then the eccentric rod so that the wrist plate will vibrate equal distances each way from its central position which is marked on top of the hub. (See Fig. 36.) It will be noticed that there are four marks, A, B, C and D. Marks A and B are on the hub of the wrist plate and the stationary flange against which it turns, and when they are in line, indicate that the wrist plate is central. Marks C and D are on the stationary flange at equal distances each way from B, and when the engine is running mark A should travel to the right until it is in line with D and to the left until in line with C, or it may happen that A will travel past C and D or perhaps not quite to them, but which ever it does, it should stop at equal distances from them. This adjustment should be carefully made before setting the valves, because if any

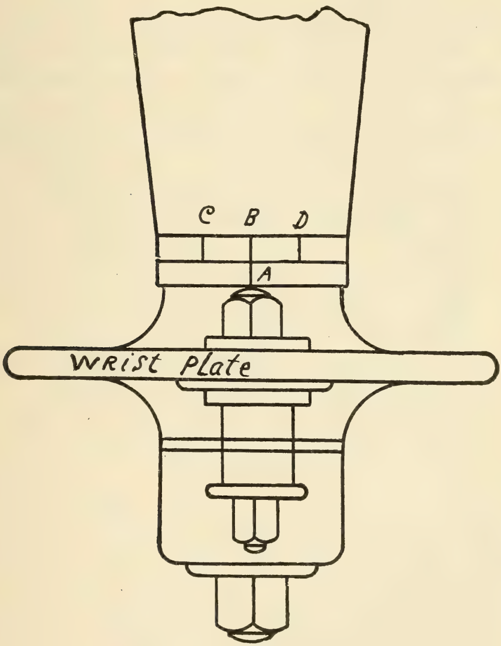


FIGURE 36.

change is made in the lengths of the eccentric rod or hook rod after the valves are once set it will seriously affect the action of all the valves.

The method of adjusting the rocker arm so that it will vibrate correctly has been already described and it is very desirable that its travel should be equidistant in either direction from a vertical position, but if it is found that the hook rod is non-adjustable as to length and that the wrist plate still vibrates too far in one direction, then the adjustment must be made on the length of the eccentric rod, which can be screwed into or out of the strap. The vibration of the wrist plate should then be tested by turning the eccentric around on the shaft in the direction the engine is to run. When this is found to be correct the next step is to remove the back bonnets from the valve chambers. Fig. 37 represents one of the steam valves and Fig. 38

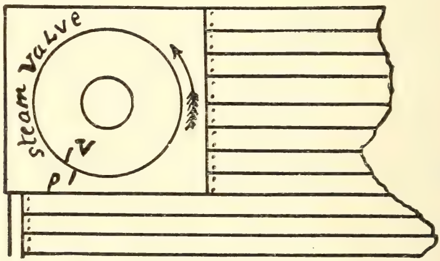


FIGURE 37.

one of the exhaust valves, each with back bonnet removed, showing the ends of the valves.

The working edges of the valves, as well as the ports of a corliss engine, cannot be seen when the valves are in place, owing to the fact that the circular ends of the valves fill the spaces at the ends of the valve chambers, but certain marks will be found on the ends of the valves, and corresponding marks on the faces of the chambers which serve as a guide in setting the valves. Referring to Fig. 37, mark V on the end of the valve is in line with the edge of the valve, and P indicates the edge of the port. The same letters apply to Fig. 38. Having removed the bonnets and found the marks, temporarily secure the wrist plate in its central position by tightening one of the set screws on the eccentric. Then connect the valve rods, adjusting their lengths so that the steam valves will have from 3/16 to 3/8 in. lap, and the exhaust valves from 1/16 to 1/4 in. lap. These figures vary according to the size of the engine, the smaller figures being for small size engines and the larger figures apply to large sizes.

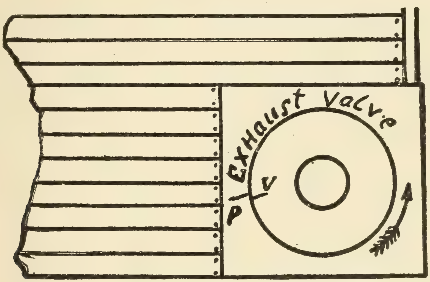


FIGURE 38.

In adjusting the steam valves be sure and note the direction in which they turn to open. In most corliss engines the arm of the crank to which the valve rod is connected extends downwards from the valve stem, as in Fig. 35. This will cause the valve to move towards the wrist plate in opening. After the valve rods have been properly adjusted as to length, place the engine on either center by the method previously explained and move the eccentric around on the shaft in the direction in which the engine is to run until it is far enough ahead of the crank to allow the steam valve the proper amount of lead opening, which will vary according to the size of the engine. Table 7 gives the lap and lead for various sizes of corliss engines from 8 to 36 in. bore. Having tightened the eccentric set screws, turn the engine around to the opposite center and note whether the lead is the same on each end. If there is a difference it can generally be equalized by slightly altering the length of one of the valve rods. The valves should also be adjusted by means of the indicator at the first opportunity, as that is the only absolutely correct method.

TABLE 7

TABLE FOR SETTING CORLISS VALVES.

Diameter of Cylinder.	Lap of Steam Valves.	Lap of Exhaust Valves.	Lead of Steam Valves.
8	3-16	1-16	1-32
10	3-16	1-16	1-32
12	3-16	1-16	1-32
14	1-4	1-8	1-32
16	1-4	1-8	1-32
18	1-4	1-8	1-32
20	1-4	1-8	1-32
22	5-16	3-16	3-64
24	5-16	3-16	3-64
26	5-16	3-16	3-64
28	5-16	3-16	3-64
30	5-16	3-16	3-64
32	3-8	1-4	1-16
34	3-8	1-4	1-16
36	3-8	1-4	1-16

The next point to receive attention is the adjustment of the lengths of the horizontal rods extending from the governor to the releasing mechanism, so that the steam valves will cut off at equal points in the stroke. This is done by raising the hook rod clear of the wrist plate pin, and with the bar provided for the purpose move the wrist plate to either one of its extreme positions as shown by the marks on the hub (see Fig. 36) and holding it in this position adjust the length of the governor rod for the steam valve (which will then be wide open) so that the boss or roller which trips the releasing mechanism is just in contact, or within $\frac{1}{32}$ in. of it. Then move the wrist plate to the other extreme of its travel and adjust the length of the other rod in the same manner. To prove the accuracy of the adjustment, raise the governor balls to their medium position, or about where they would be when the engine is running at its normal speed and block them there. Then having again connected the hook rod to the wrist plate, turn the engine around in the direction in which it is to run, and when the valve is released, measure the distance upon the guide that the crosshead has traveled from the end of the stroke. Now continue to turn the engine in the same direction until the other valve is released, and measure the distance that the crosshead has traveled from the opposite end of the stroke, and if the cut off is equalized these two distances will be the same. If there is a difference, lengthen one rod and shorten the other until the point of cut off is the same for both ends.

The lengths of the dash pot rods should also be adjusted so that when the plunger is at the bottom of the dash pot the valve lever will engage the hook.

After all adjustments have been made tighten the lock nuts on all the rods.

Questions

1. What important features in the operation of an engine are dependent upon a correct adjustment of the valves?

2. How many different types of valves are there in general use?

3. What are the basic principles governing the adjustment of the valves of an engine?

4. Name two important functions of a valve.

5. What is the effect of increasing the outside lap?

6. What is the result of increasing the inside lap?

7. What advantage has an engine of the four valve type over one with but a single valve?

8. Suppose a valve had neither lap nor lead, what would be the position of the eccentric in relation to the crank?

9. What is meant by the term "angular advance," and why is it necessary?

10. What is the first function of the valve at the commencement of the stroke?

11. What is the second function?

12. What is the travel of a slide valve equivalent to?

13. What is the third function of the valve?

14. What is the fourth function?

15. What will be the effect if a valve has no inside lap?

16. How can the action of a slide valve be graphically illustrated?

17. Name the two most commonly used valve diagrams.

18. What is meant by the expression, "radius of eccentricity"? (See Chapter VIII.)

19. Why must a valve have outside lap?

20. What is the object in giving a valve inside lap?

21. What is the result of decreasing the angular advance?

22. What will be the result if the travel of the valve is decreased?

23. What three changes must be made in order to

cause an earlier cut off in an engine that has a fixed cut off?

24. What is the first step in the operation of valve setting?

25. When is an engine on the dead center?

26. What precautions should be observed in turning an engine to place it on the center?

27. Why is this necessary?

28. Describe briefly the process of placing an engine on the dead center.

29. What is the next move in the routine of valve setting?

30. What should be done with the valve before connecting it to the valve rod?

31. How may the outside lap be ascertained?

32. How is the amount of inside lap found?

33. Should the valve be rigidly secured to the stem?

34. Describe the proper method of adjusting the length of the rod in order that the valve may travel correctly.

35. How is the correct position of the eccentric on the shaft ascertained?

36. If the lead is not the same at each end of the stroke, how may it be equalized?

37. If there is more lead than is desired, how may it be decreased?

38. What is the function of a shaft governor in relation to the eccentric?

39. Why is the four valve type of engine more economical in the use of steam than the single valve type with fixed cut off?

40. How should the wrist plate be adjusted?

41. If the wrist plate does not vibrate correctly what will be the result?

42. How should the rods connecting the governor with the releasing mechanism be adjusted?

43. How may this adjustment be tested?

44. How should the dash pot rods be adjusted as to length?

CHAPTER VII

THE INDICATOR

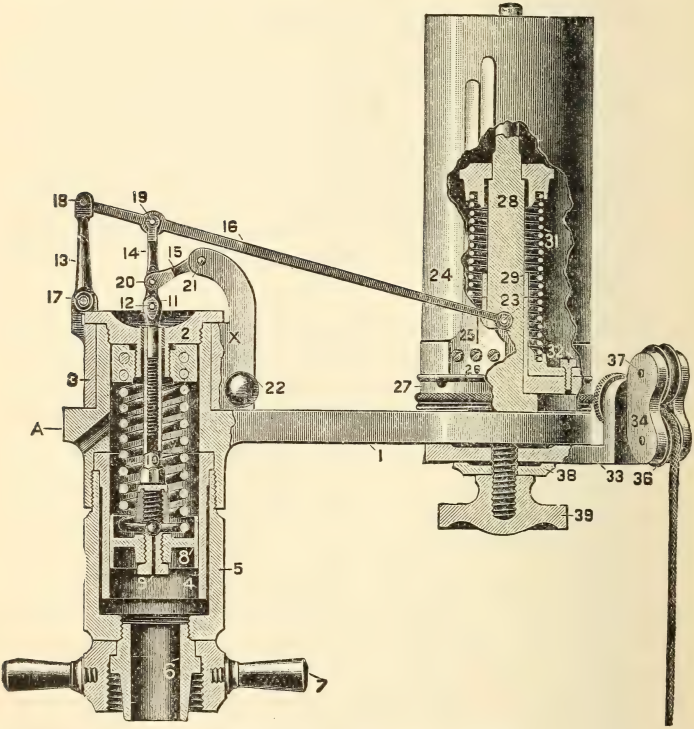
The indicator—Its invention and improvement—Principles governing its operation—Diagrams from condensing and non-condensing engines—Sizes of springs to be used for various pressure—Reducing mechanism—The reducing wheel—Different forms of pendulum reducing motion—Brumbo pulley—The pantograph—Attaching the indicator—Parts of the cylinder to which indicator pipes should not be connected—Care of the instrument—Cleaning, oiling, etc.—Directions for taking diagrams.

The Indicator. One of the greatest aids to the economical operation of the steam engine is the indicator, and it is the privilege of every engineer to have at least an elementary, if not a thorough knowledge of its principles and working. The time devoted to the study of the indicator, and in its application to the engine, is time well spent, and in the end will well repay the student of steam engineering.

Inventor. The indicator was invented and first applied to the steam engine by James Watt, whose restless genius was not satisfied with a mere outside view of his engine as it was running, but he desired to know more about the action of the steam in the cylinder, its pressure at different portions of the stroke, the laws governing its expansion after being cut off, etc. Watt's indicator, although crude in its design and construction, contained embodied within it all of the principles of the modern instrument.

Principles. These principles are:

First. The pressure of the steam in the engine cylinder throughout an entire revolution, against a small piston in the cylinder of the indicator, which in turn is controlled or resisted in its movement by a

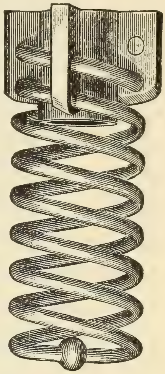


SECTIONAL VIEW CROSBY INDICATOR.

spring of known tension, so as to confine the stroke of the indicator piston within a certain small limit.

Second. The stroke of the indicator piston is communicated by a multiplying mechanism of levers and parallel motion to a pencil moving in a straight line. The distance through which the pencil moves being governed by the pressure in the engine cylinder and the tension of the spring.

Third. By the intervention of a reducing mechanism and a strong cord, the motion of the piston of the engine throughout an entire revolution is communicated to a small drum attached to and forming a part of the indicator. The movement of the drum is rotative and in a direction at right angles to the movement of the pencil. The forward stroke of the engine piston causes the drum to rotate through part of a revolution and at the same time a clock spring connected within the drum is wound up. On the return stroke the motion of the drum is reversed and the tension of the spring returns the drum to its original position and also keeps the cord taut.

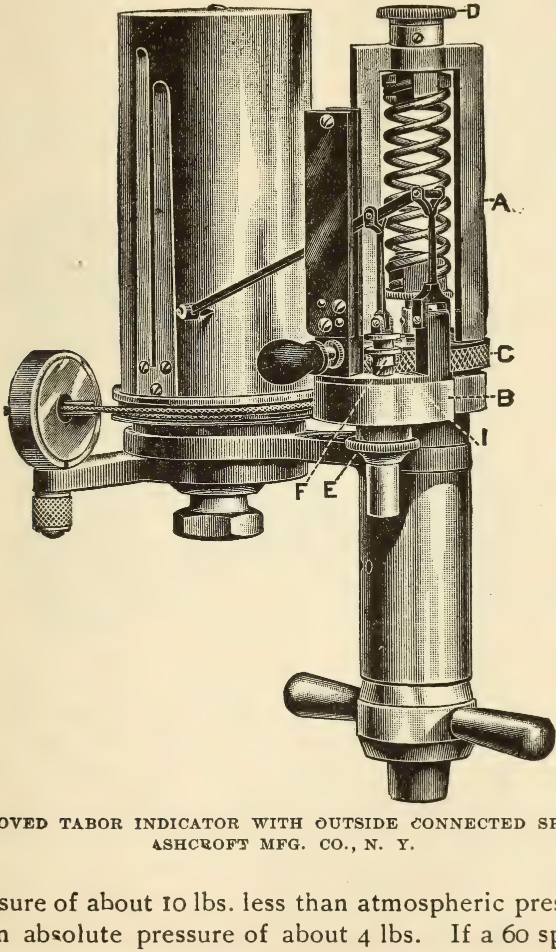


CROSBY INDICATOR SPRING.

To the outside of the drum a piece of blank paper of suitable size is attached and held in place by two clips. Upon this paper the pencil in its motion up and down traces a complete diagram of the pressures and other interesting events transpiring within the engine cylinder during the revolution of the engine. In fact the diagram traced upon the paper is the compound result of two concurrent movements. First, that of the pencil caused by the pressure of the steam against the indicator piston; second, that of the paper drum caused by, and coincident with, the motion of the engine piston. The upper end of the indicator cylinder is always open to the atmosphere, the steam acting only upon the underside of the small piston, and when the cock connecting the cylinders of the engine and indicator is closed, both ends of the indicator cylinder are open to atmospheric pressure, and the pencil then stands at its neutral position. If now the pencil is held against the paper and the drum rotated either by hand or by connecting it with the cord, a horizontal line will be traced. This line is called the atmospheric line, meaning the line of atmospheric pressure, and it is a very important factor in the study of the diagram.

If the engine is a non-condensing engine the pencil in tracing the diagram will, or at least, should not fall below the atmospheric line at any point, but will on the return stroke trace a line called the line of back pressure at a distance more or less above the atmospheric line and very nearly parallel with it. If the engine is a condensing engine the pencil will drop below the atmospheric line while tracing the line of back pressure on the diagram, and the distance this line is below the atmospheric line will depend upon the number of inches of vacuum in the condenser.

As before stated, the length of stroke of the indicator piston and the pencil movement as well is controlled by a spiral steel spring which acts in resistance to the pressure of the steam. These springs are made of different tensions in order to be suitable to different steam pressures and speeds, and are numbered 20, 40, 60, etc., the number meaning that a pressure per square inch in the engine cylinder corresponding to the number on the spring will cause a vertical movement of the pencil through a distance of one inch. Thus, if a number 20 spring is used and the pressure in the cylinder at the commencement of the stroke is 20 lbs. per square inch, the pencil will be raised one inch, or if the pressure is 30 lbs., the pencil will travel 1½ in., and if there is a vacuum of 20 in. in the condenser, the pencil will drop ½ in. below the atmospheric line for the reason that 20 in. of vacuum corresponds to a



IMPROVED TABOR INDICATOR WITH OUTSIDE CONNECTED SPRING
ASHCROFT MFG. CO., N. Y.

pressure of about 10 lbs. less than atmospheric pressure or an absolute pressure of about 4 lbs. If a 60 spring is used a pressure of 60 lbs. in the engine cylinder will be required to raise the pencil one inch, or 90 lbs. to raise it 1½ in.

The Ashcroft Manufacturing Co. of New York, makers of the well known Tabor indicator, have recently introduced a new feature in indicator work by connecting the spring on top of the cylinder and in plain view of the operator. This arrangement removes the spring from the influence of direct contact with the

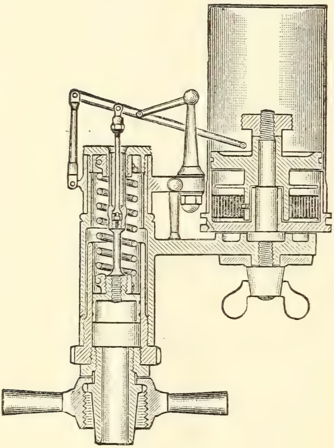


FIGURE 39.

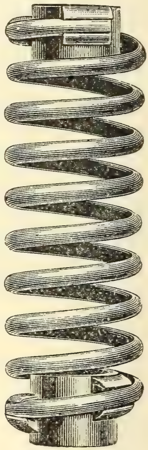


FIGURE 40.

steam, and it is subject only to the temperature of the surrounding atmosphere. It is claimed that as a result of this the accuracy of the spring is insured and that no allowance need to be made in its manufacture for expansion caused by the high temperature to which it is subject when located within the cylinder. Another good feature of this design is, that the spring can be easily removed without disconnecting any one part of the instrument in case it is desired to change springs.

A cut of the improved instrument is herewith presented.

Fig. 39 is a sectional view of the American Thompson improved indicator. Fig. 40 shows the spring. Fig. 41 is a three way cock for attaching the indicator to the cylinder.

Reducing Mechanism. Probably the only practically universal mechanism for reducing the motion of the crosshead is the reducing wheel, a device in which, by

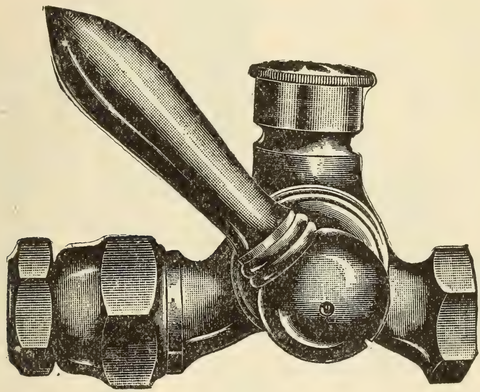


FIGURE 41.

the employment of gears and pulleys of different diameters, the motion is reduced to within the compass of the drum, and the device is applicable to almost any make of engine, whether of high or low speed. Some makers of indicators attach the reducing wheel directly to the indicator, thus producing a neat and very convenient arrangement. Fig. 42 shows the indicator complete with reducing wheel attached.

One of the most accurate and easily applied devices for reducing the motion of the piston is the wooden pendulum in its various forms. (See Figs. 43, 44 and 45.) It consists of a flat strip of pine or other light wood of a length not less than one and a half times the stroke of the engine, and if made longer it will be better. It should be from ¾ to ⅞ in. thick and have an average width of about 4 in. If the engine to be

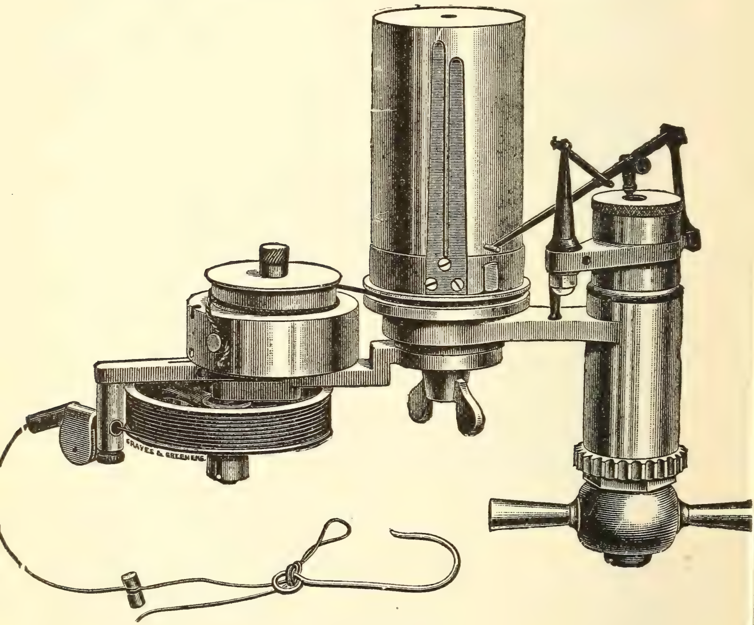


FIGURE 42.

indicated is horizontal the bar or pendulum is to be pivoted at a fixed point directly above and in line with the side of the crosshead, as that is generally the most convenient point of attachment. The pivot can be fixed to a permanent standard bolted to the frame of the engine (Fig. 46), or it may be secured to the ceiling of the room or even to a post fastened to the floor. If the engine is vertical the bar can be pivoted to the wall of the room or a strong post firmly secured to the floor. The connection with the crosshead is best accomplished by means of a short bar or link. A convenient length for this bar is one-half the stroke of the engine. To locate the correct point for the pivot,

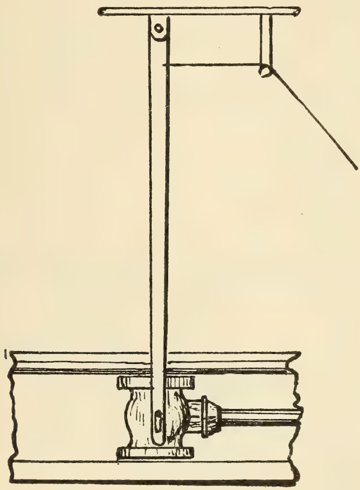


FIGURE 43.

assuming the length of the short bar to be one-half the length of the stroke, proceed as follows:

Place the engine on the center with the crosshead at the end of the stroke towards the crank. Then having previously bored a hole for the pivot in one end of the pendulum bar and in the other end a hole for connecting with the link, suspend the pendulum by a temporary pin, as a large wood screw, directly above and in line with the stud or bolt hole which has previously been tapped into the crosshead at any convenient point. The pendulum should be temporarily suspended at such a height that when it hangs perpendicular the hole in its lower end will line up accurately with the hole or stud in the crosshead. Now swing the pendulum in either direction a distance equal to the length of the link (one-half the stroke of the

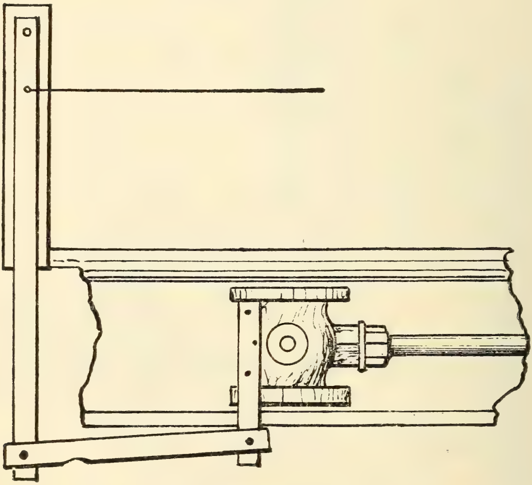


FIGURE 44.

engine) from the crosshead connection and note the distance that the bottom hole is above a straight edge laid horizontal and in line with the center of the stud in the crosshead. This will give the total vibration of the free end of the link from a line parallel with the line of the engine and the permanent location of the pivot should be one-half of this distance below the temporary point of suspension. This will allow the link to vibrate equally above and below the center of its connection with the crosshead. Fig. 47 shows a complete connection of this character.

Sometimes the end is slotted and thus directly connected to the stud in the crosshead, dispensing with the link. In this case it is necessary to locate the pivot at a point perpendicular to the center of travel of the stud in the crosshead. (See Fig. 43.) The link

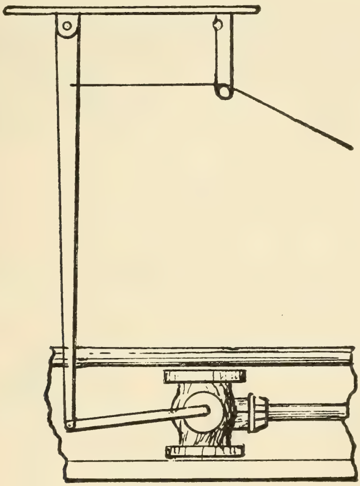


FIGURE 45.

connection is to be preferred, however. The cord can be attached to the pendulum at a point near the pivot which will give the desired length of diagram. This point can be determined by multiplying the length of the pendulum by the desired length of diagram and dividing the product by the stroke. For convenience these terms should be expressed in inches. Thus, assume stroke of engine to be 48 in., length of pendulum 1½ times length of stroke = 72 in. Desired length of diagram 3 in. Then $72 \times 3 \div 48 = 4.5$ in., which is

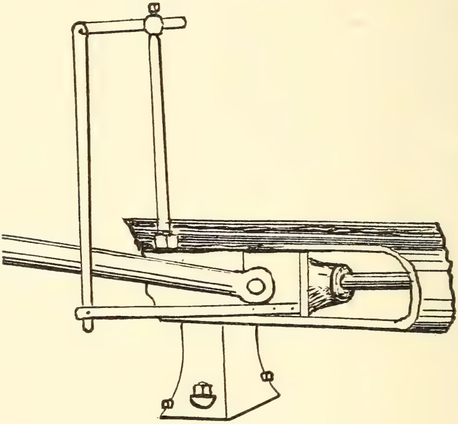


FIGURE 46.

the distance from center of pivot to point of connection for the cord. This can be either a small hole

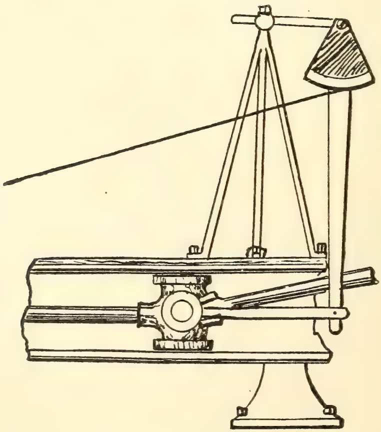


FIGURE 47.

bored through the pendulum or a wood screw to which the cord can be attached. From this point the cord should be led over a guide pulley located at such height that when the pendulum is vertical the cord will leave it at right angles. After leaving the guide pulley the cord can be carried at any angle desired.

The Brumbo Pulley. Another method of connecting the cord to the pendulum is to run the cord over a grooved segment, called a Brumbo pulley, connected

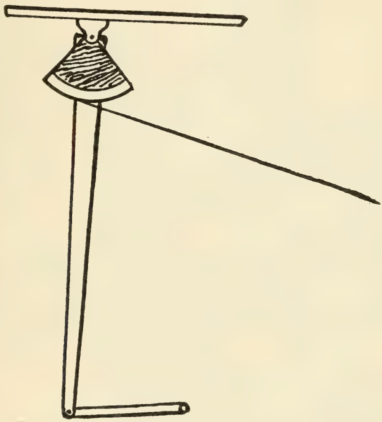


FIGURE 48.

with the pivoted end of the pendulum (Fig. 48), but with this arrangement, owing to the curved travel of the pendulum, there is greater liability to distortion of the diagram than in the first method. In case it is desired to use the Brumbo pulley, the radius of the segment can be found by the same process as that used for finding the point for connecting the cord directly to the pendulum.

One of the neatest and most easily applied devices for reducing the motion of the crosshead is the pantograph. (See Fig. 49.) No dimensions are essential except that it shall be made reasonably strong of some light, tough variety of wood, and that the pins and holes be nicely fitted to each other so that while the movement may be free there shall at the same time not be too much lost motion. The pantograph should be of such capacity that it will just close up nicely when the engine is at mid stroke and open out nicely when at its extreme travel. The two ends, C and D,

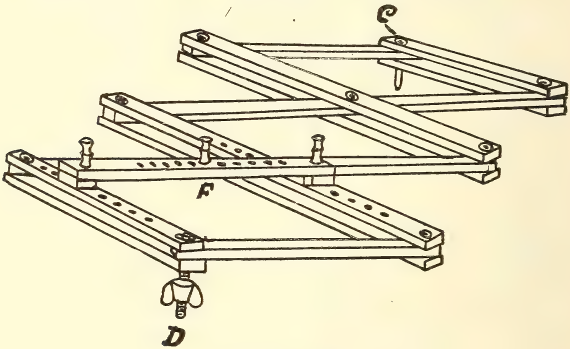
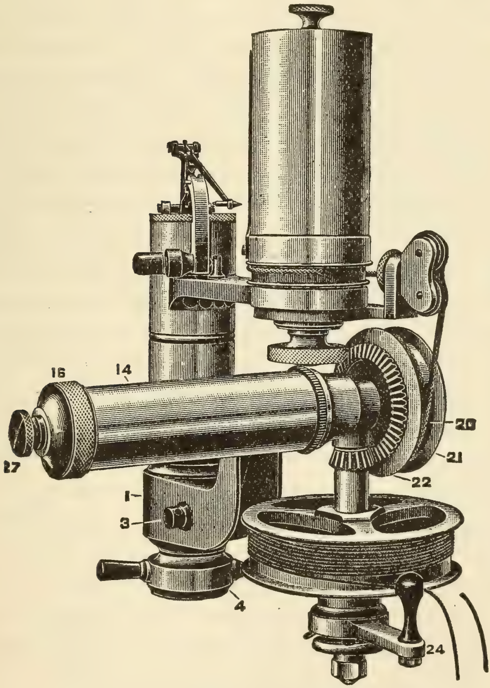


FIGURE 49.

are each to be fitted with a pin extending through far enough so that pin C can be hooked into a hole or socket on the crosshead, while pin D rests in a socket in the top of a post secured to the floor at a point opposite the center of travel of the crosshead and of such height as will allow the pantograph to lie in a horizontal position. Also the distance of the post from the guides must be adjusted so as to allow the device to close up at mid stroke and open out at full stroke without any straining of the parts. The point F of connection for the cord will always have a motion parallel with, and simultaneous with, that of the cross-head; the pin to which the cord is attached can be set in any one of the holes that will give the desired length for the diagram. The motion given by this device is accurate, although it may become necessary



CROSBY REDUCING WHEEL.

in some cases, especially with long stroke engines, to introduce a guide pulley to carry the cord from the pantograph.

Attaching the Indicator. The cylinders of most engines at the present time are drilled and tapped for indicator connections before they leave the shop, which is eminently proper, as no engine builder, or purchaser either, should be satisfied with the performance of a new engine until after it has been accurately tested and adjusted with the indicator.

The main requirements in these connections are that the holes shall not be drilled near the bottom of the cylinder where water is likely to find its way into the pipes, neither should they be in a location where the inrush of steam from the ports will strike them directly, nor where the edge of the piston is liable to partly cover them when at its extreme travel. An engineer before he undertakes to indicate an engine should satisfy himself that all these requirements are fulfilled. Otherwise he is not likely to obtain a true diagram. The cock supplied with the indicator is threaded for one-half inch pipe and unless the engine has a very long stroke it is the practice to bring the two end connections together at the side or top of the cylinder and at or near the middle of its length, where they can be connected to a three way cock. The pipe connections should be as short and as free from elbows as possible in order that the steam may strike the indicator piston as nearly as possible at the same moment that it acts upon the engine piston.

The work of taking diagrams is very much simplified by having both ends of the cylinder connected to one common tee or a three way cock as above described, but for long stroke engines there should be two indicators, one for each end and the diagrams should be taken simultaneously if it is desired to adjust the valves by the indicator. In this case an assistant would be required to manipulate one of the instruments.

The pipes should always be thoroughly blown out by allowing the steam to blow through the open cock during several revolutions of the engine, before connecting the indicator. If this is not done there is a moral certainty that grit and dirt will get into the cylinder of the indicator, where the pressure of the least atom of grit will cause the delicate instrument to work badly.

Selecting a Spring. The proper number of spring to use depends upon the boiler pressure in the case of an automatic cut off engine, but for an engine with a fixed cut off and throttling governor the number of the spring to be selected will depend upon the initial pressure in the cylinder. A convenient rule is to select a spring numbered one-half as high as the pressure; for instance, if the boiler pressure is 80 lbs., use a No. 40 spring, which will give a diagram 2 in. in height.

Care of the Instrument. The indicator should be cleaned and oiled both before and after using. The best material for wiping it is a clean piece of old soft muslin of fine texture, as there is not so much liability of lint sticking to or getting into the small joints. Use good clock oil for the joints and springs, and before taking diagrams it is a good practice to rub a small portion of cylinder oil on the piston and the inside of the cylinder, but when about to put the instrument away these should be oiled with clock oil also. None but the best cord should be used for connecting the paper drum with the reducing motion, as a cord that is liable to stretch will cause trouble. Suitable cord and also blank diagrams can generally be secured from firms manufacturing and selling indicators. After the indicator has been screwed on to the cock connecting with the pipe, the cord must be adjusted to the proper length before hooking it on to the drum. This must be done while the engine is running, by taking hold of the loop on the cord connected with the reducing motion with one hand, and with the other hand grasp the hook on the short cord attached to the drum, then by holding the two ends near each other during a revolution or two it will be seen whether the long cord needs to be shortened or lengthened.

The length of the diagram is determined by the point of connection of the cord to the pendulum as has been heretofore explained. Care should be exercised in placing the paper on the drum to see that it is stretched tight and firmly held by the clips. The pencil point having been first sharpened by rubbing it on a piece of fine emery cloth or sand paper should be adjusted by means of the pencil stop with which all indicators should be provided, so that it will have just sufficient bearing against the paper to make a fine, plain mark. If the pencil bears too hard on the paper it will cause unnecessary friction and the diagram will be distorted. The best method of ascertaining this fact and also whether the travel of the drum is equally divided between the stops, is to place a blank diagram on the drum, connect the cord and while the engine makes a revolution hold the pencil against the paper. Then unhook the cord, remove the paper and if the travel of the drum is not divided correctly it can be changed.

Having thus arranged all the preliminary details, place a fresh blank on the drum, being careful to keep the pencil out of contact with it, connect the cord, open the cock admitting steam to the indicator and after the pencil has made a few strokes to allow the cylinder to become warmed up, then gently swing it around to the paper drum and hold it there while the engine makes a complete revolution. Then move the pencil clear of the paper, close the cock and unhook the cord. Now trace the atmospheric line by holding the pencil against the paper while the drum is revolved by hand. This method of tracing the atmospheric line is preferable to that of tracing it immediately after closing the cock and while the drum is still being moved by the engine, for the reason that there is not so much liability of getting the atmospheric line too high owing to the presence of a slight pressure of steam remaining under the indicator piston for a second or two just after closing the cock; also the line drawn by hand will be longer than one drawn while the drum is moved by the motion of the engine and will therefore be more readily distinguished from the line of back pressure.

Having secured a truthful diagram, it now remains to take as many as are desired, and if the object is to set the valves of the engine, the diagrams from each end of the cylinder should follow each other as quickly as possible in order that the conditions of load and steam pressure may be the same. When the indicator is connected so that diagrams can be taken from both ends without changing it, the above conditions can generally be realized. But if diagrams can only be taken from one end at a time, the only way to arrive at correct conclusions in relation to the adjustment of the valves will be to see that the boiler pressure is practically the same at the time of taking diagrams from either end and that the position of the governor is also the same, assuming that the load on the engine is practically constant. This applies of course to an automatic cut off.

As soon as the diagrams are taken the following data should be noted upon them: The end of the cylinder, whether head or crank; boiler pressure; and time when taken. Other data can be added afterwards. If the engine is an automatic cut off of the corliss type and the point of cut off on one end does not coincide with the other, the difference can generally be adjusted while the engine is running by changing the length of the rods extending from the governor to the tripping device. These rods are, or should be, fitted with right and left threads on the ends for this purpose. Any changes in the valves, such as giving them more lead, compression, etc., and which necessitates changing the length of the reach rods connecting them with the wrist plate, will have to be made while the engine is stopped, although with slow speed engines and the exercise of caution it is possible to make alterations in these rods while the engine is running.

Questions

1. What instrument is a necessary part of an engineers outfit?
2. Who invented the indicator?
3. Name the principles governing the action of the indicator.
4. What will a truthful diagram from a steam cylinder show?
5. Does the steam act upon both sides of the indicator piston?
6. What does the atmospheric line show?
7. Is this line important in the study of the diagram?
8. Where should the line of back pressure appear in a diagram from a non-condensing engine?

9. Where will the line of back pressure appear on a diagram from a condensing engine?

10. What controls the length of stroke of the indicator piston?

11. What does the number on the spring mean?

12. What is one of the most convenient appliances for reducing the motion of the crosshead within the compass of the drum?

13. What other appliances besides the reducing wheel may be employed for this purpose?

14. What is a Brumbo pulley?

15. What are the main requirements in indicator connections?

16. What should be done with the pipes before attaching the indicator?

17. Upon what does the selection of the scale of spring depend?

18. What is a convenient rule to be observed in the selection of a spring?

19. What is the best method of tracing the atmospheric line?

20. What data should be noted on the diagram as soon as it is taken?

CHAPTER VIII

DEFINITIONS AND TABLES

Definition of words, terms and phrases—Table of hyperbolic logarithms—Table of areas and circumferences of circles.

In order to facilitate the study and analysis of indicator diagrams, the following definitions of technical terms, some of which have already been explained in another part of this book, are here given.

Absolute pressure. Pressure reckoned from a perfect vacuum. It equals the boiler pressure plus the atmospheric pressure.

Boiler pressure or gauge pressure. Pressure above the atmospheric pressure as shown by the steam gauge.

Initial pressure. Pressure in the cylinder at the beginning of the stroke.

Terminal pressure (*T. P.*). The pressure that would exist in the cylinder at the end of the stroke provided the exhaust valve did not open until the stroke was entirely completed. It may be graphically illustrated on the diagram by extending the expansion curve by hand to the end of the stroke. It is found theoretically by dividing the pressure at point of cut off by the ratio of expansion. Thus, absolute pressure at cut off = 100 lbs., ratio of expansion = 5; then 100 ÷ 5 = 20 lbs., absolute terminal pressure.

Mean effective pressure (*M. E. P.*). The average pressure acting upon the piston throughout the stroke minus the back pressure.

Back pressure. Pressure which tends to retard the forward stroke of the piston. Indicated on the diagram from a non-condensing engine by the height of the back pressure line above the atmospheric line. In a condensing engine the degree of back pressure is shown by the height of the back pressure line above an imaginary line representing the pressure in the condenser corresponding to the degree of vacuum in inches, as shown by the vacuum gauge.

Total or absolute back pressure, in either a condensing or non-condensing engine, is that indicated on the diagram by the height of the line of back pressure above the line of perfect vacuum.

Ratio of expansion. The proportion that the volume of steam in the cylinder at point of release bears to the volume at cut off. Thus, if the point of cut off is at one-fifth of the stroke, and release does not take place until the end of the stroke, the ratio of expansion, or in other words, the number of expansions, is 5. When the T. P. is known the ratio of expansion may be found by dividing the initial pressure by the T. P.

Wire drawing. When through insufficiency of valve opening, contracted ports, or throttling governor, the steam is prevented from following up the piston at full initial pressure until the point of cut off is reached, it is said to be wire drawn. It is indicated on the diagram by a gradual inclination downwards of the steam line from the admission line to the point of cut off. Too small a steam pipe from boiler to engine will also cause wire drawing and fall of pressure.

Condenser pressure may be defined as the pressure existing in the condenser of an engine, caused by the lack of a perfect vacuum. As, for instance, with a vacuum of 25 in. there will still remain the pressure due to the 5 in. which is lacking. This will be about 2.5 lbs.

Vacuum. That condition existing within a closed vessel from which all matter, including air, has been expelled. It is measured by inches in a column of mercury contained within a glass tube a little over 30 in. in height, having its lower end open and immersed in a small open vessel filled with mercury. The upper end of the glass tube is connected with the vessel in which the vacuum is to be produced. When no vacuum exists the mercury will leave the tube and fill the lower vessel. When a vacuum is maintained in the condenser, or other vessel, the mercury will rise in the glass tube to a height corresponding to the degree of vacuum. If the mercury rises to the height of 30 in. it indicates a perfect vacuum, which means the absence of all pressure within the vessel, but this condition is never realized in practice; the nearest approach to it being about 28 in.

For purposes of convenience the mercurial vacuum gauge is not generally used, it having been replaced by the Bourdon spring gauge, although the mercury gauge is used for testing.

The vacuum in a condenser is generally maintained by an air pump, although it can be produced and maintained by the mere condensation of the steam as it enters the condenser by allowing a spray of cold water to strike it. The steam when it first enters the condenser drives out the air and the vessel is filled with steam which, when condensed, occupies about 1,600 times less space than it did before being condensed, hence a partial vacuum is produced.

While the vacuum in a condenser cannot be considered as power at all, yet it occupies the anomalous position of increasing, by its presence, the capacity of the engine for doing work. This is owing to the fact that the atmospheric pressure or resistance which is always ahead of the piston in a non-condensing engine is, in the case of a condensing engine, removed to a degree corresponding to the height of the vacuum, thus making available just so much more of the pressure behind the piston. Thus, if the average steam pressure throughout the stroke is 30 lbs. and there is a vacuum of 26 in. maintained in the condenser, there will be 13 lbs. of resistance per square inch removed from in front of the piston, thus making available $30 + 13 = 43$ lbs. pressure per square inch.

Absolute zero has been fixed by calculation at 461.2° below the zero of the Fahrenheit scale.

Piston displacement. The space or volume swept through by the piston in a single stroke. Found by multiplying the area of piston by length of stroke.

Piston clearance. The distance between the piston and cylinder head when the piston is at the end of the stroke.

Steam clearance, ordinarily termed clearance. The space between the piston at the end of the stroke and the valve face. It is reckoned in per cent. of the total piston displacement.

Horse power (H. P.). 33,000 pounds raised one foot high in one minute of time.

Indicated horse power (I. H. P.). The horse power as shown by the indicator diagram. It is found as follows:

Area of piston in square inches × M. E. P. × piston speed in feet ÷ 33,000.

Piston speed. The distance in feet traveled by the piston in one minute. It is the product of twice the length of stroke expressed in feet multiplied by the number of revolutions per minute.

R. P. M. Revolutions per minute.

Net horse power. I. H. P. minus the friction of the engine.

Compression. The action of the piston as it nears the end of the stroke, in reducing the volume and raising the pressure of the steam retained in the cylinder ahead of the piston by the closing of the exhaust valve.

Boyle's or Mariotte's law of expanding gases. "The pressure of a gas at a constant temperature varies inversely as the space it occupies." Thus, if a given volume of gas is confined at a pressure of 50 lbs. per square inch and it is allowed to expand to twice its volume, the pressure will fall to 25 lbs. per square inch.

Adiabatic curve. A curve representing the expansion of a gas which loses no heat while expanding. Sometimes called the curve of no transmission.

Isothermal curve. A curve representing the expansion of a gas having a constant temperature but partially influenced by moisture, causing a variation in pressure according to the degree of moisture or saturation. It is also called the theoretical expansion curve.

Expansion curve. The curve traced upon the diagram by the indicator pencil showing the actual expansion of the steam in the cylinder.

First law of thermodynamics. Heat and mechanical energy are mutually convertible.

Power. The rate of doing work, or the number of foot pounds exerted in a given time.

Unit of work. The foot pound, or the raising of one pound weight one foot high.

First law of motion. All bodies continue either in a state of rest or of uniform motion in a straight line, except in so far as they may be compelled by impressed forces to change that state.

Work. Mechanical force or pressure cannot be considered as work unless it is exerted upon a body and causes that body to move through space. The product of the pressure multiplied by the distance passed through and the time thus occupied is work.

Momentum. Force possessed by bodies in motion, or the product of mass and density.

Dynamics. The science of moving powers or of matter in motion, or of the motion of bodies that mutually act upon each other.

Force. That which alters the motion of a body, or puts in motion a body that was at rest.

Maximum theoretical duty of steam is the product of the mechanical equivalent of heat, viz., 778 ft. lbs. multiplied by the total heat units in a pound of steam. Thus, in one pound of steam at 212° reckoned from 32° the total heat equals 1,146.6 heat units. Then 778 × 1,146.6 equals 892,054.8 ft. lbs. = maximum duty.

Steam efficiency may be expressed as follows:

$$\frac{\text{Heat converted into useful work}}{\text{Heat expended}}$$ and maximum efficiency can only be attained by using steam at as high an initial pressure as is consistent with safety and at as large a ratio of expansion as possible. The percentage of efficiency of steam used at atmospheric pressure in a non-expansive engine is very low; as, for instance, the heat expended in the evaporation of one pound of water at 32° into steam at atmospheric pressure = 1,146.6 heat units, and the volume of steam so generated = 26.36 cu. ft.

One cubic foot of steam at 212° contains energy equal to 144 × 14.7 = 2,116.8 ft. lbs., and 26.36 cu.

ft. = 2,116.8 × 26.36 = 55,798.84 ft. lbs., which divided by the mechanical equivalent of heat, viz., 778 ft. lbs. = 71.72 heat units, available for useful work. The per cent. of efficiency therefore is $\frac{71.72 \times 100}{1,146.6} = 6.28$ per cent. But suppose the initial pressure to have been 200 lbs. absolute, and that the steam is allowed to expand to thirty times its original volume. The heat expended in evaporating a pound of water at 32° into steam at 200 lbs. absolute pressure = 1,198.3 heat units, and the volume of steam so generated = 2.27 cu. ft. The average pressure during expansion would be 29.34 lbs. per square inch and the volume when expanded thirty times would equal 2.27 × 30 = 68.1 cu. ft.

One cubic foot of steam at 29.34 lbs. pressure equals 144 × 29.34 = 4,224.96 ft. lbs., and 68.1 cu. ft. will equal 4224.96 × 68.1 = 287,719.7 ft. lbs. of energy, which divided by the equivalent, 778, equals 370.2 heat units, and the per cent. of efficiency will be $\frac{370.2 \times 100}{1,198.3} = 30.8$ per cent.

Engine efficiency. If the engine is considered merely as a machine for converting into useful work the heat energy in the steam regardless of the cost of fuel, its efficiency may be expressed as follows:

$$\frac{\text{Heat converted into useful work}}{\text{Total heat received in the steam}}$$

Example. Assume an engine to be receiving steam at 95 lbs. absolute pressure, that the consumption of dry steam per horse power per hour equals 20 lbs., that the friction of the engine amounts to 15 per cent., and that the temperature of the feed water is raised from 60° to 170° by utilizing a portion of the exhaust.

In a pound of steam at 95 lbs. absolute there are 1,180.7 heat units, and in a pound of water at 170° there are 138.6 units of heat, but 28.01 of these heat units were in the water at its initial temperature of 60°. Therefore the total heat added to the water by the exhaust steam equals 138.6 – 28.01 = 110.59 heat units, and the total heat in each pound of steam to be charged up to the engine is 1,180.7 – 110.59 = 1,070.11, and the total for each horse power developed per hour will be 1,070.11 × 20 = 21,402.2 heat units.

A horse power equals 33,000 ft. lbs. per minute, or sixty times 33,000 = 1,980,000 ft. lbs. per hour. From this must be deducted 15 per cent. for friction of the engine, leaving 1,683,000 ft. lbs. for useful work. Dividing this by the equivalent, viz., 778 ft. lbs., gives 2,163.2 heat units as the heat converted into one horse power of work in one hour, and the percentage of efficiency of the engine will be $\frac{2,163.2 \times 100}{21,402.2}$ = 10.1 per cent.

Efficiency of the plant as a whole includes boiler and engine efficiency and is to be figured upon the basis of

$$\frac{\text{Heat converted into useful work}}{\text{Calorific or heat value of fuel}}$$

Horse power constant of an engine is found by multiplying the area of the piston in square inches by the speed of the piston in feet per minute and dividing the product by 33,000. It is the power the engine would develop with one pound mean effective pressure. To find the horse power of the engine, multiply the M. E. P. of the diagram by this constant.

Logarithms. A series of numbers having a certain relation to the series of natural numbers, by means of which many arithmetical operations are made comparatively easy. The nature of the relation will be understood by considering two simple series, such as the following, one proceeding from unity in geometrical progression and the other from 0 in arithmetical progression:

Geom. series, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, etc.
Arith. series, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, etc.

Here the ratio of the geometrical series is 2 and any term in the arithmetical series expresses how often 2 has been multiplied into 1 to produce the corresponding term of the geometrical series. Thus, in proceeding from 1 to 32 there have been 5 steps or multiplications by the ratio 2; in other words, the ratio of 32 to 1 is compounded 5 times of the ratio of 2 to 1. The above is the basic principle upon which common logarithms are computed.

Hyperbolic logarithms. Used in figuring the M. E. P. of a diagram from the ratio of expansion and the initial pressure. Thus, hyperbolic logarithm of ratio of expansion + 1 multiplied by absolute initial pressure and divided by ratio of expansion = mean forward pressure. From this deduct total back pressure and the remainder will be mean effective pressure. The hyperbolic logarithm is found by multiplying the common logarithm by the constant 2.302585. Table 8 gives the hyperbolic logarithms of numbers usually required in calculations of the above nature.

Steam consumption per horse power per hour. The weight in pounds of steam exhausted into the atmosphere or into the condenser in one hour divided by the horse power developed. It is determined from the diagram by selecting a point in the expansion curve just previous to the opening of the exhaust valve and measuring the absolute pressure at that point. Then the piston displacement up to the point selected, plus the clearance space, expressed in cubic feet, will give the volume of steam in the cylinder, which multiplied

Table 8.

Hyperbolic Logarithms.

No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.01	0.0099	3.00	1.0986	5.00	1.6094	7.00	1.9459	9.00	2.1972
1.05	0.0487	3.05	1.1151	5.05	1.6194	7.05	1.9530	9.05	2.2028
1.10	0.0953	3.10	1.1341	5.10	1.6292	7.10	1.9600	9.10	2.2083
1.15	0.1397	3.15	1.1474	5.15	1.6390	7.15	1.9671	9.15	2.2137
1.20	0.1823	3.20	1.1631	5.20	1.6486	7.20	1.9740	9.20	2.2192
1.25	0.2231	3.25	1.1786	5.25	1.6582	7.25	1.9810	9.25	2.2246
1.30	0.2623	3.30	1.1939	5.30	1.6677	7.30	1.9879	9.30	2.2310
1.35	0.3001	3.35	1.2090	5.35	1.6771	7.35	1.9947	9.35	2.2354
1.40	0.3364	3.40	1.2238	5.40	1.6864	7.40	2.0015	9.40	2.2407
1.45	0.3715	3.45	1.2384	5.45	1.6956	7.45	2.0018	9.45	2.2460
1.50	0.4054	3.50	1.2527	5.50	1.7047	7.50	2.0149	9.50	2.2513
1.55	0.4382	3.55	1.2669	5.55	1.7138	7.55	2.0215	9.55	2.2565
1.60	0.4700	3.60	1.2809	5.60	1.7228	7.60	2.0281	9.60	2.2618
1.65	0.5007	3.65	1.2947	5.65	1.7316	7.65	2.0347	9.65	2.2670
1.70	0.5306	3.70	1.3083	5.70	1.7405	7.70	2.0412	9.70	2.2721
1.75	0.5596	3.75	1.3217	5.75	1.7491	7.75	2.0477	9.75	2.2773
1.80	0.5877	3.80	1.3350	5.80	1.7578	7.80	2.0541	9.80	2.2824
1.85	0.6151	3.85	1.3480	5.85	1.7664	7.85	2.0605	9.85	2.2875
1.90	0.6418	3.90	1.3610	5.90	1.7750	7.90	2.0668	9.90	2.2925
1.95	0.6678	3.95	1.3737	5.95	1.7834	7.95	2.0731	9.95	2.2976
2.00	0.6931	4.00	1.3863	6.00	1.7918	8.00	2.0794	10.00	2.3026
2.05	0.7178	4.05	1.3987	6.05	1.8000	8.05	2.0857	10.25	2.3273
2.10	0.7419	4.10	1.4010	6.10	1.8083	8.10	2.0918	10.50	2.3514
2.15	0.7654	4.15	1.4231	6.15	1.8164	8.15	2.0988	10.75	2.3749
2.20	0.7885	4.20	1.4351	6.20	1.8245	8.20	2.1041	11.00	2.3979
2.25	0.8110	4.25	1.4469	6.25	1.8326	8.25	2.1102	12.00	2.4849
2.30	0.8329	4.30	1.4586	6.30	1.8405	8.30	2.1162	13.00	2.5626
2.35	0.8544	4.35	1.4701	6.35	1.8484	8.35	2.1222	14.00	2.6390
2.40	0.8755	4.40	1.4816	6.40	1.8563	8.40	2.1282	15.00	2.7103
2.45	0.8961	4.45	1.4929	6.45	1.8640	8.45	2.1342	16.00	2.7751
2.50	0.9163	4.50	1.5040	6.50	1.8718	8.50	2.1400	17.00	2.8332
2.55	0.9361	4.55	1.5151	6.55	1.8795	8.55	2.1459	18.00	2.8903
2.60	0.9555	4.60	1.5260	6.60	1.8870	8.60	2.1518	19.00	2.9444
2.65	0.9746	4.65	1.5369	6.65	1.8946	8.65	2.1576	20.00	2.9957
2.70	0.9932	4.70	1.5475	6.70	1.9021	8.70	2.1633	21.00	3.0445
2.75	1.0116	4.75	1.5581	6.75	1.9095	8.75	2.1690	22.00	3.0910
2.80	1.0296	4.80	1.5686	6.80	1.9169	8.80	2.1747	23.00	3.0355
2.85	1.0473	4.85	1.5790	6.85	1.9242	8.85	2.1804	24.00	3.1780
2.90	1.0647	4.90	1.5892	6.90	1.9315	8.90	2.1860	25.00	3.2189
2.95	1.0818	4.95	1.5994	6.95	1.9387	8.95	2.1916	30.00	3.3782

by the weight per cubic foot of steam at the pressure as measured will give the weight of steam consumed during one stroke. From this should be deducted the steam saved by compression as shown by the diagram, in order to get a true measure of the economy of the engine. Having thus determined the weight of steam consumed for one stroke, multiply it by twice the number of strokes per minute and by 60, which will give the total weight consumed per hour. This divided by the horse power will give the rate per horse power per hour.

Cylinder condensation and reëvaporation. When the exhaust valve opens to permit the exit of the steam there is a perceptible cooling of the walls of the cylinder, especially in condensing engines when a high vacuum is maintained. This results in more or less condensation of the live steam admitted by the opening of the steam valve; but if the exhaust valve is caused to close at the proper time so as to retain a portion of the steam to be compressed by the piston on the return stroke, a considerable portion of the water caused by condensation will be reëvaporated into steam by the heat and consequent rise in pressure caused by compression.

Ordinates. Parallel lines drawn at equal distances apart across the face of the diagram, and perpendicular to the atmospheric line. They serve as a guide to facilitate the measurement of the average forward pressure throughout the stroke, or the pressure at any point of the stroke if desired.

Eccentric. A mechanical device used in place of a crank for converting rotary into reciprocating motion. An eccentric is in fact a form of crank in which the crank pin, corresponding to the eccentric sheave, embraces the shaft, but owing to the great leverage at which the friction between the sheave and the strap acts, compared with its short turning leverage, it can only be used to advantage for the purpose named above.

Eccentric throw is the distance from the center of the eccentric to the center of the shaft. This definition also applies to the term "radius of eccentricity."

Eccentric position. The location of the highest point of the eccentric relative to the center of the crank pin, measured or expressed in degrees.

Angular advauce. The distance that the high point of the eccentric is set ahead of a line at right angles with the crank. In other words, the lap angle plus the lead angle. If a valve had neither lap nor lead, the position of the high point of the eccentric would be on a line at right angles with the crank; as for instance, the crank being at 0° the eccentric would stand at 90°.

Valve travel. The distance covered by the valve in its movement. It equals twice the throw of the eccentric. This refers to engines having a fixed cut off. In the case of an engine with a variable automatic cut off the travel of the cut off valve is regulated by the governor.

Lap. The amount that the ends of the valve project over the edges of the ports when the valve is at mid travel.

Outside or steam lap. The amount that the end of the valve overlaps or projects over the outside edge of the steam port.

Inside lap. The lap of the inside or exhaust edge of the valve over the inside edge of the port.

Lead. The amount that the port is open when the crank is on the dead center. The object of giving a valve lead is to supply a cushion of live steam which, in conjunction with that already confined in the clearance space by compression, shall serve to bring the moving parts of the engine to rest quietly at the end of the stroke, and also quicken the action of the piston in beginning the return stroke.

Compression. Closing of the exhaust passage before the steam is entirely exhausted from the cylinder. A certain quantity of steam is thus compressed into the clearance space.

Throttling governor. Used to regulate the speed of engines having a fixed cut off. The governor controls the position of a valve in the steam pipe, opening or closing it according as the engine needs more or less steam in order to maintain a regular speed.

Automatic or variable cut off. In engines of this type the full boiler pressure is constantly in the valve chest and the speed of the engine is regulated by the governor controlling the point of cut off, causing it to take place earlier or later according as the load on the engine is lighter or heavier.

Fixed cut off. This term is applied to engines in which the point of cut off remains the same regardless of the load, the speed being regulated by a throttling governor as explained above.

Isochronal or shaft governor. This device in which the centrifugal and centripetal forces are utilized, as in the fly ball governor, is generally applied to automatic cut off engines having reciprocating or slide valves. It is attached to the crank shaft and its function is to change the position of the eccentric, which is free to move across the shaft within certain prescribed limits, but is at the same time attached to the

Table 9.

Areas and Circumferences of Circles.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
.25	.049	.7854	15.5	188.692	48.694	31	754.769	97.389
.5	.1963	1.5708	16	201.062	50.265	31.25	766.992	98.175
1.0	.7854	3.1416	16.25	207.394	51.051	31.5	799.313	98.968
1.25	1.2271	3.9270	16.5	213.825	51.836	32	804.249	100.53
1.5	1.7671	4.7124	17	226.980	53.407	32.25	816.86	101.31
2	3.1416	6.2832	17.25	233.705	54.192	33	855.30	103.67
2.25	3.9760	7.0686	17.5	240.520	54.978	33.25	868.30	104.45
2.5	4.9087	7.8540	18	254.469	56.548	33.5	881.41	105.24
3	7.0686	9.4248	18.25	261.587	57.334	34	907.92	106.81
3.25	8.2957	10.210	18.5	268.803	58.119	34.25	921.32	107.60
3.5	9.6211	10.995	19	283.529	59.690	34.5	934.82	108.38
4	12.566	12.566	19.25	291.039	60.475	35	962.11	106.95
4.25	14.186	13.351	19.5	298.648	61.261	35.25	975.90	110.74
4.5	15.904	14.137	20	314.160	62.832	35.5	989.80	111.52
5	19.635	15.708	20.25	322.063	63.617	36	1017.8	113.09
5.25	21.647	16.493	20.5	330.064	64.402	36.25	1032.06	113.88
5.5	23.758	17.278	21	346.361	65.973	36.5	1046.35	114.66
6	28.274	18.849	21.25	354.657	66.759	37	1075.21	116.23
6.25	30.679	19.635	21.5	363.051	67.544	37.25	1089.79	117.01
6.5	33.183	20.420	22	380.133	69.115	37.5	1104.46	117.81
7	38.484	21.991	22.25	388.822	69.900	38	1134.11	119.38
7.25	41.282	22.776	22.5	397.608	70.686	38.25	1149.08	120.16
7.5	44.178	23.562	23	415.476	72.256	38.5	1164.15	120.95
8	50.265	25.132	23.25	424.557	73.042	39	1194.59	122.52
8.25	53.456	25.918	23.5	433.731	73.827	39.25	1209.95	123.30
8.5	56.745	26.703	24	452.390	75.398	39.5	1225.42	124.09
9	63.617	28.274	24.25	461.864	76.183	40	1256.64	125.66
9.25	67.200	29.059	24.5	471.436	76.969	40.25	1272.39	126.44
9.5	70.882	29.845	25	490.875	78.540	40.5	1288.25	127.23
10	78.540	31.416	25.25	500.741	79.325	41	1320.25	128.80
10.25	82.516	32.201	25.5	510.706	80.110	41.25	1336.40	129.59
10.5	86.590	32.986	26	530.930	81.681	41.5	1352.65	130.37
11	95.033	34.557	26.25	541.189	82.467	42	1385.44	131.94
11.25	99.402	35.343	26.5	551.547	83.252	42.25	1401.98	132.73
11.5	103.869	36.128	27	572.556	84.823	42.5	1418.62	133.51
12	113.097	37.699	27.25	583.208	85.608	43	1452.20	135.08
12.25	117.859	38.484	27.5	593.958	86.394	43.25	1469.13	135.87
12.5	122.718	39.270	28	615.753	87.964	43.5	1486.17	136.65
13	132.732	40.840	28.25	626.798	88.750	44	1520.53	138.23
13.25	137.886	41.626	28.5	637.941	89.535	44.25	1537.86	139.01
13.5	143.130	42.411	29	660.521	91.106	44.5	1555.28	139.80
14	153.938	43.982	29.25	671.958	91.891	45	1590.43	141.37
14.25	159.485	44.767	29.5	683.494	92.677	45.25	1608.15	142.15
14.5	165.130	45.553	30	706.860	94.248	45.5	1625.97	142.94
15	176.715	47.124	30.25	718.690	95.033	46	1661.90	144.51
15.25	182.654	47.909	30.5	730.618	95.818	46.25	1680.01	145.29

TABLE 9—*Continued.*

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
46.5	1698.23	146.08	62.25	3043.47	195.56	78	4778.37	245.04
47	1734.94	147.65	62.5	3067.96	196.35	78.25	4809.05	245.83
47.25	1753.45	148.44	63	3117.25	197.92	78.5	4839.83	246.61
47.5	1772.05	149.22	63.25	3142.04	198.71	79	4901.68	248.19
48	1809.56	150.79	63.5	3166.92	199.50	79.25	4932.75	248.97
48.25	1828.46	151.58	64	3216.99	201.06	79.5	4963.92	249.76
48.5	1847.45	152.36	64.25	3242.17	201.85	80	5026.56	251.33
49	1885.74	153.93	64.5	3267.46	202.68	80.5	5089.58	252.90
49.25	1905.03	154.72	65	3318.31	204.20	81	5153.00	254.47
49.5	1924.42	155.50	65.25	3343.88	204.99	81.5	5216.82	256.04
50	1963.50	157.08	65.5	3369.56	205.77	82	5281.02	257.61
50.25	1983.18	157.86	66	3421.20	207.34	82.5	5345.62	259.18
50.5	2002.96	158.65	66.25	3447.16	208.13	83	5410.62	260.75
51	2042.82	160.22	66.5	3473.23	208.91	83.5	5476.00	262.32
51.25	2062.90	161.00	67	3525.66	210.49	84	5541.78	263.89
51.5	2083.07	161.79	67.25	3552.01	211.27	84.5	5607.95	265.46
52	2123.72	163.36	67.5	3578.47	212.06	85	5674.51	267.04
52.25	2144.19	164.14	68	3631.68	213.63	85.5	5741.47	268.60
52.5	2164.75	164.19	68.25	3658.44	214.41	86	5808.81	270.17
53	2206.18	166.50	68.5	3685.29	215.20	86.5	5876.55	271.75
53.25	2227.05	167.29	69	3739.28	216.77	87	5944.66	273.32
53.5	2248.01	168.07	69.25	3766.43	217.55	87.5	6013.21	274.89
54	2290.22	169.64	69.5	3793.67	218.34	88	6082.13	276.46
54.25	2311.48	170.43	70	3848.46	219.91	88.5	6151.44	278.03
54.5	2332.83	171.21	70.25	3875.99	220.70	89	6221.15	279.60
55	2375.83	172.78	70.5	3903.63	221.48	89.5	6291.25	281.17
55.25	2397.48	173.57	71	3959.20	223.05	90	6371.64	282.74
55.5	2419.22	174.35	71.25	3987.13	223.84	90.5	6432.62	284.31
56	2463.01	175.92	71.5	4015.16	224.62	91	6503.89	285.88
56.25	2485.05	176.71	72	4071.51	226.19	91.5	6573.56	287.46
56.5	2507.19	177.5	72.25	4099.83	226.98	92	6647.62	289.03
57	2551.76	179.07	72.5	4128.25	227.75	92.5	6720.07	290.60
57.25	2574.19	179.85	73	4185.39	229.34	93	6792.92	292.17
57.5	2596.72	180.64	73.25	4214.11	230.12	93.5	6866.16	293.74
58	2642.08	182.21	73.5	4242.92	230.91	94	6939.79	295.31
58.25	2664.91	182.99	74	4300.85	232.48	94.5	7013.81	296.88
58.5	2687.83	183.78	74.25	4329.95	233.26	95	7088.23	298.45
59	2733.97	185.35	74.5	4359.16	234.05	95.5	7163.04	300.02
59.25	2757.19	186.14	75	4417.87	235.62	96	7238.25	301.59
59.5	2780.51	186.92	75.25	4447.37	236.40	96.5	7313.80	303.16
60	2827.44	188.49	75.5	4476.97	237.19	97	7389.81	304.73
60.25	2851.05	189.28	76	4536.37	238.76	97.5	7466.22	306.30
60.5	2874.76	190.06	76.25	4566.36	239.55	98	7542.89	307.88
61	2922.47	191.64	76.5	4596.35	240.33	98.5	7620.09	309.44
61.25	2946.47	192.42	77	4656.63	241.90	99	7697.70	311.02
61.5	2970.57	193.21	77 25	4686.92	242.69	99.5	7775.63	312.58
62	3019.07	194.78	77.5	4717.30	243.47	100	7854.00	314.16

governor. The angular advance of the eccentric is thus increased or diminished, in fact is entirely under the control of the governor, and cut off occurs earlier or later according to the demands of the load on the engine.

Adjustable cut off. One in which the point of cut off may be regulated or adjusted by hand by means of a hand wheel and screw attached to the valve stem, the supply of steam being regulated by a throttling governor.

QUESTIONS

1. What is absolute pressure?
2. What is gauge pressure?
3. What is initial pressure?
4. What is terminal pressure and how may it be ascertained theoretically?
5. What is back pressure?
6. What is absolute back pressure?
7. What is meant by ratio of expansion?
8. What does the term wire drawing mean when applied to an indicator diagram?
9. What is condensor pressure?
10. What does the term vacuum imply?
11. What is absolute zero?
12. What is meant by the term piston displacement?
13. What is piston clearance?
14. What is steam clearance?
15. What is a horse·power?
16. What is meant by piston speed?
17. Define Boyle's law of expanding gases.
18. What is an adiabatic curve?
19. What is an isothermal curve?
20. What is the first law of thermodynamics?
21. What is the unit of work?

22. Define the first law of motion.
23. What is momentum?
24. What is the maximum theoretical duty of steam?
25. What is meant by the term steam efficiency?
26. How may the term engine efficiency be defined?
27. What is meant by the term efficiency of the plant, and how may it be ascertained?
28. How is the horse power constant of an engine found, and what does it mean?
29. What are common logarithms?
30. What are hyperbolic logarithms, and how are they found?
31. What are ordinates as applied to an indicator diagram?
32. What is an eccentric?
33. What is meant by the throw of an eccentric?
34. What is meant by position of the eccentric?
35. What is angular advance?
36. What is valve travel?
37. What is lap?
38. What is inside lap?
39. What is outside lap?
40. What is lead?
41. What is a throttling governor?
42. What is meant by the term fixed cut off?
43. What is meant by an automatic cut off?
44. What is an isochronal governor?
45. What is an adjustable cut off?

CHAPTER IX

DIAGRAM ANALYSIS

Diagram analysis—Figure illustrating the various points in an indicator diagram—Disadvantage of unequal cut off—Diagram from compound condensing engine—Rules for finding M. E. P. when the initial and terminal pressures are known, and the ratio of expansion—Equalizing the work done in the high and low pressure cylinders—Misleading diagrams caused by dirt in indicator cylinder—Diagrams showing effect of cramped exhaust—Table of factors for calculating the steam consumption from the terminal pressure.

In the following study of indicator diagrams all the illustrations are reproductions of actual diagrams taken under ordinary working conditions. Figs. 50 and 51 are here introduced in order to define the different

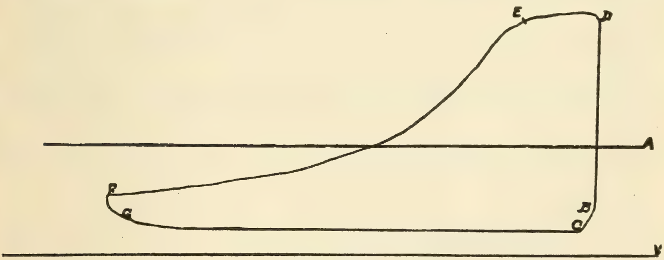


FIGURE 50.

points, lines and curves. Fig. 50 was taken from a large vertical engine with the corliss valve motion.

The engine being of slow speed and extremely long stroke (10 ft.) with a clearance of but 1 per cent., the compression beginning at C and ending at B is somewhat lighter than is ordinarily given to shorter stroke engines. From B to D is the admission line, which being practically perpendicular to the atmospheric line A, shows sufficient lead and ample port area. From D to E is the steam line. Cut off occurs at E, and from E to F is the expansion curve. At F the point of release is quite sharply defined, as it should be. From F to G is the exhaust line, and from G to C the line of back pressure, sometimes called the line of counter pressure for the reason that the pressure indicated by it acts counter or in opposition to the forward pressure of the steam on the piston. This engine is a

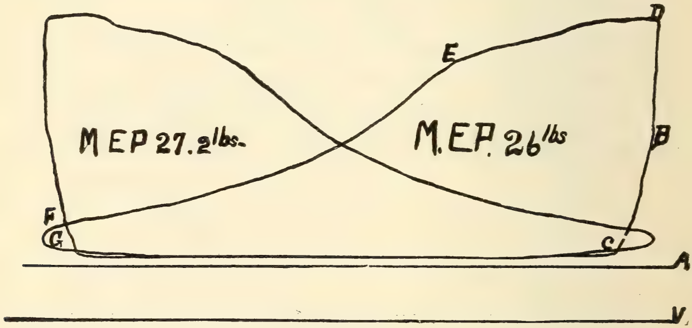


FIGURE 51.

simple condensing engine and the nearness of the back pressure line to the line of perfect vacuum V shows that an excellent vacuum was maintained in the condenser.

Fig. 51 is from a Buckeye automatic cut off engine having a shaft governor and what is termed a riding cut off, that is the cut off valve slides to and fro on the back of the main valve. The engine is horizontal non-condensing, the cylinder being 28 in. bore by 56 in. stroke, and, at the time the diagram was taken, developed 357.58 horse power with a piston speed of 728 ft. per minute. The steam consumption per I. H. P. per hour was 26 lbs., a rather high rate, but this was owing to the fact that the engine was located too far from the boilers, and as there were a large number of elbows in the steam pipe the pressure was greatly reduced at the engine. Thus wire drawing of the steam was caused, which is plainly indicated by the downward inclination of the steam line, D E.

In a well proportioned engine having a steam pipe of sufficiently large area, the steam line should parallel the atmospheric line up to the point of cut off. Fig. 51 indicates proper release of the steam at F, and the back pressure from G to C, which is 3 lbs. above the atmospheric line, shows a reasonably free passage of the exhaust steam.

Figs. 52 to 57 illustrate diagrams from three new vertical corliss engines supplying power for an electric lighting plant, which the author was requested to test and adjust after they had been in operation a few months. The valves had previously been set by the erecting engineer at the time the engines were set up. Each one of these engines exhausted into a separate condenser of the Jet type, into which the condensing water was forced under pressure and from which the overflow was discharged by gravity into a sewer. There was no air pump and as a consequence the vacuum maintained was very low, usually from 10 to 15 in., and at times still less, so that the beneficial results of condensing were only partially realized.

For convenience the diagrams from each engine will be treated in numerical order, beginning with engine No. 1. This engine was 24 × 48 in., running 70 R. P. M., with a boiler pressure of 68 lbs. A 40 spring was used in the indicator. The principal defect was the lack of sufficient lead on both ends, as indicated by the inclination inward of the admission lines and the rounded corners of the steam lines at the beginning of

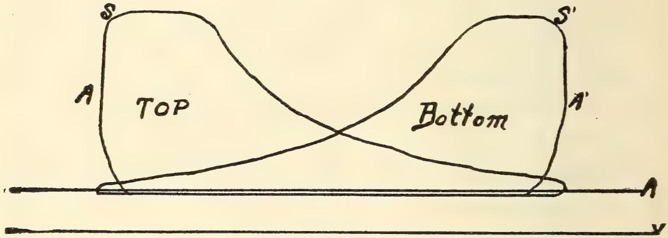


FIGURE 52.

the stroke. (See Fig. 52.) There was also more compression, especially on the bottom end, than was necessary, considering the size of the engine and the speed. The necessary changes having been made, the indicator was again applied and the diagram Fig. 53 was

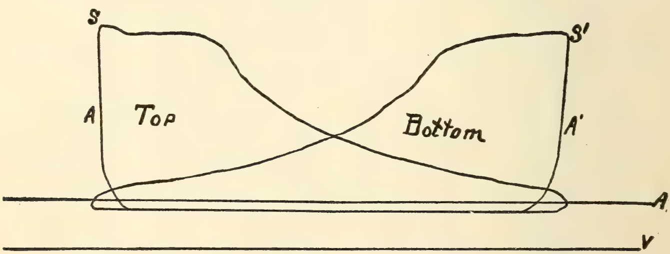


FIGURE 53.

obtained, which shows the distribution of the steam to be satisfactory, although at the time of taking this diagram the boiler pressure was only 60 lbs., while it should have been 68 or 70 lbs., because with the latter pressure still better results could have been attained. The I. H. P. was 235 and the steam used per I. H. P. per hour was 18 lbs.

Fig. 54 is the original diagram from engine No. 2,

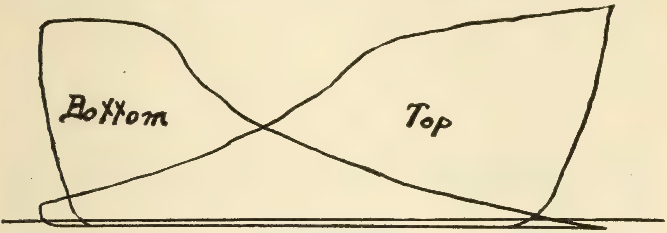


FIGURE 54.

and shows bad valve adjustment all around, with the exception of lead on the top end. The variation in the points of cut off is the worst feature; cut off taking place on the bottom at 29 per cent. of the stroke, while on the top end it does not occur until

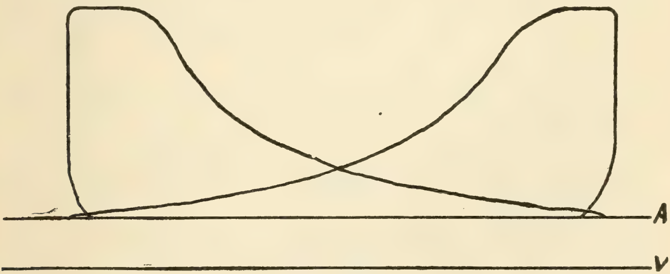


FIGURE 55.

the piston has traveled through 42 per cent. of the stroke. There is more compression also than is needed. This engine was 18 × 42 in., running at a speed of 78 R. P. M., and the steam consumption, according to diagram Fig. 54, was 33 lbs. per I. H. P. per hour. Having equalized the cut off and reduced the compression by making the necessary changes in the valve gear, the indicator was again applied, resulting in diagram Fig. 55, which may be considered prac-

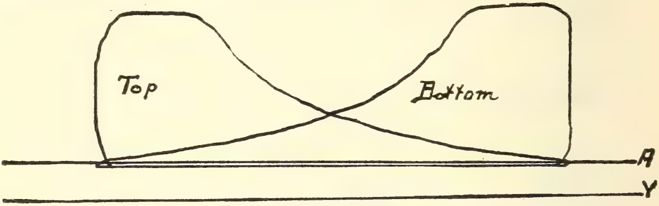


FIGURE 56.

tically perfect. The boiler pressure was 68 lbs. and the spring used was a No. 40. The steam consumption was reduced to 22 lbs. per I. H. P. per hour as compared to 33 lbs. in Fig. 54.

Figs. 56 and 57 represent diagrams from engine No. 3, which was the same size as No. 1, viz., 24 × 48 in.,

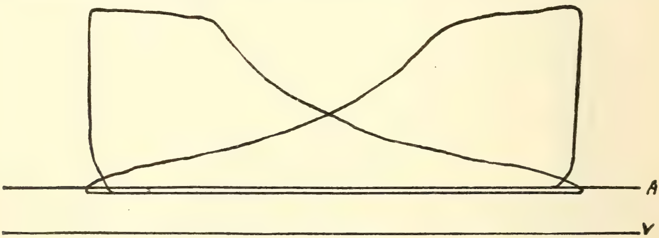


FIGURE 57.

and running at 72 R. P. M. The original diagram, Fig. 56, shows too little lead on both ends, but especially on the top. There is also lack of compression on the bottom end. The boiler pressure was 60 lbs. and the scale of spring 40. Fig. 57, taken after the necessary adjustments had been made, shows much better valve performance. The horse power developed was 251 and the steam consumption was 20.5 lbs. per I. H. P. per hour. The rather high rate of steam consumption for this engine as compared with engine No. 1, which was the same size but consumed only 18 lbs. of steam per I. H. P. per hour, was due to two causes. First, a low vacuum; second, low initial pressure necessitating a late cut off.

Figs. 58 to 61, inclusive, are diagrams from a Bullock horizontal non-condensing corliss engine which had

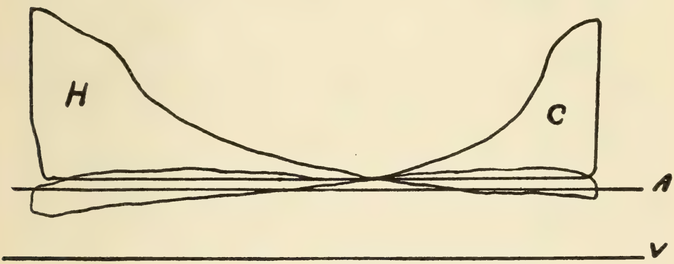


FIGURE 58.

been running about eight or nine months when it fell to the author's lot to apply the indicator to the engine, not only for the purpose of adjusting the valve motion, but also to make a series of tests for the purpose of ascertaining the amount of power delivered by the engine to each one of several different departments which were receiving power from this source.

The dimensions of the engine were as follows: bore of cylinder, 32 in.; stroke, 5 ft. At the time Fig. 58 was taken the engine was making 62 R. P. M. and the boiler pressure was only 50 lbs. A 30 spring was used. Although the load on the engine was very light at the time, yet the diagram served as a guide to some extent in setting the valves, and by taking off the bonnets from the valve chests and making the necessary changes in the adjustment by the marks on the valves

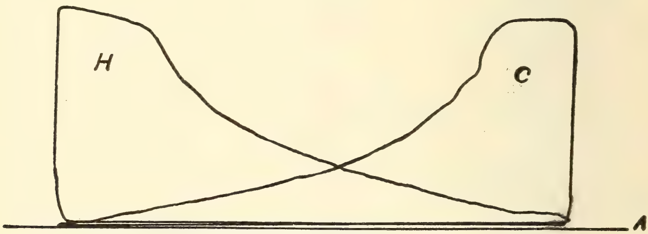


FIGURE 59.

a pretty fair job was made of it, as will be seen by referring to Fig. 59. The reducing motion was a pantograph, described in Chapter VIII, and as it is very easy to vary the travel of the paper drum with this motion, diagrams of different lengths were taken until the one which appeared to be the most satisfac-

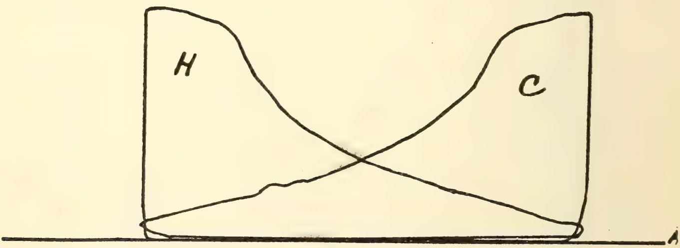


FIGURE 60.

tory was obtained. The slight hump in the expansion curve immediately after cut off was probably caused by a speck of dirt or grit which momentarily checked the indicator piston on the down stroke. The compression on the crank end is not sufficient and the exhaust valve rod on that end was slightly lengthened, resulting in the production of diagram Fig. 60. In this diagram the familiar hump in the crank end expansion curve reappears, but in a different location, being nearer the end of the stroke. It will also be noticed that the length of Fig. 60 has been considerably reduced from that of Figs. 58 and 59, it being about one inch shorter.

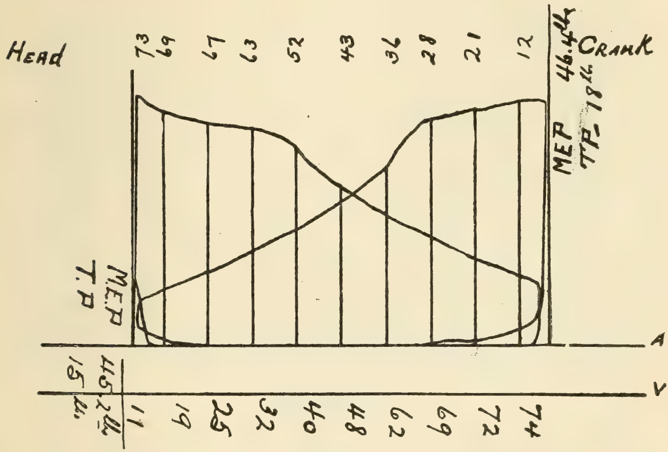


FIGURE 61.

The boiler pressure and the load on this engine were gradually increased from time to time, from 50 lbs. and a light load, (as shown by Fig. 58) to 60 lbs. and 335 horse power, (as indicated by Fig. 59 taken some three months later) and when Fig. 61 was taken, about two years and eight months later, the boiler pressure had been increased to 87 lbs. and the I. H. P. was over 700.

Diagram Fig. 61 shows good economy in the use of steam in spite of the fact that the cut off occurs rather late. There is no back pressure worth mentioning, the back pressure line forming part of the atmospheric line through the largest part of the stroke. The reason for this is that the areas of the exhaust ports as well as the exhaust pipe were sufficiently large to permit a free passage for the steam. The exhaust pipe, also, was made as short and direct as possible and all superfluous elbows were dispensed with. The steam con-

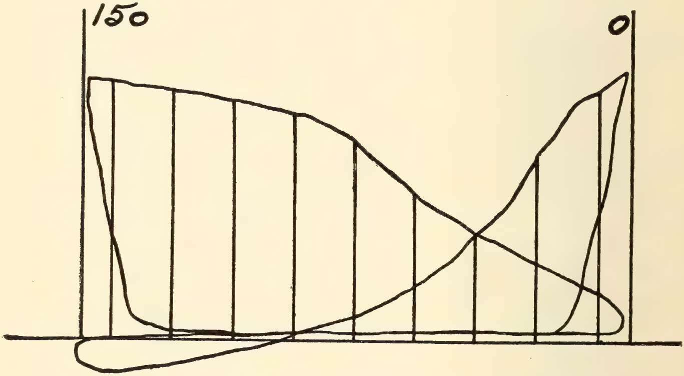


FIGURE 62.

sumed per I. H. P. per hour as per diagram Fig. 61 was 22.3 lbs., and the horse power developed was 710.6.

Figs. 62 to 64, inclusive, represent diagrams from a Buckeye engine 24 × 48 in., and are introduced for the purpose of emphasizing the need of caution and good judgment in setting valves by the indicator when the load on the engine is variable. Fig. 62, which was the first to be taken, would seem to indicate that the valve was badly adjusted, but when Fig. 63 was taken immediately afterwards, the cause of the trouble became apparent. The engine was furnishing power for operating an electric street railway on a small scale, and the variation in the points of cut off was caused by the stopping and starting of the cars.

Fig. 63 is a notable example of the quick and delicate action of the shaft governor, as it will be seen that during four successive revolutions there was a different load each time, as shown by the diagram from the crank end.

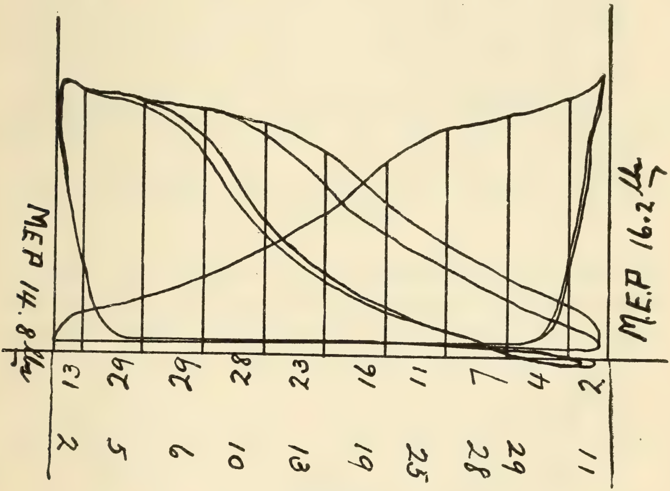


FIGURE 63.

Fig. 64 was secured by quick manipulation of the instrument when it was known that the load was to be steady for a few seconds.

Fig. 65 is from an Atlas single valve automatic cut off engine with shaft governor. This engine was 16 × 24 in., running at 105 R. P. M., and at the time the diagram was taken the boiler pressure was only 50 lbs. The spring used was a No. 30. The diagram is a fairly good one for the type of engine. Owing to the variation in the angular advance of the single eccentric

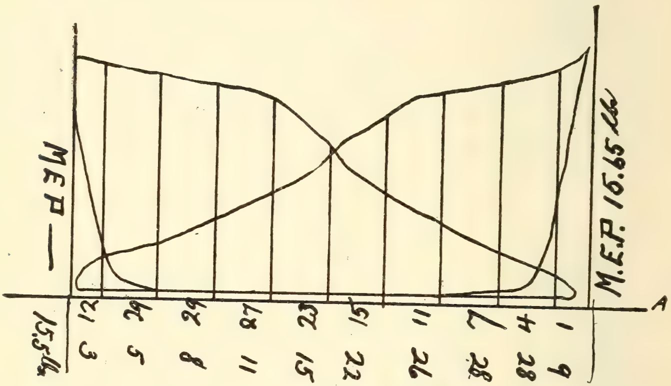


FIGURE 64.

actuated by a shaft governor, the degree of compression varies with the point of cut off in the single valve engine, the compression being higher with an early

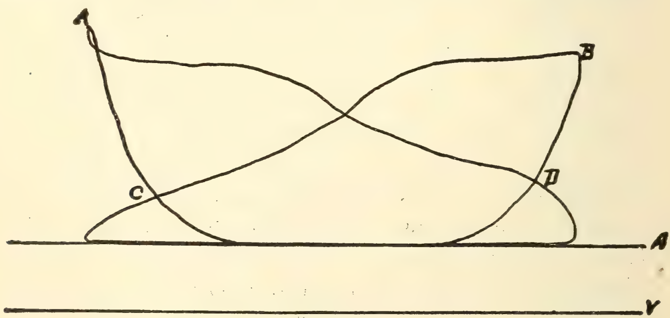


FIGURE 65.

cut off than it is when cut off occurs later in the stroke. The loop at A is caused by too much lead which, together with the compression, caused a momentary rise in the pressure above the normal. The lead at B is approximately correct. The differ-

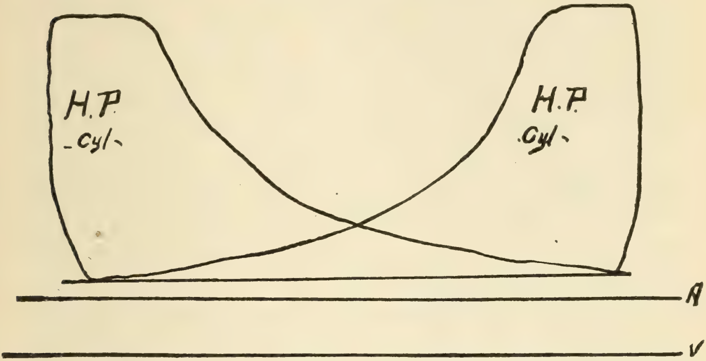


FIGURE 66.

ence in terminal pressures at C and D is the result of shifting of the points of cut off caused by variations in the load. The back pressure lines are almost identical with the atmospheric line, showing that the exhaust is

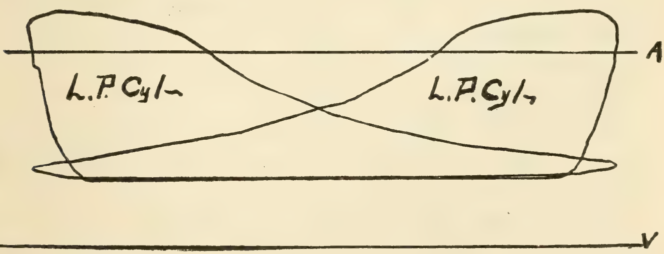


FIGURE 67.

in no way restricted or cramped. I. H. P. is 65.7 and steam consumption 21 lbs. per I. H. P. per hour.

Figs. 66 and 67 are diagrams taken from a cross compound condensing corliss engine. The high pressure cylinder was 24 × 48 in., and the low pressure cylinder was 44 × 48 in. The steam from the high pressure exhausted into a receiver and from thence into the low pressure cylinder. The receiver pressure was 5.3 lbs. above atmospheric pressure. The ratio of piston areas was 3.36 to 1. That is, the area of the low pressure piston was 3.36 times the area of the high pressure piston, which was about the correct ratio for the pressure carried, viz., 84 lbs. gauge or 99 lbs. absolute. A No. 40 spring was used on the high pressure and a No. 12 on the low pressure cylinder. The number of expansions in the two cylinders was 14. Thus, the ratio of expansion in the high pressure cylinder was 4.5 and in the low pressure the ratio was 3.1. Then $4.5 \times 3.1 = 14$; or, Thus, initial pressure = 99 lbs. absolute, terminal pressure in L. P. cylinder = 7 lbs. absolute; then $99 \div 7 = 14$.

To illustrate the process of finding the M. E. P. without the use of ordinates when the absolute initial and terminal pressures and the number of expansions in each cylinder are known, the following problems will be worked out:

Find M. E. P. in L. P. cylinder.

First, find initial pressure.

Rule. T. P. multiplied by number of expansions. Thus, $7 \times 3.1 = 21.7$ lbs. absolute initial pressure in L. P. cylinder.

Second, find mean forward pressure (M. F. P.).

Rule. Multiply initial pressure by hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus the hyperbolic logarithm of 3.1 = 1.1314, to which add 1 = 2.1314. Then $\frac{21.7 \times 2.1314}{3.1} = 14.9$ lbs. M. F. P. Deduct from this the back pressure, which was 5 lbs. absolute. Thus, 14.9 − 5 = 9.9 lbs. M. E. P. in L. P. cylinder.

Next find M. E. P. in H. P. cylinder.

First, find T. P. in H. P. cylinder.

This will equal the initial pressure in the L. P. cylinder + 2 per cent for loss in the receiver. Thus, 21.7 + .4 = 22.1 lbs., terminal pressure in H. P. cylinder.

Second, find initial pressure in H. P. cylinder.

Rule. Multiply T. P. by number of expansions. Thus, 22.1 × 4.5 = 99.4 lbs., absolute initial pressure in H. P. cylinder.

Third, find mean forward pressure (M. F. P.).

The hyperbolic logarithm of 4.5 = 1.5041, add 1 = 2.5041. Then $\frac{99.4 \times 2.5041}{4.5} = 55$ lbs., M. F. P. in H. P. cylinder. Deduct back pressure 22.1; thus, 55 lbs. − 22.1 lbs. = 32.9 lbs., M. E. P. in H. P. cylinder.

The ratio of piston areas being 3.36 to 1, it may be of interest to pursue the subject a little farther and ascertain how the distribution of the steam in the two cylinders corresponds to the ratio of areas. The ratio and pressures may be expressed as follows:

Ratio of areas—H. P. cylinder, 1; L. P. cylinder, 3.36.
M. E. P.—H. P. cylinder, 32.9; L. P. cylinder, 9.9 lbs.
which is very nearly correct; sufficiently so for all practical purposes, and clearly demonstrates that with the intelligent use of the indicator it is possible to so adjust the valves and establish the points of cut off on a compound or triple expansion engine that the work done in each cylinder will be practically the same. As for instance, the product of the area of the H. P. piston and the M. E. P. = 14,883.6 lbs., and that of the L. P. piston × M. E. P. = 15,052.9 lbs., a difference of only 169.3 lbs. If the two products had been equal,

the horse power exerted in the two cylinders would have been the same. As it was, the horse power of the H. P. cylinder was 263.4 and that of the L. P. cylinder was 266.4, showing a difference of only three horse power in the amount of work done in each cylinder.

Fig. 68 was taken from one of a pair of Fishkill corliss engines connected to a common crank shaft. The engines were each 24 × 48 in., and run at 65 R. P. M., with a boiler pressure of 65 lbs. They were equipped with a jet condenser and a bucket plunger air pump served for both engines. These engines had been in

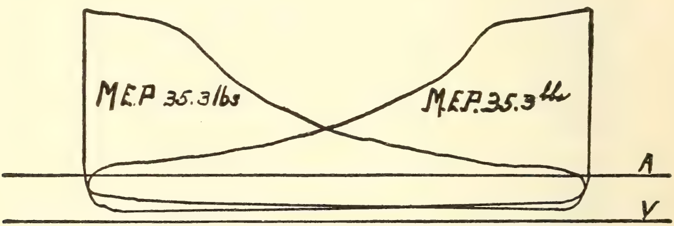


FIGURE 68

continuous service for nearly seventeen years when the author was called upon to indicate them and adjust the valves. A diagram taken at the same time from the mate of this engine was very nearly an exact counter part of Fig. 68. The horse power, as shown by Fig. 68, was 248, and the steam per I. H. P. per hour was 15.2 lbs. The vacuum gauge showed 27 in. and a 50 spring was used.

Figs. 69 and 70 are from an old Fishkill corliss engine 16 × 42 in., to which the author applied the indicator after he had set the valves, according to the ordinary rules for valve setting, by the marks placed on the ends of the valves and valve chests. These diagrams are introduced especially for the purpose of showing the need of exercising the greatest of care to prevent dirt or grit of any kind from getting into the

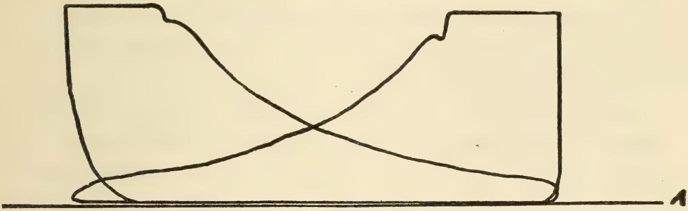


FIGURE 69.

indicator cylinder. After the indicator pipes had been blown out sufficiently, as it was thought, the indicator, which was a thoroughly reliable instrument, was attached and diagram Fig. 69 was obtained. It showed the valve adjustment to be very nearly correct, but the perfectly straight steam lines and the sharp

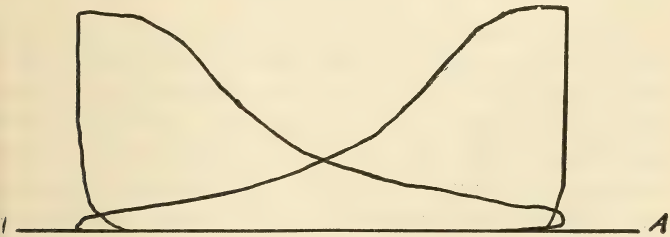


FIGURE 70.

corners and sudden drop at cut off were a puzzle, especially in an old engine where the valves and valve seats were known to be much worn down. After taking several more diagrams with precisely the same result, the indicator was removed, and upon taking out the piston a quantity of dirt was found on it and also on the inside of the cylinder. This fully explained the cause of the sharp corners, etc., on the diagram. After the indicator had been cleaned and oiled it was again connected and Fig. 70 was produced, which is a truthful presentation of the performance of the steam in the cylinder.

Many diagrams are misleading, owing to causes similar to the above, and a diagram with too sharp angles at cut off or release should be regarded with suspicion until it is proved beyond all doubt to be truthful.

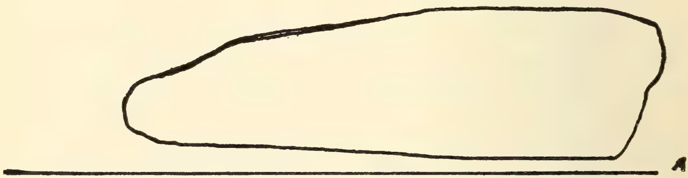


FIGURE 71.

Fig. 71 represents a diagram from a vertical non-condensing engine 14 × 16 in. with riding cut off, which the author was called upon to adjust. This engine was nearly new, having been run but a few months, and although the size of it was ample to do all the work required, yet it had failed, so far, to supply one-half the power needed. After taking the diagram and making a few outside investigations, the cause of the trouble was apparent. Indeed, the wonder was that the engine had supplied as much power as it had under the circumstances.

First. It was situated too far from the boiler plant, being fully 1,200 ft., and although a pressure of 85 lbs.

was carried at the boilers and the steam was conveyed through a 6-inch pipe, yet owing to the many drains on the pipe for heating buildings, running other small engines, etc., by the time the steam reached the engine in question the pressure was reduced so much that a 3 spring was found to be too strong, although that was the scale of Fig. 71.

Second, the end of the exhaust pipe was found to be submerged in a nearby pond of water to which it had been carried, probably with a view of making a condensing engine out of it! It was also found that

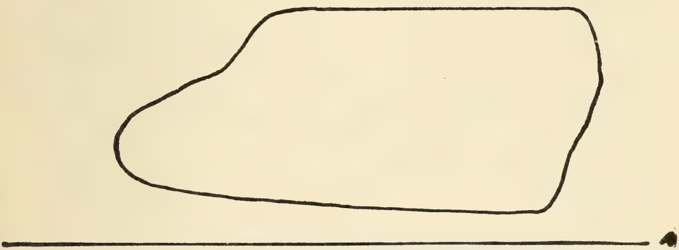


FIGURE 72.

there were no less than four superfluous elbows in the exhaust pipe that could easily be dispensed with. The diagram shows that the cut off was practically useless. That the back pressure was nearly 6 lbs. above the atmosphere, and that the engine was using 55 lbs. of steam and 7 lbs. of coal per horse power per hour, all of which conditions were about as bad as they could be.

After increasing the lead and adjusting the cut off a No. 16 spring was used and Fig. 72 was produced which, although still showing late admission, is an improvement over the original diagram. The initial pressure being only 30 lbs. above the atmosphere, further work with the indicator was deferred until changes were made in the steam and exhaust pipes, by which the initial pressure was increased to 55 lbs. and the exhaust pipe was freed of extra turns and raised from its watery grave into the open air. The engine has since then given perfect satisfaction.

Fig. 73 is from a Buckeye automatic cut off engine 18 × 36 in. The engine had been running for several years with the valves in the condition shown by the diagram, and in the meanwhile, the load having been increased from time to time, the engine finally refused

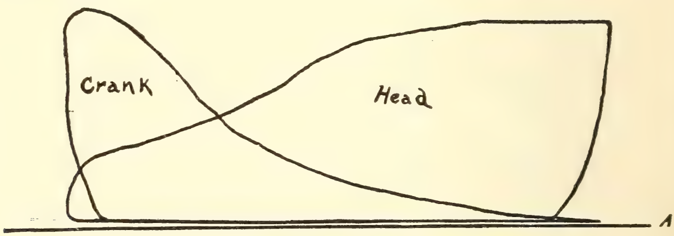


FIGURE 73.

to run up to speed and something had to be done. The superintendent of the plant said that he had an idea that something was the matter with the engine but could not ascertain what it was, and so he finally called upon the author to apply the indicator. The result was that diagram Fig. 73 was obtained, showing that the principal cause of the trouble was unequal cut off. After equalizing the cut off and increasing the lead on the crank end by a small fraction diagram Fig. 74 was taken, and after this the engine gave no further trouble. The depression in the steam lines might have been rectified to some extent by increasing the boiler pressure, thus giving a higher initial pressure and an earlier cut off. The speed of the engine was 94 R. P. M., with a boiler pressure of 70 lbs. A 40 spring was used with the indicator.

In order to more fully illustrate the process of ascertaining the M. E. P. without dividing the diagram into ordinates, the following computation is given together with rules, etc. In this process two important factors are necessary, viz., the absolute initial pressure and the absolute terminal pressure, and they can both be obtained from the diagram by measuring with the

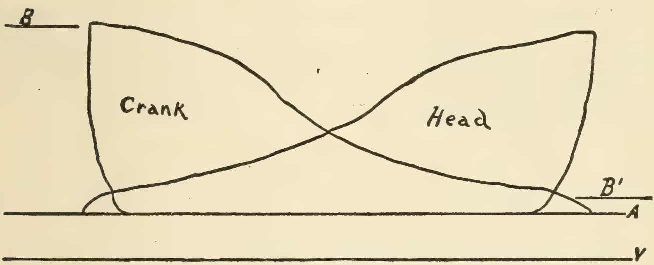


FIGURE 74.

scale adapted to the spring used. Thus, in Fig. 74 the absolute initial pressure measured from the line of perfect vacuum V to line B is 77 lbs., and the absolute terminal pressure measured from V to line B′ is 21 lbs. The ratio, or number of expansions, is found thus:

Rule. Divide the absolute initial pressure by the absolute terminal pressure; thus, $77 \div 21 = 3.65$ = number of expansions.

Second. Find mean forward pressure.

Rule. Multiply absolute initial pressure by the hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus, referring to Table 8, it will be seen that the hyperbolic logarithm of 3.65 is 1.2947, to which 1 must be added. Then $\frac{77 \times 2.2947}{3.65} = 48.4$ lbs., which is the absolute mean forward pressure. From this deduct the absolute back pressure, which is 16 lbs. or 1 lb. above atmosphere; thus, $48.4 - 16 = 32.4$ lbs. M. E. P.

Third. Find I. H. P.

Area of piston minus one-half area of rod × M. E. P. × piston speed in feet per minute, divided by 33,000. Thus (the diameter of rod being 3 in.), $\frac{250.96 \times 32.4 \times 564}{33000} =$ 138.9 I. H. P.

The steam consumption per I. H. P. per hour may also be computed by means of Table 10, which was originally calculated by Mr. Thomson, and is based upon the following theory:

TABLE 10.

T. P.	W.	T. P.	W.	T. P.	W.
3	117.30	13	466.57	23	798.10
3.5	135.75	13.5	483.43	23.5	814.39
4	153.88	14	500.22	24	830.64
4.5	171.94	14.5	517.07	24.5	846.96
5	186.75	15	533.85	25	863.25
5.5	207.60	15.5	550.64	25.5	879.49
6	225.24	16	567.36	26	895.70
6.5	242.97	16.5	584.10	26.5	911.86
7	260.54	17	600.78	27	927.99
7.5	278.06	17.5	617.40	27.5	944.07
8	295.44	18	633.96	28	960.12
8.5	312.80	18.5	650.46	28.5	976.27
9	330.03	19	666.90	29	992.38
9.5	347.27	19.5	683.38	29.5	1008.46
10	364.40	20	699.80	30	1024.50
10.5	381.57	20.5	716.27	30.5	1040.51
11	398.64	21	732.69	31	1056.48
11.5	415.73	21.5	749.06	31.5	1072.42
12	432.72	22	765.38	32	1088.32
12.5	449.69	22.5	781.76	32.5	1104.35

A horse power = 33,000 ft. lbs. per minute, or 1,980,-000 ft. lbs. per hour, or 1,980,000 × 12 = 23,760,000 in. lbs. per hour, meaning that the same amount of energy required to lift 33,000 lbs. one foot high in one minute of time would lift 23,760,000 lbs. one inch high in one minute of time. Now if an engine were driven by a fluid that weighed one pound per cubic inch, and the mean effective pressure of this fluid upon the piston was one pound per square inch, it would require 23,760,000 lbs. of the fluid per horse power per hour. But, if in place of the heavier fluid we substitute pure distilled water of which it requires 27.648 cu. in. to weigh one pound, the consumption per I. H. P. per hour will be considerably less; as, for instance, 23,760,-000 ÷ 27.648 = 859,375 lbs., which would be the rate per hour of the water driven engine if the M. E. P. of the water was one pound per square inch and if the M. E. P. was increased to 20 lbs.; then twenty times more power would be developed with the same volume of water, but the weight of water consumed per H. P. per hour would be proportionately less. Now if the engine is driven by steam it will consume just as much less water in proportion as the water required to make the steam is less in volume than the steam used. Therefore if the above constant number, 859,375, be divided by the M. E. P. of any diagram and by the volume of the terminal pressure, the quotient will be the water (or steam) consumption per I. H. P. per hour.

Referring to Table 10, the numbers in the W columns are the quotients obtained by dividing the constant, 859,375, by the volumes of the absolute pressures given in the columns under T. P. and which represent terminal pressures. The table is considerably abridged from the original, which was very full and complete, the pressures advancing by tenths of a pound from 3 lbs. to 60 lbs.; but it is seldom that in ordinary practice there is needed such accuracy. If at any time, however, a diagram should show a terminal pressure not given in the table, the correct factor for that pressure can be easily found by dividing the constant 859,375, by the relative volume of the pressure as found in Table 5 of the properties of saturated steam given in another chapter.

Referring again to Fig. 74, it is seen that the terminal pressure is 21 lbs. absolute, and by reference to Table 10 and glancing down column T. P. until 21 is reached, it will be seen that the number opposite in column W is 732.69. This number divided by the M. E. P. of the diagram Fig. 74, which is 32.4 lbs., gives 22.6 lbs. per I. H. P. per hour as the steam consumption. The rate thus found makes no allowance for clearance and compression, however, and these two very important items will be treated in a succeeding chapter together with the method of correction for the above, viz., clearance and compression, as they enter largely into the steam economy of an engine.

Questions

1. What effect has back pressure upon the work of an engine?

2. Name some of the causes of wire drawing of the steam.

3. What relation should the steam line of an indicator diagram bear to the atmospheric line?

4. What is the effect of insufficient lead upon the admission line of a diagram?

5. How does an unequal cut off affect the working of an engine?

6. How is the number of expansions in a compound engine ascertained?

7. What is the rule for finding the initial pressure by calculation?

8. Give the rule for finding the mean forward pressure.

9. When the M. F. P. is known, how may the mean effective pressure be found?

10. How should the steam be distributed in the cylinders of a compound engine?

11. What is the rule for finding the horse power developed by an engine?

12. What is meant by the steam consumption of an engine?

13. What is considered an economical rate of steam consumption for a non-condensing engine?

14. What is a fairly good rate of steam consumption for a condensing engine?

CHAPTER X

DIAGRAM ANALYSIS—*CONTINUED*

Diagram analysis continued—Corliss Centennial engine and diagrams from it—Calculating steam consumption from indicator diagrams—Clearance and compression, and how to correct a diagram for the same—How to estimate the theoretical clearance from a diagram—Measuring the volume of the clearance space with water—The theoretical expansion curve—Illustration of hyperbolic law in its application to the expansion of gases—The adiabatic curve and how to draw it—Power calculations—Method of finding the M. E. P. of a diagram—The planimeter and how to use it.

Figs. 75 to 77 are reproductions of diagrams taken by the author from the once famous engine built by Geo. H. Corliss for the Centennial Exposition which was held at Philadelphia in 1876. A brief description of this engine may not be out of place here, as it will enable the reader to study the diagrams to a better advantage.

This engine is, in fact, two simple condensing beam engines, exactly alike in every detail, standing vertical side by side and connected to a common crank shaft by means of the working beams overhead which are pivoted at their centers to the A frame of the engine. The cylinders are 40 in. bore by 10 ft. stroke and the engine runs at a speed of 36 R. P. M., thus giving a piston speed of 720 ft. per minute. The valve gear is of the regular corliss type adapted to a vertical engine, and motion is transmitted from the eccentric through the medium of a rock shaft placed horizontally on the frame. The steam and exhaust valves are located in the cylinder heads, thereby reducing the clearance to 1.5 per cent. Each engine has its own jet condenser and air pump, which latter is of the regular bucket plunger type and receives its motion from the overhead beam through long connecting rods. The crank shaft is 18 in. in diameter and carries a gear fly-wheel 30 ft. in diameter, weighing 56 tons, the teeth of which mesh into another gear wheel 10 ft. in diameter carried on the jack shaft through which the power is transmitted to the various departments of the works. The face of the rim of the gear wheel is 24 in.

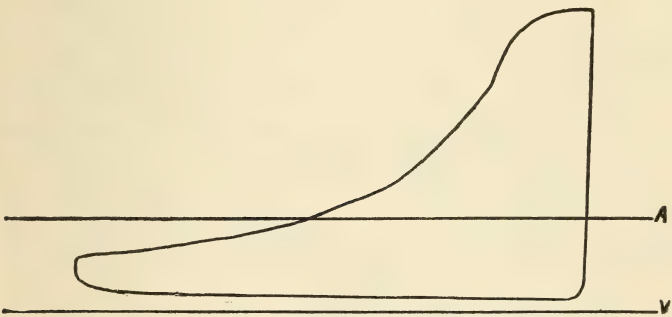


FIGURE 75

in width, which allows the length of the teeth to be 24 in., while the pitch, or distance from center to center of the teeth, is 5 in. The steam pipe is 18 in. inside diameter and the cylinders are jacketed with live steam.

This engine showed remarkable economy in the use of steam when working at or near the capacity for which it was designed by Mr. Corliss, which was 1,400 horse power. At the time Fig. 75 was taken the load was 1,122 horse power and the boiler pressure was 32.5 lbs. gauge, or 47.5 lbs. absolute. The spring used was a No. 20, although a much better appearing diagram would have been obtained by using a No. 30 spring.

The diagram shows very slight compression, but the lead is correct. The point of cut off is not so clearly defined as it should be, and the author attributes the cause of this to the spring being too weak for the reason that when Fig. 76 was taken some eight months later from the same end of the same cylinder, but with a spring of the proper tension for the pressure, the point of cut off is much more plainly defined. (See Fig. 76.)

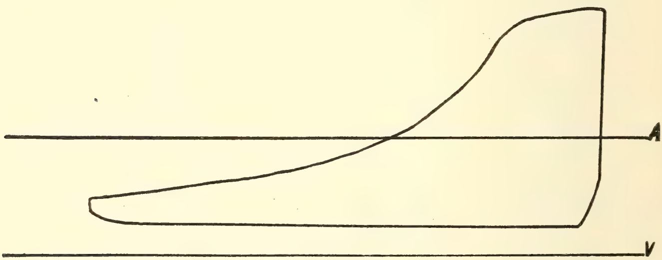


FIGURE 76.

The absolute initial pressure, as shown by Fig. 75, was 47.5 lbs., and the absolute terminal pressure was 8.5 lbs. The ratio of expansion would therefore be $47.5 \div 8.5 = 5.6$. The steam consumption per I. H. P. per hour was 14 lbs.

Fig. 77 is from the same engine, and is here introduced for the purpose of showing the great advantage resulting from a good vacuum. In fact the largest portion of the work in this case was done through the help of the vacuum, as indicated by much the largest portion of the area of the diagram being below the line of atmospheric pressure. The diagram would appear to be a kind of connecting link between the times of Watt and Newcomen, when the vacuum did all the work, and these modern times of high steam pressure.

The circumstances under which Fig. 77 was obtained were as follows: At certain times it became necessary to run a part of the shops overtime, and the load at such times being light, the boiler pressure was allowed to drop to the point at which the engine would run the most quietly, and that point was found to be about 7 lbs. gauge pressure. A No. 10 spring was used. The horse power developed was 227.5, which multiplied by

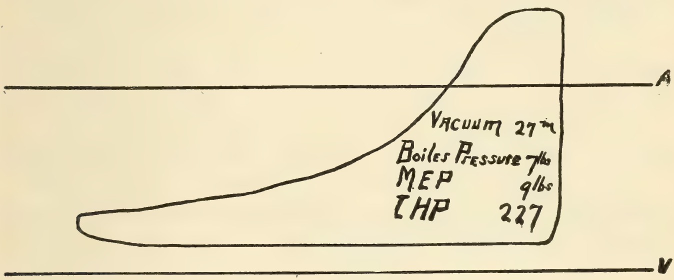


FIGURE 77.

2, as there were two engines, would equal 455 I. H. P. But the rate of steam consumption, which was 23.3 lbs. per I. H. P. per hour, was considerably higher than it was with the ordinary load, as when Fig. 75 was taken, showing that it is very poor economy to run an engine very much below its rated capacity.

Fig. 78 is from a Hamilton corliss non-condensing engine 32⅝ in. bore by 72 in. stroke. A No. 60 spring was used, the boiler pressure being 85 lbs. gauge. The I. H. P. was 652.2 and the steam consumption per I. H. P. per hour was 22.9 lbs.

There are but few points about the diagram that are open to criticism. The compression is rather high for so large an engine and the steam lines should be maintained more nearly horizontal up to the point of cut off.

Steam Consumption from Indicator Diagrams. In calculating the steam consumption of an engine, two very important factors must not be lost sight of, viz., clearance and compression. Especially is this the case in regard to clearance when there is little or no compression, for the reason that the steam required to fill the clearance space at each stroke of the engine is prac-

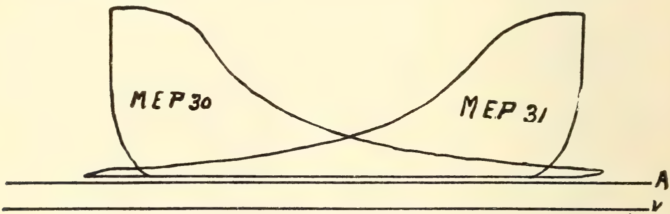


FIGURE 78.

tically wasted, and all of it passes into the atmosphere or the condensor, as the case may be, without having done any useful work except to merely fill the space devoted to clearance. On the other hand, if the exhaust valve is closed before the piston completes the return stroke, the steam then remaining in the cylinder will be compressed into the clearance space and can be deducted from the total volume which, without compression, would have been exhausted at the terminal pressure.

Figs. 79 and 80, which are reproductions of diagrams taken by the author while adjusting the valves on a 16 × 42 in. corliss engine, will serve to graphically illustrate this point. Fig. 79, which was the first one to be taken, shows no compression. The point of admission at A is plainly defined by the square corner at the extreme end of the stroke. The clearance of

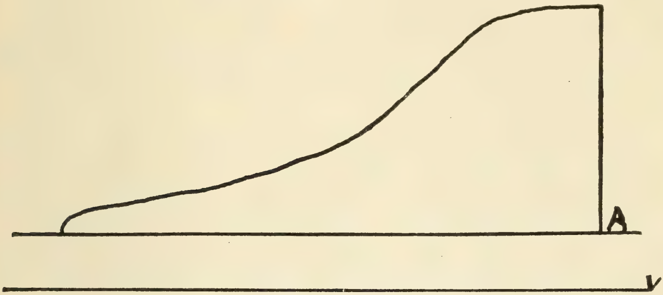


FIGURE 79.

this engine is 4 per cent. of the volume of the piston displacement. The engine being 16 in. bore by 42 in. stroke, the piston displacement is found by the following calculation: Area of piston, 201.06 sq. in. × stroke,

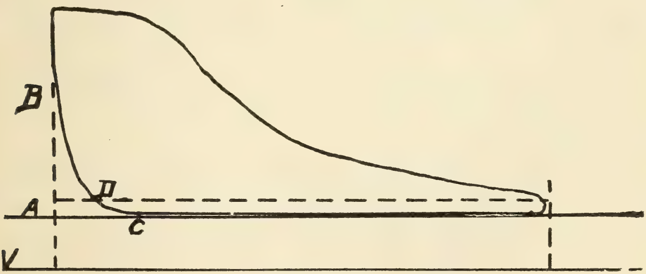


FIGURE 80.

42 in. = 8444.52 cu. in. The volume of clearance space is equal to 8444.52 cu. in. × .04 = 337.78 cu. in., which divided by 1,728 = .195 cu. ft.

By reference to Fig. 80, taken after adjusting the valves for compression, it will be noticed that the steam is there compressed to 37 lbs., the compression curve beginning at C and ending at B. There is therefore compressed during each stroke a volume of steam equal to .195 cu. ft. at a pressure of 37 lbs. gauge, or 52 lbs. absolute.

One cubic foot of steam at 52 lbs. absolute pressure weighs .1243 lbs., and .195 cu. ft. will weigh .1243 × .195 = .0242 lbs.

The engine was running at 70 R. P. M., or 140 strokes per minute. Thus, according to Fig. 80, the total weight of steam compressed and doing useful work during one hour, and which without compression would have passed out through the exhaust pipe, is equal to .0242 × 140 × 60 = 203.28 lbs.

Now in order to estimate the steam consumption of the above engine from diagram Fig. 79, it would be necessary to account for all the steam occupying not only the volume of the piston displacement at the end of the stroke, but the clearance as well, for the reason, as before stated, that it would all be released before exhaust closure. This would equal 8444.52 cu. in. + 337.78 cu. in = 8782.3 cu. in., which divided by 1,728 = 5.08 cu. ft. each stroke, or 10.16 cu. ft. each revolution.

The absolute terminal pressure of Fig. 79 is 20 lbs. One cubic foot of steam at this pressure weighs .0507 lbs., and the weight of steam consumed each revolution would therefore be 10.16 × .0507 = .515 lbs., which multiplied by 70 R. P. M. = 36.05 lbs. per minute, or 2,163 lbs. per hour. The horse power developed by the engine at the time was 80. Therefore the steam consumption per I. H. P. per hour = 2,163 ÷ 80 = 27 lbs.

Referring again to Fig. 80 it will be remembered that the total weight of steam compressed during one hour was 203.28 lbs. The weight of steam consumed per hour, therefore, equals $2,163 - 203.28 = 1959.7$ lbs.

Owing to compression, the work area of Fig. 80 is somewhat smaller than that of Fig. 79, amounting in fact to the area of the irregular figure enclosed between the points A, B and C. The work represented by this figure amounts to a very small proportion of the total work indicated by Fig. 79, still in order to arrive at correct conclusions, it should be deducted therefrom.

Assuming the negative work to be equal to .55 horse power, we have $80 - .55 = 79.45$ I. H. P. as the work represented by Fig. 80. As the total weight of steam consumed in one hour was 1959.7 lbs., the steam consumption per I. H. P. per hour will be $1959.7 \div 79.45 = 24.67$ lbs., a saving by compression of 2.33 lbs. per H. P. per hour, besides the great advantage of having a cushion of steam in contact with the piston at the termination of the stroke, thus bringing the moving parts of the engine to rest quietly without shock or jar.

The steam consumption may also be computed from the diagram, regardless of the dimensions of the cylinder or the horse power developed. The mean effective pressure and also the absolute terminal pressure must, however, be known. This method was referred to in the preceding chapter, but in the computation therein made no correction was made for clearance and compression.

Having reviewed these two factors at considerable length it will now be in order to more fully explain the methods of treating diagrams when it is desired to make these corrections.

First, draw vertical lines C and D, Fig. 81, at each end of the diagram, and perpendicular to the atmospheric line. Draw line V, representing perfect vacuum, 14.7 lbs. below the atmospheric line, as indicated on the scale adapted to the diagram, which in this case is 50 lbs. to the inch. Continue the expansion from R, where release begins, until it intersects line D V, from which point the absolute terminal pressure can be measured.

Having ascertained the terminal pressure, which for Fig. 81 is 30 lbs., draw line D E, which may be called

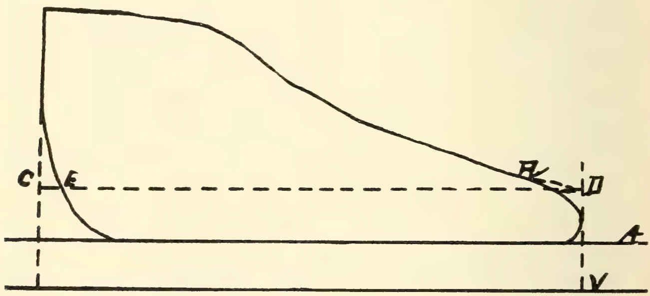


FIGURE 81.

the consumption line for 30 lbs. The terminal being 30 lbs., refer to Table 10 and find in column W, opposite 30 in column T. P., the number 1,024.5. Divide this number by the M. E. P which in Fig. 81 is 41 lbs., and the quotient, which is 24.99 lbs., is the uncorrected rate of steam consumption. This rate stands for the total consumption throughout the whole stroke represented on the diagram by the distance from D to C, which measures 3.25 in., but it is evident that there is a small portion of the return stroke, that indicated by the distance from E to C, during which the steam compressed in the clearance space should not be charged to the consumption rate, but should be deducted therefrom. In order to do this, multiply the uncorrected rate by the distance from D to E, which is 3⅛ in, or 3.125 in., and divide the product by the distance from D to C, 3¼ in., or 3.25 in. Thus, 24.99 × 3.125 ÷ 3.25 = 24.03 lbs., which is the corrected rate and represents a saving by compression of 24.99 – 24.03 = .96 lbs., or nearly 3.7 per cent.

In many cases the terminal pressure greatly exceeds the compression, an illustration of which is given in Fig. 82 which is a reproduction of a diagram from an

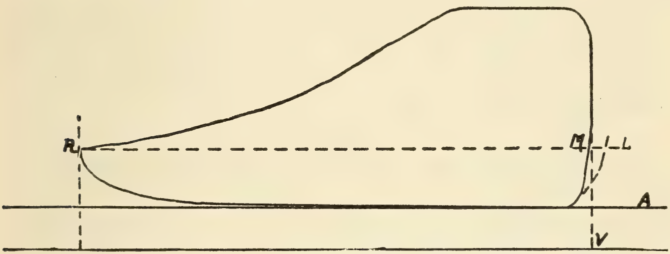


FIGURE 82.

old Wheelock engine. It now becomes necessary to extend the compression curve to L, a point equidistant from the vacuum line with the terminal at R. The consumption line R. L. now becomes longer than the stroke line R. M., therefore the corrected rate will exceed the uncorrected rate by just so much; as for instance, terminal pressure = 34 lbs. The factor, as per Table 10, = 1152.26, and the M. E. P. of the diagram is 47 lbs. Then, 1,152.26 ÷ 47 = 24.5 lbs., uncorrected rate; 24.5 × 3.125 in. (distance R. L.) ÷ 3 in. (distance R. M.) = 25.52 lbs., corrected rate, a loss of a little more than one pound, or about 4 per cent.

There is another class of diagrams very frequently encountered in which the terminal pressure is considerably below the compression curve, and in order to compute the consumption rate by the above method it becomes necessary to continue the compression curve downwards until it meets the terminal, as illustrated at A, Fig. 83, which is a friction diagram from a Buckeye engine. R is the point of release, D A represents the consumption line, and D C the stroke. The terminal

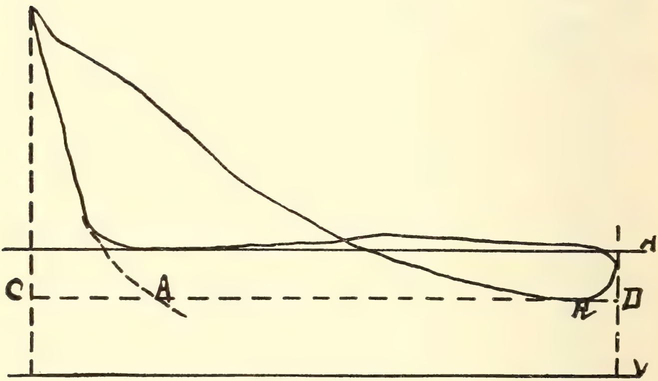


FIGURE 83.

is 8.5 lbs., and the factor for that pressure, according to Table 10, is 312.8. Dividing this number by the M. E. P., which was 7 lbs., gives 44.6 lbs. as the uncorrected rate. The distance D to A, where the compression curve intersects the consumption line, is 2.625 in., and the total length of the diagram C to D is 3.375 in. Then $44.6 \times 2.625 \div 3.375 = 35$ lbs. as the corrected rate. The extremely high rate is owing to the fact that the engine was running light, no load except a line of empty shafting.

Theoretical Clearance. The expansion and compression curves of a diagram are created by the expansion and compression of all the steam admitted during the stroke. This includes the steam in the clearance space as well as in the cylinder proper. It is evident, therefore, that the volume of the clearance is one of the factors controlling the form of these curves, and when the clearance is known a correct expansion or isothermal curve may be theoretically constructed, as will be explained later on. Also if the actual curves, either expansion or compression, of a diagram assume an approximately correct form, the clearance, if not already known, may be determined theoretically from them; although too much confidence should not be put in the results as they are liable to show either too little or too much clearance, generally the latter, especially if figured from the compression curve.

For the benefit of those who may desire to test this method of ascertaining the percentage of clearance of their engines, several illustrations will be given of its application to actual diagrams taken from engines in which the clearance was known.

Fig. 84 is from an engine in which the clearance was known to be 5 per cent. As compression cuts but a very small figure in this diagram, the expansion curve alone will be utilized for obtaining the theoretical clearance, and the process is as follows:

Select two points, C and R, in the curve as far apart as possible, but be sure that they are each within the limits of the true curve. Thus C is located just after cut off takes place, and R is at a point just before release begins. From C draw line C D parallel with the atmospheric line. From D draw line D R, and from C draw line C E, both perpendicular to the atmospheric line. Then from R draw line R E, forming a rectangular parallelogram, C D R E, with two opposite corners, C and R, within the curve. Now through the other two corners, D and E, draw the diagonal D E, extending it downwards until it intersects the vacuum line V. From this point erect the vertical line V W, which is the theoretical clearance line.

To prove the result proceed as follows: Measure the length of diagram from F to G, which in this case

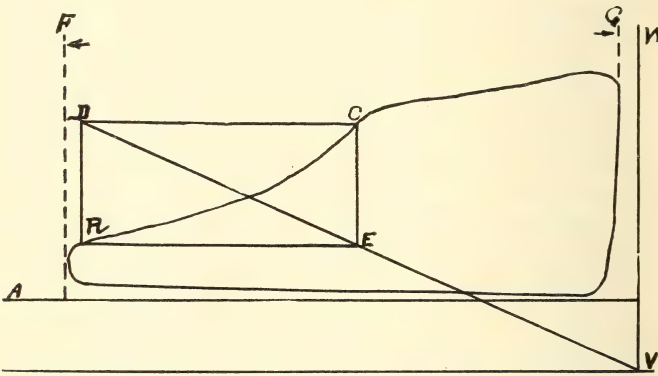


FIGURE 84.

is 3.75 in., representing piston displacement. Next measure the distance from F to the clearance line V W, which is 3.91 in., representing piston displacement with volume of clearance added. Then 3.91 – 3.75 = .16, which represents volume of clearance; and .16 × 100 ÷ 3.75 = 4.3 per cent., which is approximately near the actual clearance, which, as before stated, was 5 per cent.

Fig. 85 serves to illustrate the same method applied to the compression curve. This diagram is a reproduction of one taken from the low pressure cylinder of a large compound condensing corliss engine in which the actual clearance was 2.25 per cent. Two points, G and H, are selected in the compression curve, and from them the parallelogram G H I K is erected with two of its opposite corners, G and H, well within the limits of the curve, while through the other two corners, I and K, the diagonal I K C is drawn intersecting the vacuum line at C, thus locating the

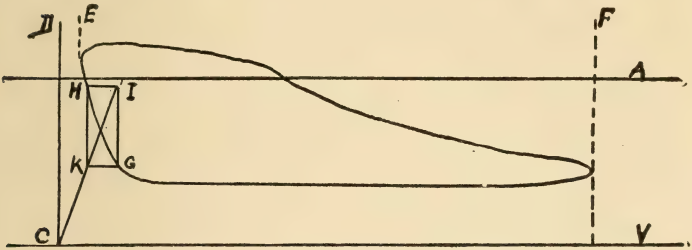


FIGURE 85.

point from which the clearance line C D can be drawn. The measurements in this case are as follows:

Total length of diagram, E to F = 3.75 in.

Distance from clearance line, D C, to F = 3.875 in.

Volume of clearance = 3.875 − 3.75 = .125 in.

.125 × 100 ÷ 3.75 = 3.33 per cent. clearance, which is 1.08 per cent. more than the known clearance.

However, notwithstanding the liability to error in many cases, still this method of computing clearance may often be utilized to good advantage.

Another and more practical method of measuring clearance is as follows: Place the engine on the dead center. Remove the valve chest cover and take out the valve. Close the cylinder cock on that end of the cylinder to which the piston has been moved, leaving the cock on the opposite end of the cylinder open and disconnected from its drip pipe, so as to give an opportunity for catching any water that may leak past the piston while measuring the clearance space. Then having first provided a known weight of water, always making sure of having a little more than enough, pour it into the steam port until the clearance space is filled to a level with the valve seat. When this is done, weigh the water that is left and deduct it from the original quantity, and the remainder will be the number of pounds of water required to fill the clearance, from which it is an easy matter to compute the number of cubic inches or cubic feet in the space devoted to clearance. If any water leaks past the piston during the operation it should be weighed and deducted from the total quantity poured into the port.

In the case of an engine having the valve chest on the side of the cylinder it will be necessary to close the steam port either by blocking the valve against it or by fitting a piece of soft wood into it, making it water tight. The water can then be poured into the clearance space through a pipe conncted to the indicator opening in that end of the cylinder. Care should be exercised to allow a vent for the air to escape as it is displaced by the water.

The Theoretical Expansion Curve. According to Boyle's law the volume of all elastic gases is inversely as their pressures, and steam being a gas conforms substantially to this law; although the expansion curves of indicator diagrams are affected more or less by the loss of heat transmitted through the cylinder walls, and by the change in the temperature of the steam produced by the changes in pressure during the progress of the stroke. The pressure generally falls more rapidly during the first part of the stroke, and less rapidly during the last portion than it should in order to conform strictly to the above law, and the terminal pressure usually is greater than it should be to agree with the ratio of expansion. But this fullness of the expansion curve of the diagram near the end compensates in a measure for the too rapid fall near the beginning of the stroke. Therefore, if the engine is in fairly good condition with the valves properly adjusted and not leaking, and the piston rings are steam tight,

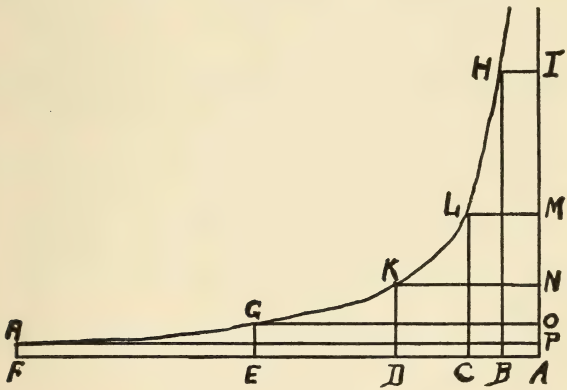


FIGURE 86.

it may be assumed that the expansion of the steam in the cylinder takes place according to Boyle's law and it is found that the expansion curve drawn by the indicator practically coincides with a hyperbolic curve constructed according to that law.

Fig. 86 graphically illustrates the application of the hyperbolic law to the expansion of gases. The horizontal lines represent volumes and the vertical lines represent pressures. The base line, A F, represents the full stroke of a piston in the cylinder of an engine, and the vertical line A I represents the pressure of the steam at the commencement of the stroke.

Suppose there is no clearance and that the steam has been admitted up to point H when it is cut off. The rectangle A B H I is the product of the pressure multiplied by the volume of the steam thus admitted. When the piston has traveled from A to C the volume of the steam has been doubled and the pressure C L has been reduced to just one-half what it was at A I, but the area of the rectangle A C L M is equal to the area of the initial rectangle, and, as before, is the product of the pressure C L multiplied by the volume A C. As the piston travels still farther, as from A to D, the steam is expanded to four volumes while the pressure at D K will only be one-fourth that of the initial pressure; but the new rectangle A D K N is still equal in area to either of the others, A B H I or A C L M.

The same law applies to each of the remaining rectangles; A E G O representing five volumes and one-fifth of the initial pressure, and A F R P representing six times the initial volume and one-sixth of the initial pressure, but each having the same area as the initial rectangle A B H I. Now the area of the rectangle A B H I represents the work done by the steam up to the point of cut off, and the area of the hyperbolic figure enclosed by the lines B H R F represents the work done by the expansion of the steam after cut off occurs. This area and the amount of work it represents may be computed by means of the known relations of hyperbolic surfaces with their base lines; as for instance, if the base lines A B, A C, A D, etc., extend in geometrical ratio, as 1, 2, 4, 8, 16, etc., the successive areas, B H L C, B H K D, B H G E, etc., increase in arithmetical ratio, as 1, 2, 3, 4, etc.

On the principles of common logarithms, which represent in arithmetical ratio natural numbers in geometrical ratio, tables of hyperbolic logarithms have been computed for the purpose of facilitating the calculation of areas of work due to different degrees of expansion. Such a table is given elsewhere in this book, and in Chapter IX is described the method of calculating the M. E. P. by this means.

A theoretical curve may be constructed conjointly with the actual expansion curve of a diagram by first locating the clearance and vacuum lines and then pur-

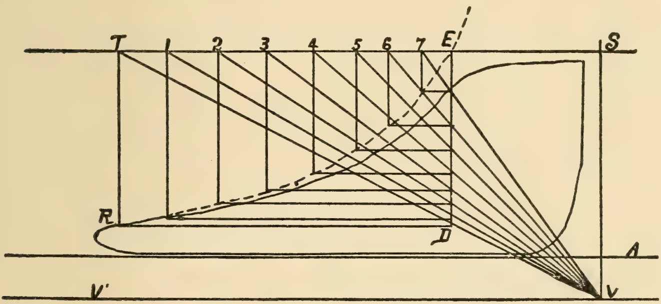


FIGURE 87.

suing the method illustrated by Fig. 87. A curve so produced is called an isothermal curve, meaning a curve of the same temperature.

Referring to Fig. 87, suppose, first, that it is desired to ascertain how near the expansion curve of the diagram coincides with the isothermal curve, at or near the point of cut off. Select point R near where release begins, but still well within the expansion curve. From this point draw the vertical line, R T, parallel with the clearance line, V S. Then draw the horizontal line, S T, parallel with the atmospheric line, and at such a height above it as will equal the boiler pressure as measured by the scale adapted to the diagram; such measurement to be made from the atmospheric line to correspond with the gauge pressure. From T draw the diagonal T V, and from R draw the horizontal line R D parallel with the atmospheric line. From D, where this line intersects T V, erect the perpendicular D E, thus forming the parallelogram R D E T, and as line T V passes through two of its opposite angles and meets the junction of the clearance and vacuum lines, the other two angles, R and E, will be in the theoretical curve, and R being the starting point, it is obvious that this curve must pass through E, which would be the theoretical point of cut off on the steam line S T.

Two important points in the theoretical curve have now been located, viz., E as the cut off, and R as the point of release. In order to obtain intermediate points, draw any desired number of lines downward from points in S T, as 1, 2, 3, 4, 5, etc., and continue them downwards far enough to be sure that they will meet the intended curve, and from the same points in S T draw diagonals 1 V, 2 V, 3 V, 4 V, 5 V, etc., all to converge accurately at V. From the intersection of these diagonals with D E draw horizontal lines parallel with V V′, and the points of junction of these lines with the vertical lines will be points in the theoretical curve. It will now be an easy matter to trace the curve through these points. If, on the other hand, it be desired to compare the curves toward the exhaust end of the diagram, draw lines E D and E T, Fig. 88, also T R, locating R near where release commences, after which draw line R D, completing the parallelogram E T R D, fixing R as a point in the theoretical curve started at E. After drawing the diagonal T V, proceed in the same manner as before to locate the intermediate points.

It will be observed that in order to ascertain the performance of the steam near the beginning of the stroke, the starting point of the isothermal curve must be near the point of release, and conversely, if the starting point of the curve is located near the point of cut off and coincident with the actual curve, the test will apply towards the end of the stroke. It is not to be expected that the expansion curve of any diagram taken in practice will conform strictly to the lines of

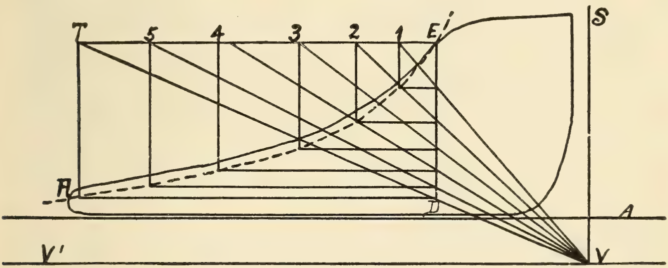


FIGURE 88.

the isothermal curve, especially towards the latter end of the stroke, owing to the reëvaporation of water resulting from the condensation of steam which was retained in the cylinder by the closing of the exhaust valve. This reëvaporation commences just as soon as the temperature of the steam, owing to reduction of pressure due to expansion, falls below the temperature of the cylinder walls, and it continues at an increasing rate until release occurs. The tendency of this reëvaporation or generation of steam within the cylinder during the latter portion of the stroke is to raise the terminal pressure considerably above what it would be if true isothermal expansion took place. The terminal pressure may also be augmented by a leaky steam valve, while, on the other hand a leaky piston would cause a lowering of the terminal and an increase in the back pressure.

The Adiabatic Curve. If it were possible to so protect or insulate the cylinder of a steam engine that there would be absolutely no transmission of heat either to or from the steam during expansion, a true adiabatic curve or "curve of no transmission" might

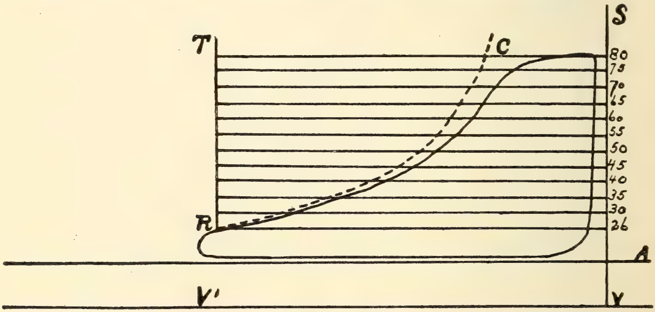


FIGURE 89.

be obtained. The closer the actual expansion curve of a diagram conforms to such a curve, the higher will be the efficiency of the engine as a machine for converting heat into work.

Fig. 89 illustrates a method of figuring a curve which, while not strictly adiabatic, will be near enough for all practical purposes, while at the same time it will give the student an opportunity to study the laws governing the expansion of saturated steam.

To draw the curve, first locate the clearance and vacuum lines V S and V V′. Next locate point R in the expansion curve near where release begins, making this the starting point, and also the point of coincidence of the expansion curve with the adiabatic curve. The other points in the curve are located from the volumes of steam at different pressures during expansion; the pressures being measured from the line of perfect vacuum, and the volumes from the clearance line.

The absolute pressure at R, Fig. 89, is 26 lbs. From point R erect the perpendicular R T. Also draw horizontal line R 26 parallel with the vacuum line and at a height equal to 26 lbs. above vacuum line V V′, as shown by the scale, which in this case was 40. The length of line R 26, measured from R to the clearance line, is $3\frac{1}{16}$ in., or 3.0625 in. By reference to Table 5 it will be seen that the volume of steam at 26 lbs. absolute, as compared with water at 39°, is 962. Now if the length of line R 26 be divided by this volume, and the quotient multiplied by each of the volumes of the other pressures represented at points 30, 35, 40, 45, etc., up to the initial pressure, the products will be the respective distances from the clearance line of points in the adiabatic curve. These points can be marked on the horizontal lines drawn from the clearance line to line R T.

Starting with line R 26, it has been noted that its length is 3.0625 in., and that the volume was 962. $3.0625 \div 962 = .003$. Then the volume of steam at 30 lbs. is 841, which being multiplied by $.003 = 2.5$ in., the length of line 30. Next the volume at 35 lbs. = 728. Multiplying this volume by $.003 = 2.1$ in., length of line 35, and so in like manner for each of the other points.

The process involves considerable figuring and careful and accurate measurements, which should be made with a steel rule with decimal graduations. It is not expected that the cut Fig. 89 will be found accurate enough in its measurements to serve as a standard; it being intended only to serve as an illustration of the process. The diagram from which the illustration was drawn was taken from a 600 H. P. engine situated some 200 ft. from the boilers, and there was a considerable cooling of the steam by the time it reached the engine, the effect of which is apparent. The curve produced by the measurements is shown by the broken line. The process can be applied to any diagram.

Power Calculations. The area of the piston (minus one-half the area of rod) multiplied by the M. E. P., as shown by the diagram, and this product multiplied by the number of feet traveled by the piston per minute (piston speed) will give the number of foot pounds of work done by the engine each minute, and if this product be divided by 33,000, the quotient will be the indicated horse power (I. H. P.) developed by the engine.

Therefore one of the first requisites in power calculations is to ascertain the M. E. P. Beginning with the most simple, though only approximately correct, method of obtaining the average pressure, as illustrated by Fig. 90, draw line A B touching at A and cutting the diagram in such manner that the space D above it will equal in area spaces C and E taken together, as nearly as can be estimated by the eye. Then with the scale measure the pressure along the line F G at the middle of the diagram, which will be the M. E. P.

The process is based upon the theory that the average width of any tapering figure is its width at the middle of its length. This method should not be relied upon as accurate, but is convenient at times when it is desired to make a rough estimate of the horse power of an engine.

Figuring the M. E. P. by Ordinates. This is a very common method and one which can be relied upon to give accurate results, provided care is exercised in its use.

The process consists in drawing any convenient

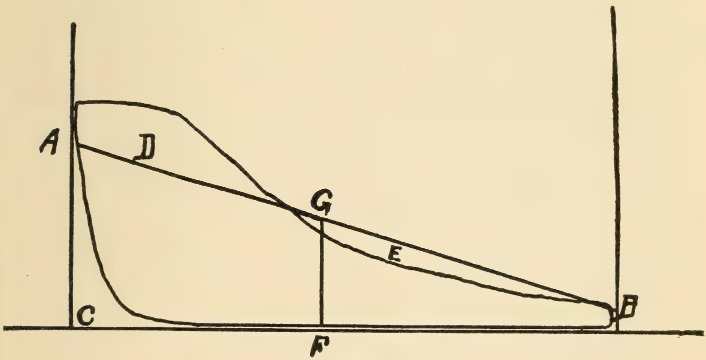


FIGURE 90.

number of vertical lines perpendicular to the atmospheric line across the face of the diagram, spacing them equally, with the exception of the two end spaces, which should be one-half the width of the others, for the reason that the ordinates stand for the centers of equal spaces, as for instance, line 1, Fig. 91, stands for that portion of the diagram from the end to the middle of the space between it and line 2. Again, line 2 stands for the remaining half of the second space and the first half of the third, and so on. This is an important matter, and should be thoroughly understood, because if the spaces are all made of equal width, and measurements are taken on the ordinates, the results will be incorrect, especially in the case of high initial pressure and early cut off, following which the steam undergoes great changes.

If the spaces are all made equal, the measurements will require to be taken in the middle of them, and errors are liable to occur, whereas if spaced as before described, the measurements can be made on the

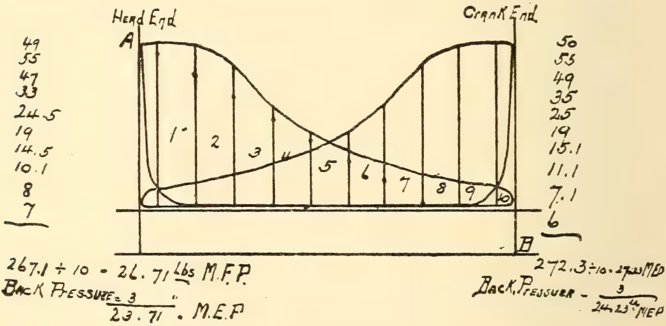


FIGURE 91.

ordinates, which is much more convenient and will insure correct results. Any number of ordinates can be drawn, but ten is the most convenient and is amply sufficient, except in case the diagram is excessively long. For spacing the ordinates, dividers may be used, or a parallel ruler may be procured from the makers of the indicator; but one of the most convenient and easily procurable instruments for this purpose is a common two-foot rule, and the method of using it is illustrated in Fig. 91.

First draw vertical lines at each end of the diagram, perpendicular to the atmospheric line and extending downwards to the vacuum line, or below it if necessary, in order to have a point on which to lay the rule. In Fig. 91 points A and B are found to be the most convenient. Now lay the rule diagonally across the diagram, touching at A and B, and the distance will be found to be 3¾ in., or 60 sixteenths.

Suppose it be desired to draw 10 ordinates. Divide 60 by 10, which will give 6 sixteenths, or ⅜ in. as the width of the spaces, but as the two end spaces are to be one-half the width of the others, there will be 11 spaces altogether, the two outer ones having a width equal to one-half of ⅜ or $\frac{3}{16}$. Now apply the rule again in the same manner, touching at points A and B, and with a sharp pointed pencil begin at A and mark the location of the first ordinate according to the rule, at a distance of $\frac{3}{16}$ from the end. Then ⅜ from this mark make another one, which will locate the second ordinate, and proceed in like manner to locate the others. The last two or three marks generally come below the diagram, and if the diagram be taken from a condensing engine it may be necessary to tack it on to a larger sheet of paper in order to get these points. Having correctly located the ordinates, they may now be drawn perpendicular to the atmospheric line or vacuum line, either of which will answer.

It should be noted that, owing to the diagonal position of the rule with relation to the atmospheric line, the spaces are not of the actual width as described by the rule, but this is unimportant, so long as they are of a uniform width. This method can be applied to any diagram, no matter what its length may be, and point B may be located at any distance below the atmospheric or vacuum lines, wherever it is the most convenient for the subdivisions on the rule, sixteenths, eighths, etc., so long as it is in line with the end of the diagram. Having thus drawn the ordinates, the M. E. P. may be found by measuring the pressure expressed by each one, using for this purpose the scale adapted to the spring used, adding all together and dividing by the number of ordinates which will give the average pressure.

Referring to Fig. 91, begin with ordinate No. 1 on the diagram, from the head end of the cylinder. In this case a 40 spring was used. Lay the scale on the ordinate with the zero mark where it intersects the compression curve. The pressure is seen to be 49 lbs. Set this down at that end of the card and measure the pressure along ordinate No. 2, which is 55 lbs. Proceed in this manner to measure all the ordinates, placing the resulting figures in a column, after which add them together and divide by 10. The result is 26.71 lbs., which is the mean forward pressure (M. F. P.). To obtain the mean effective pressure, deduct the back pressure, which is represented by the distance of the exhaust line of the diagram above the atmospheric line in a non-condensing engine, and in a condensing engine the back pressure is measured from the line of perfect vacuum, 14.7 lbs., according to the scale below the atmospheric line.

In Fig. 91 the back pressure is found to be 3 lbs. Therefore the M. E. P. of the head end will be $26.71 - 3 = 23.71$ lbs. On the crank end the M. F. P. is 27.23 lbs, and $27.23 - 3 = 24.23$ lbs. = M. E. P. The average effective pressure on the piston, therefore, will be $23.71 + 24.23 \div 2 = 23.97$ lbs.

Unless great care is exercised in the measurements, errors are liable to occur in applying this method, especially with scales representing high pressures, as 60, 80, etc. The most convenient and reliable method is to take a narrow strip of paper of sufficient length, and starting at one end, apply its edge to each ordinate in succession and mark their lengths on it consecutively with the point of a knife blade or a sharp pencil. Having thus marked on the paper the total length of all the ordinates, ascertain the number of inches and fractions of an inch thereon, the fractions to be expressed decimally, and divide by the number of ordinates. The quotient will be the average height of the diagram, and as the scale expresses the number of pounds pressure for each inch or fraction of an inch in height, if the average height of the diagram be multiplied by the number of the scale, the product will be the M. F. P.

Referring again to Fig. 91, if the lengths of the ordinates drawn on the head end diagram be measured, their sum will be found to be $6\frac{8}{12}$ or 6.666 in. Dividing this by 10 gives .666 in. as the average height. The mean forward pressure will then be as follows: $.666 \times 40 = 26.64$ lbs., or practically the same as found by the other method.

Fig. 92 illustrates a type of diagram frequently met with, and one which requires somewhat different treatment in estimating the power developed. It will be noticed that, owing to light load and early cut off, the expansion curve drops considerably below the atmospheric line, notwithstanding that the engine from which this diagram was taken is a non-condensing engine. When release occurs at R, and the exhaust side of the piston is exposed to the atmosphere, the pressure immediately rises to a point equal to, or slightly above, that of the atmosphere.

Fig. 92 was taken during a series of experiments made by the author for the purpose of ascertaining the friction of shafting and machinery, and the engine it was obtained from is a Buckeye 24 × 48 in. The boiler pressure at the time was only 40 lbs., and a No. 20 spring was used. The ordinates are drawn according to the method illustrated in Fig. 91. By placing the rule on points A and B, the distance between those two points is found to be 3⅝ in., or 58 sixteenths. Dividing this by 10 gives 5.8 sixteenths, or nearly ⅜

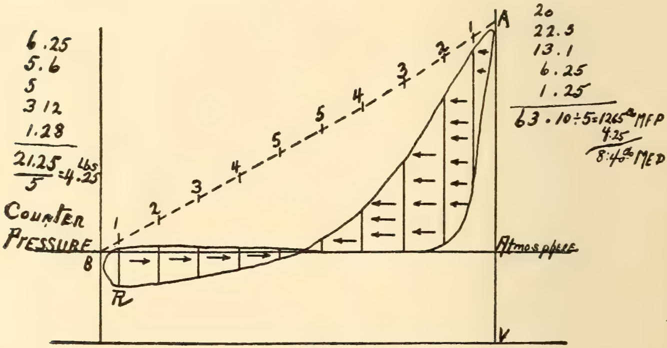
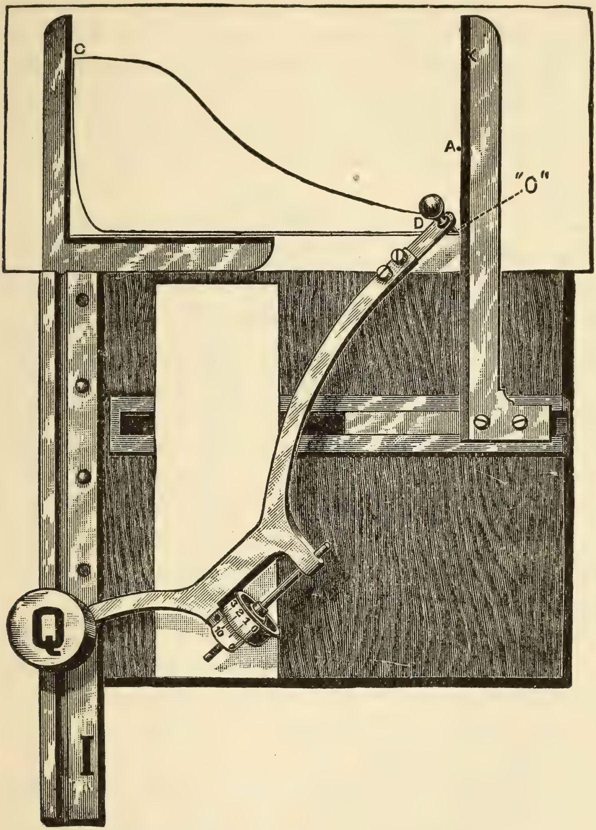


FIGURE 92.

in., as the width of the spaces; the two end spaces being one-half of this, or $\frac{3}{16}$ in. wide. The first five ordinates, counting from A, express forward pressure, represented by the arrows. The remaining five ordinates, counting from B, express counter or back pressure, represented by the arrows pointing in the opposite direction. Measuring the pressures along the first five ordinates, and adding them together, gives 63.1 lbs., which divided by 5 gives 12.65 lbs. as the mean forward pressure (M. F. P.).

Then figuring up the counter pressure in the same manner on the other five ordinates, beginning at B,



COFFIN AVERAGER OR PLANIMETER.

the result is 4.25 lbs. The M. E. P. therefore will be 12.65 – 4.25 = 8.4 lbs.

Obtaining the M. E. P. with the Planimeter. The area of the diagram represents the actual work done by the steam acting upon the piston. In a non-condensing engine the lower or exhaust line of the diagram must be either coincident with or slightly above the atmospheric line in order to express positive work. Any deviation of this line, either above or below the atmospheric line, represents counter pressure, the amount of which may be ascertained by measurements with the scale, and should be deducted from the mean forward pressure.

On the other hand, the exhaust line of a diagram from a condensing engine falls more or less below the atmospheric line, according to the degree of vacuum maintained, and the nearer this line approaches the line of perfect vacuum, as drawn by the scale, 14.7 lbs. below the atmospheric line, the less will be the counter pressure, which in this case is expressed by the distance the exhaust line is above that of perfect vacuum.

The prime requisite therefore in making power calculations from indicator diagrams is to obtain the average height or width of the diagram, supposing it were reduced to a plain parallelogram instead of the irregular figure which it is.

The planimeter, Fig. 93, is an instrument which will accurately measure the area of any plane surface, no matter how irregular the outline or boundary line is, and it is particularly adapted for measuring the areas of indicator diagrams, and in cases where there are many diagrams to work up, it is a very convenient instrument and saves much time and mental effort. In fact, the planimeter has of late years become an almost indispensable adjunct of the indicator. It shows at once the area of the diagram in square inches and decimal fractions of a square inch, and when the area is thus known it is an easy matter to obtain the average height by simply dividing the area in inches by the length of the diagram in inches. Having ascertained the average height of the diagram in inches or fractions of an inch the mean or average pressure is found by multiplying the height by the scale. Or the process may be made still more simple by first multiplying the area, as shown by the planimeter in square

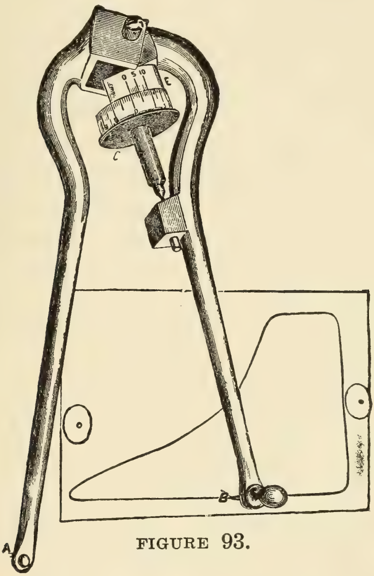


FIGURE 93.

inches and decimals of an inch, by the scale, and dividing the product by the length of the diagram in inches. The result will be the same as before, and troublesome fractions will be avoided.

QUESTIONS

1. What advantage is gained by placing the valves of a corliss engine in the cylinder head?

2. What two important factors must be considered in calculating the steam consumption of an engine?

3. What advantage, in an economical way, is gained by compression?

4. How is the piston displacement of an engine ascertained?

5. How is the steam consumption per horse power per hour calculated? (See Figs. 79 and 80.)

6. What effect does compression have upon the work area of an indicator diagram? (See Fig. 80.)

7. How can the steam consumption, as shown by the diagram, be corrected for clearance and compression? (See Figs. 81, 82 and 83.)

8. What do the expansion and compression curves of a diagram show? (See theoretical clearance.)

9. If the clearance of an engine is not known, how may it be determined theoretically from an indicator diagram? (See Figs. 84 and 85.)

10. What other method may be employed to ascertain the clearance?

11. What is Boyle's law for gases?

12. Is steam a gas?

13. What is a hyperbolic curve? (See Fig. 86.)

14. How may a theoretical curve be constructed from an indicator diagram? (See Fig. 87.)

15. What effect does reëvaporation have upon the expansion curve?

16. When does reevaporation take place within the cylinder?

17. How does a leaky steam valve affect the terminal pressure?

18. If the piston rings leak, what is the result?

19. What is an adiabatic curve, and what conditions are necessary in order to produce it?

20. What is the rule for computing the horse power developed by an engine?

21. What important factor is necessary in all power calculations?

22. How may the M. E. P. be found? (See Figs. 91 and 92.)

23. What does the area of the diagram represent?

24. In a diagram from a non-condensing engine, where should the exhaust line be?

25. If the exhaust line of a diagram is above the atmospheric line, what does it show?

26. Where should the exhaust line of a diagram from a condensing engine be?

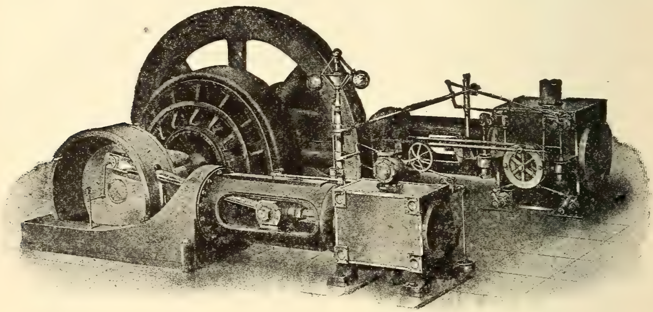
27. How is the M. E. P. ascertained by the planimeter?

CHAPTER XI

ENGINE OPERATION

Engine operation — Simple engines — Compound engines—Condensing and non-condensing engines—Condensers—Surface and jet condensers—Starting a condensing engine—Rules for estimating quantity of condensing water required—The governor—Speed regulation—How to keep a governor in good working condition—Lubrication of an engine—Running "over" or "under"—Oiling the bottom guide on horizontal engines—Oiling the crank pin and main bearings—Shaft governors—Keying up an engine—What to do with a hot pillow block—Feed water heaters—Economy of using exhaust steam for heating feed water—Changing the speed of an engine.

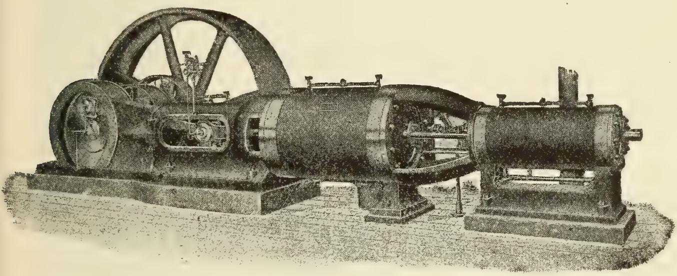
The following general suggestions regarding the operation of engines are made with the object in view



CROSS COMPOUND DIRECT CONNECTED CORLISS ENGINE, ALLIS CHALMERS CO.

of assisting young engineers or those whose experience has been limited to one or two types of engines.

In many cases a young man starts in as a fireman in a certain plant, and by industry and a strict devotion to duty becomes able in course of time to handle not only the boilers successfully, but is at times required to run the engine in the absence of the engineer. He thus acquires the ability to operate that particular engine, while at the same time he may be comparatively ignorant of the peculiarities of other types. Or an engineer may have had years of experience with simple non-condensing engines, but if called upon to operate a compound condensing engine, he would find that he had a great deal to learn.

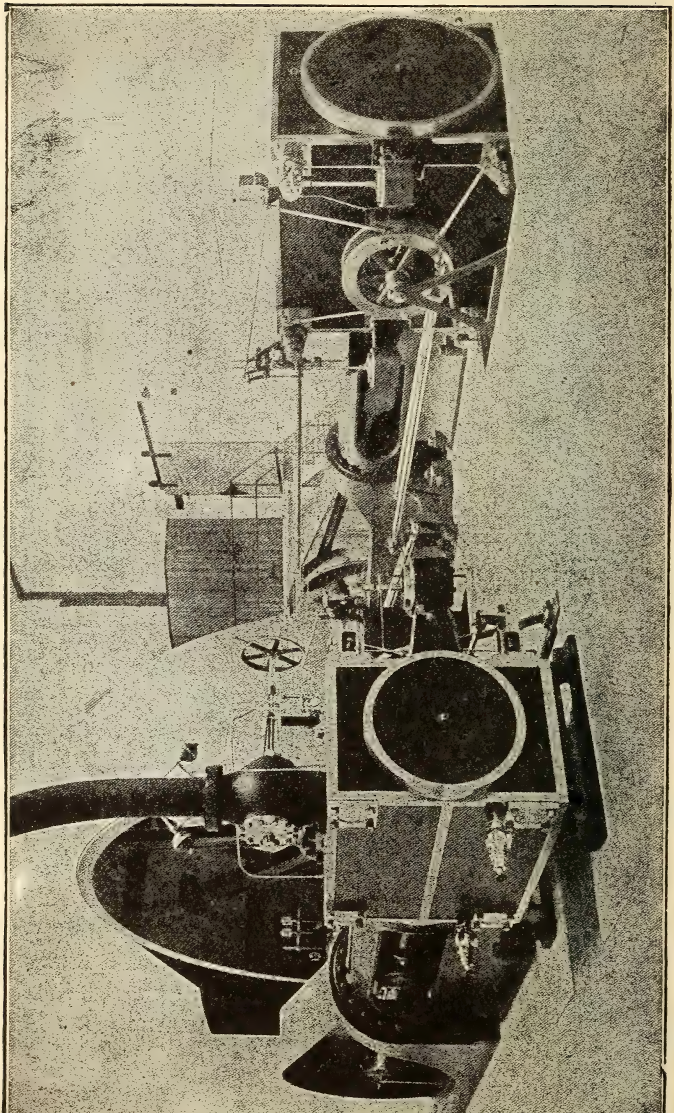


TANDEM COMPOUND ENGINE, BUCKEYE ENGINE CO.

Engines may be divided into two general classes, viz., simple and compound.

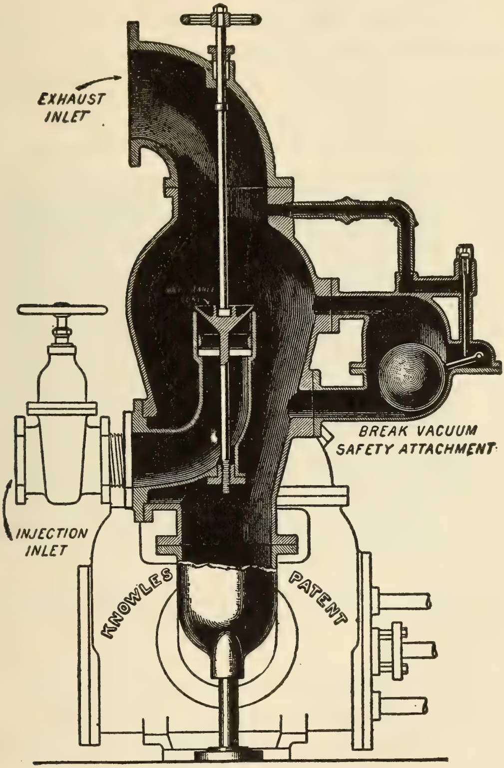
A simple engine may be either condensing or non-condensing, but its leading characteristic is, that the steam is used in but one cylinder, and from thence it is exhausted either into the atmosphere or into a condenser.

A compound engine is one in which the steam is made to do work in two or more cylinders before it is allowed to exhaust, and this class of engine may be either condensing or non-condensing.



CROSS COMPOUND HAMILTON CORLISS ENGINE.

In a non-condensing engine the pressure of the atmosphere, amounting to 14.7 lbs. per square inch at sea level, is constantly in resistance to the motion of



KNOWLES JET CONDENSER.

the piston. Therefore the exhaust pressure cannot fall below the atmospheric pressure, and is generally from two to five pounds above it, caused by the resistance of bends and turns in the exhaust pipe, or other causes which tend to retard the free passage of the steam.

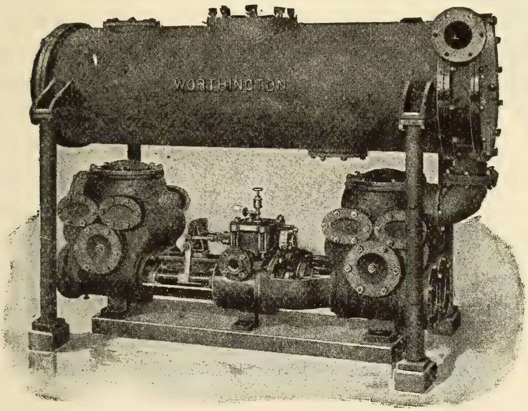
The advantage, from an economical point of view, of exhausting the steam into a condenser in which a vacuum is maintained, is fully set forth in Chapter VIII. on Definitions. (See Vacuum.)

Condensers are of two classes, viz., jet condensers and surface condensers.

In a jet condenser the steam is exhausted into an air-tight iron vessel of any convenient shape, generally cylindrical and of suitable size, and is there condensed by coming in contact with a jet of cold water, admitted in the form of a spray. The air pump, which also maintains a vacuum in the condenser, draws this water, together with the condensed steam, away from the condenser.

The surface condenser, like the jet condenser, consists of an air-tight iron vessel, either cylindrical or rectangular in shape, but unlike the jet condenser, it is fitted with a large number of brass or copper tubes of small diameter, through which cold water is forced by a pump, called a circulating pump. A vacuum is also maintained in the body of the condenser by the air pump, and the steam exhausting into this is condensed by coming in contact with the cool surface of the tubes. Or, as is often the case, the exhaust steam passes through the tubes in place of around them, and the condensing water is forced into and through the body of the condenser, the vacuum in this case being maintained in the tubes. Owing to the fact that in a surface condenser the steam does not mix with the water, a larger quantity of condensing water is required than in a jet condenser, but on the other hand, an advantage is gained by having the pure water of condensation; in other words, the condensed steam, which may be returned to the boilers along with the regular feed water supply, and will greatly aid in preventing the formation of scale, while the water of condensation as it comes from a jet condenser, being mixed with oil and other impurities, is not, as a rule, suitable to be fed to boilers.

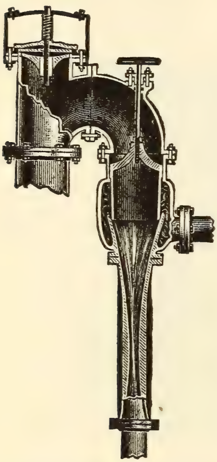
There are many different types of jet condensing



WORTHINGTON SURFACE CONDENSER, WITH AIR AND CIRCULATING PUMP.

apparatus, in some of which no air pump is used; their action being based somewhat upon the principle of the injection used for feeding boilers. In this type of jet condenser the supply of condensing water is drawn from outside pressure, either from an overhead tank or other source, and passing into an annular enlargement of the exhaust pipe, is discharged downwards in the form of a cylindrical sheet of water into a nozzle which gradually contracts. The exhaust steam, entering at the same time, is condensed, and the contracting neck of the cone shaped nozzle gradually brings the water to a solid jet, and it rushes through the nozzle with a velocity sufficient to create a vacuum. This type of condenser can only be used where the discharge pipe has a free outlet.

The jet condenser with air pump attached is the most reliable as well as economical for general purposes, for the reason that with this type the supply of condensing water may be drawn from a well or other source lower than the level of the condenser. These condensers are also generally fitted with a "force injection," as it is called, which is simply a connection between the condenser and water main or tank, for the purpose of letting cold water into the condenser to condense the exhaust steam when starting the engine, and thus aid in forming a vacuum. When a good vacuum has been established and the engine is running up to speed, the force injection may be shut off, and the water will flow into the condenser from the well by suction. The above refers to engines in which the air pump receives its motion directly from the engine.



SIPHON CONDENSER.

Another type of jet condensing apparatus is the independent air pump and condenser, which is still better, for the reason that the air pump, which is simply an ordinary double acting steam pump, may be started independently of the engine, and, in fact, before the engine is started, thus creating a vacuum in the condenser, and greatly facilitating the starting of the engine. Another great advantage in the independent condensing apparatus is that there is not so much danger of the water backing up into the cylinder in case of a sudden shut down of the engine, because the air pump may be kept in operation, thus relieving the condenser of water; whereas, if the air pump gets its motion from the engine, it will of course stop when the engine stops, and unless the injection water is shut off immediately after closing the throttle there is great danger of the cylinder becoming flooded with water, resulting very often in a broken cylinder head, or a bent piston rod.

The quantity of water required to condense the exhaust steam of an engine is determined by three factors: First, the density, temperature and volume of the steam to be condensed in a given time; second, the temperature of the overflow or discharge, and third, the temperature of the injection water. For instance, the temperature of the injection water may be 35° in the winter and 70° in the summer. Or it may be desired to keep the overflow at as high a temperature as possible for the purpose of feeding the boilers. Again, the pressure, and consequently the temperature of the exhaust steam as it enters the condenser, varies witn different engines, and often with the same engine, according as the load is light or heavy. Therefore the only accurate method of estimating the amount of condensing water required per minute or per hour, under any and all conditions, is to first ascertain the weight of water required to condense one pound weight of steam at the temperature and pressure at which the steam is being exhausted

In these calculations the total heat in the steam must be considered. This means not only the sensible heat, but the latent heat also.

The formula for solving the above problem may be expressed as follows: $\frac{H - T}{T - I} = W$, in which

H = total heat in the steam,
T = temperature of the overflow,
I = temperature of the injection water,
W = weight of water required to condense one pound weight of steam.

To illustrate, suppose the absolute pressure of the exhaust, as shown by the indicator diagram, is 7 lbs. Referring to Table 5, it will be seen that the total heat in steam at 7 lbs. absolute is 1135.9 heat units. Assume the temperature of the overflow to be 110°, which is as high as is consistent with a good vacuum Now the total heat to be absorbed from each pound weight of steam in this case would be 1135.9 – 110 = 1025.9 B. T. U.

Suppose the temperature of the condensing water to be 55° and the temperature of the overflow being 110°, there will be 110° – 55° = 55° of heat absorbed by each pound of water passing into and through the condenser, and the number of pounds of water required to condense one pound weight of steam under the above conditions will equal the number of times 55 is contained in 1025.9. Expressed in plain figures the calculation is $\frac{1135.9 - 110}{110 - 55} = 18.65$ lbs.

In order to ascertain the quantity of condensing water required per horse power per hour, it is only necessary to know the number of pounds weight of steam consumed by the engine per horse power per hour, as shown by the indicator diagram, and multiply this by the weight of condensing water required per pound of steam, as found by the above solution.

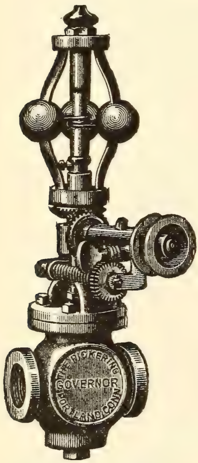
Thus, suppose the steam consumption of the engine to be 17 lbs. per I. H. P. per hour. Then $17 \times 18.65 = 317.05$ lbs. per hour, which reduced to gallons = 38.2 gals.

Or, if the steam consumption is not known, and the weight only of condensing water required per hour is desired, regardless of the horse power developed by the engine, it will be necessary, first, to estimate the total volume of steam exhausted per hour and calculate its weight from its known pressure.

Thus, assume the engine to be 24 × 48 in., and the R. P. M. to be 80. Then the piston displacement will equal area of piston less one-half area of rod multiplied by length of stroke. Referring to Table 9, the area of a circle 24 in. in diameter = 452.39 sq. in Suppose the piston rod to be 4.5 in. in diameter, its area, according to Table 9, is 15.904 sq. in., one-half of which = 7.952 sq. in. The effective area of the piston now becomes $452.39 - 7.952 = 444.43$ sq. in., and the piston displacement equals $444.43 \times 48 = 21332.64$ cu. in. Dividing this by 1728 (number of cubic inches in a cubic foot) gives 12.34 cu. ft. of piston displacement. The total volume of steam exhausted per minute, therefore, will be $12.34 \times 2 \times 80 = 1974.4$ cu. ft.

The absolute pressure of the exhaust may again be assumed to be 7 lbs. per square inch. Referring to Table 5, the weight of one cubic foot of steam at 7 lbs. absolute is .0189 lbs., and the total weight of steam exhausted per minute, therefore, would be $1974.4 \times .0189 = 37.3$ lbs., and if 18.65 lbs. water is required to condense one pound of steam, the quantity required per minute would be $37.3 \times 18.65 = 695.8$ lbs., or per hour, 41748 lbs., equal to 5029 gals. This is at the rate of 8.7 lbs., or a little more than one gallon per revolution for a 24×48 in. simple condensing engine.

The Governor. The proper regulation of speed is a very important point in the operation of engines, and in order to attain this most desirable object, due attention must be paid to the governor. If it be a throttling governor (see Chapter VIII, on Definitions), care should be taken to not pack the small valve stem too tight, nor allow the packing to become hard from long usage. The packing nuts should be left loose enough to allow a slight leakage of steam past the stem. This will keep it lubricated and the slightest variation of the governor balls will be transmitted to the valve, and the speed will be regular.

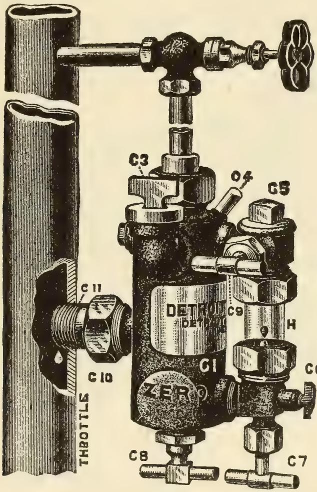


PICKERING HORIZONTAL GOVERNOR.

If the engine has an automatic cut off mechanism actuated by a fly ball governor, it is obvious that all the moving parts of the governor should work with as little friction as possible. Good oil and enough of it should be used. Particular attention should be paid to the dash pot connected with the governor, the object of which is to regulate the variations of the governor and prevent a jerky movement. It often happens, especially with new engines, that the small piston in the dash pot fits too snug, and the consequence is that it sticks; causing the governor to be slow in responding to changes in the speed of the engine.

It is a good plan sometimes to take the dash pot piston out, and putting it in a lathe, reduce its diameter slightly, and also round off the sharp edges. The oil used in the dash pot should not be allowed to become gummy by being used too long without changing it for fresh oil.

Lubrication. The proper lubrication of all the working parts of an engine is a matter of prime importance,



DOUBLE CONNECTION LUBRICATOR.

not only in prolonging the life of the engine, but in reducing friction, and thus increasing efficiency. Various types of lubricators have been devised for introducing oil into the valve chest and cylinder, but probably the most reliable and easily managed apparatus for this purpose is a good oil pump worked by the engine itself, for the reason that it is positive and the flow of oil is not easily affected by changes in temperature. In the case of large horizontal engines especially, it is good practice to introduce a little graphite along with the cylinder oil once or twice a day.

In many cases trouble is experienced with the bot-

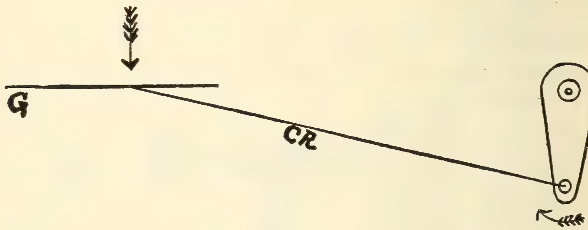


FIGURE 94.

tom guides of horizontal engines, especially if the engine "runs over," as illustrated by Figs. 94 and 95, where it will be seen that in addition to the weight of the crosshead, the thrust or pressure consequent upon the pull, Fig. 94, and push, Fig. 95, also comes upon the bottom guide both with the inward and outward

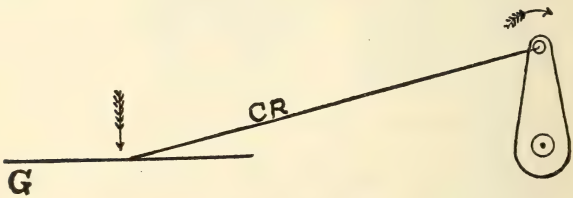


FIGURE 95.

strokes; whereas with an engine "running under," the thrust is just in the opposite direction, and the pressure comes upon the top guide.

The best method of lubricating the lower guide of a horizontal engine is to drill through from the underside at a point near the center of the guide, and connect a small size pipe, 3/8 or 1/2 in., to which an oil or grease cup can be attached. The oil thus forced up from beneath will serve a much better purpose than if dropped on the guide, to be instantly scraped off by the crosshead.

One of the best devices for oiling the crank pin is the center oiler, illustrated in Fig. 96. An oil hole is drilled along the center line of the pin to a point about midway of its length, and another hole from the

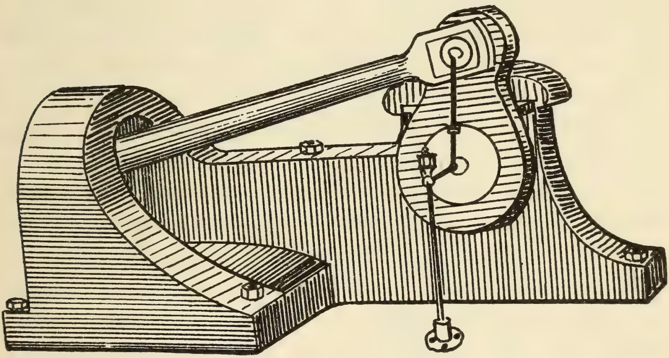


FIGURE 96.

wearing surface of the pin at right angles to the first hole. The two holes meet at the center of the pin and form a route by which the oil is conducted to the point where it is most needed. The hole at the outer end of the pin is enlarged and threaded to receive the oil pipe, one end of which is connected to the pin by means of a short nipple and elbow, while the other end is in line with the center of the main shaft and remains in that position while the crank revolves. The oil is fed into this end of the pipe through an elbow or hollow ball screwed to the end of the pipe, and the supply may be regulated at will by the engineer, as the cup is at all times under his control.

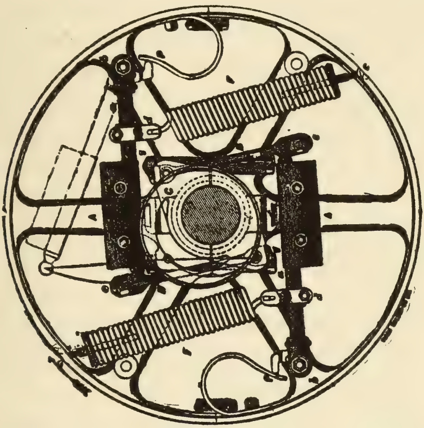
The pillow block or main bearing of an engine demands and should receive the most careful attention from the engineer, for the reason that there is where the greatest friction occurs, and if neglected for even a short time, trouble will occur.

The main bearings of most engines are fitted with apparatus for oiling them by which the oil is dropped upon the top of the journal, when in fact the place that the oil is most needed is at the bottom or underside of the bearing. In horizontal engines, especially, there is a constant pressure on the bottom of the bearing, due to the weight of the flywheel and main shaft, and this pressure prevents the greater part of the oil, if fed in on top, from reaching the lower surface. Therefore the lubrication of pillow blocks may be greatly facilitated by connecting, whenever it is possible to do so, at least one oil pipe in such a way that it will conduct the oil to the bottom of the bearing. In case a pillow block or other bearing shows signs of warming up, good results may often be obtained by using from 25 to 50 per cent. of cylinder oil mixed with the regular engine oil.

Every engineer should establish a regular system of oiling his engine, as for instance, by having regular intervals of time for going around the engine and inspecting all the working parts. A good rule is to make the rounds about every twenty minutes. In this way no part will be neglected, and the danger of having hot bearings or of other accidents happening will be greatly lessened.

Many automatic cut off engines, especially those of the high speed type, are fitted with isochronal or shaft governors. There are various styles of these governors, but all or nearly all of them control the admission of steam to the cylinder, and consequently the point of cut off by varying the angular advance of the eccentric, which in such engines is free to move across the shaft, being entirely under the control of the governor.

Very close regulation is generally obtained by the



ISOCHRONAL OR SHAFT GOVERNOR, BUCKEYE ENGINE CO.

use of shaft governors, but particular attention should be given to the lubrication of the steam valve, which, with this class of engines, is generally a slide valve of some description, and although it may be ever so nicely balanced, yet if it does not get sufficient oil, the friction due to dry surfaces rubbing together, will put extra work on the governor, and the speed is liable to be irregular.

Keying Up. To keep the working parts of an engine properly keyed up so as to take up the lost motion without causing the bearings to heat, is one of the most delicate and exacting duties of the engineer. Every engineer worthy of the name should aim to have a smooth and quietly running engine. In fact, this is one of the principal tests of his skill as an engineer.

A few general suggestions may be given here, but much more depends upon the good judgment of the engineer himself.

In connecting up an engine, as for instance, the crank pin and crosshead, the key should first be driven in until it is solid, that is, until the brasses clamp the pin tightly. Then place a small ruler across the face of the gib and key, and with the point of a knife blade, or a steel scriber, make a fine mark along the edge of the ruler. This will be the "solid mark." Now back the key up by light blows with the hammer, which should be of copper, until the brasses are just loose enough on the pin to permit a side movement of the rod. If the rod is very heavy, hold a block of wood against the side of the rod near the pin and give it a blow with a sledge. If there is no movement, back the key a little more, and keep trying until there is a side movement. There should be a space of at least $\frac{1}{32}$ in. between the sides of the brasses and the flange of the pin, so as to allow a slight side play. If it is found, after running a while, that there is too much lost motion, causing the engine to pound, put the ruler across the gib and key again, and with a lead pencil draw a line. Then loosen the set screw and drive the key in a distance equal to the width of the line, and no more. This process should be repeated at intervals until the pound is all gone, or the bearing begins to warm up slightly, indicating that the brasses are up as close as they will run.

The adjustment of pillow blocks also requires a large measure of skill and good judgment, and should be done by degrees; but when once adjusted properly and kept well oiled, the matter of keeping them in good working condition becomes greatly simplified.

If a pillow block, or other bearing filled with babbit metal, should become heated to such a temperature as to cause the metal to run, do not shut down the engine at once and turn on a stream of cold water, because this will only make matters worse, causing the metal to stick to the journal, and the labor and trouble of cleaning it out will be increased. The best method to pursue in such an emergency is to gradually slow the engine down and keep it moving at as slow a speed as it will run, and in the meantime a small stream of cold water may be allowed to flow over the bearing, applying it to all parts as nearly as possible until it is cooled, after which the engine may be stopped and repairs made.

Heating Feed Water. Every steam plant should be provided with one or more heaters for the purpose of utilizing the exhaust steam for heating the feed water, and the exhaust, not only of the engine, but of the feed pumps and all other steam pumps connected with the plant, should be led into it if possible. This applies especially to non-condensing engines, and even if the engine be a condensing engine the exhaust may be passed through a closed heater before going into the condenser.

The percentage of saving in heat effected by heating the feed water with exhaust steam which would otherwise go to waste, may be ascertained by the following rule:

Multiply the difference in the total heat in the water above 32°, before and after heating, by 100, and divide the product by the total heat required to convert the water into steam from the initial temperature. The quotient will be the per cent. of saving.

The following example will serve to illustrate the process: Suppose the initial temperature of the water to be 50°, and that by means of the heater its temperature is increased to 183° before entering the boiler. The steam pressure being 100 lbs. gauge, or 115 lbs. absolute. By referring to Table 5, it will be seen that

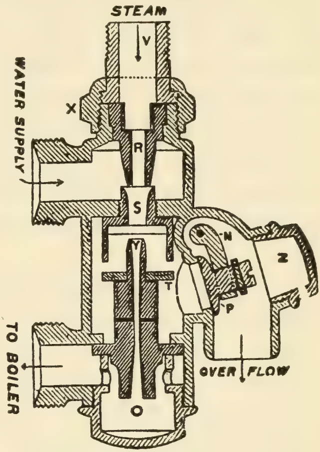
Water at 182.9° temp.	contains	151.5	heat units,
" " 50.0° "	"	18	" "
	The difference =	133.5	heat units.

One pound of steam at 115 lbs. absolute pressure contains above 32°, 1,185 heat units, and for each pound of water, at 50°, converted into steam at the above pressure, there would be required 1,185 − 18 = 1167 heat units; but 133.5 heat units having been added to the water while passing through the heater, the problem now becomes $\frac{133.5 \times 100}{1167} = 11.44$ per cent., saving in heat.

Two classes of heaters are available for this purpose, viz., open heaters and closed heaters.

In the open heater the exhaust steam comes in contact with and mingles with the water, and a portion of it is condensed and returns to the boiler. In this respect the open heater has an advantage over the closed type, in which the water is kept separate from the exhaust steam by passing it through tubes that are surrounded by the steam which is confined in the outer shell of the heater. In some types of the closed heater the steam passes through the tubes, which are in turn surrounded by the water. A heater of either class should be sufficiently large to allow the water to pass through it slowly, in order that it may absorb all the heat possible. About one-third of a square foot of heating surface should be allowed per horse power for a closed heater, and it should have sufficient volume to contain water enough to supply the boilers for a quarter of an hour. If a heater is too small for the engine it is liable to cause back pressure on the exhaust.

There is no saving in heat, but rather a loss in using live steam to heat the feed water, but on the other hand, if the water is bad, it can be purified to a certain extent by passing it through a live steam heater on its way to the boiler.



SECTIONAL VIEW OF PENBERTHY INJECTOR.

Probably the most economical device for feeding boilers is the exhaust injector, which not only feeds the boiler, but utilizes all the available heat in the exhaust steam and returns it to the boiler. The difficulties attending the use of the exhaust injector are that it cannot force water against a pressure above 75 or 80 lbs., and that it will not lift its water supply by suction.

The principle by which an injector is able to force water against a higher pressure than that of the steam by which it is operated, lies in the fact that the mixture of water and steam rushes with such velocity into the vacuum formed by the condensation of the steam, that the momentum thus acquired carries it into the boiler against the higher pressure.

Live steam injectors, while being much less economical than the steam pump with heater, are, nevertheless, a valuable adjunct of a steam plant. They are lifting and non-lifting. A lifting injector in good condition, with no air leaks in the suction pipe, will raise the water by suction about 20 ft. With the non-lifting injector the water supply must flow into the injector, and it may be handled at a temperature as high as 150°, although not so reliable as at lower temperatures.

A good free working check valve and one that will not leak, is one of the most important requisites in the feeding of boilers, and especially is this the case when an injector is used.

Sometimes an injector is prevented from working by dirt being drawn in through the suction pipe. This trouble can be avoided by fitting the pipe with a strainer. If the tubes become clogged with scale, they should be soaked in a dilute solution of muriatic acid, say one part of acid to ten parts of water. All the joints and connections should be air tight, and the valves should be properly packed, otherwise the injector will be a constant source of trouble.

Changing the Speed of an Engine. It sometimes happens that it is desired to permanently change the speed of an engine, and the method of doing this is as follows:

If it is desired to increase the speed but two or three revolutions, it can generally be accomplished by moving the counter balance (which most governors have) farther out on the lever, although there is a limit to this, because if moved too far, either in, to decrease the speed, or out to increase tne speed, the effect will be to destroy the true action of the governor, and its movements will be jerky. The location of the counter balance should be at that point where the governor works the best at the speed at which it was designed to run, and which is generally marked on the governor. And this can only be determined by much patient experimenting on the part of the engineer. If moving the counter balance does not bring about the desired increase of speed, the next move is to increase the diameter of the governor pulley so that the proportions of the pulleys on the engine shaft and the governor will be such that the governor will continue to run at its normal speed, while the speed of the engine has been increased the desired number of revolutions.

To illustrate, assume the engine to be making 75 revolutions per minute, and that the pulley on the engine shaft, upon which the governor belt runs, is 12 in. in diameter, and that the governor pulley is 8 in. in diameter.

Suppose it is desired to increase the speed of the engine to 85 revolutions per minute. First find the speed of the governor with the engine running at 75 revolutions.

The formula is,

$$\frac{\text{Speed of engine} \times \text{diameter of shaft pulley}}{\text{Diameter of governor pulley}} = \text{speed of}$$

governor. Thus, $\frac{75 \times 12}{8} = 112.5$, revolutions for governor.

Next find what the diameter of the governor pulley must be to allow the governor to still run at 112.5 revolutions while the engine runs at 85 revolutions.

The formula is,

$$\frac{\text{Speed of engine} \times \text{diameter of shaft pulley}}{\text{Speed of governor}} = \text{diameter}$$

of governor pulley. Thus, $\frac{85 \times 12}{112.5} = 9.06$ in., diameter of new pulley required for governor.

Should it be desired to decrease the speed of the engine, the same rules and formula will apply for ascertaining the diameter of the governor pulley, which in this case would have to be reduced in size.

Questions

1. Into what two general classes may engines be divided?

2. In what respect do they differ?

3. What advantage has a compound engine over a simple engine?

4. What advantage economically has a condensing engine over a non-condensing engine?

5. How many kinds of condensers are there?

6. Describe a jet condenser.

7. Describe a surface condenser.

8. Is an air pump absolutely necessary with all jet condensers?

9. What is meant by an independent air pump and condenser?

10. What three factors determine the quantity of condensing water required by an engine?

11. What is the rule for ascertaining the quantity of condensing water required by an engine?

12. How may the quantity of condensing water required per horse power per hour be ascertained?

13. What precautions should be observed with a throttling governor?

14. What general rules should be followed in the operation of an automatic cut off governor?

15. What is the most reliable device for introducing oil into the valve chest and cylinder?

16. How may the bottom guide of a horizontal engine be best lubricated?

17. What reliable device may be used in the lubrication of the crank pin?

18. What precautions should be observed in the lubrication of the main bearings or pillow blocks?

19. What should be done with a pillow block that shows signs of warming up?

20. How does an isochronal, or shaft governor, regulate the speed of an engine?

21. How is the shaft governor affected if the steam valve is not properly lubricated?

22. Describe the proper method of keying up an engine.

23. What should be done in case a main bearing becomes heated sufficiently to melt the babbitt?

24. How may the exhaust be utilized to an advantage?

25. What is the rule for ascertaining the percentage of saving in heat when an exhaust heater is used?

26. What two classes of heaters are available?

27. What is an open heater?

28. Describe a closed heater.

29. Is there a saving in heat effected by using a live steam heater?

30. What advantage then is derived from its use?

31. Upon what principle does an injector work?

32. Into what two types are injectors divided?

33. What particular valve in the feed pipe of a boiler should always be kept in good condition?

34. How may an injector that has become clogged with dirt or scale be cleaned?

35. What precautions should be observed in fitting up an injector?

36. How may the speed of an engine be slightly increased?

37. If it is desired to increase the speed considerably, how may it be done?

38. If it is desired to decrease the speed, what changes are necessary?

Engineering

PART II

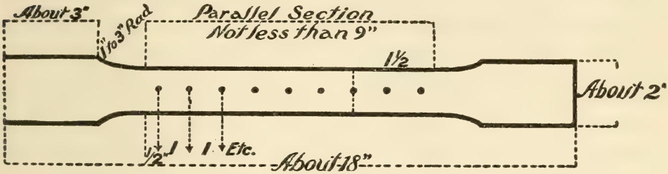
CHAPTER I

THE BOILER

Importance of correct knowledge of the construction and strength of steam boilers—Tensile strength of steel boiler plates—Dr. Thurston's specifications—Specifications of U. S. board of inspectors of steam vessels—Punched and drilled plates—Rivets and rivet iron and steel—Efficiency of the joints—Proportions of double riveted butt joints—Lloyd's rules for thickness of plate and diameter of rivets—Correct design of triple riveted butt joints—Calculations for efficiency of different forms of joints—Discussion of various ways in which failure may occur in different styles of joints—Necessity for higher efficiencies in riveted joints—Quadruple and quintuple butt joints—Staying flat surfaces—Different methods of staying a boiler—Correctly designed stays—Stay bolts for fire box boilers—The Belpaire boiler—Vanderbilt Locomotive with Morison fire box—Gusset stays—Through stay rods—Calculating strength of stayed surfaces—Area of segments—Proper spacing of stays—Strength of unstayed surfaces—Dished heads—Welded seams.

As it is of the highest importance, not only to the engineer in charge of the plant, but also to his assistants, and in fact to all persons whose business compels them to be in the vicinity of the boiler-room, that there should be absolutely no doubt as to the safe construction of the boilers and their ability to withstand the pressures under which they are operated, the author has compiled the following additional data regarding the construction and strength of boilers. The deductions and reports of tests and experiments made by such eminent authorities as Dr. Thurston, Prof. Wm. Kent, Dr. Peabody, D. K. Clark, Hutton and many other experts have been consulted, and the author has also added the results of his own observations, collected during an experience of thirty-five years as a practical engineer.

When steel was first introduced as a material for boiler plate, it was customary to demand a high tensile strength, 70,000 to 74,000 lbs. per sq. in., but experience and practice demonstrated in course of time that it was much safer to use a material of lower tensile strength. It was found that with steel boiler plate of high tenacity there was great liability of its cracking, and also of certain changes occurring in its physical properties, brought about by the variations in temperature to which it was exposed. Consequently present-day specifications for steel boiler plate call for tensile strengths running from 55,000 to 66,000 lbs., usually 60,000 lbs. per sq. in. Dr. Thurston gives what he calls "good specifications" for boiler steel as follows: "Sheets to be of uniform thickness, smooth finish, and sheared closely to size ordered. Tensile strength to be 60,000 lbs. per sq. in. for fire box sheets and 55,000 lbs. per sq. in. for shell sheets. Working test: a piece from each sheet to be heated to a dark cherry red, plunged into water at 60° and bent double, cold, under the hammer. Such piece to show no flaw after bending. The U. S. Board of Supervising Inspectors of Steam Vessels prescribes, in Section 3 of General Rules and Regulations, the following method for ascertaining the tensile strength of steel plate for boilers: "There shall be taken from each sheet to be used in shell or other parts of boiler which are subject to tensile strain, a test piece prepared in form according to the following diagram:



TEST PIECE.

The straight part in center shall be 9 in. in length and 1 in. in width, marked with light prick punch marks at distances 1 in. apart, as shown, spaced so as to give 8 in. in length. The sample must show, when tested, an elongation of at least 25 per cent in a length of 2 in. for thickness up to ¼ in. inclusive; in a length of 4 in., for over ¼ in. to $\frac{7}{16}$ in. inclusive; in a length of 6 in., for all plates over $\frac{7}{16}$ in. and under 1¾ in. in thickness. The samples shall also be capable of being bent to a curve of which the inner radius is not greater than 1½ times the thickness of the plates, after having been heated uniformly to a low cherry red and quenched in water of 82° F."

Punched and Drilled Plates. Much has been written on this subject, and it is still open for discussion. If the material is a good, soft steel, punched sheets are apparently as strong and in some instances stronger than drilled, especially is this the case with regard to the shearing resistance of the rivets, which is greater with punched than with drilled holes.

Concerning rivets and rivet iron and steel Dr.

Thurston has this to say in his "Manual of Steam Boilers": "Rivet iron should have a tenacity in the bar approaching 60,000 lbs. per sq. in., and should be as ductile as the very best boiler plate when cold. A good ⅝-in. iron rivet can be doubled up and hammered together cold without exhibiting a trace of fracture." The shearing resistance of iron rivets is about 85 per cent and that of steel rivets about 77 per cent of the tenacity of the original bar, as shown by experiments made by Greig and Eyth. The researches made by Wöhler demonstrated that the shearing strength of iron was about four-fifths of the tensile strength.

The tables that follow have been compiled from the highest authorities and show the results of a long and exhaustive series of tests and experiments made in order to ascertain the proportions of riveted joints that will give the highest efficiencies.

The following Table 11 gives the diameters of rivets for various thicknesses of plates and is calculated according to a rule given by Unwin.

TABLE 11

TABLE OF DIAMETERS OF RIVETS*

Thickness of Plate	Diameter of Rivet	Thickness of Plate	Diameter of Rivet
1/4 inch	1/2 inch	9/16 inch	7/8 inch
5/16 "	9/16 "	5/8 "	15/16 "
3/8 "	11/16 "	3/4 "	1 1/16 "
7/16 "	3/4 "	7/8 "	1 1/8 "
1/2 "	13/16 "	1 "	1 1/4 "

The efficiency of the joint is the percentage of the strength of the solid plate that is retained in the joint,

* Machine design—W. C. Unwin.

and it depends upon the kind of joint and method of construction.

If the thickness of the plate is more than ½ in., the joint should always be of the double butt type.

The diameters of rivets, rivet holes, pitch and efficiency of joint, as given in the following Table 12, which was published in the "Locomotive" several years ago, were adopted at the time by some of the best establishments in the United States.*

TABLE 12

PROPORTIONS AND EFFICIENCIES OF RIVETED JOINTS

	Inch	Inch	Inch	Inch	Inch
Thickness of plate	1/4	5/16	3/8	7/16	1/2
Diameter of rivet.............	5/8	11/16	3/4	13/16	7/8
Diameter of rivet-hole.........	11/16	3/4	13/16	7/8	15/16
Pitch for single riveting	2	2 1/16	2 1/8	2 3/16	2 1/4
Pitch for double riveting	3	3 1/8	3 1/4	3 3/8	3 1/2
Efficiency—single-riveted joint	.66	.64	.62	.60	.58
Efficiency—double-riveted joint	.77	.76	.75	.74	.73

Concerning the proportions of double-riveted butt joints, Prof. Kent says: "Practically it may be said that we get a double-riveted butt joint of maximum strength by making the diameter of the rivet about 1.8 times the thickness of the plate, and making the pitch 4.1 times the diameter of the hole."

Table 13 as given below is condensed from the report of a test of double-riveted lap and butt joints.† In

* Thurston's "Manual of Steam Boilers."

† Proc. Inst. M. E., Oct., 1888.

this test the tensile strength of the plates was 56,000 to 58,000 lbs. per sq. in., and the shearing resistance of the rivets (steel) was about 50,000 lbs. per sq. in.

TABLE 13

DIAMETER AND PITCH OF RIVETS—DOUBLE-RIVETED JOINT

Kind of Joint	Thickness of Plate	Diameter of Rivet	Ratio of Pitch to Diameter
Lap	3/8 inch	0.8 inches	3.6 inches
Butt	3/8 "	0.7 "	3.9 "
Butt	3/4 "	1.1 "	4.0 "
Butt	1 "	1.3 "	3.9 "

Lloyd's rules, condensed, are as follows:

LLOYD'S RULES—THICKNESS OF PLATE AND DIAMETER OF RIVETS

Thickness of Plate	Diameter of Rivets	Thickness of Plate	Diameter of Rivets
3/8 inch	5/8 inch	3/4 "	7/8 inch
7/16 "	5/8 "	13/16 "	7/8 "
1/2 "	3/4 "	7/8 "	1 "
9/16 "	3/4 "	15/16 "	1 "
5/8 "	3/4 "	1 "	1 "
11/16 "	7/8 "		

The following Table 14 is condensed from one calculated by Prof. Kent,* in which he assumes the shearing strength of the rivets to be four-fifths of the tensile strength of the plate per square inch, and the excess strength of the perforated plate to be 10 per cent.

* Kent's "Mechanical Engineer's Pock Book," page 362.

TABLE 14

Thickness of Plate	Diameter of Hole	Pitch		Efficiency	
		Single Riveting	Double Riveting	Single Riveting	Double Riveting
Inches	Inches	Inches	Inches	Per Cent	Per Cent
$^3/_8$	$^7/_8$	2.04	3.20	57.1	72.7
$^7/_{16}$	1	2.30	3.61	56.6	72.3
$^1/_2$	1	2.14	3.28	53.3	70.0
$^1/_2$	$1^1/_8$	2.57	4.01	56.2	72.0
$^9/_{16}$	1	2.01	3.03	50.4	67.0
$^9/_{16}$	$1^1/_8$	2.41	3.69	53.3	69.5
$^9/_{16}$	$1^1/_4$	2.83	4.42	55.9	71.5
$^5/_8$	1	1.91	2.82	47.7	64.6
$^5/_8$	$1^1/_8$	2.28	3.43	50.7	67.3
$^5/_8$	$1^1/_4$	2.67	4.10	53.3	69.5

Another table of joint efficiencies as given by Dr. Thurston* is as follows, slightly condensed from the original calculation:

TABLE 15

Single riveting

Plate thickness.	$^5/_{16}''$	$^3/_8''$	$^7/_{16}''$	$^1/_2''$	$^5/_8''$	$^3/_4''$	$^7/_8''$	$1''$
Efficiency	.55	.55	.53	.52	.48	.47	.45	.43

Double riveting

Plate thickness.	$^3/_8''$	$^7/_{16}''$	$^1/_2''$	$^3/_4''$	$^7/_8''$	$1''$
Efficiency......	.73	.72	.71	.66	.64	.63

The author has been at considerable pains to compile Tables 16, 17 and 18, giving proportions and efficiencies of single lap, double lap and butt, and triple-riveted butt joints. The highest authorities have been consulted in the computation of these tables and great care exercised in the calculations.

*Thurston's "Manual of Steam Boilers," page 119.

TABLE 16

PROPORTIONS OF SINGLE-RIVETED LAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Efficiency Per Cent
5/16	9/16	1.13	50.5
"	5/8	1.33	53.3
"	11/16	1.55	55.7
3/8	3/4	1.60	53.3
"	7/8	2.04	57.1
7/16	7/8	1.87	53.2
"	1	2.30	56.6
1/2	1	2.14	53.3
"	1 1/8	2.57	56.2
9/16	1	2.01	50.4
"	1 1/8	2.41	53.3
"	1 1/4	2.83	55.9
5/8	1 1/8	2.28	50.7
"	1 1/4	2.67	53.3

It will be noticed that in single-riveted lap joints the highest efficiencies are attained when the diameter of the rivet hole is about 2⅓ times the thickness of the plate, and the pitch of the rivet 2⅜ times the diameter of the hole.

With the double-riveted joint it appears, according to Table 17, that in order to obtain the highest efficiency the joint should be designed so that the diameter of the rivet hole will be from 1⅘ to 2 times the thickness of plate, and the pitch should be from 3⅓ to 3½ times the diameter of the hole. Concerning the thickness of plates Dr. Thurston has this to say:* "Very thin plates cannot be well caulked, and thick plates cannot be safely riveted. The limits are about ¼ of an inch for the lower limit, and ¾ of an inch for the higher limit." The riveting machine, however, overcomes the difficulty with very thick plates.

* Thurston's "Manual of Steam Boilers," page 120.

TABLE 17

PROPORTIONS OF DOUBLE-RIVETED LAP AND BUTT JOINTS

Thickness of Plate	Diameter of Rivet	Pitch of Rivet	Efficiency
5/16 inch	9/16 inch	1.71 inches	67.1 per cent
5/16 "	5/8 "	2.05 "	69.5 "
3/8 "	3/4 "	2.46 "	69.5 "
3/8 "	7/8 "	3.20 "	72.7 "
7/16 "	3/4 "	2.21 "	66.2 "
7/16 "	7/8 "	2.86 "	69.4 "
7/16 "	1 "	3.61 "	72.3 "
1/2 "	1 "	3.28 "	70.0 "
1/2 "	1 1/8 "	4.01 "	72.0 "
9/16 "	1 "	3.03 "	67.0 "
9/16 "	1 1/8 "	3.69 "	69.5 "
9/16 "	1 1/4 "	4.42 "	71.5 "
5/8 "	1 1/8 "	3.43 "	67.3 "
5/8 "	1 1/4 "	4.10 "	69.5 "
3/4 "	1 "	2.50 "	72.0 "
7/8 "	1 1/8 "	3.94 "	74.2 "
1 "	1 1/4 "	4.10 "	76.1 "

The triple-riveted butt joint with two welts, one inside and one outside, has two rows of rivets in double shear and one outer row in single shear on each side of the butt, the pitch of rivets in the outer rows being twice the pitch of the inner rows. One of the welts is wide enough for the three rows of rivets each side of the butt, while the other welt takes in only the two close pitch rows.

When properly designed this form of joint has a high efficiency, and is to be relied upon. Table 18 gives proportions and efficiencies, and it will be noted that the highest degree of efficiency is shown when the diameter of rivet hole is from 1¼ to 1½ times the thickness of plate, and the pitch of the rivets is from 3½ to 4 times the diameter of the hole. This, of course, refers to the pitch of the close rows of rivets, and not the two outer rows.

TABLE 18

PROPORTIONS OF TRIPLE-RIVETED BUTT JOINTS WITH INSIDE AND OUTSIDE WELT

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Pitch of Outer Rows Inches	Efficiency Per Cent
3/8	13/16	3.25	6.5	84
7/16	13/16	3.25	6.5	85
1/2	13/16	3.25	6.5	83
9/16	7/8	3.50	7.0	84
5/8	1	3.50	7.0	86
3/4	1 1/16	3.50	7.0	85
7/8	1 1/8	3.75	7.5	86
1	1 1/4	3.87	7.7	84

Some simple rules are given in Chapter I, Part I, for finding the percentage of efficiency, or in other words the ratio of the strength of the riveted joint to the strength of the solid plate. In those calculations the tensile strength of the rivets was assumed to be 38,000 to 40,000 lbs. per sq. in. The highest efficiency is attained in a riveted joint when the tensile strength of the rods from which the rivets are cut approaches that of the plates, and when the proportions of the joint are such that the tensile strength of the plates, the shearing strength of the rivets, and the crushing resistance of the rivets and plate, for a given section or unit strip, are as nearly equal as it is possible to secure them.

A few examples of calculations for efficiency will be given, taking the three forms of riveted joints in most common use. The following notation will be used throughout:

T.S. = Tensile strength of plate per square inch.
T = Thickness of plate.
C = Crushing resistance of plate and rivets.
A = Sectional area of rivets.
S = Shearing strength of rivets.
D = Diameter of hole (also diameter of rivets when driven).
P = Pitch of rivets.

In the calculations that follow T.S. will be assumed to be 60,000 lbs., S will be taken at 45,000 lbs., and the value of C may be assumed to be 90,000 to 95,000.

Fig. 97 shows a double-riveted lap joint. The style of riveting in this joint is what is known as chain riveting.

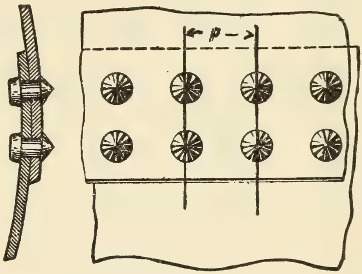


FIGURE 97.

In case the rivets are staggered, the same rules for calculating the efficiency will hold as with chain riveting, for the reason that with either style of riveting the unit strip of plate has a width equal to the pitch or distance *p*, Fig. 97.

The dimensions of the joint under consideration are as follows: P = $3\frac{1}{4}$ in., T = $\frac{7}{16}$ in., D = 1 in. (which is also diameter of driven rivet).

The strength of the unit strip of solid plate is P × T × T.S. = 85,312.

The strength of net section of plate after drilling is P – D × T × T.S. = 59,062.

The shearing resistance of two rivets is 2A × S = 70,686.

The crushing resistance of rivets and plate is $D \times 2 \times T \times C = 78{,}750$.

It thus appears that the weakest part of the joint is the net strip or section of plate, the strength of which is 59,062 and the efficiency = $59{,}062 \times 100 \div 85{,}312 = 69.2$ per cent.

A double-riveted butt joint is illustrated by Fig. 98, and the dimensions are as follows:

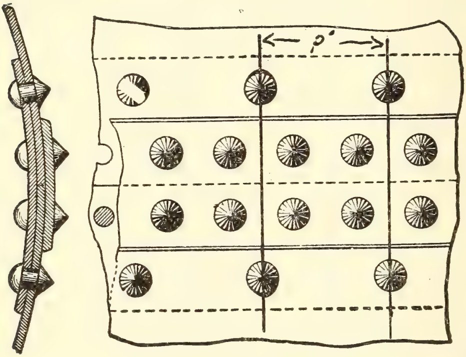


FIGURE 98.

P, inner row of rivets = $2\frac{3}{4}$ in.

P′, outer row of rivets = $5\frac{1}{2}$ in.

T of plate and butt straps = $\frac{7}{16}$ in.

D of hole and driven rivet = 1 in.

Failure may occur in this joint in five distinct ways, which will be taken up in their order.

1. Tearing of the plate at the outer row of rivets. The net strength at this point is $P - D \times T \times$ T.S., which, expressed in plain figures, results as follows: $5.5 - 1 \times .4375 \times 60{,}000 = 118{,}125$.

2. Shearing two rivets in double shear and one in single shear. Should this occur, the two rivets in the inner row would be sheared on both sides of the plate, thus being in double shear. Opposed to this strain there are four sections of rivets, two for each rivet. Then at the outer row of rivets in the unit strip there is the area of one rivet in single shear to be added.

The total resistance, therefore, is $5A \times S$ as follows: $.7854 \times 5 \times 45{,}000 = 176{,}715$.

3. The plate may tear at the inner row of rivets and shear one rivet in the outer row. The resistance in this case would be $P' - 2D \times T \times T.S. + A \times S$ as follows: $5.5 - 2 \times .4375 \times 60{,}000 + .7854 \times 45{,}000 = 127{,}218$.

4. Failure may occur by crushing in front of three rivets. Opposed to this is $3D \times T \times C$, or $1 \times 3 \times .4375 \times 95{,}000 = 124{,}687$.

5. Failure may occur by crushing in front of two rivets and shearing one. The resistance is represented by $2D \times T \times C + 1A \times S$; expressed in figures, $1 \times 2 \times .4375 \times 95{,}000 + .7854 \times 45{,}000 = 118{,}468$.

The strength of a solid strip of plate 5½ in. wide before drilling is $P' \times T \times T.S.$, or $5.5 \times .4375 \times 60{,}000 = 144{,}375$, and the efficiency of the joint is $118{,}125 \times 100 \div 144{,}375 = 81.1$ per cent.

A triple-riveted butt joint is shown in Fig. 99, the dimensions of which are as follows:

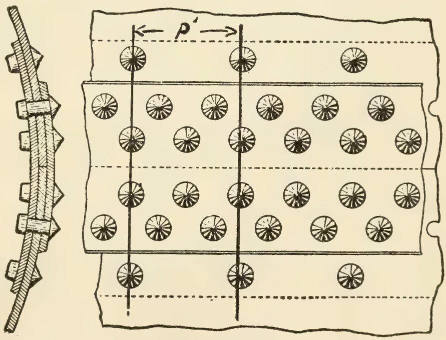


FIGURE 99.

$T = \frac{7}{16}$ in.
$D = \frac{15}{16}$ in.
$A = .69$ in.
$P = 3\frac{3}{8}$ in.
$P' = 6\frac{3}{4}$ in.

Failure may occur in this joint in either one of five ways.

1. By tearing the plate at the outer row of rivets where the pitch is 6¾ in. The net strength of the unit

strip at this point is $P' - D \times T \times T.S.$, found as follows: $6.75 - .9375 \times .4375 \times 60{,}000 = 152{,}578$.

2. By shearing four rivets in double shear and one in single shear. In this instance, of the four rivets in double shear, each one presents two sections, and the one in single shear presents one, thus making a total of nine sections of rivets to be sheared, and the strength is $9A \times S$, or $.69 \times 9 \times 45{,}000 = 279{,}450$.

3. Rupture of the plate at the middle row of rivets and shearing one rivet. Opposed to this strain the strength is $P' - 2D \times T \times T.S. + 1A \times S$, equivalent to $6.75 - (.9375 \times 2) \times .4375 \times 60{,}000 + .69 \times 90{,}000 = 190{,}068$.

4. Crushing in front of four rivets and shearing one rivet. The resistance in this instance is $4D \times T \times C + 1A \times S$, or $.9375 \times 4 \times .4375 \times 90{,}000 + .69 \times 45{,}000 = 178{,}706$.

5. Failure may be caused by crushing in front of five rivets, four of which pass through both the inside and outside butt straps, while the fifth rivet passes through the inside strap only, and the resistance is $5D \times T \times C$, equivalent to $.9375 \times 5 \times 90{,}000 = 184{,}570$.

The strength of the unit strip of plate before drilling is $P' \times T \times T.S.$, or $6.75 \times .4375 \times 60{,}000 = 177{,}187$, and the efficiency is $152{,}578 \times 100 \div 177{,}187 = 86$ per cent.

With the constantly increasing demand for higher steam pressures, the necessity for higher efficiencies in the riveted joints of boilers becomes more apparent, and of late years quadruple and even quintuple-riveted butt joints have in many instances come into use. The quadruple butt joint when properly designed shows a high efficiency, in some cases as high as 94.6 per cent. Fig. 100 illustrates a joint of this kind, and the dimensions are as follows:

$T = \frac{1}{2}$ in.
$D = \frac{15}{16}$ in.
$A = .69$ in.
P, inner rows = $3\frac{3}{4}$ in.
P', 1st outer row = $7\frac{1}{2}$ in.
P'', 2d outer row = 15 in.

The two inner rows of rivets extend through the

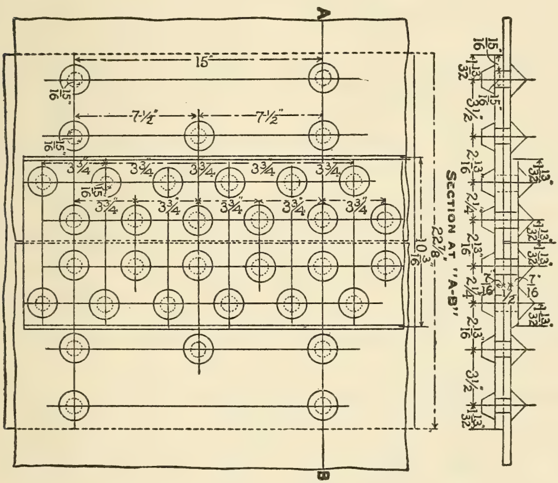


FIGURE 100.

main plate and both the inside and outside cover plates or butt straps.

The two outer rows reach through the main plate and inside cover plate only, the first outer row having twice the pitch of the inner rows, and the second outer row has twice the pitch of the first.

Taking a strip or section of plate 15 in. wide (pitch of outer row), there are four ways in which this joint may fail.

1. By tearing of the plate at the outer row of rivets. The resistance is $P'' - D \times T \times T.S.$, or $15 - .9375 \times .5 \times 60{,}000 = 421{,}875$.

2. By shearing eight rivets in double shear and three in single shear. The strength in resistance is $19A \times S$, or $.69 \times 19 \times 45{,}000 = 589{,}950$.

3. By tearing at inner rows of rivets and shearing three rivets. The resistance is $P'' - 4D \times T \times T.S. + 3A \times S$, or $15 - (.9375 \times 4) \times .5 \times 60{,}000 + .69 \times 3 \times 45{,}000 = 430{,}650$.

4. By tearing at the first outer row of rivets, where the pitch is 7½ in., and shearing one rivet. The resistance is $P'' - 2D \times T \times T.S. + A \times S$, or $15 - (.9375 \times 2) \times .5 \times 60{,}000 + .69 \times 45{,}000 = 424{,}800$.

It appears that the weakest part of the joint is at the outer row of rivets, where the net strength is 421,875. The strength of the solid strip of plate 15 in. wide before drilling is $P'' \times T \times T.S.$, or $15 \times .5 \times 60{,}000 = 450{,}000$, and the efficiency is $421{,}875 \times 100 \div 450{,}000 = 93.7$ per cent.

Staying Flat Surfaces. The proper staying or bracing of all flat surfaces in steam boilers is a highly important problem, and while there are various methods of bracing resorted to, still, as Dr. Peabody says, "the staying of a flat surface consists essentially in holding it against pressure at a series of isolated points which are arranged in regular or symmetrical pattern." The cylindrical shell of a boiler does not need bracing for the very simple reason that the internal pressure tends to keep it cylindrical. On the contrary the internal pressure has a constant tendency to bulge out the flat surface. Rule 2, Section 6, of the rules of the U. S. Supervising Inspectors provides as follows: "No braces or stays hereafter to be employed in the construction of boilers shall be allowed a greater strain than 6,000 lbs. per sq. in. of section."

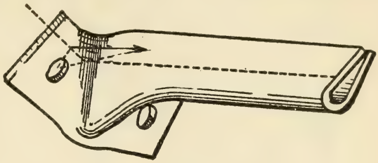


FIGURE 101.

The method to be employed in staying a boiler depends upon the type of boiler and the pressure to be carried. Formerly when comparatively low pressures were used (60 to 75 lbs. per sq. in.) the diagonal crow foot brace was considered amply sufficient for staying the flat heads of boilers of the cylindrical tubular type, both above and below the tubes, but in the present age, when much higher pressures are demanded, through stay rods are largely employed. These are soft steel or iron rods 1¼ to 2 in. in diameter, extending through from head to head, with a pull at right angles to the plate, thus having a great advantage over the diagonal stay in that the pull on the diagonal tay per square inch of section is more than 5 per cent in excess of what a through stay would have to resist under the same conditions of pressure, etc.

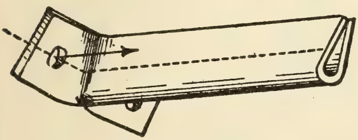


FIGURE 102.

The method of calculation for diagonal bracing is given in Chapter I and will not be discussed here.

The weakest portion of the crow foot brace when in position is at the foot end, where it is connected to the head by two rivets. With a correctly designed brace the pull on these rivets is direct and the tensile strength of the material needs to be considered only, but if the form of the brace is such as to bring the rivet holes above or below the center line of the brace, or if the rivets are pitched too far from the body of the brace, there will be a certain leverage exerted upon the rivets in addition to the direct pull. Fig. 101 shows a brace of incorrect design and Figs. 102 and 103 show braces designed along correct lines.

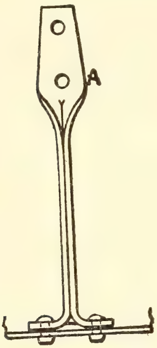


FIGURE 103.

Other methods of staying, besides the crow foot brace and through stays, consist of gusset stays, and for locomotives and other fire box boilers screwed stay bolts are employed to tie the fire box to the external shell. The holes for these stay bolts are punched or drilled before the fire box is put in place. After it is in and riveted along the lower edge to the foundation ring, or mud ring as it is sometimes called, a continuous thread is tapped in the holes in both the outside plate and the fire sheet by running a long tap through both plates. The steel stay bolt is then screwed through the plates and allowed to project enough at each end to permit of its being riveted cold. Stay bolts are liable to be broken by the unequal expansion of the fire box and outer shell, and a small hole should be drilled in the center of the bolt, from the outer end nearly through to the inner end. Then in case a bolt breaks, steam or water will blow out through the small hole, and the break will be discovered at once. The problem of properly staying the flat crown sheet of a horizontal fire box boiler, especially a locomotive boiler, is a very difficult one and has taxed the inventive genius of some of the most eminent engineers.

Before the invention of the Belpaire boiler, with its outside or shell plate flat above the fire box, the only method of staying the crown sheet was by the use of cumbersome crown bars or double girders extending across the top of the crown sheet and supported at the ends by special castings that rest on the edges of the side sheets and on the flange of the crown sheet. At intervals of 4 or 5 in. crown bolts are placed, having the head inside the fire box and the nut bearing on a plate on top of the girder. There is also a thimble for each bolt to pass through, between the top of the crown sheet and the girder. These thimbles maintain the proper distance between the crown sheet and girder and allow the water to circulate freely.

The Belpaire fire box dispenses with girders and permits the use of through stays from the top of the flat outside plate through the crown sheet and secured at each end by nuts and copper washers.

For simplicity of construction and great strength the cylindrical form of fire box known as the Morison corrugated furnace has proved to be very successful. This form of fire box was in 1899 applied to a locomotive by Mr. Cornelius Vanderbilt, at the time assistant superintendent of motive power of the New York Central and Hudson River R. R. This furnace was rolled of ¾-in. steel, is 59 in. internal diameter and 11 ft. 2¼ in. in length. It was tested under an external pressure of 500 lbs. per sq. in. before being placed in the boiler. It is carried at the front end by a row of radial sling stays from the outside plate, and supported at the rear by the back head. Figs. 104 and 105 show respectively a sectional view and an end elevation of

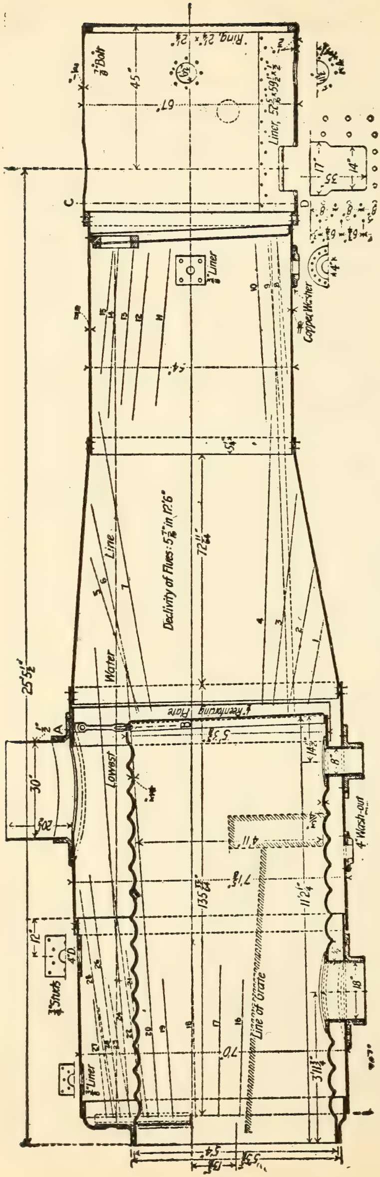


FIGURE 104.

this boiler. It will be seen at once that the question of stays for a fire box of this type becomes very simple. The boiler has proved to be so satisfactory that the company has since had five more of the same type constructed.

Gusset stays are used mainly in boilers of the Lancashire model and are triangular-shaped plates sheared to the proper form and having two angle irons riveted to the edges that come against the shell and the head. The angle irons are then riveted to the shell and the flat head. This form of brace is simple and solid, but its chief defect is, that it is very rigid and does not allow for the unequal expansion of the internal furnace flues and the shell. Fig. 106 illustrates a gusset stay and the method of applying it.

Coming now to through stay rods, it is safe to say that whenever and wherever it is possible to apply them they should be used. In all cases they should

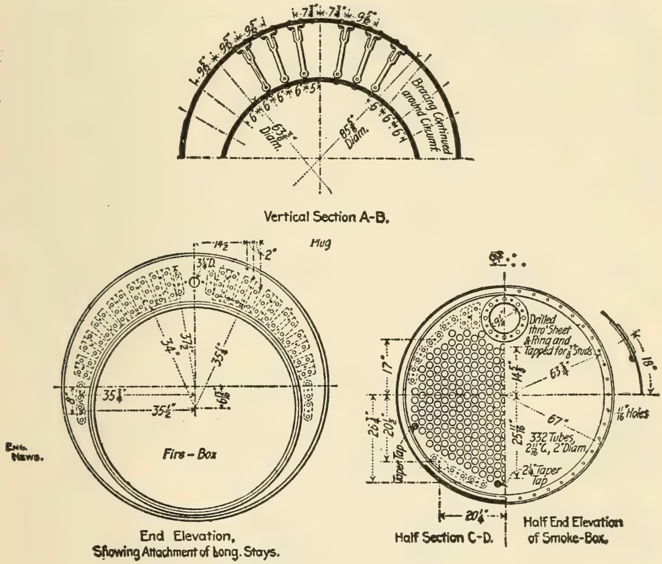


FIGURE 105.

be placed far enough apart to allow a man to pass between them for the purposes of inspection and washing out of the boiler. Through stay rods are usually spaced 14 in. apart horizontally and about the same distance vertically. The ends, as far back as the threads run, are swaged larger than the body, so that the diameter at the bottom of the thread is greater than the diameter of the body. There are several methods of applying through stays. One of the most common, especially for land boilers, is to allow the ends of the rod to project through the plates to be stayed, and holding them in place by a nut and copper washer, both inside and outside the plate. Another and still better plan is to rivet 6-in. channel bars across the head, inside above the tubes, the number of bars depending upon the height of the segment to be stayed.

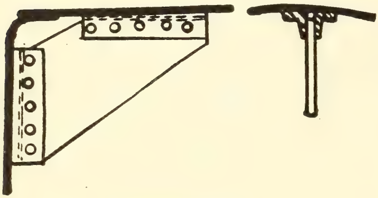


FIGURE 106.

The channel bars are drilled to correspond with the holes that are drilled in the plate to receive the stay rods, which latter are then secured by inside and outside nuts and copper washers.

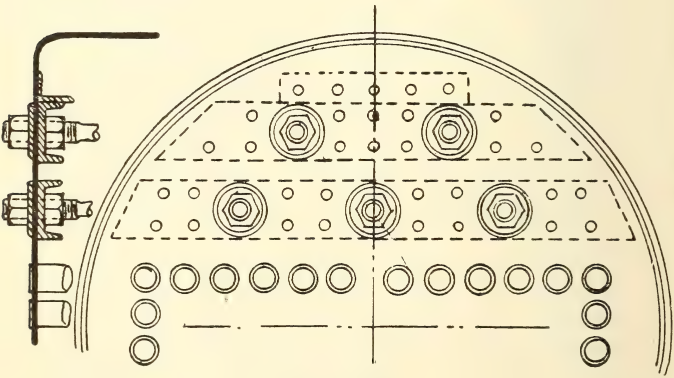


FIGURE 107.

These channel bars act as girders and serve to greatly strengthen the head or flat plate. Fig. 107 will serve to illustrate this method.

Sometimes a combination of channel bar and diagonal crow foot braces is used, as shown by Fig. 108.

A good form of diagonal crow foot stay is obtained by using double crow feet, made of pieces of boiler plate bent as shown by Fig. 109 and riveted to the plate by four rivets. A hole is drilled through the body of the crow foot, and a bolt passing through this secures the forked end of the stay.

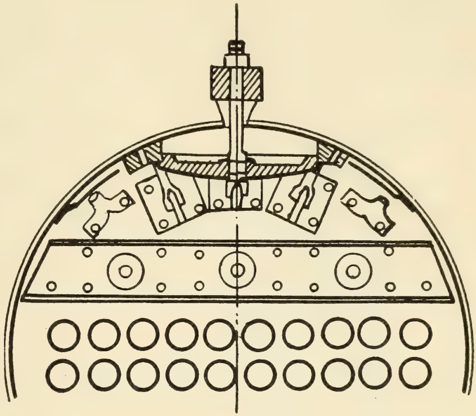


FIGURE 108.

Another method of securing through stays to the heads is shown by Fig. 110 and is applied where too many stay rods would be required to connect all the points to be stayed. A tee iron is first riveted to the flat plate to be stayed, and two V-shaped forgings are bolted to it as shown. The through stay is then bolted to the forgings, and thus two points in the flat head are supported by one stay. It will readily be seen that this method will reduce the number of through stay rods required.

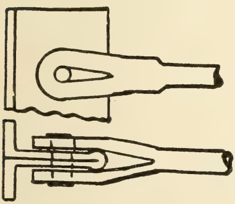


FIGURE 109.

Calculating the Strength of Stayed Surfaces. In calculations for ascertaining the strength of stayed surfaces, or for finding the number of stays required for any given flat surface in a boiler, the working pressure being known, it must be remembered that each stay is subjected to the pressure on an area bounded by lines drawn midway between it and its neighbors. Therefore the area in square inches, of the surface to

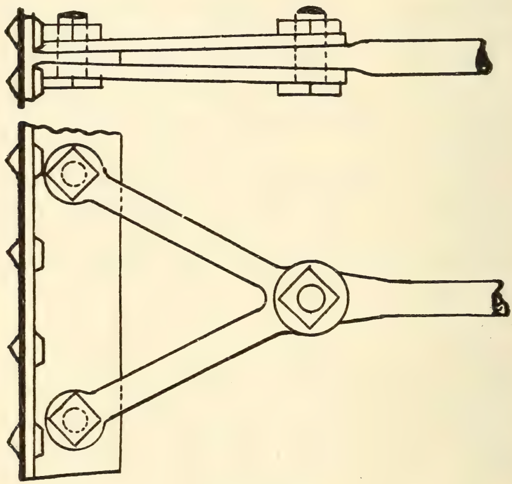


FIGURE 110.

be supported by each stay, equals the square of the pitch or distance in inches between centers of the points of connection of the stays to the flat plate. Thus, suppose the stays in a certain boiler are spaced 8 in. apart, the area sustained by each stay = 8 × 8 = 64 sq. in., or assume the stay bolts in a locomotive fire box to be pitched 4½ in. each way, the area supported by each stay bolt = 4½ × 4½ = 20¼ sq. in. Again taking through stay rods, suppose, for example, the through stays shown in Fig. 107 to be spaced 15 in. horizontally and 14 in. vertically, the area supported by each stay = 15 × 14 = 210 sq. in.

The minimum factor of safety for stays, stay bolts and braces is 8, and this factor should enter into all computations of the strength of stayed surfaces.

The pitch for stays depends upon the thickness of the plate to be supported, and the maximum pressure to be carried.

In computing the total area of the stayed surface it is safe to assume that the flange of the plate, where it is riveted to the shell, sufficiently strengthens the plate for a distance of 2 in. from the shell, also that the tubes act as stays for a space of 2 in. above the top row. Therefore the area of that portion of the flat head or plate bounded by an imaginary line drawn at a distance of 2 in. from the shell and the same distance from the last row of tubes is the area to be stayed. This surface may be in the form of a segment of a circle, as with a horizontal cylindrical boiler, or it may be rectangular in shape, as in the case of a locomotive or other fire box boiler. Other forms of stayed surfaces are often encountered, but in general the rules applicable to segments or rectangular figures will suffice for ascertaining the areas.

The method of finding the area of the segmental portion of the head above the tubes is given in Chapter I, pages 22 and 23, and will not be enlarged upon here, except to add Table 19, which covers a much greater number of segments than Table 1, page 22, does. The diameter of the circle and the rise or height of the segment being known, the area of the segment may be found by the following rule:

Rule. Divide the height of the segment by the

TABLE 19

Areas of Segments of a Circle

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.2	.11182	.243	.14751	.286	.18542	.329	.22509
.201	.11262	.244	.14837	.287	.18633	.33	.22603
.202	.11343	.245	.14923	.288	.18723	.331	.22697
.203	.11423	.246	.15009	.289	.18814	.332	.22792
.204	.11504	.247	.15095	.29	.18905	.333	.22886
.205	.11584	.248	.15182	.291	.18996	.334	.22980
.206	.11665	.249	.15268	.292	.19086	.335	.23074
.207	.11746	.25	.15355	.293	.19177	.336	.23169
.208	.11827	.251	.15441	.294	.19268	.337	.23263
.209	.11908	.252	.15528	.295	.19360	.338	.23358
.21	.11990	.253	.15615	.296	.19451	.339	.23453
.211	.12071	.254	.15702	.297	.19542	.34	.23547
.212	.12153	.255	.15789	.298	.19634	.341	.23642
.213	.12235	.256	.15876	.299	.19725	.342	.23737
.214	.12317	.257	.15964	.3	.19817	.343	.23832
.215	.12399	.258	.16051	.301	.19908	.344	.23927
.216	.12481	.259	.16139	.302	.20000	.345	.24022
.217	.12563	.26	.16226	.303	.20092	.346	.24117
.218	.12646	.261	.16314	.304	.20184	.347	.24212
.219	.12729	.262	.16402	.305	.20276	.348	.24307
.22	.12811	.263	.16490	.306	.20368	.349	.24403
.221	.12894	.264	.16578	.307	.20460	.35	.24498
.222	.12977	.265	.16666	.308	.20553	.351	.24593
.223	.13060	.266	.16755	.309	.20645	.352	.24689
.224	.13144	.267	.16843	.31	.20738	.353	.24784
.225	.13227	.268	.16932	.311	.20830	.354	.24880
.226	.13311	.269	.17020	.312	.20923	.355	.24976
.227	.13395	.27	.17109	.313	.21015	.356	.25071
.228	.13478	.271	.17198	.314	.21108	.357	.25167
.229	.13562	.272	.17287	.315	.21201	.358	.25263
.23	.13646	.273	.17376	.316	.21294	.359	.25359
.231	.13731	.274	.17465	.317	.21387	.36	.25455
.232	.13815	.275	.17554	.318	.21480	.361	.25551
.233	.13900	.276	.17644	.319	.21573	.362	.25647
.234	.13984	.277	.17733	.32	.21667	.363	.25743
.235	.14069	.278	.17823	.321	.21760	.364	.25839
.236	.14154	.279	.17912	.322	.21853	.365	.25936
.237	.14239	.280	.18002	.323	.21947	.366	.26032
.238	.14324	.281	.18092	.324	.22040	.367	.26128
.239	.14409	.282	.18182	.325	.22134	.368	.26225
.24	.14494	.283	.18272	.326	.22228	.369	.26321
.241	.14580	.284	.18362	.327	.22322	.37	.26418
.242	.14666	.285	.18452	.328	.22415	.371	.26514

TABLE 19—*Continued*

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
372	.26611	.405	.29827	.438	.33086	.471	.36373
373	.26708	.406	.29926	.439	.33185	.472	.36471
374	.26805	.407	.30024	.44	.33284	.473	.36571
.375	.26901	.408	.30122	.441	.33384	.474	.36671
.376	.26998	.409	.30220	.442	.33483	.475	.36771
.377	.27095	.41	.30319	.443	.33582	.476	.26871
.378	.27192	.411	.30417	.444	.33682	.477	.36971
.379	.27289	.412	.30516	.445	.33781	.478	.37071
.38	.27386	.413	.30614	.446	.33880	.479	.37171
.381	.27483	.414	.30712	.447	.33980	.48	.37270
.382	.27580	.415	.30811	.448	.34079	.481	.37370
.383	.27678	.416	.30910	.449	.34179	.482	.37470
.384	.27775	.417	.31008	.45	.34278	.483	.37570
.385	.27872	.418	.31107	.451	.34378	.484	.37670
.386	.27969	.419	.31205	.452	.34477	.485	.37770
.387	.28067	.42	.31304	.453	.34577	.486	.37870
.388	.28164	.421	.31403	.454	.34676	.487	.37970
.389	.28262	.422	.31502	.455	.34776	.488	.38070
.39	.28359	.423	.31600	.456	.34876	.489	.38170
.391	.28457	.424	.31699	.457	.34975	.49	.38270
.392	.28554	.425	.31798	.458	.35075	.491	.38370
.393	.28652	.426	.31897	.459	.35175	.492	.38470
.394	.28750	.427	.31996	.46	.35274	.493	.38570
.395	.28848	.428	.32095	.461	.35374	.494	.38670
.396	.28945	.429	.32194	.462	.35474	.495	.38770
.397	.29043	.43	.32293	.463	.35573	.496	.38870
.398	.29141	.431	.32392	.464	.35673	.497	.38970
.399	.29239	.432	.32941	.465	.35773	.498	.39070
.4	.29337	.433	.32590	.466	.35873	.499	.39170
.401	.29435	.434	.32689	.467	.35972	.5	.39270
.402	.29533	.435	.32788	.468	.36072		
.403	.29631	.436	.32887	.469	.36172		
.404	.29729	.437	.32987	.47	.36272		

diameter of the circle. Then find the decimal opposite this ratio in the column headed "Area." Multiply this area by the square of the diameter. The result is the required area.

Example. Diameter of circle = 72 in. Height of segment = 25 in. 25 ÷ 72 = .347, which will be found in the column headed "Ratio," and the area opposite this is .24212. Then .24212 × 72 × 72 = 1,255 sq. in., area of segment.

A boiler is 66 in. in diameter, the working pressure is 100 lbs. per sq. in. The distance from the top row of tubes to the shell is 25 in. Required, the number of diagonal crow foot braces that will be needed to support the heads above the tubes, also the sectional area of each brace. The thickness of the heads is ⅝ in. and the T.S. = 55,000 lbs. per sq. in.

Assume the head to be sufficiently strengthened by the flange for a distance of 2 in. from the shell, the diameter of the circle of which the segment above the tubes requires to be stayed is reduced by 2 + 2 = 4 in. and will therefore be 66 – 4 = 62 in. The rise or height of the segment above the tubes is 25 – 4 = 21 in. Required, the area.* 21 ÷ 62 = .338. Looking down the column headed "Ratio" in Table 19, area opposite .338 is .23358. Area of segment = .23358 × 62 × 62 = 897.88 sq. in. The total pressure on this area will be 897.88 × 100 = 89,788 lbs.

Assume the braces to be made of 1⅛ in. round steel having a T.S. of 50,000 lbs. per sq. in. and to be designed in such a manner as to allow for loss of material in drilling the rivet holes in the crow feet. Each brace will have a sectional area of .994 sq. in., and using 8 as a factor of safety, the strength or safe holding power of each stay may be found as follows: .994 × 50,000 ÷ 8 = 6,212 lbs., and the number of stays required = 89,788 lbs. (total pressure) divided by 6,212 lbs. (strength of each stay) = 14.5, or in round numbers 15. If the stays are made of flat bars of steel the sectional area should equal that of the round stays, and the dimensions of the crow feet of all stays should

* See rule for Table 19.

be such as to retain the full sectional area of the body after the rivet holes are drilled.

Each stay is connected to the plate by two ⅞-in. rivets, having a T.S. of 55,000 lbs. per sq. in. and a shearing strength of 45,000 lbs. per sq. in. These rivets are capable of resisting a direct pull of 10,818 lbs., using 5 as a factor of safety; ascertained as follows: $2A \times 45{,}000 \div 5 = 10{,}818$ = strength of two rivets. They are also subjected to a crushing strain, and the resistance to this is $D \times C \div 5$, which expressed in figures is $.875 \times 90{,}000 \div 5 = 15{,}750$ lbs.

The proper spacing comes next, and is arrived at in the following manner:

Area to be stayed = 897.88 sq. in.

Number of stays = 15.

Area supported by each stay = $897.88 \div 15 = 59.8$ sq. in.

The square root of $59.8 = 7.75$ nearly, which is the distance in inches each way that the stays should be spaced, center to center.

If through stay rods are used in place of diagonal braces for staying the boiler under consideration, the number and diameter of the rods may be ascertained by the following method:

Assuming the heads to be supported by channel bars, as previously described, and that the stays are pitched 14 in. apart horizontally and 13 in. vertically, each stay would be required to support an area of $14 \times 13 = 182$ sq. in., and the number of stays would be $897.88 \div 182 = 4.9$, in round numbers 5. See Fig. 107. The pressure being 100 lbs. per sq. in., the total stress on each stay $= 182 \times 100 = 18{,}200$ lbs. Assume the stay rods to be of soft steel having a T.S. of 50,000 lbs. per sq. in., and using a factor of safety of 8, the sectional area required for each stay will be found as follows: $18,200 \times 8 \div 50,000 = 2.9$ sq. in., and the diameter will be found as follows: $2.9 \div .7854 = 3.69$, which is the square of the diameter, and the square root of $3.69 = 1.9$ in., or practically 2 in. The same methods of calculation are applicable to the staying of the heads below the tubes, also for stay bolts in fire box boilers.

Strength of Unstayed Surfaces. A simple rule for finding the bursting pressure of unstayed flat surfaces is that of Mr. Nichols, published in the "Locomotive," February, 1890, and quoted by Prof. Kent in his "Pocket-book." The rule is as follows: "Multiply the thickness of the plate in inches by ten times the tensile strength of the material used, and divide the product by the area of the head in square inches." Thus,

Diameter of head = 66 in.
Thickness of head = ⅝ in.
Tensile strength = 55,000 lbs.
Area of head = 3,421 sq. in.

$\frac{5}{8} \times 55,000 \times 10 \div 3,421 = 100$, which is the number of pounds pressure per square inch under which the unstayed head would bulge.

If we use a factor of safety of 8, the safe working pressure would be $100 \div 8 = 12.5$ lbs. per sq. in., but as the strength of the unstayed head is at best an uncertain quantity it has not been considered in the foregoing calculations for bracing, except as regards that portion of it that is strengthened by the flange.

In all calculations for the strength of stayed surfaces, and especially where diagonal crow foot stays are used, the strength of the rivets connecting the stay to the flat plate must be carefully considered. A large factor of safety, never less than 8, should be used, and the cross section of that portion of the foot of the stay through which the rivet holes are drilled should be large enough, after deducting the diameter of the hole, to equal the sectional area of the body of the stay.

Dished Heads. In boiler work where it is possible to use dished, or "bumped up" heads as they are sometimes called, this type of head is rapidly coming into use. Dished heads may be used in the construction of steam drums, also in many cases for dome-covers, thus obviating the necessity of bracing. The maximum depth of dish, as adopted by steel plate manufacturers April 4, 1901, is ⅛ of the diameter of the head when flanged, and if the tensile strength and quality of the plate from which the heads are made are the same as those of the shell plate, the dished head becomes as strong as the shell, provided the head has the same thickness or is slightly thicker than the shell plate.

Welded Seams. A few boiler manufacturers have succeeded in making welded seams, thus dispensing with the time-honored custom of riveting the plates together. A good welded joint approaches more nearly to the full strength of the material than can possibly be attained by rivets, no matter how correctly designed the riveted joint may be. The weld also dispenses with the necessity of caulking, and a boiler having a perfectly smooth surface inside, such as would be afforded by welded seams, would certainly be much less liable to collect scale and sediment than would one with riveted joints. But in order to make a success of welded seams the material used must be of the best possible quality, and great care and skill are required in the work.

The Continental Iron Works of Brooklyn, New York, exhibited at the St. Louis World's Fair in 1904 a welded steel plate soda pulp digester without a single riveted joint. The dimensions of this vessel, which may be likened to a cylinder boiler without flues, were as follows: Thickness of plate, ¾ in.; diameter, 9 ft.; length, 43 feet. The heads were dished to the standard depth. The safe working pressure was 125 lbs. per sq. in. It appears not only possible, but probable, that the process of welding boiler joints may in time supplant the older custom of riveting.

CHAPTER II

CARE OF THE BOILER

Washing out the boiler—Duties of the boiler washer—How to prepare a boiler for washing—How to clean and inspect the inside of a boiler—Fusible plugs—Advantage of manholes, giving free access to top and bottom of boiler—Responsibility resting upon the boiler washer—Necessity of keeping water column clean—Scraping the flues—Fire cracks and how to deal with them—Firing up and how it should be done—Danger in too sudden heating up of a boiler—Advantages of filling a recently washed out boiler with warm water—Connecting with the main header and the safest method of procedure.

Washing Out. In order to get the best results from the burning of coal or any other fuel in a boiler furnace it is absolutely necessary to keep the boiler as clean as possible, both inside and outside. In large plants the boiler washer and his helper are detailed to look after this part of the work, and while the job is by no means a very desirable one, it is at the same time a very responsible one, and much depends upon the thoroughness with which the work is done. In small plants, consisting of one or two boilers, the engineer generally has to attend to the details of the work himself, and no matter whether the plant be large or small, the engineer in charge is the man above all others who should be most interested in seeing that thorough work is done, not only as a matter of safety, but for the sake of his reputation as an engineer. The boiler that is to be washed out should be allowed to gradually cool for ten or twelve hours. It will then be in a condition which will permit a man to go inside of it and do effective work, and no boiler can be thoroughly cleaned and inspected unless the boiler washer does go inside.

These remarks apply, of course, to horizontal tubular or flue boilers and water tube boilers having drums large enough for a man to crawl into. Some types of internally fired boilers are provided with man-holes, but the majority of them have only hand-holes into which the hose for washing out may be inserted.

After the water has been allowed to run out, the first step in washing out a boiler is to remove all the loose mud and scale possible by means of a steel scraper fitted to a long handle and introduced through the man-hole in the bottom part of the head. This will prevent the scale from getting into the blow-off pipe and stopping the flow of the water used for washing the boiler. If there is a man-hole on top, the next thing in order is to take the hose in through it and give the sides of the shell and also the tubes a good cleaning.

Sometimes it happens that where an exhaust heater of the open type is used, oil will find its way into the boiler and, mixing with the mud, will form a thick pasty-like substance on the sides of the boiler along the water line. This should be carefully scraped off and removed, as any matter containing oil or grease is a very dangerous thing to have inside a boiler.

After cleaning the upper part of the boiler, it should be inspected for loose braces or rivets. This can best be accomplished by tapping the parts with a light hammer. A solid rivet will give a clear metallic sound, and a little practice will enable one to easily detect the sound of a loose brace or broken rivet.

Signs of corrosion or pitting of the shell along the water line should also be carefully searched for. Fusible plugs, to be effective, must be kept clean, and the only opportunity for cleaning them is at the time of washing out the boiler. Therefore while working on the upper part of the boiler, attention should be given to the fusible plug. If it is one of the ordinary kind, screwed into the back head above the tubes, it should be taken out and cleaned and before replacing it the thread should be well coated with a mixture of cylinder oil and plumbago, which will prevent it from sticking. If the fusible plug is one of the type consisting of a brass tube extending from the top of the shell to the water level, the lower end of this tube should be cleaned of all mud or scale.

Having thus finished above the tubes, the mud and scale should again be scraped from the bottom, after which the hose should be inserted through the front man-hole that should be in every horizontal boiler.

Some authorities argue that a man-hole should not be cut in the bottom part of a boiler head, giving as their reason that it weakens the head, but the logic is not sound, for the reason that the man-hole can be reënforced in such a manner as to make it fully as strong as the solid sheet, and when we consider the great advantage of having a man-hole in the bottom, both as regards washing out and also for repairs, it is plain that it is really a necessity.

After washing out all the loose mud and scale that it is possible to get from the bottom, the boiler washer should next go inside and, with scrapers and tools made for the purpose, he should scrape and chip off all the scale that he can from the bottom, because there is where lies the greatest danger from burnt sheets caused by accumulations of scale preventing the water from getting to the metal. Much good work may be accomplished in this way and no boiler washer should consider the job complete until he has gone through the boiler both top and bottom, and not only cleaned but inspected it. Any loose rivets, broken or loose braces, signs of corrosion or pitting should be at once reported to the chief engineer or superintendent.

It will thus be seen that great responsibility rests with the boiler washer, for the reason that he is the man that is in closest touch with the inside of the boiler, and it is due to the manner in which he does his work inside the boiler whether a defect is discovered and repaired in time or whether it is allowed to go until the result is often a grave disaster. The author desires to enter a plea for this hard-worked and too often underpaid craftsman, and hereby expresses the wish that his services were better appreciated.

The water column or combination should receive particular attention each time the boiler is washed out. The lower pipe leading to the boiler is liable to become clogged with scale, and if not cleaned regularly it is sure to cause trouble by preventing a free flow of the water from the boiler to the gauge glass.

If the boiler is of the horizontal tubular type, the tubes should be scraped inside, and with water tube boilers use the steam jet to blow the soot and ashes from between the tubes. Soot, in addition to choking the draft, is also a non-conductor of heat.

After the hand-hole and man-hole plates have been replaced the boiler may be filled with water to the proper level, and while this is being done it is in order to take a look into the furnace for any broken grates or accumulations of clinkers on the side walls or bridge wall. These clinkers should be chipped off, also the bottom of the boiler should be swept clean of ashes and examined for any defects, such as fire cracks about the rivets most exposed to the heat. These cracks may often exist some time before being discovered unless a close inspection is made. They are small cracks radiating from the rivet holes outward past the rivet heads one-half to three-quarters of an inch, and are always liable to extend farther until they become a source of danger unless arrested in time. They may be closed up sometimes with the caulking tool, but if one should be found several inches in length, a hole should be drilled at the outer end of the crack and a rivet put in. This will generally stop it. Fire cracks occur in the girth seams only, and especially the seam nearest the fire.

It is essential that the bridge walls of horizontal boilers be kept in good repair, in order that as much fire brick surface as possible may be exposed to the heat. This will greatly aid combustion and prevent smoke.

Firing Up. After the boiler washer has completed his task the next thing in order is firing up, and in doing this if care and good judgment are not exercised there is danger of doing much damage to the boiler, especially if it has been filled with cold water. A very light fire should be started at first and kept that way until the water gets to the boiling point at least, after which the fire may be gradually increased until the steam gauge shows a few pounds pressure, when it will be safe to urge the fire still more. The bad effects resulting from the unequal expansion or contraction of the sheets and undue stress upon the rivets, all caused by rapid changes of the temperature of the boiler from hot to cold or vice versa, cannot be guarded against too carefully, and they are liable to be brought about in two ways: first, by haste in cooling down a hot boiler that is to be washed out, and secondly, by starting a heavy fire under a cold boiler. That part of the boiler most exposed to the heat will become hot while other parts farthest removed from the fire may still be cold. Very often there is a difference of 150° or 200° in the temperature of different parts of the boiler for a time during the firing up process, and the same dangerous conditions may be caused also by blowing all the water out of a boiler while under a pressure of 15 or 20 lbs., as is the custom of some persons when preparing a boiler for washing out. Either custom cannot be too strongly condemned.

Sometimes a boiler is needed in a hurry after having been washed out, and in such an emergency it should be filled with warm water; in fact, it is better to always fill a boiler with warm water if it is possible to do so after washing out.

Connecting with the Main Header. When the gauge shows a pressure that is within 10 or 15 lbs. of being the same as that carried on the other boilers it should be watched closely, and when the pressure becomes the same as that in the main the connecting valve should be opened slightly, just sufficient to allow a light flow of steam through it, which can be easily detected by placing the ear near the valve chamber. This steam may be passing from the boiler to the header or vice versa, but whichever way it is going the valve should not be opened any farther until the pressure in the main pipe and in the boiler is equalized, when it will be found that the valve may be opened easily. While connecting the boiler the dampers should be closed.

Care should always be exercised in connecting a recently fired up boiler, and the engineer should be certain that the steam gauge and pop valve are in good working order. Otherwise there is liability of a serious accident occurring, either in breakage of the steam pipe, or what is still worse, a boiler explosion

CHAPTER III

MECHANICAL STOKERS

Principles involved in the action of automatic stokers—Advantages and disadvantages attending their use—Classification and general description of stokers—Coal-handling machinery—Under-feed stokers—Mansfield chain grate stoker—Playford stoker—Vicars mechanical stoker—The Wilkinson stoker—Murphy stoker—Roney stoker—The American under-feed stoker—The Jones under-feed stoker—Outside furnaces—Conditions required in a boiler furnace to ensure good combustion—Hindrances to good combustion—Description of Burke outside furnace.

The principles governing the operation of mechanical or automatic stokers are in the main correct, viz., that the supply of coal and air is continuous and that provision is made for the regulation of the supply of fuel according to the demand upon the boiler for steam; also that the intermittent opening and closing of the furnace doors, as in hand firing, thereby admitting a large volume of cold air directly into the furnace on top of the fire, is avoided.

Mechanical stokers have within the last twelve years been largely adopted in the United States, especially in sections where bituminous coal is the principal fuel. The disadvantages attending their use are:

First, that the cost of properly installing them is so great that their use is practically prohibited to the small manufacturer.

Second, that in case of a sudden demand upon the boilers for more steam the automatic stoker cannot respond as promptly as in hand firing, although this objection could no doubt be met by skillful handling.

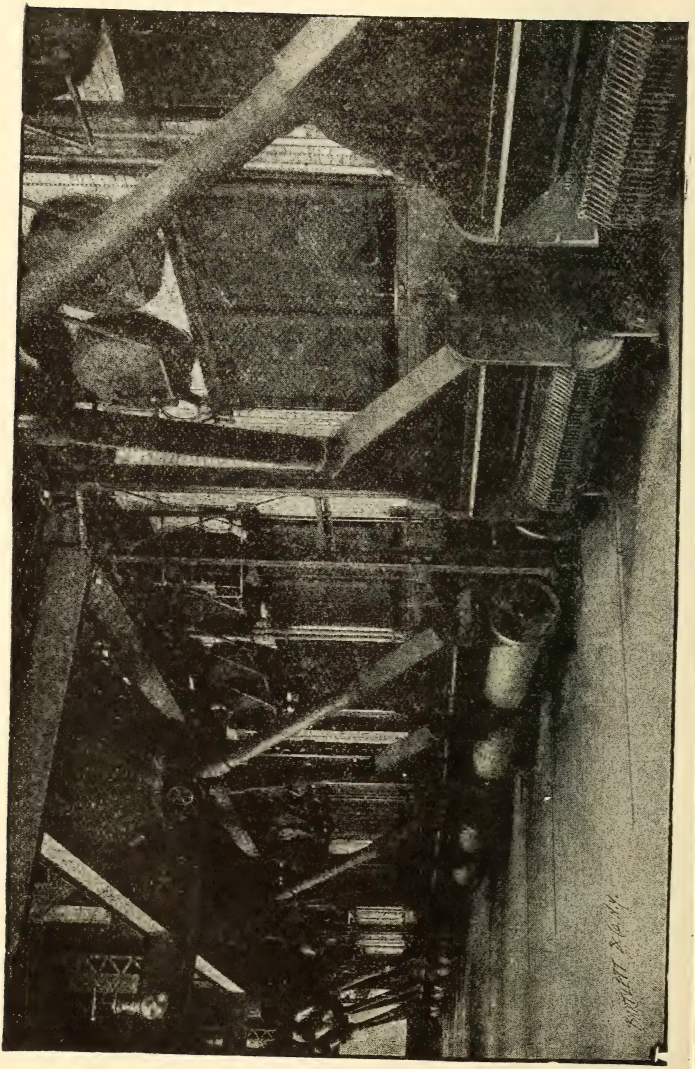
Third, the extra cost for power to operate them, although this is probably offset by the diminished expense for labor required, as compared to hand firing.

There are many different types of mechanical stokers and automatic furnaces, but they may for convenience be grouped into four general classes. In class one the grate consists of an endless chain of short bars that travel in a horizontal direction over sprocket wheels, operated either by a small auxiliary engine or by power derived from an overhead line of shafting in front of the boilers.

In class two may be included stokers having grate bars somewhat after the ordinary type as to length and size, but having a continuous motion up and down or forward and back. This motion, though slight, serves to keep the fuel stirred and loosened, thus preventing the firing from becoming sluggish. The grate bars in this class of stokers are either horizontal or inclined at a slight angle, and their constant motion tends to gradually advance the coal from the front to the back end of the furnace.

Class three includes stokers having the grate bars steeply inclined. Slow motion is imparted to the grates, the coal being fed onto the upper end and forced forward as fast as required.

Class four includes an entirely different type of stoker, in that the fresh coal is supplied underneath the grates, and is pushed up through an opening left for the purpose midway of the furnace. The gases, on being distilled, immediately come in contact with the hot bed of coke on top and the result is good combustion. In this type of stoker steam is the active agent used for forcing the coal up into the furnace, either



by means of a long, slowly-revolving screw, as in the American stoker, or a steam ram, as with the Jones under-feed stoker. A forced draft is employed, and the air is blown into the furnace through tuyeres When these stokers are intelligently handled they give good results, especially with cheap bituminous coal. The clinker formed on the grate bars or dead plates is easily removed.

The coal is supplied to mechanical stokers either by being shoveled by hand into hoppers in front of and above the grates, or, as is the case in most of the large plants using them, it is elevated by machinery and deposited in chutes, through which it is fed to each boiler by gravity. Stokers of the chain grate variety are usually constructed so that they may be withdrawn from underneath the boiler in case repairs are necessary. The coal, either nut or screenings, is fed into a hopper in front of and above the level of the grate, and is slowly carried along towards the rear end. The ash drops from the grate as it passes over the sprocket wheel at the rear.

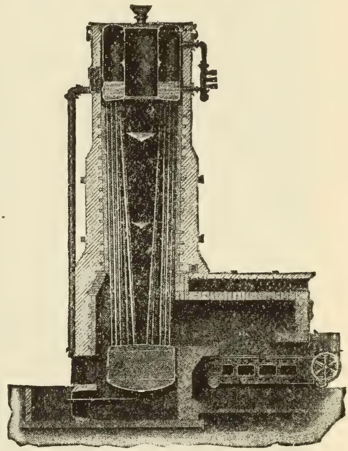


FIGURE 112.
CAHALL VERTICAL BOILER WITH CHAIN GRATE STOKER ATTACHED

Fig. 111 shows a battery of Babcock and Wilcox water tube boilers fitted with chain grate stokers. The buckets for elevating the coal to bins overhead, from whence it is fed by gravity to the stokers, are not shown. These buckets or carriers may also be utilized for conveying the ashes from the boiler-room.

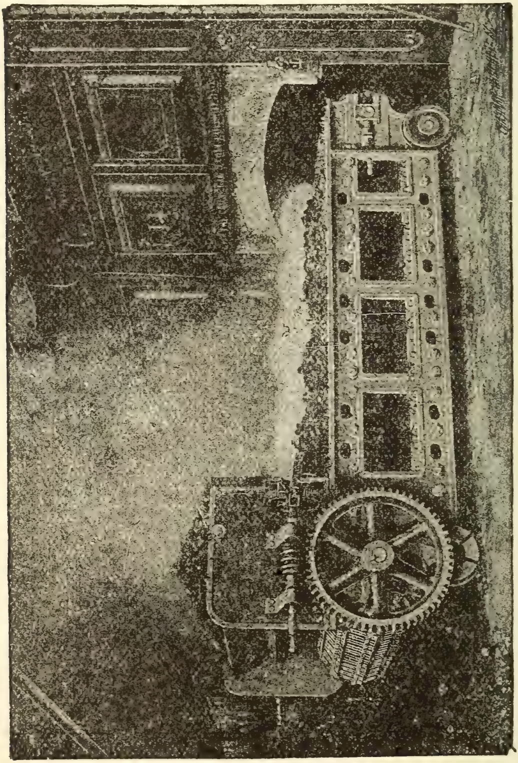


FIGURE 113.
MANSFIELD CHAIN GRATE STOKER, SHOWING HOW IT CAN BE WITHDRAWN FROM UNDER BOILER.

Fig. 112 is a sectional view of a vertical Cahall boiler with a Mansfield chain grate stoker, and Fig. 113 shows the same stoker withdrawn from the boiler.

The Coxe mechanical stoker operates upon the same general principles as do those previously described, being of the chain grate type, but it has in addition a series of air chambers just underneath the upper traveling grate. These air chambers are made of sheet iron and are open at the top and provided with dampers for regulating the air pressure for different sections of the grate. The air blast is supplied by a fan. Another feature of this stoker is a water chamber for the bottom section of the grate to travel through on its return.

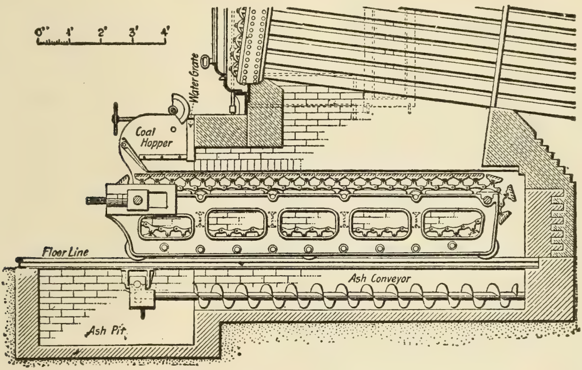


FIGURE 114.

The Playford stoker has wrought iron T bars extending across the furnace and attached to the traveling chains. These T bars carry the small cast iron sections composing the grate. A screw conveyor is also placed in the ash pit for the purpose of carrying the ashes from the rear to the front of the pit. Fig. 114 is a sectional view of the Playford stoker attached to a water tube boiler.

In class two may be included stokers having the grates inclined more or less. In some varieties the grates incline from front to rear, while in others they are made to incline from the side walls towards the center line of the furnace.

In the Vicars mechanical stoker the grate bars are somewhat of the shape of the ordinary grate and lie in two tiers in a horizontal position. The lower or back tier next the bridge wall is stationary and is placed there for the purpose of catching what coal is carried over the ends of the upper or moving grate bars. These have a slow reciprocating motion which gradually moves the hot coke back towards the bridge wall The coal is fed from a hopper into two compartments, from which it is pushed by reciprocating plungers onto a coking plate and from thence it passes to the grate bars. The motion of these bars has several intermediate variations, from a state of rest to a movement of 3½ in. They have a simultaneous movement forward by which the fuel is advanced, but on the return movement the bars act at separate intervals. In this manner the fuel remains undisturbed by the return motion of the grates. Fig. 115 illustrates this stoker.

In the Wilkinson stoker, Fig. 116, the grate bars are hollow and are set at an angle of 20°, the inclination being from front to back. Each bar is stepped along its fire surface and on the rise is perforated with a long, narrow slot. A steam pipe extends along the front of the furnace and from this pipe small branch pipes lead into the ends of the grate bars, which latter are in fact a series of hollow trunks with their front ends open. When in operation a steam blast is admitted to each of the several trunk grate bars through the small branch pipes, and this blast induces an air current of more or less pressure, which finds an outlet through the narrow slots in the stepped fire surface of the grates and directly into and through the burning mass of fuel. A slow reciprocating motion is imparted to the grates by means of cranks and links operated from an overhead shaft; see Fig. 117. These cranks are set alternately at 90° with each other, thus giving a forward movement to one-half of the grate bars while at the same time the other half is moving backward. In this manner the fuel is kept slowly moving down the inclined grates.

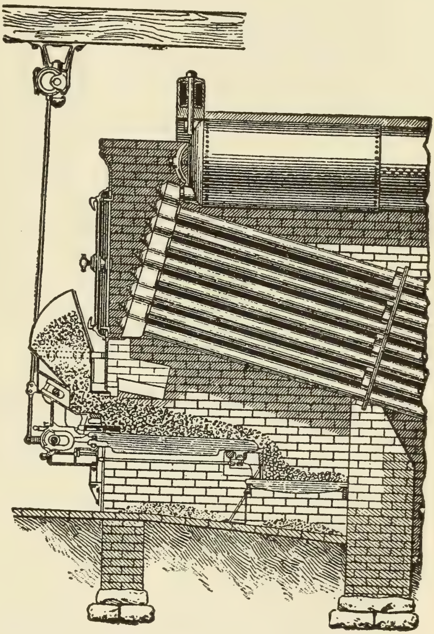


FIGURE 115.

The Murphy Automatic Furnace, a sectional view of which is shown in Fig. 118, has the grates inclined inwards from the side walls, while a fire brick arch is sprung from side to side to cover the entire length of the grate. The coal is shoveled or fed by carrier into the coal magazines, one on each side, as shown in the cut. If the furnace is placed directly under the boiler it necessitates putting these coal magazines within the side walls, but as the Murphy furnace is usually constructed at the present day as an outside furnace, the coal magazines are independent of the boiler walls.

The bottom of each magazine is used as a coking

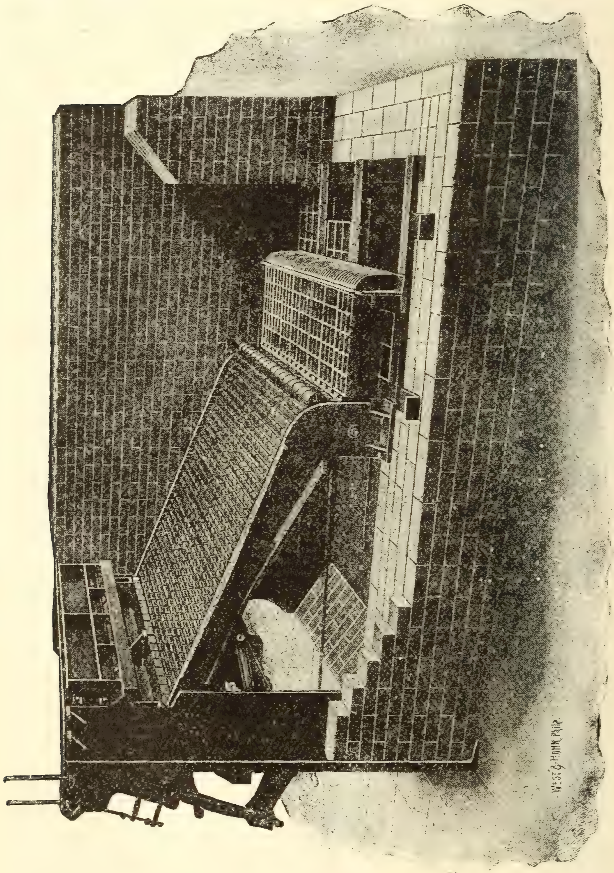


FIGURE 116.
FURNACE VIEW, WILKINSON STOKER.

plate, against which the upper ends of the inclined grates rest. On the central part of this plate is an inverted open box. This is termed the "stoker box," and it is moved back and forth across the face of the coking plate by means of a shaft with pinions that mesh into racks under each end of the box. By means

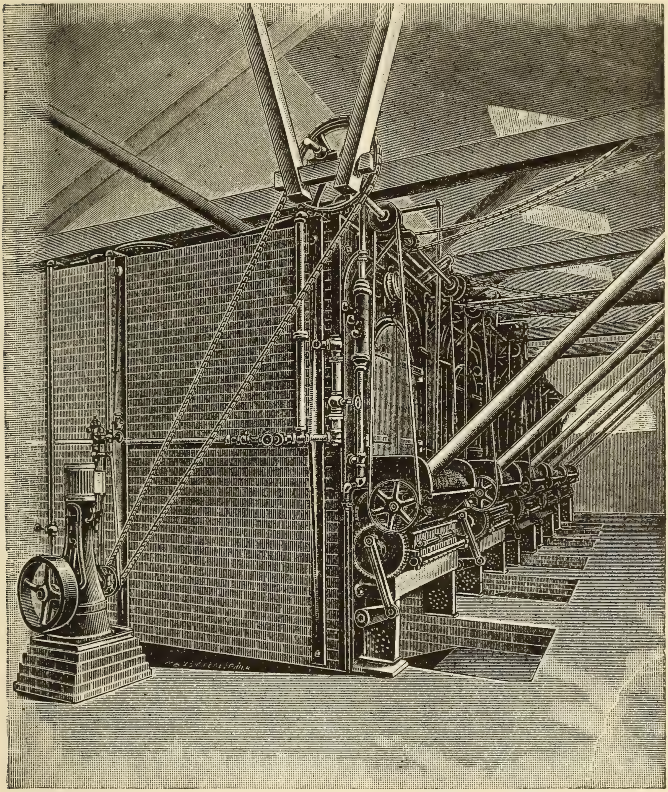


FIGURE 117. WILKINSON STOKER.

of this motion of the stoker boxes the coal is pushed forward to the edge of the coking plate and from thence it slowly passes down over the inclined grates toward the center of the furnace. At this point the slowly rotating clinker breaker grinds the clinker and other refuse and deposits them in the ash pit.

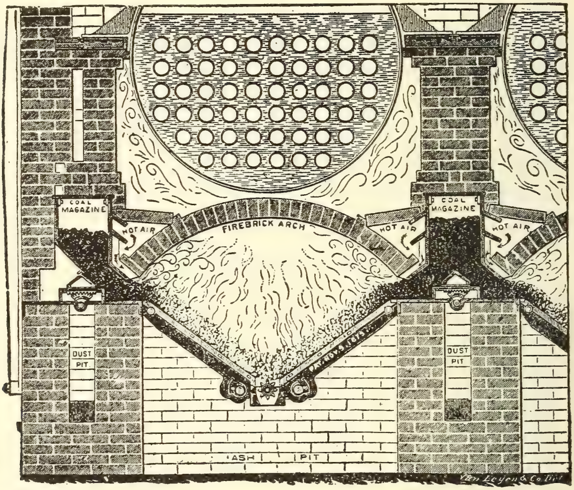


FIGURE 118. THE MURPHY AUTOMATIC FURNACE.

Above the coking plates are the "arch plates," upon which the bases of the fire brick arch rest. These plates are ribbed, the ribs being an inch apart, and, the arch resting upon these ribs, there is thus provided a series of air ducts by means of which the air, already heated by having been admitted in front and passed through the flues over the arch, is conducted into the furnace above the grates and comes directly in contact with the gases rising from the coking fuel. Air is also admitted under the coking plate and, passing up through the grates, serves to keep them cool and also furnishes the needed supply to the burning coke as it slowly moves down toward the center.

The fuel is aided in its downward movement by the constant motion of the grates, one grate of each pair being moved up and down by a rocker at the lower end.

Motion is imparted to the various moving parts of this furnace by means of a reciprocating bar extending across the outside of the entire front, and to which all the working parts are attached by links and levers. This bar is operated by a small engine at one side of the setting, the power required being about one horse-power per furnace.

The Roney stoker consists of a set of rocking stepped grate bars, inclined from the front towards the bridge wall. The angle of inclination is 37°. A dumping grate operated by hand is at the bottom of the incline for the purpose of receiving and discharging the clinker and ash. This dumping grate is divided into sections for convenience in handling.

The coal is fed onto the inclined grates from a hopper in front. The grate bars rock through an arc of 30°, assuming alternately the stepped and the inclined position. Fig. 119 is a sectional perspective view of this stoker and illustrates the working parts.

The grate bars receive their motion through the medium of a rocker bar and connecting rod. A shaft extending across the front of the stoker under the coal hopper carries an eccentric that gives motion to the connecting rod and also to the pusher in the coal hopper. This pusher, working back and forth, feeds the coal over the dead plate onto the grates, and its range of motion is regulated by a feed wheel from no stroke to full stroke, according to the demand for coal. The motion of the grate bars may also be regulated by a sheath nut working on a long thread on the connecting rod. Each grate bar consists of two parts, viz., a cast iron web fitted with trunnions on each end that rest in seats in the side bearer and a fuel plate having the under side ribbed to allow a free circulation of air.

The fuel plate is bolted to the web and carries the

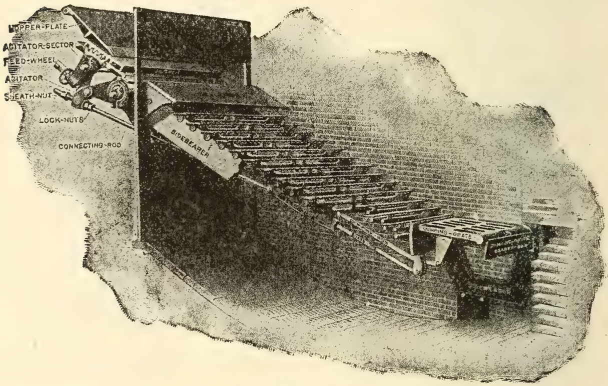


FIGURE 119.
SECTIONAL PERSPECTIVE OF THE RONEY MECHANICAL STOKER.

fuel. The grates lie in a horizontal position across the furnace in the form of steps, and ample provision is made for the admission of air through the slotted webs. A fire brick arch is also sprung across the furnace, covering the upper portion of the grate.

This arch, being heated to a high temperature, serves in a measure to partly coke the coal as it passes under it. Air is also admitted on top of the coal at the front. This air is heated by its passage through a perforated tile over the dead plate and adjoining the fire brick arch. Fig. 120 shows the location of the arch and tile.

In mechanical stokers of the under-feed type the air is supplied by forced draft.

The American stoker consists of a horizontal conveyor pipe into which the coal is fed from a hopper. The diameter of this pipe depends upon the quantity of coal to be burned, and varies from 4½ in. for the smaller sizes up to 9 and 10 in. for the larger sized stokers. The length of the conveyor pipe for the

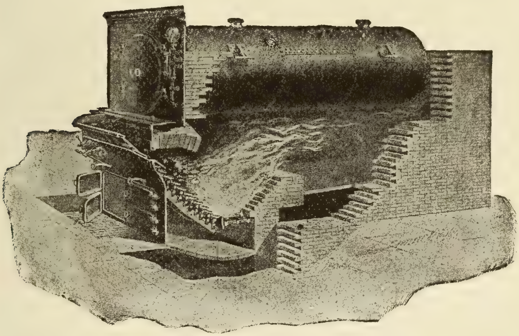


FIGURE 120.

standard 10-in. stoker is 72 in. Attached to the outer end of this conveyor pipe, and forming a part of it, is an iron box containing a reciprocating steam motor which, through the medium of a rocker arm and pawl and ratchet wheel, drives a screw conveyor shaft that slowly revolves within the pipe, thus forcing the coal forward and up through another box or trough, which latter is wholly within the furnace. Extending around the top edges of this box, and on a level with the grate bars, there is a series of tuyeres through which the air is forced.

These tuyeres, being at a high temperature, serve to heat the air in its passage through them, thus greatly

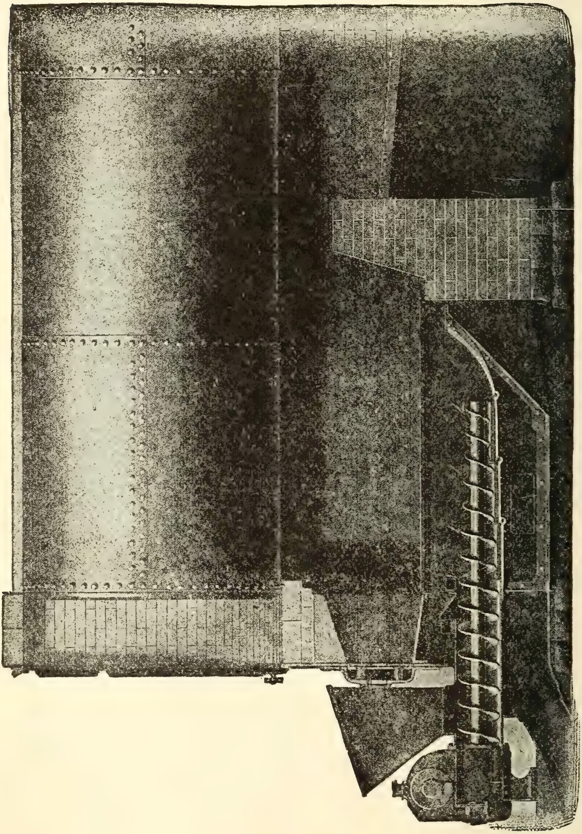


FIGURE 121.
TYPICAL SETTING OF AMERICAN STOKER UNDER A RETURN TUBULAR BOILER.

aiding combustion. Fig. 121 is a longitudinal sectional view of this stoker.

The speed of the screw conveyor is regulated by the hand throttle of the motor, according to the demand for coal. With the 9-in. standard stoker from 350 to 1,200 lbs. of coal per hour may be burned. Fig. 122 is a view of the American stoker before being placed in position in the furnace.

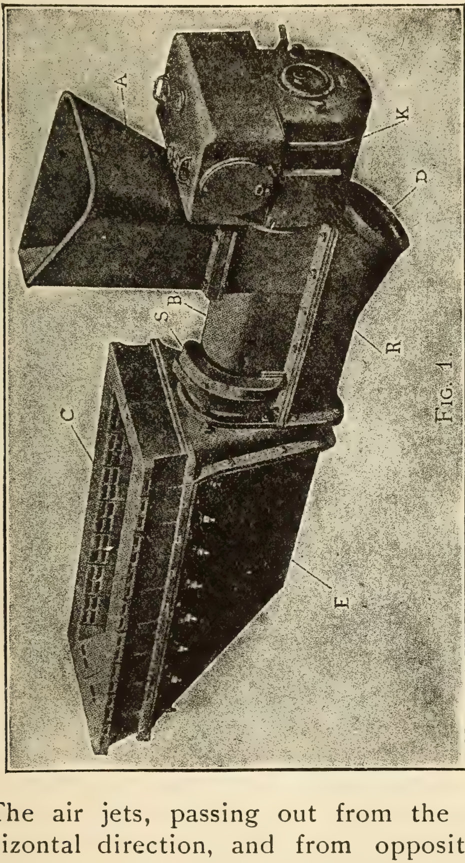


FIGURE 122. STANDARD 8 AND 9 INCH AMERICAN STOKERS.

A. Coal hopper.
B. Conveyor pipe.
C. Tuyeres for introducing air to the fuel.
D. Opening to wind-box for air connections.
E. Wind-box for supplying air to tuyeres.
K. Automatic steam motor for driving conveyor.
R. Air pipe to wind-box.
S. Gas ducts for returning volatile products from entering coal to furnace.

The air jets, passing out from the tuyeres in a horizontal direction, and from opposite sides, cut through the rounded bed of coal and the gases are thus ignited and consumed immediately after being distilled from the coal, while the pressure of the coal rising from underneath forces the already coked fuel over the edges of the trough or box onto the grates which occupy the space between the side walls and the coal trough. The air is first delivered from the fan into the air box that surrounds the coal trough on three sides and from thence it passes to the tuyeres. If this stoker is properly handled very good results may be obtained by its use, but, like all other devices for burning coal under boilers, it is bad policy to endeavor to force it beyond its capacity.

In the Jones under-feed stoker the coal is pushed forward and up into the furnace through a cast iron retort or trough. The impelling force is a steam ram connected to the outer end of the retort, and the speed of the ram is regulated automatically by the steam pressure, or by hand as desired. The coal is supplied to the ram through a cast iron hopper having a capacity of 125 to 140 lbs.

Forced draft is also employed in this stoker, the air being conducted from the fan or blower through galvanized iron pipes into the closed ash pit, which really forms an air box, as the space on either side of the retort that is usually occupied by grate bars is in this case covered by solid cast iron dead plates upon which the coked fuel lies until it is consumed. These plates, being hot, serve to heat the air coming in contact with them in its passage to the cast iron tuyeres through which it passes to the bed of burning fuel in the retort. Air entirely surrounds the retort on the sides and back end, and is at a constant pressure in the ash pit, but can only pass into the furnace through the tuyeres, the jets of air cutting through the rounded heap of incandescent fuel from opposite sides and in a direction inclined upwards.

Coal is supplied to the hopper either by hand, or by mechanical means where the plant is fitted with coal-handling machinery. The opening through which it passes from the hopper to a position in front of the ram is 8 × 10 in. in size. Each charge of the steam

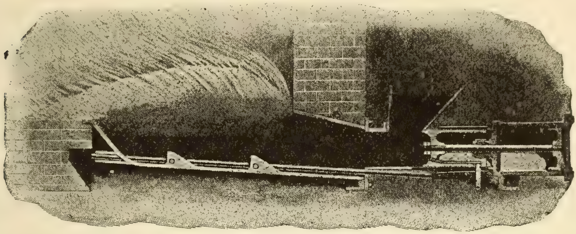


FIGURE 123.

ram carries forward 15 to 20 lbs. of coal. Connected to the ram and moving in conjunction with it is a long rod extending through the retort near the bottom. Upon this rod are carried shoes that act as auxiliary plungers and facilitate the movement of the coal.

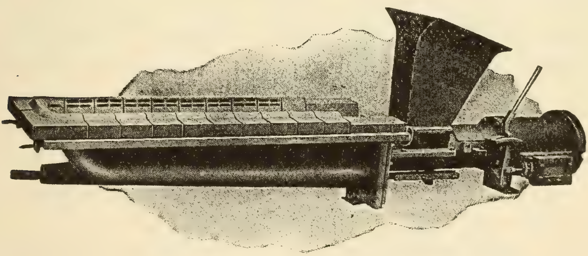


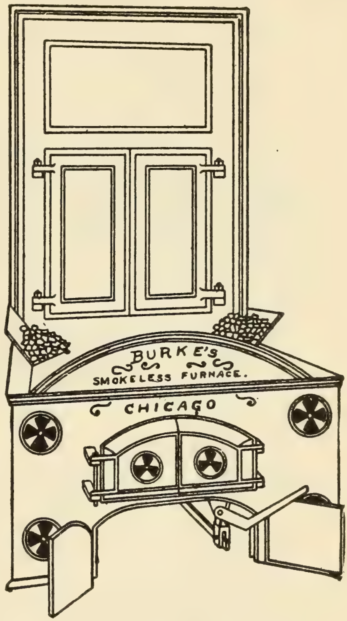
FIGURE 124.

Fig. 123 is a sectional view of the Jones stoker, showing the machine full of coal, with the ram ready to make a charge. Fig. 124 shows the stoker complete before being placed in the furnace.

It is claimed by the builders of under-feed stokers, and the claim appears to have good foundation, that by pushing the green coal up so as to meet the upper crust of glowing fuel the gases on being distilled immediately come in contact with and are consumed by the burning mass, and the formation of smoke is thus prevented. Both the Jones under-feed and the American stokers have proved to be very successful in the burning of the cheaper bituminous coals of the West. One feature tending to commend them is the fact that practically all of the coal is utilized, there being no waste caused by the slack coal or fine screenings dropping through the grate bars into the ash pit unconsumed.

A good substitute for the mechanical stoker is an outside furnace, by which is meant a boiler installation having the furnace in front of instead of underneath the boiler. One of the principal hindrances to good combustion in the ordinary type of boiler furnace is the fact that the temperature of the boiler shell or water tubes with which the gaseous products of combustion come in contact can never be higher than the temperature of the water contained within the boiler. This temperature ranges from 297° for steam at 50 lbs. gauge pressure, up to 407° for 255 lbs. pressure, while the temperature of the furnace, according to Dr. Thurston and other high authorities, ranges from 2,010° to 2,550°.

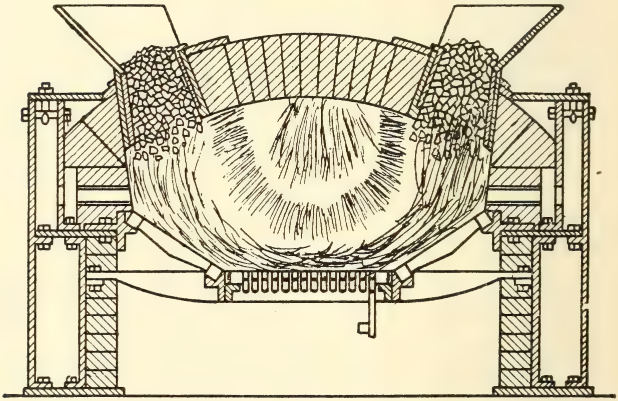
It is evident that perfect combustion does not take place until these high temperatures are reached. Each time the furnace is charged with fresh coal, especially if the boiler be hand-fired, a large volume of volatile gases is liberated but not consumed. If these gases are allowed to immediately come in contact with a comparatively cool surface, as for instance the heating surface of the boiler, the result is a cooling of the gases, incomplete combustion and the formation of smoke and soot. If on the other hand the furnace is so constructed that these gaseous products first impinge against hot surfaces, such as fire brick arches or bafflers that have a temperature corresponding to that of the furnace, good combustion is assured. This condition is in a large degree attained by the use of outside furnaces that permit the construction of a fire brick arch to cover the entire grate surface.



Front View.
FIGURE 125.

The Burke furnace, patented by James V. Burke of Chicago, is a notable example of this type of furnace. It is applicable to any type of stationary boiler. Fig. 125 shows this furnace as applied to tubular boilers. It consists of a fire brick arch extending from 6 to 8 ft. outwards from the boiler front and of a width to correspond to the diameter of the boiler. The arch rests securely upon brick work inclosed in a well ventilated iron casing. There is practically no heat radiated from this furnace, all the heat generated by it passing to the boiler. The central portion of the grate bars consists of shaking grates, while the side bars are stationary and inclined.

Fig. 126 is a sectional view and will serve to illustrate the construction of this furnace. The coal is fed through pockets on top on each side of the arch, the larger furnaces having two pockets on each side and the smaller sizes one. The doors in front are only



CROSS SECTION.
FIGURE 126.

opened for the purpose of cleaning fires or when first starting fires. The air is supplied by way of the ash pit, passing up through the grate bars. A portion of the air supply is also drawn through the ventilators and passes to the upper part of the furnace. The arch extends under the front end of the boiler 6 or 8 in., and there is a bridge wall about 4 ft. back from the front against which the gases from the furnace impinge.

There are 42 sq. ft. of grate surface in the larger sizes, and 22 sq. ft. in the smaller size. Good combustion is attained in this furnace, owing to the fact that the gases as they are distilled from the coal come immediately in contact with the highly heated surface of the arch directly over the fire.

CHAPTER IV

THE STEAM TURBINE

The steam turbine—Lack of information concerning steam turbines—Points of difference between the turbine and the reciprocating engine—Kinetic energy in steam—Hero's steam turbine—Branca's steam turbine—Fundamental principles of the steam turbine—Types of steam turbines built in the United States—The Westinghouse-Parsons turbine—Theoretical velocity of steam exhausting into a vacuum—Relation of bucket speed to steam speed—Speed of the Westinghouse-Parsons turbine—Description of cylinder and blades—Relation of stationary to moving blades—Curvature of blades—Action of the steam within the turbine explained—Balancing pistons—Construction of bearings—A floating journal—Lubrication of bearings—Water seal packing—Speed regulation—Description and diagram of governor—Efficiency of steam turbines—Tests of Westinghouse-Parsons turbines.

Although the turbine principle of utilizing the energy in steam and converting it into useful work has been experimented upon for many years, it is only since the inauguration of the twentieth century that steam turbines have been brought to the front as efficient power producers.

There are to-day in this country four distinct types of steam turbines, each one of which has its own characteristic features distinguishing it from the others, but in each the kinetic energy and velocity of the expanding steam constitute the source of power.

Notwithstanding the fact that much has been said and written during the past four years regarding the steam turbine, the machine is to-day a mystery to thousands of engineers, not because they do not desire information upon the subject, but because of a lack of opportunities for obtaining that information. The author therefore considers that a space devoted to this subject would no doubt be of benefit to his readers.

The piston of the reciprocating engine is driven back

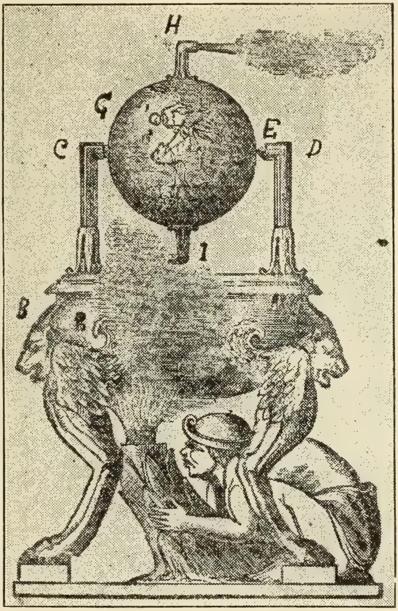


FIGURE 127.

and forth by the static expansive force of the steam, while in the steam turbine not only the expansive force is made to do work, but a still more important element is utilized, viz., the kinetic energy or heat energy latent in the steam and which manifests itself in the rapid vibratory motion of the particles of steam expanding from a high to a lower pressure, and this motion the steam turbine transforms into work.

One of the earliest descriptions of a device for converting the power of steam into work was recorded by Hero, a learned writer who flourished in the city of Alexandria in Egypt, in the second century before Christ. Hero describes a machine called an Æolipile or "Ball of Æolus," illustrated in Fig. 127. B is the boiler under which a fire was made. G is a hollow

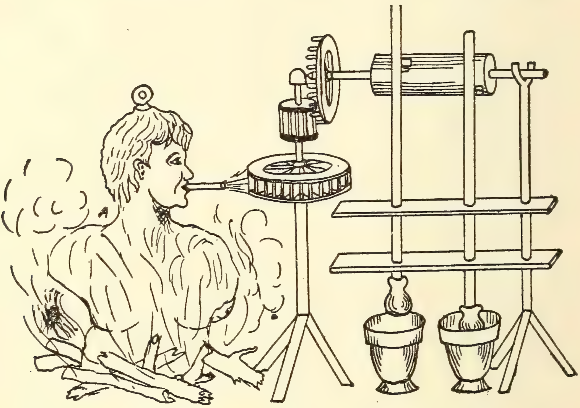


FIGURE 128.

metallic globe that revolved on trunnions C and D, one of which terminated in a pivot at E, while the other was hollow and conveyed the steam generated in the boiler B to the interior of the globe or ball, from which it escaped through the hollow bent tubes H and I, and the reaction of the escaping steam caused the globe to revolve. This was the first steam turbine, and it worked on the reaction principle.

Many centuries later, in the year A.D. 1629, Branca, an Italian, described an engine which marks a change in the method of using the steam. Branca's engine consisted of a boiler A, Fig. 128, from which the steam issued through a straight pipe and impinged upon the vanes of a horizontal wheel carried upon a vertical shaft, causing it to revolve. This device was the germ of the impulse turbine, and these two principles, viz., reaction and impulse, either one or the other and sometimes a combination of both, are the fundamental principles upon which the successful steam turbines of the present age operate.

As previously stated, there are four types of steam turbines being manufactured in this country at present, viz.,

The Westinghouse-Parsons Turbine,
The General Electric Curtis Turbine,
The Hamilton-Holzwarth-Rateau Turbine, and
The De Laval Turbine.

Each will be taken up in its regular order and its distinctive theoretical features studied.

The Westinghouse-Parsons Steam Turbine is fundamentally based upon the invention of Mr. Charles A. Parsons, who, while experimenting with a reaction turbine constructed along the lines of Hero's engine, conceived the idea of combining the two principles, reaction and impulse, and also of causing the steam to flow in a general direction parallel with the shaft of the turbine. This principle of parallel flow is common to all four types of turbines, but is perhaps more prominent in the Westinghouse-Parsons and less so in the De Laval.

A cubic foot of steam under 100 lbs. pressure, if allowed to discharge into a vacuum of 28 in., would attain a theoretical velocity of 3,860 ft. per second and would exert 59,900 ft.-lbs. of energy. A law of turbo mechanics specifies that in order to obtain the highest efficiency in the operation of turbines (whether water or steam) the relation between bucket speed and fluid speed (steam in this case) should be as follows:

For purely impulse wheels, bucket speed equals one-half of jet speed.

For reaction wheels, bucket speed equals jet speed.

Assuming the velocity of the jet of steam issuing from the nozzle to be 4,000 ft. per second, this would mean a peripheral speed of 2,000 ft. per second for an impulse wheel, and for a wheel 1 ft. in diameter the

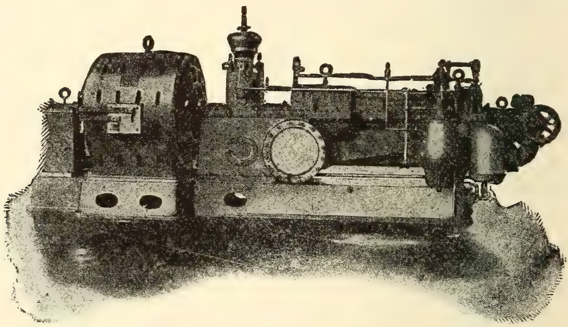


FIGURE 129.

speed would be 38,100 R. P. M. But such a speed is beyond the limits of strength of material.

As before stated, the Westinghouse-Parsons turbine operates on both impulse and reaction principles, and by a system of compounding, which will be explained later on, the peripheral velocity of the machine has been so reduced as to bring it within practical limits while at the same time the power value of the steam is utilized to a high degree of efficiency.

The speed of the Westinghouse-Parsons turbine varies from about 750 R. P. M. for a 5,000 K. W. machine to 3,600 R. P. M. for a 400 K. W. turbine.

Fig. 129 is a general view of a 400 K. W. turbine generator unit. Fig. 130 shows a 600 H. P. machine with the upper half of the cylinder, or stator as it is termed, thrown back for inspection. Fig. 131 is a sectional view of a Westinghouse-Parsons turbine, and it will be noticed that there are three sections or drums, gradually increasing in diameter from the inlet A to

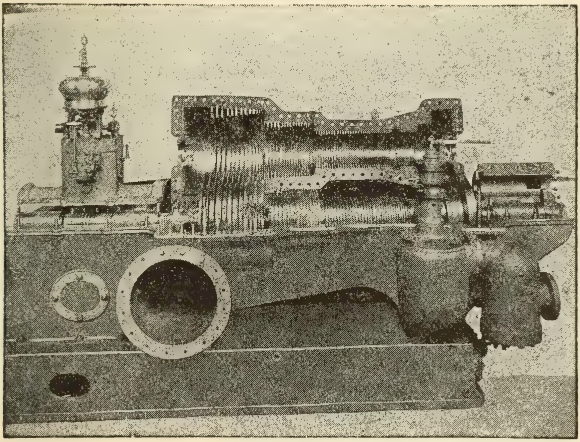


FIGURE 130.

the third and last group of blades. This arrangement may be likened in some measure to the triple compound reciprocating engine.

By reference to Fig. 130 it will be seen that the inside of the cylinder is studded with rows of small stationary blades and that the rotor or revolving part of the machine is also fitted with rows of small blades, similar in shape and dimensions to the stationary blades. When the upper half of the cylinder is in position, each row of stationary blades fits in between two corresponding rows of moving blades. This arrangement may perhaps be better understood by reference to Fig. 132, which illustrates the relation of the stationary blades to the moving blades when in position, and also shows by the arrows the course of the steam and its change of direction caused by the stationary blades.

For the purpose of explanation the moving blades or

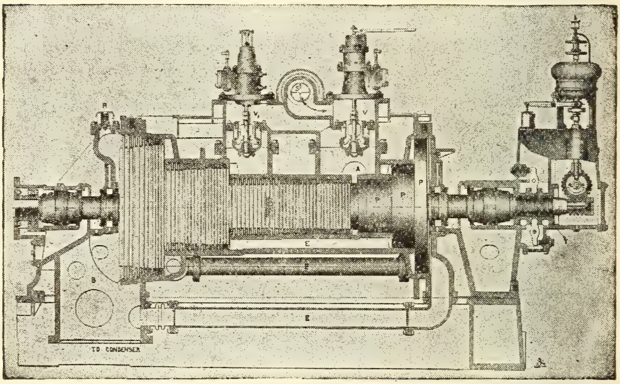


FIGURE 131.

vanes may be considered as small curved paddles projecting from the surface of the rotor, and there is a large number of them, as, for instance, taking a 400 K. W. machine, there are 16,095 moving blades and 14,978 stationary blades, a total of 31,073.

The stationary vanes, as previously explained, project from the inside surface of the cylinder. Both stationary and moving vanes are similar in shape, and are made of hard drawn material, and they are set into their places and secured by a caulking process. The blades vary in size from ½ to 7 in. in length, according to where they are used. Referring to Fig. 130, it will be observed that the shortest blades are placed at what might be termed the steam end of each section or drum of the rotor and cylinder, and that their length gradually increases, corresponding with the increased volume of steam, until a mechanical limit is reached, when a new group of blades begins on a succeeding drum of larger diameter. Referring to Fig. 132, which is a sectional view of four rows of blades, it will

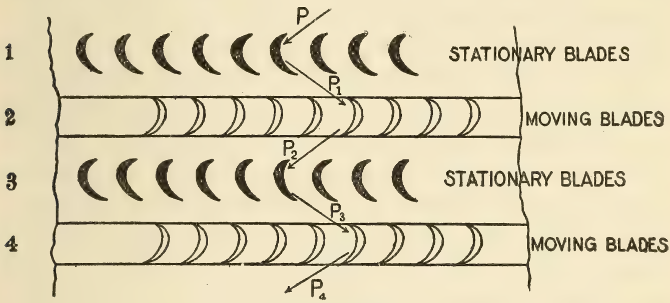


FIGURE 132.

be noticed that all the blades, whether stationary or moving, have the same curvature. Also that the curves are set opposite each other. The reason for this will be apparent as the diagram is studied. The steam at pressure P first comes in contact with row 1 of stationary blades. It expands through this row, and in expanding the pressure falls to P′.

The energy in the steam is converted into velocity, and it impinges upon row 2 of moving blades, driving them around in their course by impulse. A second expansion now occurs in row 2 and again the energy is converted into velocity, but this time the reaction of the steam as it leaves the blades of row 2 also tends to impel them around in their course. The moving blades thus receive motion from two causes—the one due to the impulse of the steam striking them, and the other due to the reaction of the steam leaving them.

This cycle is repeated in rows 3 and 4, and so on throughout the length of the rotor until the exhaust end is reached.

It should be noted that the general direction taken by the steam in its passage through the turbine is in the form of a spiral or screw line about the rotor. The clearance between the blades as they stand in the rows is ⅛ in. for the smallest size blades and ½ in. for the larger ones, gradually increasing from the inlet to the exhaust. In the 5,000 K. W. machine the clearance at the exhaust end between the rows of blades is 1 in. It will thus be seen that there is ample mechanical clearance, also allowance for lateral motion for adjustment of the rotor, although this is very slight, as the rotor is balanced at all loads and pressures by the balancing pistons PPP, Fig. 131, to which reference is now made. These pistons revolve within the cylinder, but do not come in mechanical contact with it; consequently there is no friction. The diameter of each piston corresponds to the diameter of one of the three drums.

The steam entering the chamber A through valve V presses against the turbine blades and goes through doing work by reason of its velocity. It also presses equally in the opposite direction against the first piston P, and so the shaft or rotor has no end thrust. On leaving the first group of blades and striking the second group the pressure in either direction is again equalized by the balance port E allowing the steam to press against the second balance piston P. The same event occurs at group three, the steam acting upon the third piston P.

The areas of the balancing pistons are such that, no matter what the load may be or what the steam pressure or exhaust pressure may be, the correct balance is maintained and there is practically no end thrust. Below is shown a pipe E connecting the back of the balancing pistons with the exhaust chamber. This arrangement is for the purpose of equalizing the pressure at this point with the pressure in the exhaust chamber B.

It might be thought that the blades, on account of their being so light and thin, would wear out very fast, but experience so far shows that they do not. This may be accounted for in two ways. First, the reduction of the velocity of the steam, the highest velocity in the Parsons turbine not exceeding 600 ft. a second; secondly, the light steam thrust on each blade, said to be equal to about 1 oz. avoirdupois. This is far within the bending strength of the material. A steam strainer is also placed in the admission port, to prevent all foreign substances from entering the turbine.

A rigid shaft and thrust or adjustment bearing accurately preserves the clearances, which are larger in this turbine than in other types, owing to the fact that the entire circumference of the turbine is constantly filled with working steam when in operation.

The bearings shown in Fig. 131 are constructed along lines differing from those of the ordinary reciprocating engine. The bearing proper is a gun metal sleeve that is prevented from turning by a loose-fitting dowel. Outside of this sleeve are three concentric tubes having a small clearance between them. This clearance is kept constantly filled with oil supplied under light pressure, which permits a vibration of the inner shell or sleeve and at the same time tends to restrain or cushion it. This arrangement allows the shaft to revolve about its axis of gravity, instead of the geometrical axis, as would be the case if the bearing were of the ordinary construction. The journal is thus to a certain degree a floating journal, free to run slightly eccentric according as the shaft may happen to be out of balance.

A flexible coupling is provided, by means of which the power of the turbine is transmitted to the dynamo or other machine it is intended to run. The oil from all the bearings drains back into a reservoir, and from there it is forced up into a chamber, where it forms a static head, which gives a constant pressure of oil on all the bearings. A secondary valve is located at Vs, by means of which high pressure steam may be admitted to the steam space E on the same principle that high pressure steam is admitted to the low pressure cylinder of a compound engine. This valve opens automatically in cases of emergency, such as overload, failure of the condenser to work, etc.

The shaft, where it passes through either cylinder head, is packed with a water seal packing, consisting of a small paddle wheel attached to the shaft, which, through centrifugal action, maintains a static pressure of about 5 lbs. per sq. in. in the water seal, thus preventing all leakage while at the same time it is frictionless.

The speed of the Westinghouse-Parsons turbine is regulated by a fly ball governor constructed in such manner that a very slight movement of the balls serves to produce the required change in the supply of steam. Fig. 133 is a diagram of the governor mechanism. The ball levers swing on knife edges instead of pins. The governor works both ways, that is to say, when the levers are oscillating about their mid position a head of steam corresponding to full load is being admitted to the turbine, and a movement from this point, either up or down, tends to increase or to decrease the supply of steam.

Referring to Fig. 133, B is a piston directly con-

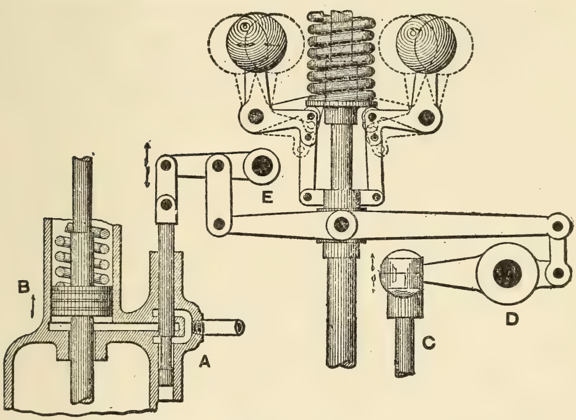


FIGURE 133.

nected to the admission valve. Steam is admitted to this piston under control of the pilot valve A, which has a slight but continuous reciprocating motion derived from the eccentric rod C, and the function of the governor is to vary the plane of oscillation of this valve, thus causing it to admit more or less steam to piston B. The admission valve, being actuated exclusively by piston B, is thus caused to remain open for a longer or shorter period of time, according to the load upon the turbine.

The vibrations of the admission valve, although very slight, are continuous and regular, about 165 per minute, and are transmitted primarily by means of an eccentric, the rod of which is shown at C, Fig. 133.

The governor sleeve is used as a floating fulcrum, and the points D and E are fixed. By means of this very ingenious device the steam is admitted to the turbine in puffs, either long or short, according to the demand for steam. At full load the puffs merge into an almost continuous blast. When the load has increased to the point where the valve is wide open continuously, a full head of steam is being admitted. Beyond this the secondary valve comes into action, thus keeping the speed up to normal.

The rotor requires perfect balancing to insure quiet running, but this is easily accomplished in the shop by means of a balancing machine used by the builders.

Steam turbines generally show higher efficiency in the use of steam than reciprocating engines do, and this fact is due to three leading causes. First, it is possible with the turbine to use highly superheated steam which, owing to the difficulties attending lubrication, could not be used in the reciprocating engine. Second, a larger proportion of the heat contained in the steam is converted into work, for the reason that the steam is allowed to expand to a much lower pressure and into a higher vacuum. In addition to this, the velocity of the expanding steam is utilized in a much higher degree in the turbine as compared with the reciprocating engine. Third, mechanical friction or lost work is reduced to the minimum. Unde test a 400 K. W. Westinghouse-Parsons steam turbine, using steam at 150 lbs. initial pressure and superheated about 180°, consumed 11.17 lbs. of steam per Brake horse power hour at full load. The speed was 3,550 R. P. M. and the vacuum was 28 in. With dry saturated steam the consumption was 13.5 lbs. per B. H. P. hour at full load, and 15.5 lbs. at one-half load.

A 1,000 K. W. machine, using steam of 150 lbs. pressure and superheated 140°, exhausting into a vacuum of 28 in., showed the very remarkable economy of 12.66 lbs. of steam per E. H. P. per hour.

A 1,500 K. W. Westinghouse-Parsons turbine, using dry saturated steam of 150 lbs. pressure with 27 in. vacuum, consumed 14.8 lbs. steam per E. H. P. hour at full load, and 17.2 lbs. at one-half load.

CHAPTER V

THE CURTIS STEAM TURBINE

The Curtis turbine an impulse and reaction machine—Admission of the steam—System of expanding nozzles—Ratio of expansion in four stage machine—Step bearing—Method of lubrication—Action of the steam in a two stage machine—Static force, and force of velocity compared—Speed regulation in Curtis turbine—Accomplished in first group of nozzles—How admission of steam is controlled—Velocity of the steam is constant, with light or full load—Two main sources of economy in the steam turbine—Efficiency tests of Curtis turbine.

In the Curtis turbine the heat energy in the steam is imparted to the wheel, both by impulse and reaction, but the method of admission differs from that of the Westinghouse-Parsons in that the steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs., from which it further expands to atmospheric pressure in passing through the wheels and intermediates. From the pressure in the first stage the steam again expands through the larger area of the second stage nozzles to a pressure slightly greater than the condenser vacuum at the entrance to the second set of moving blades, against which it now impinges and passes through still doing work, due to velocity and mass.

From this stage the steam passes to the condenser. If the turbine is a four-stage machine and the initial pressure is 180 lbs., the pressure at the different stages would be distributed in about the following manner: Initial pressure, 180 lbs.; first stage, 50 lbs.; second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

The Curtis turbine is built by the General Electric Co. at their works in Schenectady, New York, and Lynn, Mass. The larger sizes are of the vertical type, and those of small capacity are horizontal.

Fig. 134 gives a general view of a 5,000 K. W. turbine and generator. The generator is shown at the top, while the turbine occupies the middle and lower section. A portion of the inlet steam pipe is shown, ending in one nozzle group at the side. There are three groups of initial nozzles, two of which are not shown. The revolving parts of this unit are set upon a vertical shaft, the diameter of the shaft corresponding to the size of the unit. For a machine having the capacity of the one illustrated by Fig. 134 the diameter of the shaft is 14 in.

The shaft is supported by and runs upon a step bearing at the bottom. This step bearing consists of two cylindrical cast iron plates, bearing upon each other and having a central recess between them into which lubricating oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath. A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as

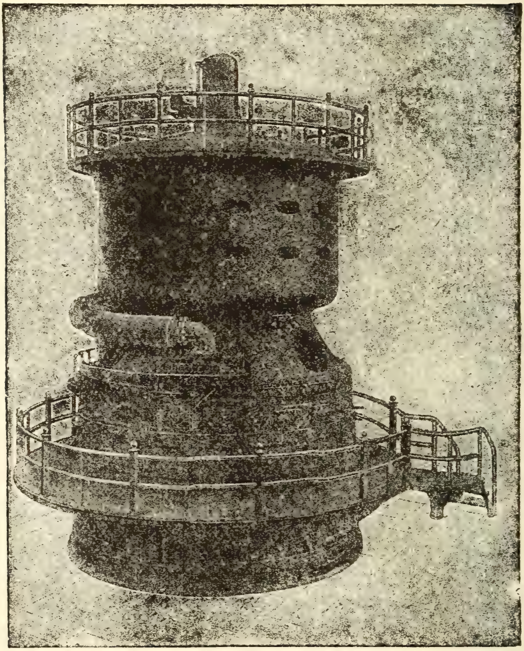


FIGURE 134.

5,000 K.W. CURTIS STEAM TURBINE DIRECT CONNECTED TO 5,000 K.W. THREE-PHASE ALTERNATING CURRENT GENERATOR.

the step bearing pumps have proven, after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings, one just above the step, one between the turbine and generator, and the other near the top. These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a con-

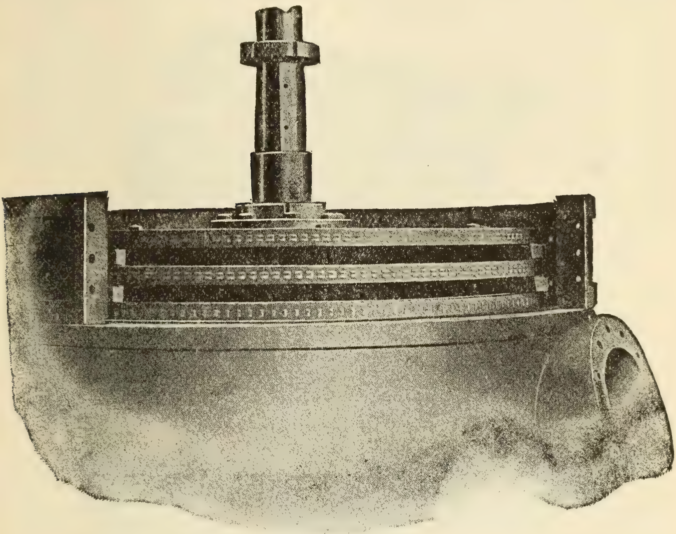
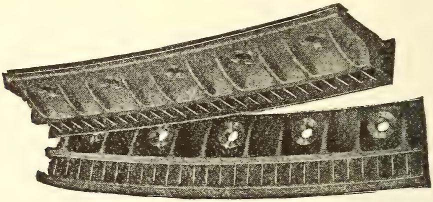


FIGURE 135.
500 K.W. CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION.

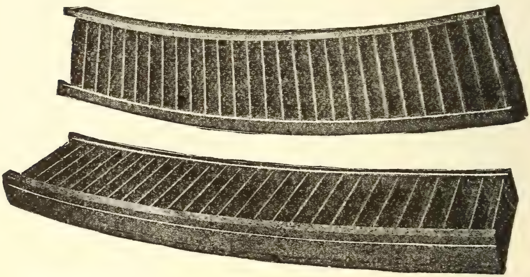
sequence, therefore, the clearances are reduced to the minimum.

The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades, bolted to the inner walls of the cylinder or casing. As in the Westinghouse-Parsons type, the function of the stationary blades is to give direction to the flow of steam.

Fig. 135 illustrates one stage of a 500 K. W. turbine in course of construction. It will be observed that there are three wheels, and that in the spaces between these wheels the stationary buckets or vanes are



REVOLVING BUCKETS FOR CURTIS STEAM TURBINE.



STATIONARY BUCKETS FOR CURTIS STEAM TURBINE.
FIGURE 136.

placed, being firmly bolted to the casing. Fig. 136 shows sections of both revolving and stationary buckets ready to be placed in position. The illustration in Fig. 135 shows the lower or last stage. The clearance between the revolving and stationary blades is from $\frac{1}{32}$ to $\frac{1}{16}$ in., thus reducing the wastage of steam to a very low percentage. The diameters of the wheels vary according to the size of the turbine, that of a 5,000 K. W. machine being 13 ft.

Fig. 137 shows a nozzle diaphragm with its various openings, and it will be noted that the nozzles are set at an angle to the plane of revolution of the wheel.

Fig. 138 is a diagram of the nozzles, moving blades and stationary blades of a two-stage Curtis steam turbine. The steam enters the nozzle openings at the top, controlled by the valves shown, the regulation of which will be explained later on. In the cut Fig. 138 two of the valves are open, and the course of the steam through the first stage is indicated by the arrows.

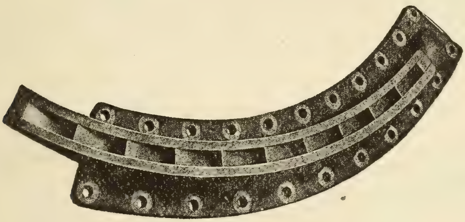


FIGURE 137. NOZZLE.

After passing successively through the different sets of moving blades and stationary blades in the first stage, the steam passes into the second steam chest. The flow of steam from this chamber to the second stage of buckets is also controlled by valves, but the function of these valves is not in the line of speed regulation but for the purpose of limiting the pressure in the stage chambers, in a manner somewhat similar to the control of the receiver pressure in a two-cylinder or three-cylinder compound reciprocating engine.

The valves controlling the admission of steam to the second and later stages differ from those in the first group in that they partake more of the nature of slide valves and may be operated either by hand or automatically; in fact, they require but very little regulation,

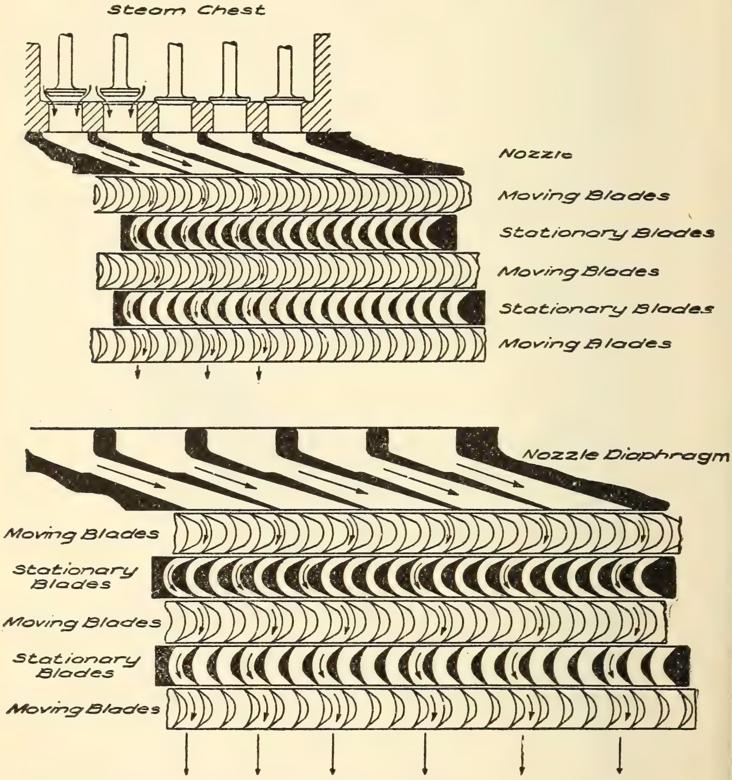


FIGURE 138.

DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE.

as the governing is always done by the live steam admission valves.

Action of the Steam in a Two-stage Machine. As previously stated, the steam first strikes the moving blades in the first stage of a two-stage machine at a pressure of about 15 lbs. above atmospheric pressure, but with great velocity. From this wheel it passes to the set of stationary blades between it and the next lower wheel. These stationary blades change the direction of flow of the steam and cause it to impinge the buckets of the second wheel at the proper angle.

This cycle is repeated until the steam passes from the first stage into the receiving chamber or steam chest for the second stage. Its passage from this chamber into the second stage is controlled by valves, which, as before stated, are regulated either by hand or automatically. The course of the steam through the nozzles and blades of the second stage is clearly indicated by the arrows, and it will be noted that steam is passing through all the nozzles.

At this point it might be well to consider the question which no doubt arises in the mind of the student in his efforts to grasp the underlying principles in the action of the steam turbine. Why is it that the impingement of the steam, at so low a pressure, against the blades or buckets of the turbine, imparts such a large amount of energy to the shaft?

The answer is, because of velocity, and a good example of the manner in which velocity may be made to increase the capacity of an agent to do work is illustrated in the following way: Suppose that a man is standing within arm's length of a heavy plate glass window and that he holds in his hand an iron ball weighing 10 lbs. Suppose the man should place the ball against the glass and press the same there with all the energy he is capable of exerting. He would make very little, if any, impression upon the glass. But suppose that he should walk away from the window a distance of 20 ft. and then exert the same amount of energy in throwing the ball against the glass, a different result would ensue. The velocity with which the ball would impinge the surface of the glass would no doubt ruin the window. Now, notwithstanding the fact that weight, energy and time involved were exactly the same in both instances, yet a much larger amount of work was performed in the latter case. owing to the added force imparted to the ball by the velocity with which it impinged against the glass.

Speed Regulation. The governing of speed is accomplished in the first set of nozzles, and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. This governor, by a very slight movement, imparts motion to levers, which in turn work the valve mechanism. The admission of steam to the nozzles is controlled by piston valves, which are actuated by steam from small pilot valves which are in turn under the control of the governor. Fig. 139 shows the form of governor for a 5,000 K. W. turbine, and Fig. 140 shows the electrically operated admission valves for one set of nozzles.

Speed regulation is effected by varying the number of nozzles in flow, that is, for light loads fewer nozzles are open and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

The Curtis Steam Turbine is the result of the investigations and experiments of Mr. C. G. Curtis of New

York, and while retaining the advantage of the expanding nozzle of De Laval, it at the same time utilizes the energy acquired by velocity, by causing the steam to

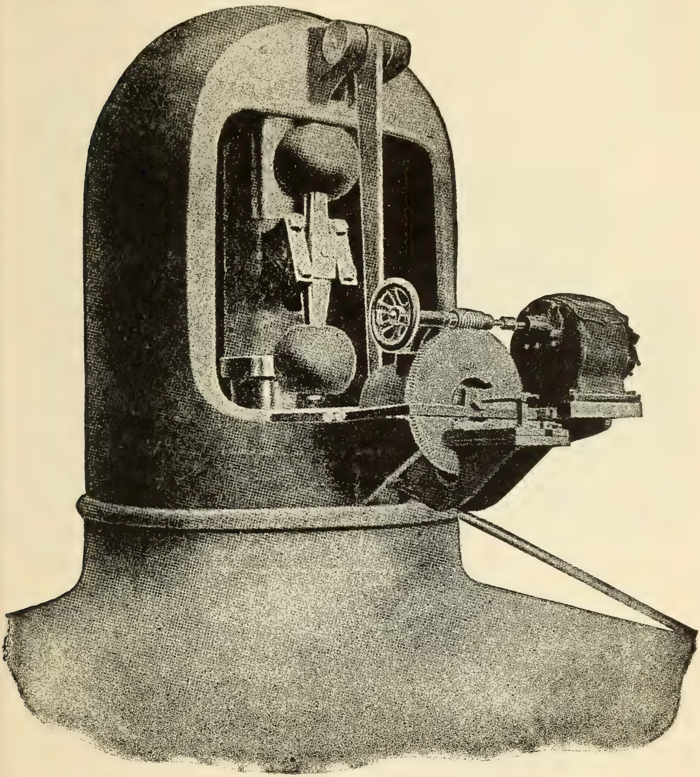


FIGURE 139. GOVERNOR FOR 5,000 K.W. TURBINE.

impinge the moving buckets of two or more wheels in succession. A portion of this velocity force is given up in the first stage, and another portion in the second stage, and this process is repeated, the steam in each case being first caused to expand in divergent nozzles and thus acquire new velocity before it is allowed to impinge the moving blades of the next lower stage. The pressure in each succeeding stage of expansion becomes lower and lower, until finally vacuum is reached.

As previously stated, two of the main sources of economy that the steam turbine possesses in a much higher degree than does the reciprocating engine are: first, its adaptability for using superheated steam, and second, the possibility of maintaining a higher degree of vacuum.

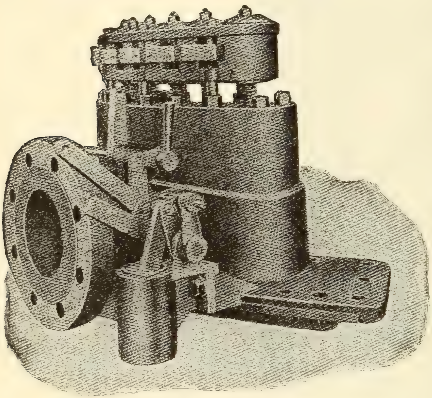


FIGURE 140. ELECTRICALLY OPERATED VALVE.

The efficiency shown by the steam turbine is certainly remarkable, and one peculiar feature regarding the machine is, that its efficiency is not affected by variations in load to the same degree as is the efficiency of the reciprocating engine.

A 600 K. W. Curtis turbine operating at 1,500 R. P. M., with steam at 140 lbs. gauge pressure and 28.5 in. vacuum, showed a steam consumption as follows, steam superheated 150°:

At full load, 12.5 lbs. per E. H. P. per hour.

At half load, 13.25 lbs. per E. H. P. per hour.

At one-sixth load, 16.2 lbs. per E. H. P. per hour.

And at one-third overload, 12.4 lbs. per E. H. P. per hour.

This would seem to indicate that the efficiency of the steam turbine increases with overload, at least up to a certain point.

In another test of a Curtis turbine, using dry saturated steam of 145 lbs. gauge pressure, the steam consumption at full load was 14.76 lbs. per E. H. P. hour, and at half load the rate was 15.95 lbs. per E. H. P. hour. The same machine using steam superheated 150° showed a steam consumption of 13.27 lbs. per E. H. P. hour, at full load.

A Curtis turbine carrying a commercial load on a 15-hour run showed an average coal consumption as follows; the turbine was operated with one boiler independently of the other boilers in the battery, and the steam was not superheated: Coal consumed per E. H. P. hour, 1.86 lbs.

The highest type of modern reciprocating engine, triple expansion, condensing, having steam jacketed cylinders, shows a coal consumption of 1.5 to 2 lbs. per H. P. per hour, assuming the evaporation to be 8 lbs. water per pound of coal.

CHAPTER VI

THE HAMILTON-HOLZWARTH STEAM TURBINE

The Hamilton-Holzwarth steam turbine—Points of difference between it and the Westinghouse-Parsons—Small clearances necessary—Stationary discs and guide vanes—Running wheels—Expansion of the steam and where it occurs—Action of the steam within the machine—Various stages in high and low pressure casings—Curvature of vanes—Purpose of stationary discs—Thrust ball bearings—Description of the governor and regulating mechanism—Close regulation—Method of changing speed while running.

This turbine resembles the Westinghouse-Parsons turbine in some respects, prominent of which is that it is a full stroke turbine, that is, that the steam flows through it in one continuous belt or veil in screw line, the general direction being parallel with the shaft. But, unlike the Parsons type, the steam in the Hamilton-Holzwarth turbine is made to do its work only by impulse, and not by impulse and reaction combined. It might thus be termed an action turbine.

The Hamilton-Holzwarth steam turbine is based upon and has been developed from the designs of Prof. Rateau, and is being manufactured in this country by the Hooven-Owens-Rentschler Co. of Hamilton, Ohio. It is horizontal and placed upon a rigid bed plate of the box pattern. All steam, oil and water pipes are within and beneath this bed plate, as are also the steam inlet valve and the regulating and by-pass valves.

The smaller sizes of this turbine are built in a single casing or cylinder, but for units of 750 kilowatts and larger the revolving element is divided into two parts, high and low pressure.

There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

The clearance allowed is as small as practical, as it is in this clearance between the revolving hub and the circumference of the bore of the stationary disc that the leakage losses occur. It should be noted that between each two stationary discs there is located a running wheel, and that the clearance between the running vanes and the stationary vanes is made as slight as is consistent with safe practice; otherwise leakage would occur here also, and besides this there would be a distortion of the steam jet and entrainment of the surrounding atmosphere, resulting in a rapid decline in economy if the clearance between the stationary and moving elements was not reduced to as small a fraction as possible.

As before stated, the stationary discs are firmly secured to the interior walls of the casing. At intervals on the outside periphery of these discs are located the stationary or guide vanes. These are made of drop forged steel. They are set in a groove on the outside edge of the disc and fastened with rivets. Both disc and vanes are then ground, giving the vanes the profile that they should have for the most efficient expansion of the steam. After this is done a steel ring is shrunk on the outside periphery of the vanes and the steam channels in the disc. These discs are then placed in the grooves in the casing at regular intervals, and in the spaces between them are the running wheels.

The casing is divided into an upper and lower half. The running wheels are built with a cast steel hub having a steel disc riveted on to each side, thus forming a circumferential ring space into which the running vanes are riveted. A thin steel band or rim is tied on the outer edge of the vanes, thus forming an outer wall to the steam channels and confining the steam within the vanes. These vanes are also milled on both edges, on the influx and efflux side of the wheel, thus forming them to the shape corresponding to the theoretical diagram.

The running vanes conform in section somewhat to the Parsons type, but the action of the steam upon them and also within the stationary vanes is different. The expansion of the steam and consequent development of velocity takes place entirely within the stationary vanes, which also change the direction of flow of the steam and distribute it in the proper manner to the vanes of the running wheels, which, according to the claims of the makers, the steam enters and leaves at the same pressure, thus allowing the wheel to revolve in a uniform pressure.

Fig. 141 shows a general view of the Hamilton-Holzwarth turbine, and the action of the steam within the machine may be described as follows: After leaving the steam separator that is located beneath the bed plate, the steam passes through the inlet or throttle valve, the stem of which extends up through the floor near the high pressure casing and is protected by a floor stand and equipped with a hand wheel, shown in Fig. 141. The steam now passes through the regulating valve, which will be described later on. From this valve it is led through a curved pipe to the front head of the high pressure casing or cylinder. In this head is a ring channel into which the steam enters, and from whence it flows through the first set of stationary vanes. In these vanes the first stage of expansion occurs, the velocity of the flow is accelerated, and the direction of flow is changed by the curve of the vanes in such manner that the steam impinges the vanes of the first running-wheel at the proper angle and in a full cylindrical belt, imparting by impulse a portion of its energy to the wheel. Passing through the vanes of this wheel, the steam immediately enters the vanes of the second stationary disc, which are larger in area than those of the first, and here occurs the second stage of expansion, another acceleration of velocity, and also the proper change in direction, and the steam leaves this distributer and impinges the vanes of the second

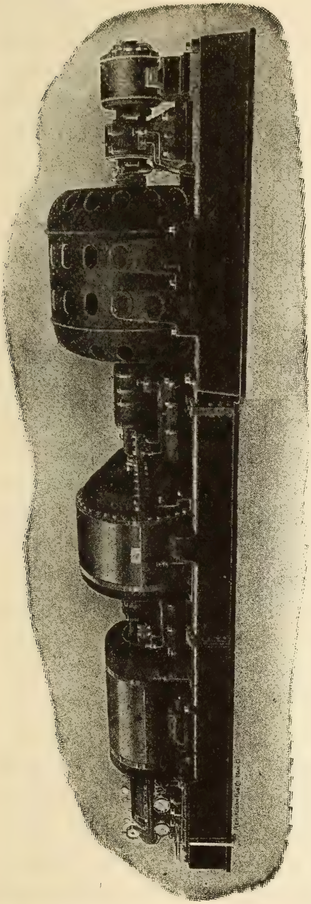


FIGURE 141.

running wheel. This cycle is repeated throughout the several stages of the turbine, a certain percentage of the heat energy in the steam being imparted by impulse to each wheel and thence to the turbine shaft. From the last running wheel the steam is led through receiver pipes to the front head of the low-pressure cylinder, or, if there is but one cylinder, directly to the condenser or the atmosphere.

In the low-pressure casing, which is larger in diameter than the high-pressure the steam is distributed in the same manner as it is in the high-pressure casing. There is, however, in the front head of the low-pressure casing an additional nozzle through which live steam may be admitted in case of overload. The design of this nozzle is such that the live steam entering and passing through it and controlled by the governor exerts no back pressure on the steam coming from the receiver, but, on the contrary, its action is similar to the action of an injector, that is, it tends to suck the low-pressure steam through the first set of stationary vanes of the low-pressure turbine.

The first stationary disc of the low-pressure turbine has guide vanes all around its circumference, so that the steam enters the turbine in a full cylindrical belt, interrupted only by the guide vanes. To provide for the increasing volume as the steam expands in its course through the turbine, the areas of the passages through the distributers and running vanes must be progressively enlarged. The gradual increase in the dimensions of the stationary vanes permits the steam to expand within them, thus tending to maintain its velocity, while at the same time the vanes guide the steam under such a small angle that the force with which it impinges the vanes of the next running wheel is as effective as possible. The curvature of the vanes is such that the steam while passing through them will increase its velocity in a ratio corresponding to its operation.

The purpose of the stationary discs is, as has been stated, to distribute the steam to the running wheels. They also take the back pressure of the steam as it impinges the vanes of the running wheels, thus in a sense acting as balancing pistons.

In all steam turbines one of the main requisites for a quiet-running machine is that the revolving element or rotor shall be perfectly balanced. The rotary body of the Hamilton-Holzwarth turbine consists of a plurality of running wheels, each one of which is balanced by itself before being placed upon the shaft. All the bearings are lubricated in a thorough manner by oil forced up into the bottom bushing or shell under slight pressure. Flexible couplings are used between the high and low-pressure shafts, and for connecting the turbine shaft to the generator shaft or other shaft to be driven. By means of the thrust ball-bearing on the exhaust end of the turbine the shaft may be adjusted in an axial direction in such manner as to accurately preserve the desired position of the running wheels with relation to the stationary discs.

The governor is of the spring and weight type, adapted to high speed, and is designed especially for turbine governing. It is directly driven by the turbine shaft, revolving with the same angular velocity. Its action is as follows: Two discs keyed to the shaft drive, by means of rollers, two weights sliding along a cross bar placed at right angles through the shaft and compressing two springs against two nuts on the cross bar. Every movement of the weights, caused by increasing or decreasing the angular velocity of the turbine shaft, is transmitted by means of levers to a sleeve which actuates the regulating mechanism. These levers are balanced so that no back pressure is exerted upon the weights. The whole governor is closed in by the discs, one on each side, and a steel ring secured by concentric recesses to the discs. In order to decrease the friction within the governor and regulating mechanism, thrust ball-bearings and frictionless roller-bearings are used.

As previously stated, the regulating valve is located beneath the bed plate. One side of it is connected by a curved pipe with the front head of the high-pressure cylinder and the other side is connected with the inlet valve. The regulating valve is of the double-seated poppet valve type. Valves and valve seats are made of tough cast steel, to avoid corrosion as much as possible, and the valve body is made of cast iron.

Immediately below the regulating valve and forming a part of it in one steam chamber is located the by-pass regulating valve. Thus the use of a second stuffing box for the stem of this valve is avoided. The function of this valve is to control the volume of the live steam supply that flows directly to the by-pass nozzles in the front head of the low-pressure casing. This valve is also a double-seated poppet valve.

The main regulating valve is not actuated directly by the governor, but by means of the regulating mechanism. The construction and operation of this regulating mechanism is as follows: The stem of the regulating valve is driven by means of bevel gears by a shaft that is supported in frictionless roller-bearings. On this shaft there is a friction wheel that the governor can slide across the face of a continuously revolving friction disc by means of its sleeve and bell crank lever. This revolving disc is keyed to a solid shaft which is driven by a coupling from a hollow shaft. This hollow shaft is driven by the turbine shaft through the medium of a worm gear. The solid shaft, with the continuously revolving friction disc, can be slightly shifted by the governor sleeve so that the two friction discs come into contact when the sleeve moves, that is, when the angular velocity changes. If this change is relatively great, the sleeve will draw the periodically revolving friction disc far from the center of the always revolving one, and this disc will quickly drive the stem of the regulating valve and the flow of steam will thus be regulated. As soon as the angular velocity falls below a certain percentage of the normal speed, the driving friction disc is drawn back by the governor, the regulating valve remains open and the whole regulating mechanism rests or stops, although the shaft is still running.

Should the angular velocity of the shaft reach a point 2.5 per cent higher than normal, the governor will shut down the turbine. If an accident should happen to the governor, due to imperfect material or breaking or weakening of the springs, the result would be a shut-down of the turbine.

In order to change the speed of the turbine while running, which might be necessary in order to run the machine parallel with another prime mover, a spring balance is provided, attached to the bell crank lever of the regulating mechanism. The hand wheel of this spring balance is outside of the pedestal for regulating mechanism and near the floor-stand and hand wheel. With this spring balance the speed of the turbine may be changed 5 per cent either way from normal.

All the bearings of the unit are thoroughly lubricated with oil forced under pressure by the oil pump driven by means of worm gearing by the turbine itself. After flowing through the bearings the oil is passed through a filter and from thence to the oil tank located within the bed plate, from whence it is taken by the oil pump. All revolving parts are enclosed, and the principal part of the regulating mechanism operates in a bath of oil.

CHAPTER VII

DE LAVAL STEAM TURBINE

De Laval steam turbine—High velocity—The De Laval divergent nozzle—Adiabatic expansion of steam within nozzle—Conversion of static energy into kinetic—Form of De Laval wheel—Speed of buckets—Speed of turbine shaft, and how it is reduced—Construction of the wheel—Number of buckets required—Number of nozzles—Gear and flexible shaft—Description of governor—Vacuum valve—Operation of governor—Efficiency tests—Steam consumption—Cross section of wheel showing correct design—Table of sizes, giving speed and weight.

The De Laval steam turbine, the invention of Carl De Laval of Sweden, is noted for the simplicity of its construction and the high speed of the wheel—10,000 to 30,000 R. P. M. The difficulties attending such high velocities are, however, overcome by the long, flexible shaft and the ball and socket type of bearings, which allow of a slight flexure of the shaft in order that the wheel may revolve about its center of gravity, rather than the geometrical center or center of position. All high speed parts of the machine are made of forged nickel steel of great tensile strength. But one of the most striking features of this turbine is the diverging nozzle, also the invention of De Laval.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet of steam issuing from the nozzle is equal to the amount of energy that would be developed if an equal volume of steam were allowed to adiabatically expand behind the piston of a reciprocating engine, a condition, how-

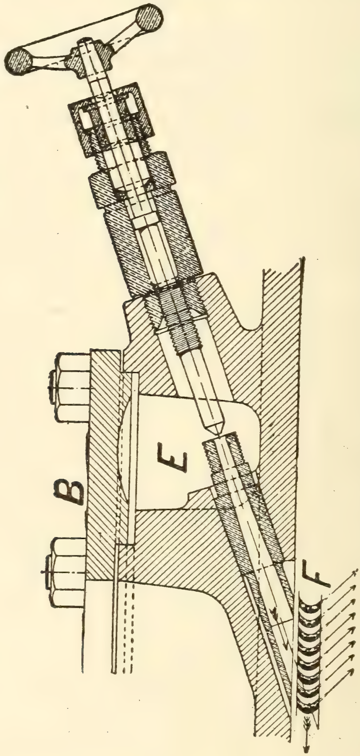


FIGURE 142. DE LAVAL NOZZLE

ever, which for obvious reasons has never yet been attained in practice with the reciprocating engine. But with the divergent nozzle the conditions are different.

Referring to Fig. 142, a continuous volume of steam at maximum pressure is entering the nozzle at E, and, passing through it, expands to minimum pressure at F, the temperature of the nozzle being at the same time constant and equal to the temperature of the passing steam. The principles of the De Laval expanding nozzle are in fact more or less prominent in all steam

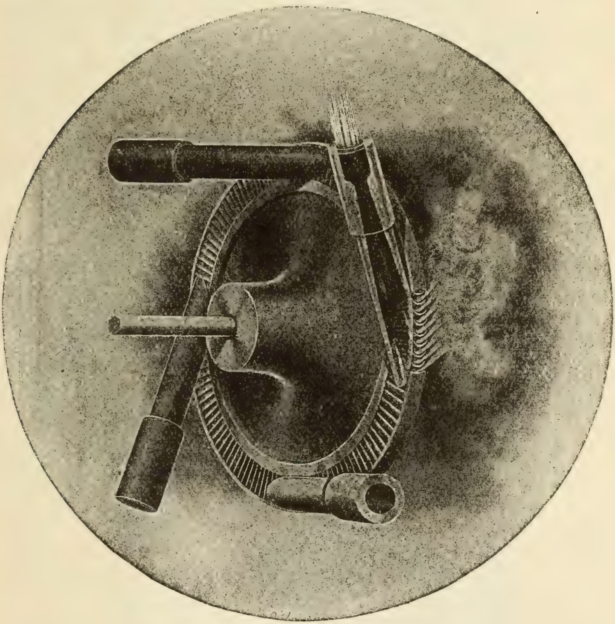


FIGURE 143. THE DE LAVAL TURBINE WHEEL AND NOZZLES.

turbines. The facilities for converting heat into work are increased by its use, and the losses by radiation and cooling influences are greatly lessened.

The De Laval steam turbine is termed by its builders a high-speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or

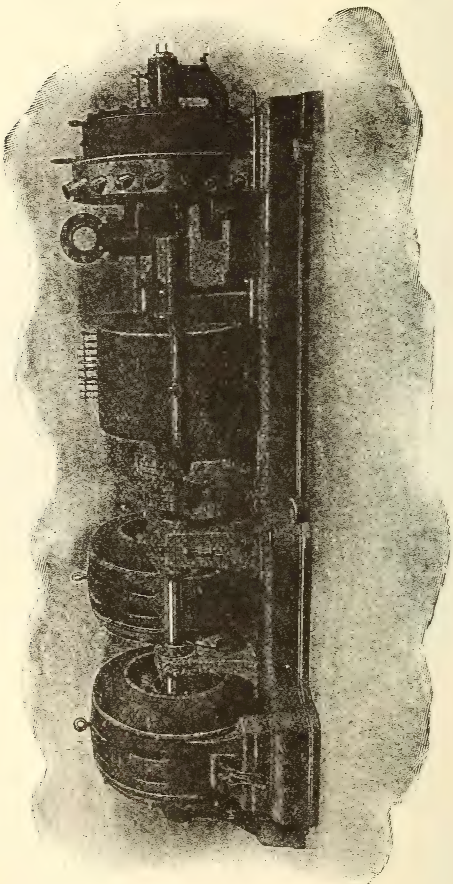


FIGURE 144.

guide blades, the angular position of the nozzles giving direction to the jet. Fig. 143 shows the form of wheel and the nozzles. The nozzles are placed at an angle of 20° to the plane of motion of the buckets, and the course of the steam is shown by the illustration.

The heat energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 ft. per second. To attain the maximum of efficiency the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 ft. per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 ft. per second.

Fig. 144 shows a De Laval steam turbine motor of 300 H. P., which is the largest size built up to the present time, its use having been confined chiefly to light work.

The turbine illustrated in Fig. 144 is shown directly connected to a 200 K. W. two-phase alternator. The steam and exhaust connections are plainly shown, as also the nozzle valves projecting from the turbine casing. The speed of the turbine wheel and shaft is entirely too high for most practical purposes, and it is reduced by a pair of very perfectly cut spiral gears, usually made 10 to 1. These gear wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90° to each other. This arrangement insures smooth running and at the same time checks any tendency of the shaft towards end thrust, thus dispensing with a thrust bearing.

The working parts of the machine are clearly illus-

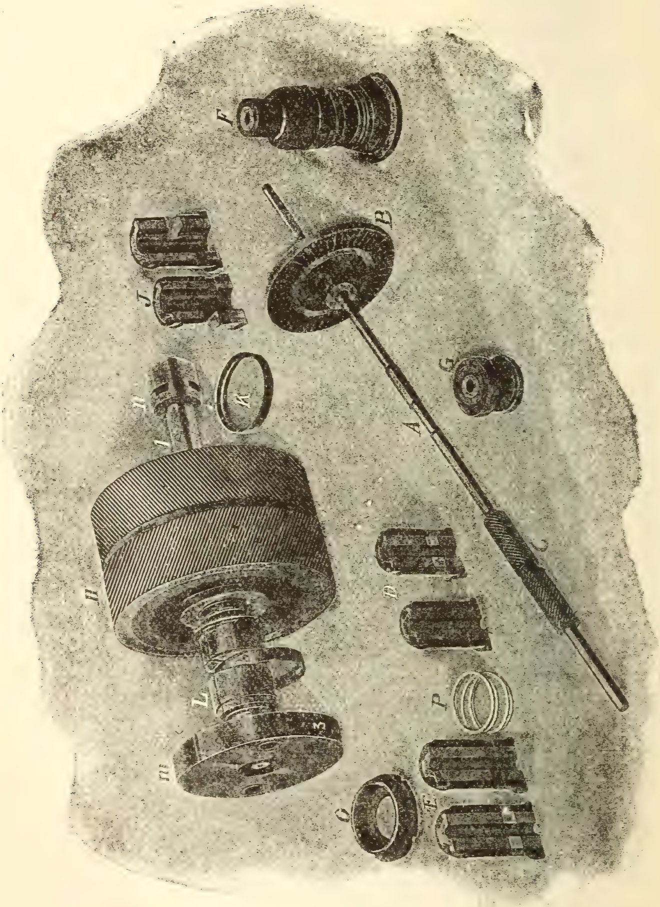


FIGURE 145.

trated in Fig. 145, and a fairly good conception of the assembling of the various members, and especially the reducing gears, may be had by reference to Fig. 146, which shows a 110 H. P. turbine and rotary pump with the upper half of the gear case and field frame removed for purposes of inspection. The slender shaft is seen projecting from the center of the turbine case, and upon this shaft are shown the small pinions meshing into the large spiral gears upon the two pump shafts.

Referring to Fig. 145, A is the turbine shaft, B is the turbine wheel, and C is the pinion. As the turbine wheel is by far the most important element, it will be taken up first. It is made of forged nickel steel, and it is claimed by the builders, the De Laval Steam Turbine Co. of Trenton, New Jersey, that it will withstand more than double the normal speed before showing any signs of distress. A clear idea of the construction of the wheel and buckets may be had by reference to Fig. 143. The number of buckets varies according to the capacity of the machine. There are about 350 buckets on a 300 H. P. wheel. The buckets are drop forged and made with a bulb shank fitted in slots milled in the rim of the wheel.

Fig. 147 is a sectional plan of a 30 H. P. turbine connected to a single dynamo, and Fig. 148 is a sectional elevation of the same.

The steam, after passing the governor valve C, Fig. 148, enters the steam chamber D, Fig. 147, from whence it is distributed to the various nozzles. The number of these nozzles depends upon the size of the machine, ranging from one to fifteen. They are generally fitted with shut-off valves (see Fig. 144) by which one or more nozzles can be cut out when the load is light. This renders it possible to use steam at boiler pressure, no matter how small the volume required for the load. This is a matter of great importance, especially where the load varies con-

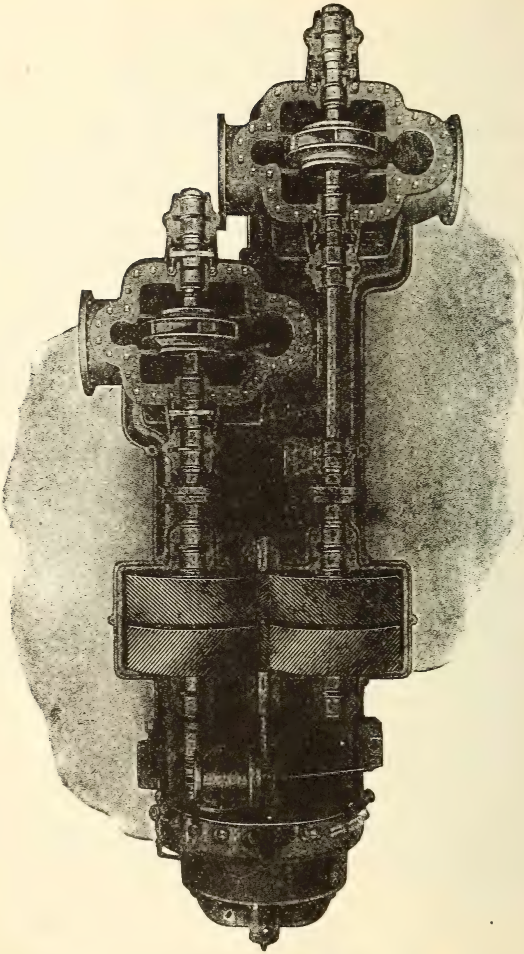


FIGURE 146.

siderably, as, for instance, there are plants in which during certain hours of the day a 300 H. P. machine may be taxed to its utmost capacity and during certain

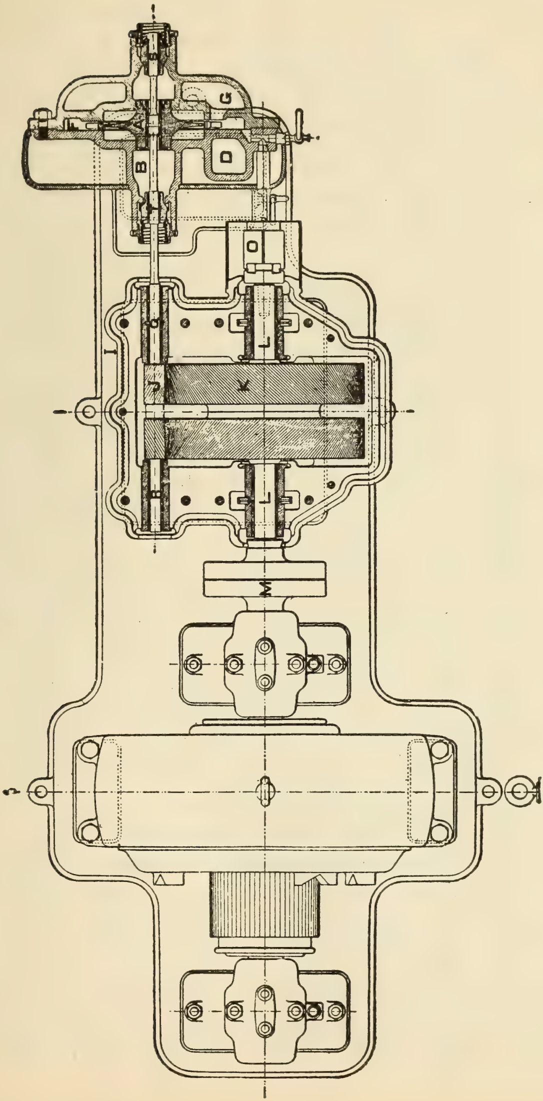


FIGURE 147.

other hours the load on the same machine may drop to 50 H. P. In such cases the number of nozzles in action may be reduced by closing the shut-off valves until the required volume of steam is admitted to the wheel. This adds to the economy of the machine. After passing through the nozzles, the steam, as elsewhere explained, is now completely expanded, and in impinging on the buckets its kinetic energy is transferred to the turbine wheel. Leaving the buckets, the steam now passes into the exhaust chamber G, Fig. 147, and out through the exhaust opening H, Fig. 148, to the condenser or atmosphere as the case may be.

The gear is mounted and enclosed in the gear case I, Fig. 147. J is the pinion made solid with the flexible shaft and engaging the gear wheel K. This latter is forced upon the shaft L, which, with couplings M, connects to the dynamo or is extended for other transmission.

O, Fig. 148, is the governor held with a taper shank in the end of the shaft L, and by means of the bell crank P operates the governor valve C. The flexible shaft is supported in three bearings, Fig. 147. Q and R are the pinion bearings and S is the main shaft bearing which carries the greater part of the weight of the wheel. This bearing is self-aligning, being held to its seat by the spring and cap shown.

T, Fig. 147, is the flexible bearing, being entirely free to oscillate with the shaft. Its only purpose is to prevent the escape of steam when running non-condensing, or the admission of air to the wheel case when running condensing. The flexible shaft is made very slender, as will be observed by comparing its size with that of the rotary pump shaft in Fig. 146. It is by means of this slender, flexible shaft that the dangerous feature

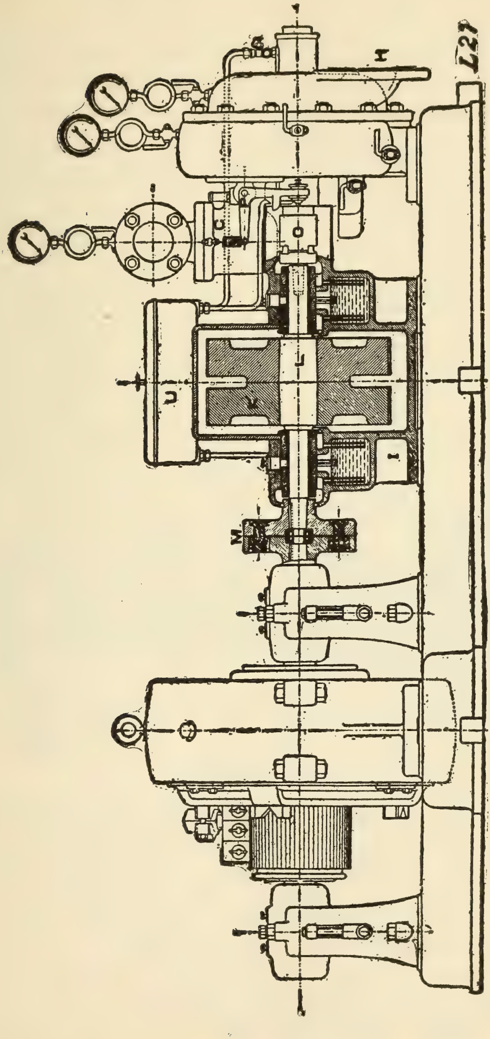


FIGURE 148.

of the enormously high speed of this turbine is eliminated.

The governor is of the centrifugal type, although differing greatly in detail from the ordinary fly ball governor, as will be seen by reference to Fig. 149. It is connected directly to the end of the gear wheel shaft. Two weights B are pivoted on knife edges A with

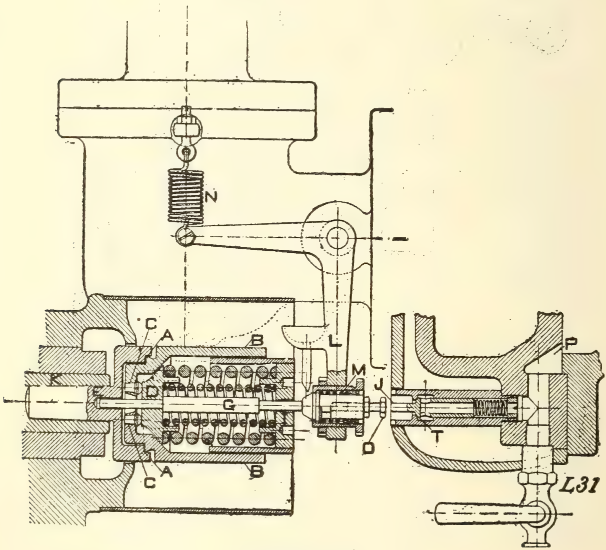


FIGURE 149.

hardened pins C, bearing on the spring seat D. E is the governor body fitted in the end of the gear wheel shaft K and has seats milled for the knife edges A. It is afterwards reduced in diameter to pass inside of the weights and its outer end is threaded to receive the adjusting nut I, by means of which the tension of the spring, and through this the speed of the turbine, is adjusted. When the speed accelerates, the weights, affected by centrifugal force, tend to spread apart, and pressing on the spring seat at D push the governor pin G to the right, thus actuating the bell crank L and cutting off a part of the flow of steam.

It has been found necessary with this turbine, when running condensing, to introduce a valve termed a vacuum valve, also controlled by the governor, as it has been found that the governor valve alone is unable to hold the speed of the machine within the desired limit. The function of the vacuum valve is as follows: The governor pin G actuates the plunger H, which is screwed into the bell crank L, but without moving the plunger relative to said crank. This is on account of the spring M being stiffer than the spring N, whose function is to keep the governor valve open and the plunger H in contact with the governor pin. When a large portion of the load is suddenly thrown off, the governor opens, pushing the bell crank in the direction of the vacuum valve T. This closes the governor valve, which is entirely shut off when the bell crank is pushed so far that the screw O barely touches the vacuum valve stem J. Should this not check the speed sufficiently, the plunger H is pushed forward in the now stationary bell crank and the vacuum valve is opened, thus allowing the air to rush into the space P in which the turbine wheel revolves, and the speed is immediately checked.

The main shaft and dynamo bearings are ring oiling. The high-speed bearings on the turbine shaft are fed by gravity from an oil reservoir, and the drip oil is collected in the base and may be filtered and used over again.

The fact that the steam is used in but a single stage or set of buckets and then allowed to pass into the exhaust chamber might appear at first thought to be a great loss of kinetic energy, but, as has been previously stated, the static energy in the steam as it enters the nozzles is converted into kinetic energy by its passage through the divergent nozzles, and the result is a greatly increased volume of steam leaving the nozzles at a tremendous velocity, but at a greatly reduced

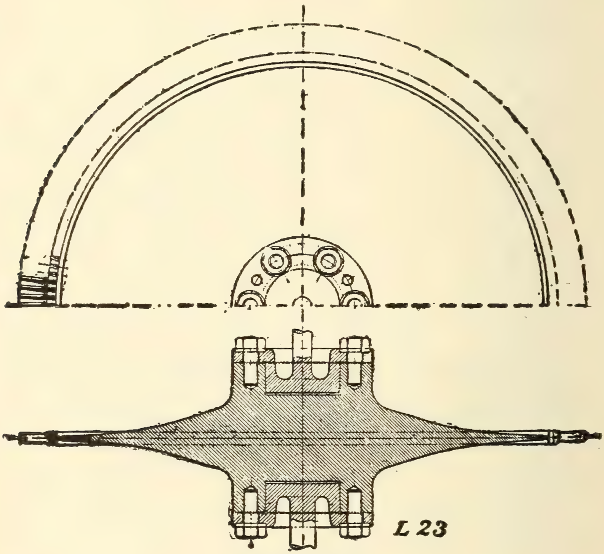


FIGURE 150.

pressure—practically exhaust pressure—impinging against the buckets of the turbine wheel and thus causing it to revolve.

Efficiency tests of the De Laval turbine show a high economy in steam consumption, as, for instance, a test made by Messrs. Dean and Main of Boston, Mass., on a 300 H. P. turbine, using saturated steam at about 200 lbs. pressure per sq. in. and developing 333 Brake

H. P., showed a steam consumption of 15.17 lbs. per B. H. P., and the same machine, when supplied with superheated steam and carrying a load of 352 B. H. P., consumed but 13.94 lbs. per B. H. P. These results compare most favorably with those of the highest type of reciprocating engines.

Fig. 150 shows a cross section of a 300 H. P. De Laval wheel, showing the design necessary for withstanding the high centrifugal stress to which these wheels are subjected. All De Laval wheels are tested to withstand the centrifugal stress of twice their normal velocity without showing signs of fatigue.

The following table gives the sizes and weights of some of these turbines, together with revolutions per minute of the turbine shaft and the main shaft.

Horse Power	Revolutions Turbine Shaft	Revolutions Main Shaft	Approximate Weight Pounds
5	30,000	3,000	330
10	24,000	2,400	650
20	20,000	2,000	1,250
75	16,400	1,500	5,000
110	13,000	1,200	8,000
225	11,060	900	15,000
300	10,500	900	20,000

CHAPTER VIII

DISPOSAL OF THE EXHAUST STEAM OF STEAM TURBINES

Advantages of exhausting into a condenser—Possible to maintain higher vacuum in condenser of a turbine than with reciprocating engine—Surface condensers—Bulkley injector condenser—Steam turbine condensing apparatus at St. Louis Exposition, 1904—Dry air pump—Gain in economy from high vacuum—Cost of operating auxiliaries—Necessity of excluding all air from condensing system—Ways in which air may be entrained—Comparative efficiency of turbines and reciprocating engines—Percentage of saving per each inch increase in vacuum above 25 inches—Advantages of superheating the steam—Outlook for future of steam turbines.

As in the case of the reciprocating engine, the highest efficiency in the operation of the steam turbine is obtained by allowing the exhaust steam to pass into a condenser, and experience has demonstrated that it is possible to maintain a higher vacuum in the condenser of a turbine than in that of a reciprocating engine. This is due, no doubt, to the fact that in the turbine the steam is expanded down to a much lower pressure than is possible with the reciprocating engine.

The condensing apparatus used in connection with steam turbines may consist of any one of the modern improved systems, and as no cylinder oil is used within the cylinder of the turbine, the water of condensation may be returned to the boilers as feed water. If the condensing water is foul or contains matter that would be injurious to the boilers, a surface condenser should be used. If the water of condensation is not to be used in the boilers, the jet system may be employed. Another type of condenser that is being successfully used with steam turbines is the Bulkley injector condenser.

Among the steam turbines that were on exhibition at the St. Louis exposition in 1904 the Westinghouse-Parsons and the General Electric Curtis turbines were each equipped with Worthington surface condensers, fitted with improved auxiliary apparatus consisting of dry vacuum pumps, either horizontal of the well-known Worthington type, or rotative motor-driven, a hot well pump, and a pump for disposing of the condensed steam from the exhaust system. The two latter pumps were of the Worthington centrifugal type. The Hamilton-Holzwarth turbine was equipped with a Smith-Vaile surface condenser, fitted with a duplex double-acting air pump, a compound condensing circulating pump, and a rotative dry vacuum pump, motor-driven. The vacuum maintained was high, 28 to 28.5 in.

As an instance of the great gain in economy effected by the use of the condenser in connection with the steam turbine, a 750 K. W. Westinghouse-Parsons turbine, using steam of 150 lbs. pressure not superheated and exhausting into a vacuum of 28 in., showed a steam consumption of 13.77 lbs. per B. H. P. per hour, while the same machine operating non-condensing consumed 28.26 lbs. of steam per B. H. P. hour. Practically the same percentage in economy effected by condensing the exhaust applies to the other types of steam turbines.

With reference to the relative cost of operating the several auxiliaries necessary to a complete condensing outfit, the highest authorities on the subject place the power consumption of these auxiliaries at from 2 to 7 per cent of the total turbine output of power. A portion of this is regained by the use of an open heater for the feed water, into which the exhaust steam from the auxiliaries may pass, thus heating the feed water and returning a part of the heat to the boilers.

A prime requisite to the maintenance of high vacuum, with the resultant economy in the operation of the condensing apparatus, is that all entrained air must be excluded from the condenser. There are various ways in which it is possible for air to find its way into the condensing system. For instance, there may be an improperly packed gland, or there may be slight leaks in the piping, or the air may be introduced with the condensing water. This air should be removed before it reaches the condenser, and it may be accomplished by means of the "dry" air pump.

This dry air pump is different from the ordinary air pump that is used in connection with most condensing systems. The dry air pump handles no water, the cylinder being lubricated with oil in the same manner as the steam cylinder. The clearances also are made as small as possible. These pumps are built either in one or two stages.

A barometric or a jet condenser may be used, or a surface condenser. The latter type lessens the danger of entrained air, besides rendering it possible to return the condensed steam, which is pure distilled water, to the boilers along with the feed water, a thing very much to be desired in localities where the water used for feeding the boilers is impregnated with carbonate of lime or other scale-forming ingredients.

In comparing the efficiency of the reciprocating engine and the steam turbine it is not to be inferred that reciprocating engines would not give better results at high vacuum than they do at the usual rate of 25 to 26 in., but to reach and maintain the higher vacuum of 28 to 28.5 in. with the reciprocating engine would necessitate much larger sizes of the low-pressure cylinder, as also the valves and exhaust pipes, in order to handle the greatly increased volume of steam at the low pressure demanded by high vacuum.

The steam turbine expands its working steam to within 1 in. of the vacuum existing in the condenser, that is, if there is a vacuum of 28 in. in the condenser there will be 27 in. of vacuum in the exhaust end of the turbine cylinder. On the other hand, there is usually a difference of 4 or 5 in. (2 to 2.5 lbs.) between the mean back pressure in the cylinder of a reciprocating condensing engine and the absolute back pressure in the condenser.

It therefore appears that the gain in economy per inch increase of vacuum above 25 in. is much larger with the turbine than it is with the reciprocating engine. Mr. J. R. Bibbins estimates this gain to be as follows: between 25 and 28 in. there is a gain of 3½ to 4 per cent per inch of increase, and at 28 in. 5 per cent. These results have been obtained by means of exhaustive tests conducted by Mr. Bibbins. Other high authorities on the steam turbine all agree as to the great advantages to be derived by incurring the extra expense of erecting a condensing plant that is capable of maintaining the high vacuum necessary to high efficiency.

Another method by which the steam consumption of the turbine may be materially decreased and a great gain in economy effected is by superheating the steam. The amount of superheat usually specified is 100°, and the apparatus employed for producing it may be easily mounted in the path of the waste gases. The steam may thus be superheated without extra cost in fuel, and an increase of 8 to 10 per cent in economy effected. The independent superheater requires extra fuel and labor, and the gain in this case is doubtful, but there can be no question as to the wisdom of utilizing the waste flue gases for superheating the steam.

As previously stated, the steam turbine is peculiarly adapted for the use of highly superheated steam and high vacuum, and in these two particulars it excels the reciprocating engine At the present time many large plants are equipped with turbine engines that are giving the best of results, and the outlook for the future employment of this type of power producer is certainly very promising.

CHAPTER IX.

THE ALLIS-CHALMERS STEAM TURBINE.

Since the publication of the first edition of this work, the Allis-Chalmers Company of Milwaukee, Wisconsin, have entered the field as manufacturers of steam turbines of the Parsons type. Fig. 151 shows a general view of the Allis-Chalmers steam turbine, and although it is essentially of the "Parsons" type, still there are a number of modifications in details of construction, as compared with the Westinghouse Parsons steam turbine, some of which, no doubt may be considered as adding to the efficiency, and durability of the machine.

Fig. 152 is a sectional view of the elementary "Parsons" type of steam turbine and Fig. 153 shows a sectional view of the "Parsons" turbine with the Allis-Chalmers modifications. The action of the steam, and the general arrangement of the stationary and moving blades is practically the same in the two turbines, with the exception that, in the larger sizes of the Allis-Chalmers turbine the "balance" pistons for neutralizing the end thrust, are arranged in a different manner, the largest one of the three pistons, (piston N—Fig. 152) is replaced by a smaller balance piston.

This piston presents the same effective area for the steam to act upon, as did the larger piston, for the reason that the working area of the latter in its original location consisted only of the annular area, included between its periphery, and the periphery of the next smaller piston.

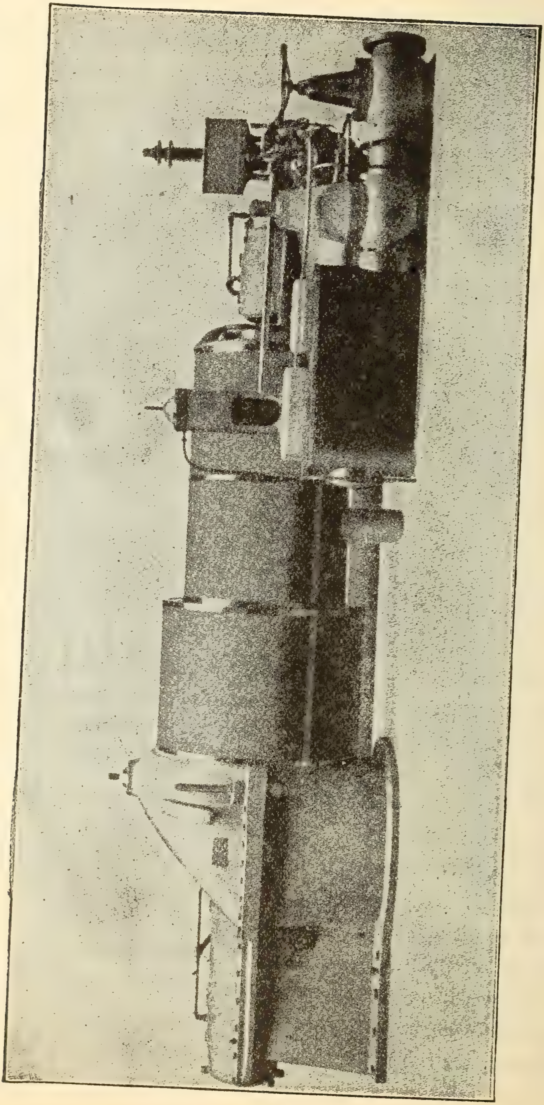


FIGURE 151.
THE ALLIS CHALMERS STEAM TURBINE.

The pressure of the steam is brought to bear upon this equalizing piston in its new position, by means of passages or ports through the body of the rotor, connecting the third stage of the cylinder with the supplementary cylinder, in which the piston revolves. Fig. 154 shows the arrangement of blading, the course of the steam being

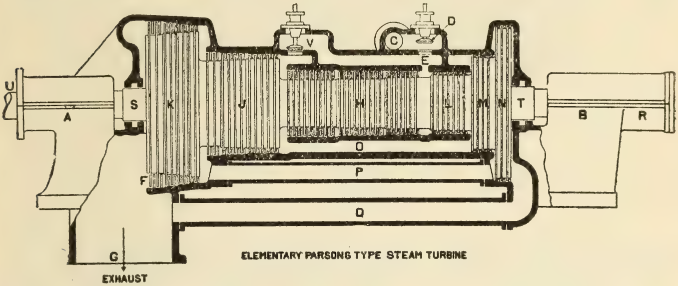


FIGURE 152.

Main bearings, A and B. Thrust bearing, R. Steam pipe, C. Main throttle valve, D, which is balanced, and operated by the governor. Steam enters the cylinder through passage E, passes to the left through the alternate rows of stationary and revolving blades, leaving the cylinder at F and passes into the condenser, or atmosphere through passage G. H, J and K are the three steps or stages of the machine. L, M and N are the three balance pistons. O, P and Q are the equalizing passages, connecting the balance pistons with the corresponding stages.

indicated by the arrows. The clearances between the edges of the revolving and stationary blades, as shown in the cut, are relatively out of proportion to the actual clearances allowed.

This clearance is preserved by means of a small thrust-bearing provided inside the housing of the main bearing.

This thrust-bearing can be adjusted to locate and hold the rotor in such a position as will allow sufficient clearance to prevent actual contact between the moving and stationary blades and yet reduce the leakage of steam to a minimum.

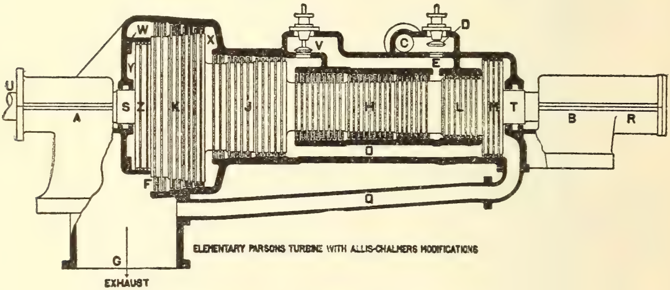


FIGURE 153.

Sectional view of elementary Parsons steam turbine, with Allis Chalmers modifications. L and M are the two balance pistons at the high pressure end. Z is a smaller balance piston placed in the low pressure end, yet having the same effective area as did the larger piston N shown in Fig. 152. O and Q are the two equalizing passages for pistons L and M. Passage P is omitted in this construction and balance piston Z is equalized with the third stage pressure at Y. Valve V is a by-pass valve to allow of live steam being admitted to the second stage of the cylinder in case of a sudden overload. This by-pass valve is the equivalent of the by-pass valve used to admit live steam to the low pressure cylinder of a compound reciprocating engine. Valve V is arranged to be operated, either by the governor or by hand, as the conditions may require. Frictionless glands made tight by water packing are provided at S and T where the shaft passes out of the cylinder. The shaft is extended at U and connected to the generator shaft by a flexible coupling.

The method by which the blades are fitted to and held in the rotor and cylinder of the Allis-Chalmers steam turbine is as follows: Each blade is individually formed by special machine tools, so that its root or foot is of an angular, or dove tail shape, and at its tip there is a projection. In order that the roots of the blades may be firmly held in position, a foundation ring, A Fig. 155, is provided, which after being formed to a circle of the proper diameter, has slots cut in it by a special milling machine.

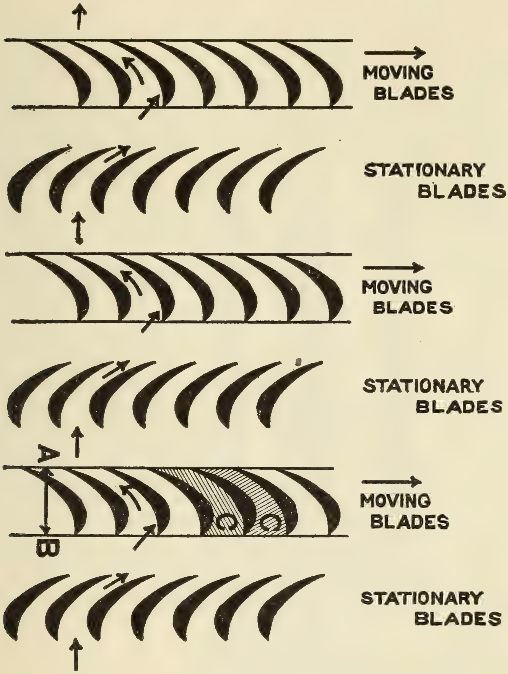


FIGURE 154.

Fig. 154 showing arrangement of blading and course of the steam in Parsons steam turbine.

These slots are formed of dove-tail shape to receive the roots of the blades and are at the same time accurately spaced, and inclined so as to give the required pitch and angle to the blades.

The foundation rings are also of dove-tail shape in cross-section, those holding the stationary blades are inserted in dove-tail grooves in the cylinder and those holding the revolving blades being pressed into the rotor or spindle.

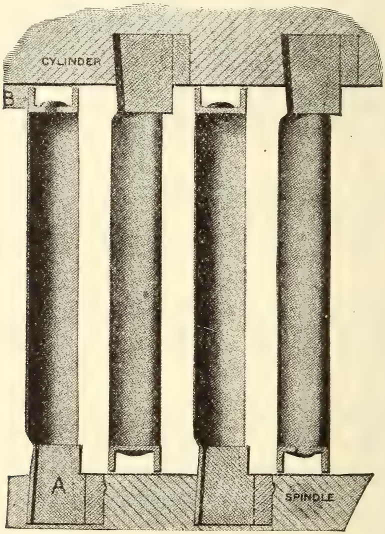


FIGURE 155.

The rings are firmly held in their places by key-pieces driven into place and upset into under-cut grooves, thus positively locking the whole structure together, and making it practically impossible for a blade to get out of place.

The tips of the blades are held and firmly bound together by a shroud-ring, B. Fig. 155.

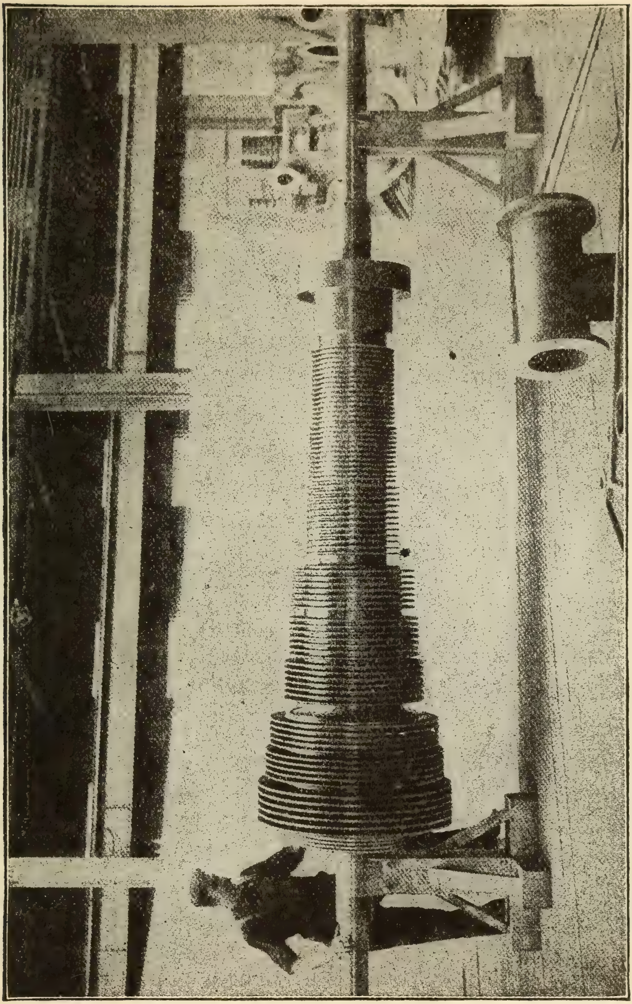


FIGURE 156.
SPINDLE OR ROTOR, ALLIS CHALMERS STEAM TURBINE.
The rings which carry the blades are pressed on.

The shroud-rings are made channel-shape in cross-section, the flanges being made thin in order to prevent dangerous heating in case of accidental contact with either the walls of the cylinder or the surface of the rotor.

Fig. 155 gives a clear idea of the construction and fitting of both the stationary and revolving blades.

Fig. 156 shows the construction of the rotor of the Allis-Chalmers steam turbine.

Fig. 157 shows an enlarged view of the blading as fitted in the turbine, the shroud-rings being clearly shown.

The rings of blades are made up complete in half-rings in the shop ready for insertion in the turbine.

Two of these half-rings are shown in figure 158, one with smaller blades, and one with larger blades for a turbine of moderate size.

Fig. 159 illustrates the appearance of a number of rings of stationary blades inserted in the cylinder of an Allis-Chalmers steam turbine; the cut having been made from an actual photograph and shows the mechanical accuracy of the work.

The bearings of this turbine are of the self-adjusting ball and socket type, designed for high speed. Shims are provided for proper alignment. The lubrication of the four bearings, two for the turbine, and two for the generator, is accomplished by supplying an abundance of oil to the middle of each bearing and allowing it to flow out at the ends where it is caught, passed through a cooler, and pumped back to the bearings.

The fact that the oil is supplied in large quantities to the bearings does not involve a heavy oil bill.

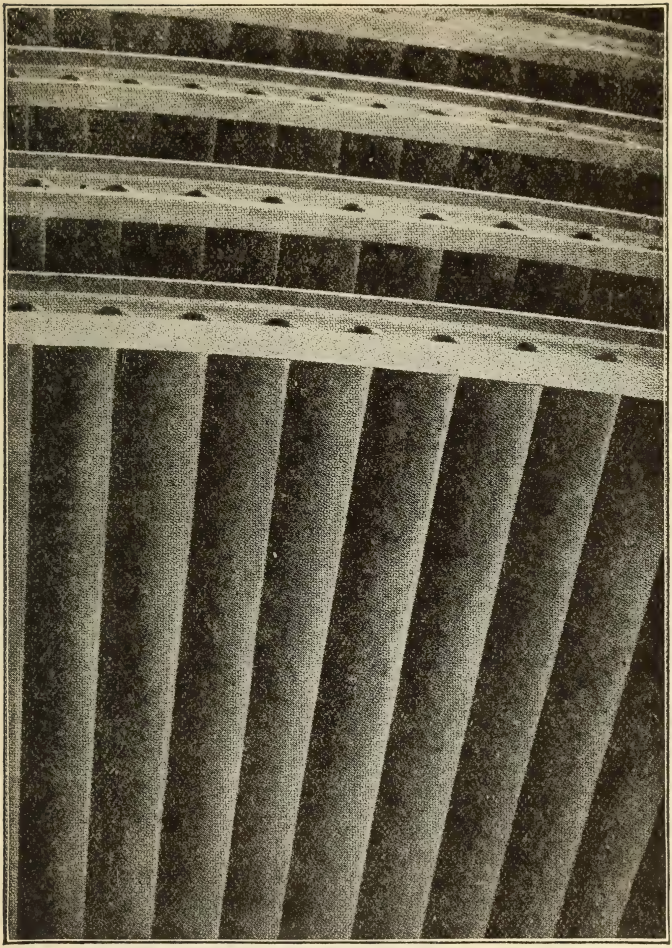


FIGURE 157.

Fig. 157 illustrates blades as fitted in the rotor of Allis Chalmers steam turbine. The shroud ring protecting the tips of the blades is also shown.

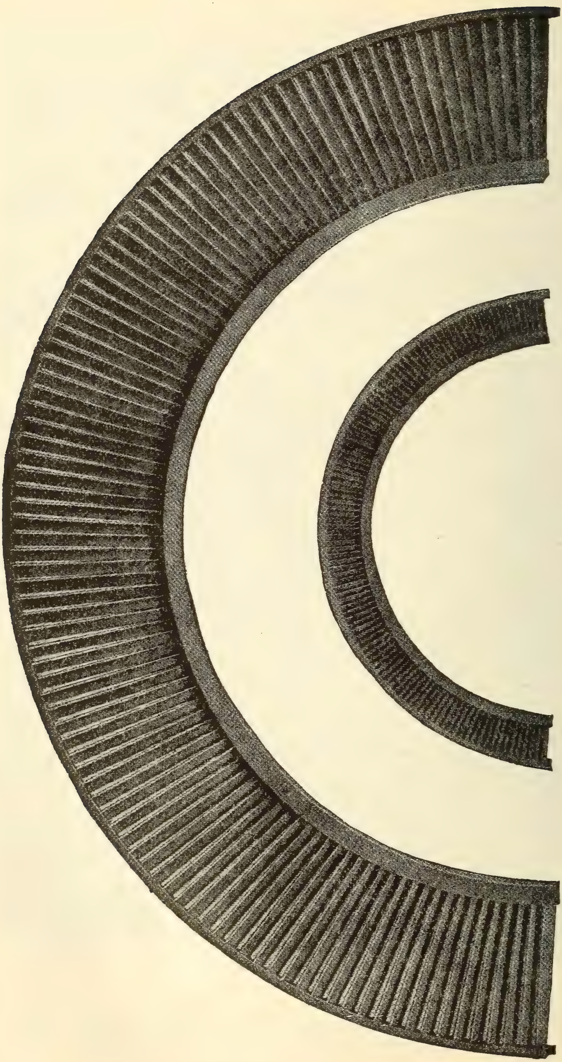


FIGURE 158.

Half ring of blades inserted in the foundation ring before being placed upon the rotor, showing substantial construction.

The journals are practically floating on films of oil, thus preventing that "wearing out" of the oil that occurs when it is supplied in small "doses."

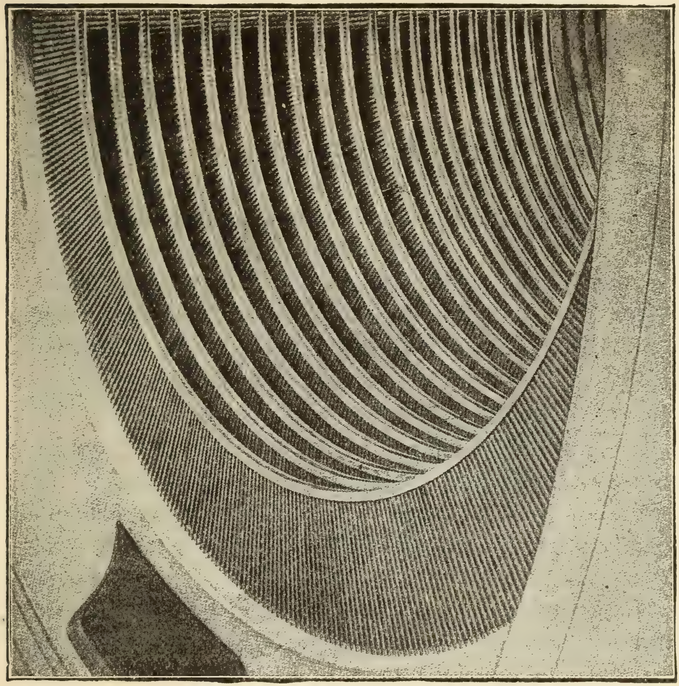


FIGURE 159.

Shows a number of rows of stationary blades fitted in the cylinder of an Allis Chalmers steam turbine.

As evidence of the economical use of oil the builders of this turbine cite the following examples: One 400 K. W. turbine used only 50 gallons of oil in six months.

In another installation of two 1,000 K. W. turbines only one-half gallon of oil was used per turbine a week.

The governor is driven from the turbine-shaft by means of cut gears working in an oil-bath.

The governor operates a balance throttle valve by means of a relay, except in very small sizes in which the valve is worked direct.

In order to provide for any possible accidental derangement of the main governing mechanism, an entirely separate safety or over-speed governor is furnished. This governor is driven directly by the turbine shaft without the intervention of gearing, and is so arranged and adjusted that if the turbine should reach a predetermined speed above that for which the main governor is set, the safety governor will come into action and trip a valve, shutting off the steam and stopping the turbine. A strainer is provided through which the steam is passed before admission to the turbine.

It is no unusual thing for careless workmen to leave in steam pipes and valves such articles as bolts, nuts, pieces of gaskets, tools, etc. Should these find their way into a steam turbine they would damage the blading, perhaps seriously. To guard against such contingency, each Allis-Chalmers turbine is provided with a steam strainer, with perforations large enough not to obstruct the flow of steam, yet small enough to prevent the passage of almost anything of such size as would damage the turbine blades.

For connecting the rotors of the turbine and generator a special type of flexible coupling is used to provide for any slight inequality in the wear of the bearings, to permit axial adjustment of the turbine spindle, and to allow for differences in expansion. This coupling is so made that it can be readily disconnected for the removal of the turbine spindle or of the revolving field of the generator. Provision is made for ample lubrication of the adjoining faces of the coupling. The coupling is enclosed in the bearing housing, so that it is completely protected against damage, and cannot cause injury to the attendants.

Waste of heat by radiation is prevented in the following manner:

The hot parts of the turbine, up to the exhaust chamber, are covered with an ample thickness of non-conducting material and lagged with planished steel.

For large Allis-Chalmers turbines the bedplate is divided into two parts, one carrying the low-pressure end of the turbine and the bearings of the generator, the other carrying the high-pressure end of the turbine. The turbine is secured to the former, while the latter is provided with guides which permit the machine to slide back and forth with differences of expansion caused by varying temperature, at the same time maintaining the alignment.

It may be said in general of the steam turbine, that it has passed the experimental stage, and has come to the front as an efficient power producer, having a bright future before it. It has solved the problem of using superheated steam, owing to the absence of all rubbing parts exposed to the steam. This permits the use of steam of high temperature thus making it possible to realize the advantages of economical operation.

CHAPTER X.

REFRIGERATION.

The process of refrigeration consists in the abstraction of heat from a substance, and if air, water, or ice is at hand at a lower temperature than it is desired to attain in the body or substance to be cooled the cooling element may be employed to perform the refrigeration directly without the aid of a machine.

If a temperature of 32 degrees and not lower is desired ice can be used directly but if it is necessary to reach a temperature lower than 32 degrees a mixture of salt and ice or other freezing mixture must be used.

By mixing one pound of calcium chloride with 0.7 lbs. of snow a solution is produced which will give a temperature of 67° below zero. But freezing mixtures are too expensive to be used for practical purposes, and it therefore becomes necessary to employ machinery.

The theory and practice of mechanical refrigeration are based upon the two first laws of thermo-dynamics, that is to say first: that mechanical energy and heat are mutually convertible; and second: that an external agent is necessary in order to complete or bring about the transformation.

The generally accepted theory concerning the nature of heat together with definitions of the terms, specific heat, latent heat, the mechanical equivalent of heat, etc., are fully discussed in Chapter 4 of this book and therefore it will not be necessary to enlarge upon these subjects in this connection except to state that the phrase commonly used, "heat is generated by compression," is somewhat misleading, because the amount of heat in the Universe is a fixed quantity, and the intrinsic energy possessed by any gas is under given conditions a quantity that can be accurately calculated. Thus if a pound of air at a temperature of 70 degrees Fahrenheit, and at normal atmospheric pressure be taken as an example, the total quantity of energy it possesses is at once known. If this air be placed in a compressor and its volume be reduced to say one half of its original volume, and if this be done so rapidly that there is no time for heat to escape at the end of the compression, that is to say adiabatically or instantaneous compression without transmission of heat, then its energy will have been increased by the amount of work done upon it. Its statical pressure will be increased, and its temperature will also have risen, by reason of its changed state or condition internally. Now if the temperature be reduced to its former amount, that is to say to 70 degrees Fahrenheit, its volume will contract, so that a small additional quantity of air will have to be forced in in order that the pressure may remain unchanged as the temperature is reduced. It will be seen that there will be now, consequently upon the above, rather more than a pound of air to deal with at the higher pressure, and this is what actually occurs in practice, but is a point which is easily overlooked. Now if this air be allowed to expand in a cylinder, it will give up more of its heat in order to overcome the resistance, and in this way it will lose or part with more heat. The amount of work done is shown by the indicator card, and can be estimated. The mechanical work done by the air in this expansion is exactly the same as that done upon it during its compression, but there is in addition the further loss of energy, due to the internal work done in the air during the expansion, so that what has been done to the air during the entire process has been to extract some of its original store of heat, thus reducing its temperature; and the cold air is now ready to restore its deficiency at the expense of the surrounding hotter bodies.

It should be borne in mind by the student that all bodies contain more or less heat and that heat can neither be created nor destroyed because it remains a fixed quantity throughout the universe.

Therefore the only method by which the temperature of a body or substance can be reduced is by the transference of more or less of the heat contained in the body to some other body or substance.

The work demanded of a refrigerating machine is to extract heat from a cold body, say from the air in an enclosed space, such as a refrigerating chamber, and by the expenditure of mechanical energy to sufficiently raise the temperature of this heat to admit of its being carried away by a suitable external agent, the latter being most usually water, which is not only the cheapest one available, but also has a greater capacity for heat, weight for weight, than any other known substance, and is taken as the standard of comparison, its specific heat being taken as unity.

A refrigerating or ice-making machine may then properly be defined as a heat-pump for the simple reason that its main function is the abstraction of heat from one body (the body to be cooled) and continuously and automatically transferring that heat to the refrigerating or cooling agent.

The various inventions for refrigerating and ice-making that are now in use, can be conveniently classified for the present purpose under the following five principal heads, viz.:—

First, those wherein the more or less rapid dissolution or liquefaction of a solid is utilized to abstract heat. This is, strictly speaking, more a chemical process.

Second, those wherein the abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by an air-pump. This is known as the vacuum system.

Third, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of a more or less volatile nature, which agent is subsequently restored to its original physical condition by mechanical compression and cooling. This is called the compression system.

Fourth, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of more or less volatile nature under the direct action of heat, which agent again enters in solution with a liquid. This is termed the absorption system.

Fifth, those wherein air or other gas is first compressed, then cooled, and afterwards permitted to expand whilst doing work, or practically by first applying heat, so as to ultimately produce cold. These are usually designated as cold-air machines.

Of the various systems of refrigeration using different refrigerating mediums, only two, namely the ammonia compression system and the ammonia absorption system have come into anything like general use in this country, and these two systems the author proposes to take up and discuss in a practical way beginning with the compression system.

In this system the process of refrigeration is divided into three distinct stages, viz.:—compression, condensation, and expansion.

Anhydrous ammonia is selected as the refrigerating medium on account of its low boiling point (—28.6° F.), its high latent heat of vaporization, its non-corrosive effect on iron and steel, and because the pressures under which it is used are such as to render it perfectly safe to handle with properly constructed apparatus.

When nitrogen and hydrogen combine to form ammonia one volume of nitrogen unites with three volumes of hydrogen, hence the chemical formula of ammonia is NH_3. As the atomic weight of nitrogen is 14 and of hydrogen 1, the formula also indicates that 14 parts, by weight, of nitrogen, combine with 3 parts of hydrogen, to create 17 parts of ammonia.

Gaseous ammonia can be liquefied at a pressure of 128 lbs. to the square inch, at a temperature of 70° Fahr., and at a pressure of 150 lbs. at a temperature of 77° Fahr., the pressure required to produce liquefaction rising very rapidly with the temperature. To liquefy by cold it requires to be reduced to a very low temperature, viz.,—85.5° Fahr.

The gaseous ammonia is drawn into the ammonia compressor, or pump, and is there compressed to a pressure varying from 125 to 175 pounds per square inch.

During this compression, the latent heat of the vapor (that is, that quantity of heat which was imparted to it to effect its expansion from a liquid to a vapor) is converted into active or sensible heat.

The vapor, under this high pressure, is forced into the condenser, consisting of a series of pipes over which cold water is allowed to flow (atmospheric condenser) or through pipe coils submerged in a body of cold water (submerged condenser), where the now active and sensible heat developed during compression is transferred to the cooling water, thus withdrawing from the vapor that heat which was necessary to keep it in a gaseous condition, and re-converting it into a liquid at the temperature and pressure existing in the condenser.

The ammonia, so liquefied in the condenser, is then allowed to pass in small quantities through a regulating or expansion valve into pipe coils placed in the rooms to be cooled, or in a bath of brine, when it again expands into a vapor, owing to the lower pressure maintained in such pipes, *taking up from whatever substance surrounds it, an amount of heat exactly equivalent to that which was given up during condensation.*

The expanded vapor is then drawn back into the compressor, again compressed, condensed, and expanded, the cycle of operation being repeated indefinitely with the same ammonia, which is used continuously and which never comes in contact with the substance to be refrigerated.

There are two systems of refrigeration by compression, viz.: the "wet" system and the "dry" system.

As the Linde ice-machine manufactured by the Fred W. Wolf Co. of Chicago is a good example of the workings of the "wet" or humid system, a short description of the construction and operation of the machine will be given. (Fig. 160.)

The theory of the action of the Linde machine is as follows:

So long as ammonia vapor is in a humid or saturated condition (that is, while still in contact with any of its originating liquid), temperature and pressure are func-

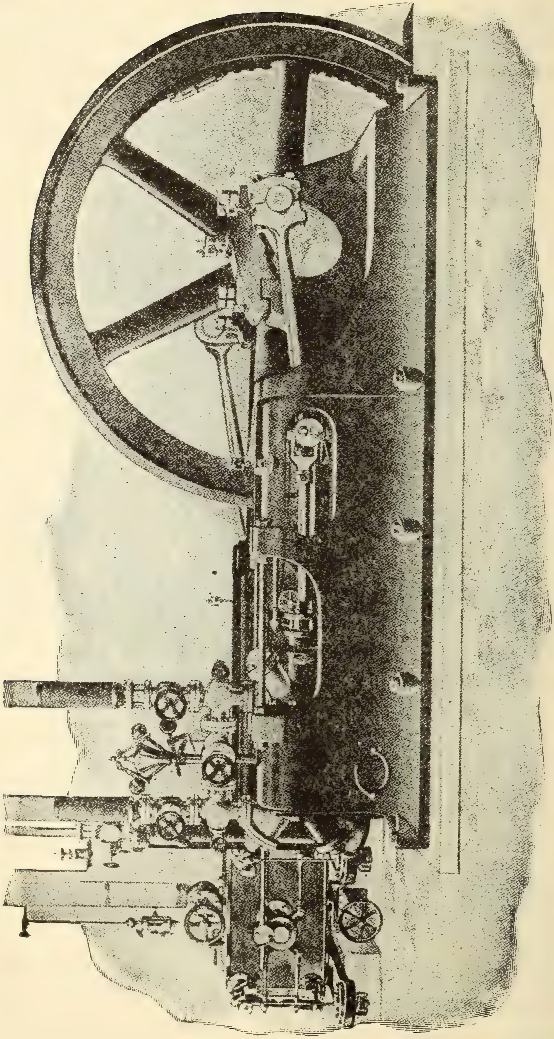


FIGURE 160.
LINDE ICE MACHINE.

tions of one another, and to a given temperature belongs a certain pressure.

On the contrary, when ammonia (now properly called a gas) is not in contact with any of its mother liquid, its temperature may be very much higher than that corresponding to its pressure.

For example, the pressure of the steam in a boiler depends entirely upon its temperature, which is always equal to that of the remaining water. It is therefore evident that in the case of steam, while in contact with the originating water, temperature and pressure are interdependent.

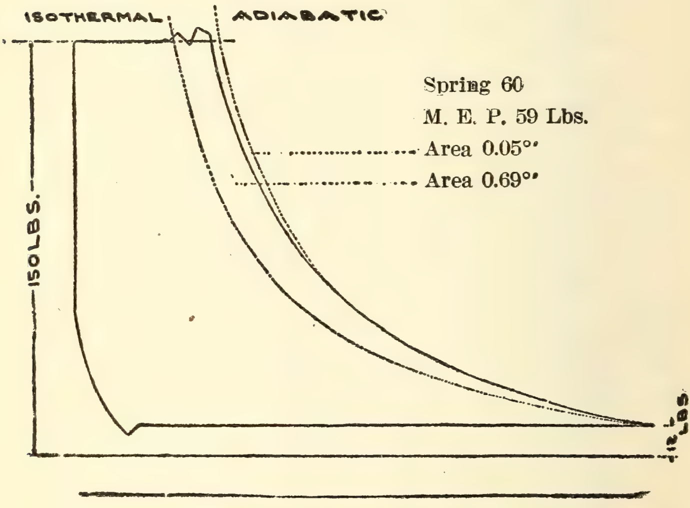
Separate the steam from the water, and apply heat (superheat it), and it may have the same pressure at widely different temperatures.

When a gas or vapor is compressed, the heat equivalent of the mechanical work of compression tends to raise its temperature, and consequently its pressure, more rapidly than would be the case if it would be maintained at constant temperature.

In the compression of a dry gas, unless heat is withdrawn by means of a water-jacket, or other cooling device, the adiabatic curve will be traced on the indicator diagram. This is the curve which represents the compression or expansion of a gas without loss or gain of heat.

In the Linde machine the cooling of the vapor in the compression cylinder is effected by the introduction into the latter of a small quantity of liquid ammonia with the gas or vapor at the commencement of each stroke whereby it is cooled down to a refrigerating temperature. The ammonia is carried back to the compressor in a saturated condition and the heat of compression is taken care of in the unexpanded ammonia which in the form of fog or vapor, entered the compressor on the suction stroke.

The diagrams Figs. 161 and 162 illustrate the comparative efficiency of this method of cooling the compression cylinder, termed the "wet" system, and the other



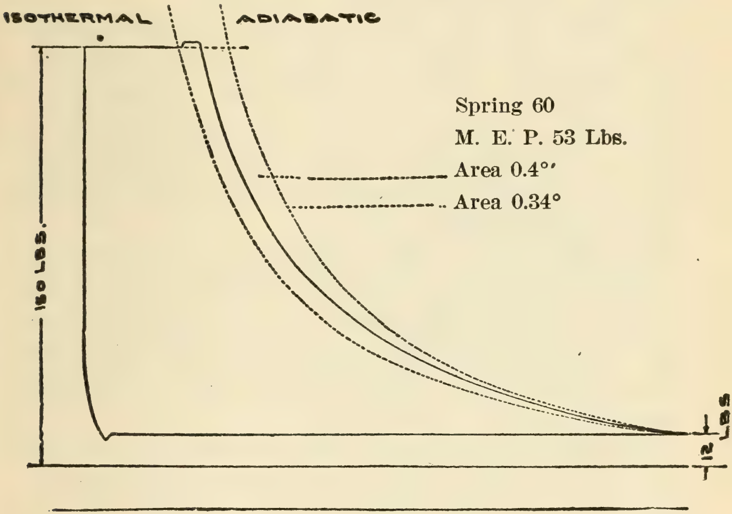
Dry Gas.

FIGURE 161.

method wherein a water-jacket system is employed termed the "dry" gas system.

The initial volume and pressure and the terminal pressure are the same in each case. In the compression of the dry gas, the compression curve necessarily follows for a considerable distance the adiabatic line.

This for the reason that the gas coming into the cylinder from the expansion coils is at a temperature of —5° F. and no heat can be transmitted from it to the cooling water in the water-jacket until the temperature of the gas has been raised above that of the water, which is probably 60° to 70° F.



Saturated Vapor.

FIGURE 162.

The compression curve then leaves the adiabatic and during the last part of the stroke, before the discharge valve opens, approaches the isothermal line.

In the compression of saturated vapor, the unexpanded ammonia begins immediately to absorb the heat of compression and the compression curve at once leaves the adiabatic and approaches the isothermal line, making a diagram that is much smaller in area and which therefore represents work requiring less power.

The efficiency ratio of any cylinder cooling device is found by dividing the area between the actual compression curve and the adiabatic curve, by the total area between the adiabatic and isothermal curves.

Assuming that the diagrams shown are from eighteen by thirty inch double-acting compressors, running at fifty revolutions per minute, the effective horse-power required for the compression of the saturated vapor would be 102.1 horse-power, as against 113.7 horse-power for the dry-gas machine, *a gain of 10.2% in favor of the humid system of operation.*

Fig. 163 shows a sectional view of the compressor cylinder, piston, and valves. It will be observed that the piston and heads are spherical and of the same radius. The valve discs conform absolutely to this radius, and when the valves are seated these discs are exactly flush with the heads.

The clearance between the piston and the cylinder head is very small, being only 1/32 in., therefore the clearance losses are very small, being less than two per cent. of the total cylinder volume. The cylinders are made of clear, hard iron, tested to 1,000 lbs. hydrostatic pressure. The finishing cut through the cylinder is made after it is placed in the frame, the final cut on crosshead guides being taken at the same time, and on the same boring bar, thus insuring their correct alignment. Proper openings are provided for the application of the indicator.

The lubrication of the piston is accomplished in large measure by the moisture in the ammonia itself. Oil is used to seal the stuffing box against the leakage of ammonia. Very little of this oil is carried into the cylinder on the piston rod.

The piston is ground on the tapered shoulder of the piston rod, and is secured by lock nuts, as shown in Fig. 163. The follower head is then screwed on and held

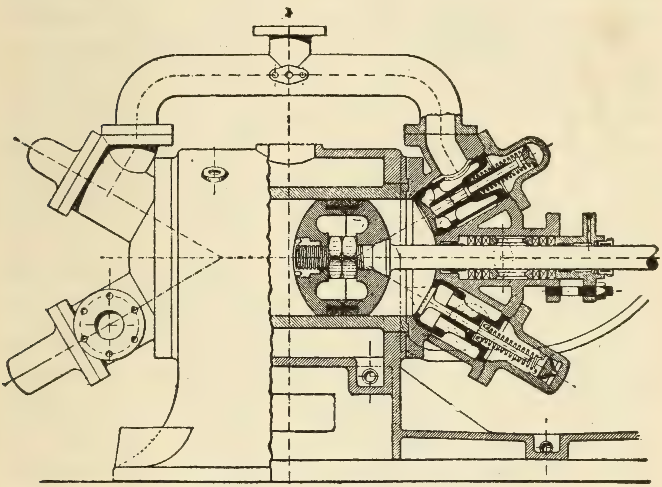


FIGURE 163.
Sectional view of the Linde compressor cylinder and valves.

firmly in place by the flush nut, which in turn is prevented from backing off by a screw set into the face of the follower and riveted over. Those who have experienced the annoying effect of pistons working loose on the rod will appreciate the advantages of this method, permitting, as it does, the ready removal of the piston when necessary, while at the same time absolutely precluding the possibility of its accidentally becoming loose. *Many serious accidents have resulted from inattention to this detail.* The piston is packed with removable bull rings and cast-iron packing rings.

The valves are of large area, the discharge valve being placed at the lowest point of the cylinder, insuring the perfect draining of any liquid present at the end of the compression period. The importance of this feature cannot be overestimated; the many records of compressors wrecked by the piston coming in contact with incompressible liquid being familiar to all users of this class of machinery. The stems and discs are of the finest forged steel, set in cast-steel housings. The valve lift is governed by positive stops and controlled by springs. The suction valve is provided with a safety stop to prevent its falling into the cylinder.

The Linde stuffing box is shown in section, in Fig. 164 —to which reference is now made. The numbers 2, 4, 5, 9, 10, 12 and 14 indicate composition packing rings. These should never be used solid but should be cut as shown in sketch "A." Numbers 3, 6, 8, and 11 represent metal rings, made from pure tin. They are intended to keep the rubber rings in proper condition. These rings should always be one-sixteenth of an inch larger than the rod and should never be cut in two, as otherwise they are apt to score the rod. If necessary to put in new metal rings, disconnect the piston rod from the crosshead and slip the rings over the end of the rod. *Under no circumstances pack the compressor without the metal rings.*

Number 7 designates the lantern which forms an oil storage in the middle of the stuffing box. The oil supply is taken in at the point marked "a" through a pipe con-

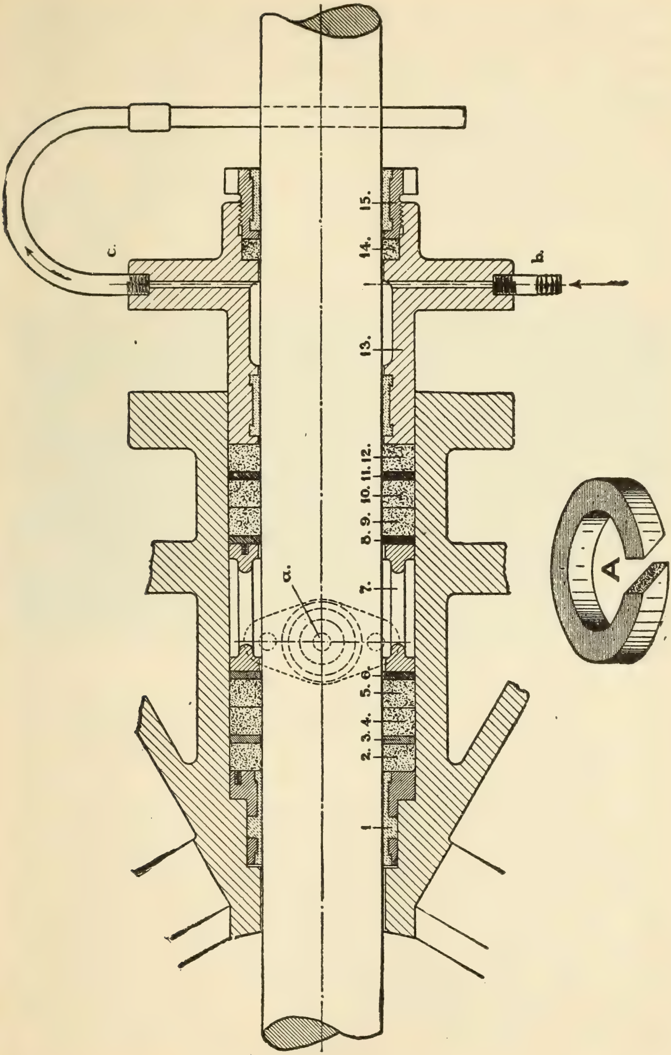


FIGURE 164.
Sectional view of Linde Stuffing Box.

nection from the oil trap. This passage being always open, the oil is forced into the stuffing-box by the high pressure gas in the oil trap, keeping this stuffing-box and lantern always full and instantly replacing what little oil is carried into the cylinder on the rod. Number 13 is the stuffing-box gland which is supplied with oil through the inlet "b" from a small oil pump operated from the main shaft. This oil overflows at "c" and is led back to the oil pan to be recirculated.

Number 15 is the oil gland which should be kept just tight enough to keep the oil in the stuffing-box gland. The points of contact with the rod are numbers, 1, 13, and 15, and they must fit the rod properly. If it becomes scored and is turned down, these parts must be rebabbitted.

When repacking be sure to place the different parts of the packing in strict accordance with the above instructions and with the cut shown, insuring the best results. Great care should be used not to tighten the stuffing gland 13 more than is necessary to prevent the ammonia from leaking.

The Linde compressor is of the horizontal double acting type, and consequently the lines of strain are brought close to, and parallel with the foundations. The machine is so constructed, as to be easily attached to any steam engine, either by being direct connected, or by belting from a counter shaft. In small plants, electric motors are often used for operating these machines. Fig. 165 shows an installation of this kind.

There are two distinct methods of utilizing refrigeration; viz.; the *Brine System* and the *Direct Expansion System*. In the former the coils of pipe in which the ammonia is expanded are placed in a tank containing a solution of salt or calcium chloride of such density as to insure a low freezing point. This body of brine, after being reduced to a low temperature by the transfer of its heat to the expanding ammonia, is pumped through coils of pipe in the rooms to be cooled, taking up from the atmosphere of such rooms a part of its heat. It is then returned to the brine tank, recooled and again circulated through the rooms.

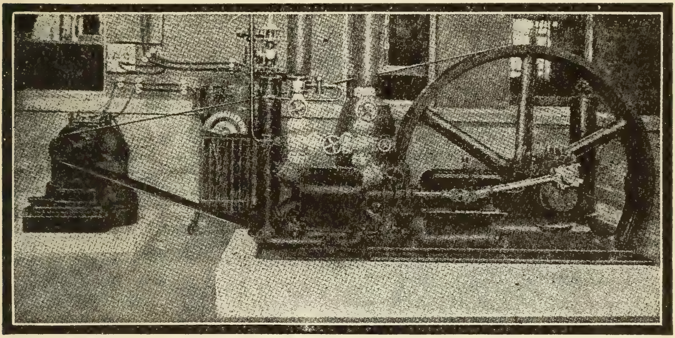


FIGURE 165.
12-ton Linde ice machine—motor operated.

In the Direct Expansion System the expansion pipes are placed in the rooms to be cooled, the heat necessary for the expansion of the ammonia being drawn directly from the atmosphere surrounding the pipes.

Of the two systems, the direct expansion system is probably the most efficient as may be seen by the following summary of its advantages over the brine system:

1st. All intermediate agencies are dispensed with, the refrigeration being produced at the place where it is utilized. Every transfer of energy means loss. The brine tank, even if insulated, furnishes immense surface for loss by radiation.

2d. The whole plant is much simpler, considerable auxiliary apparatus, such as pumps, etc., is unnecessary, the requirement of power is therefore reduced and repairs are correspondingly lessened.

3d. The expansion surface is enlarged and better distributed, making possible the using of the entire capacity of the compressor to the best advantage.

4th. The ammonia is expanded at a much higher temperature and pressure, and is therefore drawn back to the compressor at higher density, resulting in the machine circulating a much greater weight of ammonia per minute. Each pound of ammonia has just so much potential refrigerating energy and the capacity of a compressor is therefore dependent solely upon the weight of ammonia pumped in a given time. For example, if it is desired to maintain a temperature of 32° F. in a certain room, it will require a compressor displacement of 22 per cent. more with the Brine System than with Direct Expansion.

5th. The Brine System is much more expensive to install, owing to the far greater quantity of pipe required, the additional pumps, tanks, etc.

One of the advantages claimed for the Brine System is the ability to store refrigerating energy in the brine tank, which may be drawn upon during the night, thus rendering the continued operation of the compressor unnecessary. It has been claimed that by doing this the fuel consumption is reduced; but this is not good logic, since just so much work must be done to produce a given quantity of refrigeration and it makes no difference

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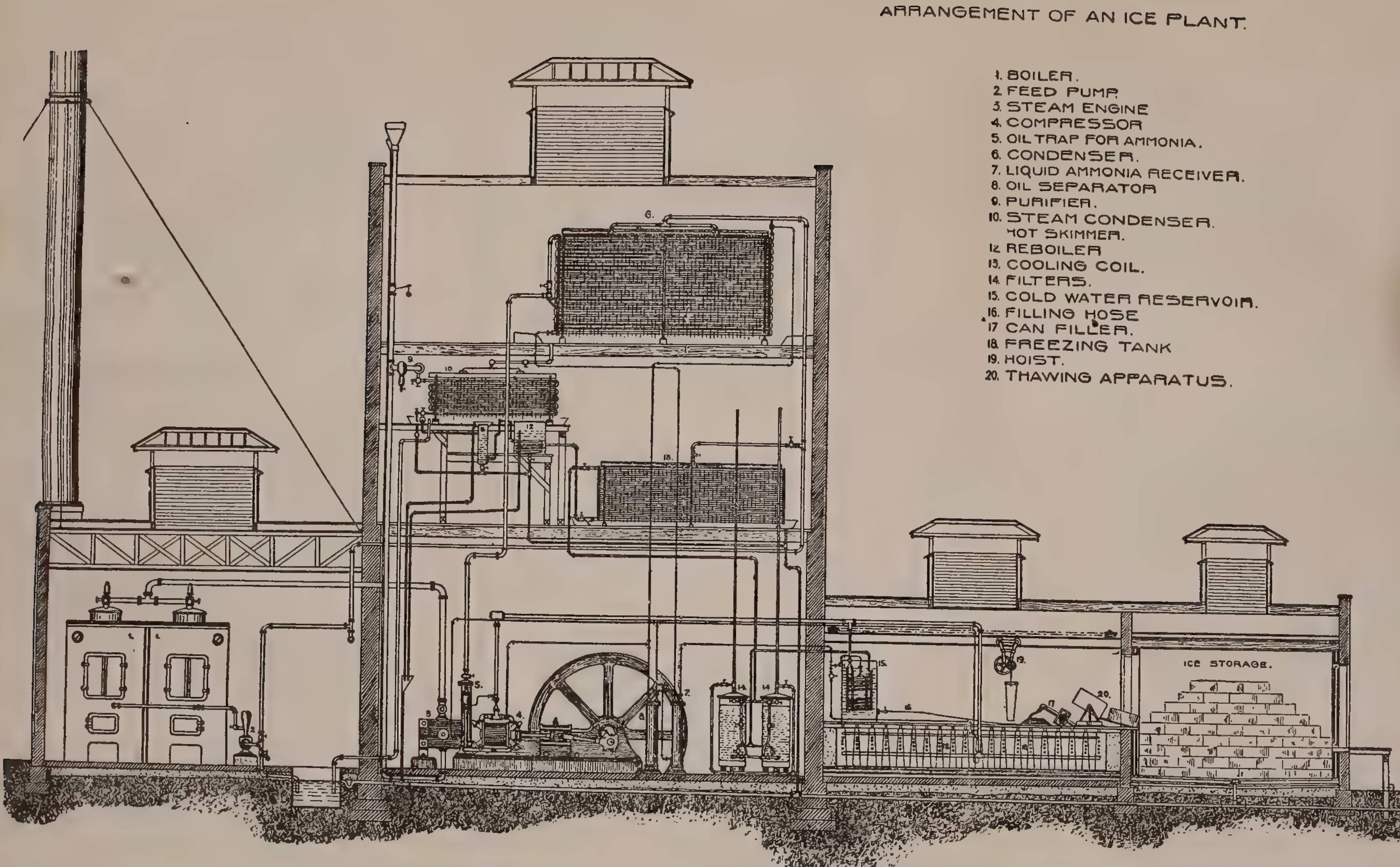

ARRANGEMENT OF AN ICE PLANT.
1. BOILER.
2. FEED PUMP.
3. STEAM ENGINE
4. COMPRESSOR
5. OIL TRAP FOR AMMONIA.
6. CONDENSER.
7. LIQUID AMMONIA RECEIVER.
8. OIL SEPARATOR
9. PURIFIER.
10. STEAM CONDENSER.
HOT SKIMMER.
12. REBOILER
13. COOLING COIL.
14. FILTERS.
15. COLD WATER RESERVOIR.
16. FILLING HOSE
17. CAN FILLER.
18. FREEZING TANK
19. HOIST.
20. THAWING APPARATUS.
ICE STORAGE.

Figure 166

whether this work is distributed throughout the twenty-four hours or is crowded into a shorter period. If the work is to be done in a short time the compressor must be correspondingly larger.

The development of the ice-making industry during the past ten years has been astonishingly rapid. This may be attributed to the fact that the ice-using public has come to a realization of the vast superiority, from a hygienic standpoint, of manufactured over natural ice, and to the further fact that owners of electric light plants, mills, water-works and other power plants have found that the ice-making business is one that is peculiarly adapted to being operated in combination with other industries requiring the use of power.

Ice is made artificially by either the Can System or Plate System.

In order to obtain absolutely pure and crystal ice by this system, a complete distilling and filtering process must be employed. Water, when evaporated into steam, parts with all of its impurities; the steam is condensed, the water of condensation being entirely pure. All the air must then be expelled from it, as otherwise it will freeze into opaque or so-called "snow" ice.

The inserted illustration, Fig. 166, shows an arrangement for the production of can ice from distilled water. The compression and condensation of the ammonia is carried on as already described, the ammonia being expanded in expansion coils placed in the freezing tank. (No. 18.)

The steam generated in the boiler is first used to drive the steam engine. The exhaust steam then passes to the steam condenser (No. 10), first passing through an oil extractor (No. 9), where any lubricating matter which has been carried along from the cylinder is removed. The steam condenser is designed on the same principle as the ammonia condenser, being a series of pipes over which cooling water is allowed to flow. The exhaust steam is not usually sufficient to make the full capacity of ice, and sufficient live steam is therefore supplied to the steam condenser to make up the deficiency. The water resulting from the condensing of the steam passes to the skimmer (No. 11), where any oil that may pass the oil extractor is removed.

From the skimmer the water goes to the re-boiler (No. 12), at the bottom of which is placed a small steam coil by means of which the water is kept boiling and the air contained in it expelled. It then passes to the flat cooler (No. 13), an apparatus similar to a condenser, where its temperature is reduced to that of the cooling water available. Thence it is led to the filters (No. 14), which are furnished in duplicate so that one may be shut off and cleaned without interfering with the operation of the plant. In special cases, where the nature of the water requires it, sponge, silicate, or bone charcoal filters are used. From the filters the water passes to the cold-water storage tank (No. 15), which contains an ammonia expansion coil. By the use of the coil the distilled water is reduced to the freezing temperature before going into the freezing cans.

By means of a can filler (No. 17), so arranged that the water is automatically shut off when the can is filled to the proper depth, the galvanized iron freezing cans are filled with distilled water from the cold-water tank. The freezing tank (No. 18) is usually made of iron or steel and thoroughly insulated at the bottom and sides. It is provided with suitable hardwood frame and covers and has an efficient agitating device for keeping the brine in motion. The brine acts as a medium for the transfer of the heat from the distilled water within the cans to the expanding ammonia in the expansion coils, which are placed longitudinally of the tank and between which the cans are inserted.

The ice when frozen is hoisted out of the tank by means of the hoisting apparatus (No. 19). The ice is loosened from the cans by the use of warm water from the condenser, either by employing a sprinkling apparatus (No. 20) or by dipping the can bodily into a tank.

TABLE 20.

TABLE GIVING NUMBER OF CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES, TO PRODUCE ONE TON OF REFRIGERATION IN TWENTY-FOUR HOURS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per Sq. In.	Temperature of the Gas in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), lbs. per Sq. In.								
		103	115	127	139	153	168	184	200	218
	G. Pres									
–27	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
–20	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
–15	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
–10	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
– 5	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

In the De La Vergne refrigerating machine the cooling of the heated gas is effected by passing it through pipes surrounded by running water. The characteristic feature of this machine consists in the patented system for preventing the occurrence of any leakage of gas taking place past the stuffing box, piston, and valves, and of extracting the heat from the gas during compression, by the simple device of injecting into the compressor, at each stroke, a certain quantity of oil or other suitable lubricating fluid. By means of this sealing, lubricating and cooling oil, not only are the stuffing box, piston, and

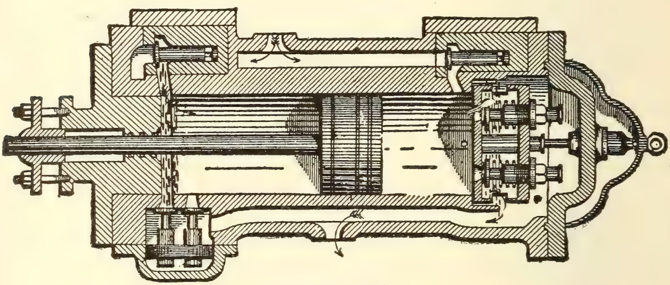


FIGURE 167.
Double-acting type of De La Vergne ammonia compressor.

valves effectually sealed, and the heat developed during compression taken up, but all clearances are entirely filled up. This latter is a matter of great importance, as it ensures a complete discharge of the gas from the pump cylinder, and obviates the above-mentioned loss of power and efficiency.

This method of sealing the stuffing box and piston prevents leakage and consequent introduction of air into the pump, or wasting of the refrigerating gas at each alternate stroke of the piston without necessitating the packing of piston so tightly as to cause excessive fricion. Fig. 167 shows a sectional view of a double acting De La Vergne compressor fitted with Louis Block's arrangement of valves, the main object of which is to secure the discharge of the oil at the lower end of the cylinder taking place immediately after all the gas is gone and not before, as in the latter case re-expansion will take place, resulting in loss of efficiency of the pump. To effect this, two valves are provided in the lower end of the compressor cylinder, one above the other.

Either or both of these valves may open on the down stroke of the piston, until the latter covers the upper one, when only the lower one is left open to the condenser. During the remainder of the stroke of the piston, after the lower valve is also closed, the other or upper one opens communication with an annular chamber formed in the said piston. In the bottom of this annular chamber are provided, moreover, valves which open as soon as all the other outlets from the underside of the piston are closed, to ensure which they are loaded with springs, so arranged as to require somewhat more pressure to open them than the discharge valves on the side of the cylinder. The gas, and afterwards the oil, then all pass out through the piston, no trace of the former being present at the completion of the down stroke. In this manner the oil system of sealing can be advantageously retained, and the pump will work as well at the lower side as the upper.

Fig. 168 shows a complete installation of a refrigerating plant on the De La Vergne system, the vertical compressor being driven by a horizontal engine. The circulation of the ammonia, and the sealing oil is as follows: A is the compressor cylinder, double acting, and

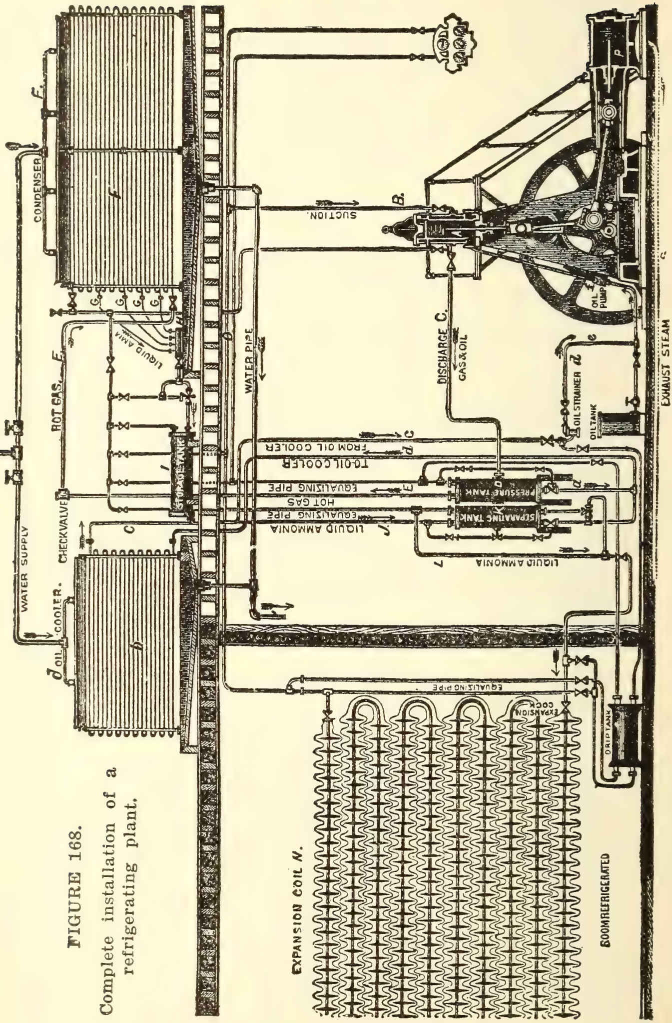


FIGURE 168.

Complete installation of a refrigerating plant.

similar in construction to that shown in section in Fig. 167. R is the steam engine cylinder. B is the pipe through which the gas is drawn from the evaporating coils into the compressor A. The gas is then discharged by the action of the compressor through the pipe C, into the pressure tank D, where the sealing oil or liquid falls to the bottom. Suitable cast-iron baffle plates are fitted in the upper portion of the pressure tank, which serve to retain the oil, and insure its deposition. From the pressure tank D the gas which still retains the heat due to compression, passes through pipe E into the bottom or lower pipe of the condenser F, wherein, by the cooling action of cold water running over the pipes, the heated gas is first cooled and then liquefied. The ammonia, in this liquid condition, is then led by the small liquid pipes G, through the liquid header H, into the storage tank I, from whence it flows through the pipe J into the lower part of the separating tank K, which latter must be constantly maintained at the very least three-quarters full. L is a pipe of small bore, through which the liquid ammonia is forced, by reason of the pressure to which it is now subjected, to the expansion cock or valve, through which it is injected into the evaporating or expansion coil N which is situated in the room or chamber to be refrigerated or cooled.

The ammonia gas resulting from the expansion and evaporation of the liquid ammonia in the evaporating or expansion coil N, having absorbed or taken up the heat from the surrounding atmosphere, passes away through the pipes O and B, back again into the compressor cylinder, and the cycle of operations of compressing, etc., are again performed as above.

Secondly. Following the course of the oil employed for sealing, lubricating, and cooling purposes, which, as previously mentioned, is heated with the gas during compression, and is passed into the tank D, to the bottom of which it falls. From the bottom of the tank D, the heated oil is conducted through a pipe *a* to the lowermost pipe of the oil-cooler *b*, which is practically similar in construction, but on a smaller scale, to the ammonia condenser, and is likewise cooled by sprayed or atomized cold water. After being sufficiently reduced in temperature in the oil-cooler *b*, the oil flows through the pipe *c*, strainer *d*, and pipe *e*, into the oil pump *f*, which latter is so constructed that it delivers the cooled oil into the compressor, distributing it to either side of the piston or plunger during its compression stroke, that is to say, in such a manner that no oil is furnished during the suction stroke of the piston, but only during the time of compressing, thereby cooling the gas during its period of heating. The heated oil, after leaving the compressor, then again returns, together with the hot compressed gas, to the pressure tank D, and follows the same round through the oil-cooler *b*, strainer *d*, and oil pump *f*, back to the compression cylinder. It will be obvious that the oil, as well as the ammonia, is used over and over again, no loss or waste of either taking place except that which may occur through leakage.

Any small quantities of oil, however, that may be carried over with the current of the gas from the pressure tank D into the condenser F, pass along with the liquid ammonia into the separating tank K, where, by reason of its greater weight, this oil falls to, and collects at the bottom of the tank. As soon as a sufficient quantity of oil has become thus deposited, it is drawn off, and passed through the oil cooler back to the oil pump. The oil reservoir or tank is also connected to the oil pump F. When the apparatus is employed for the manufacture of ice, the evaporating coils N are placed in a tank containing brine, sufficient space being left between them to allow of the insertion of cans or moulds containing the water to be frozen. As before stated the exhaust steam of the engine driving the compressor is condensed and purified, and supplies the water to be made into ice.

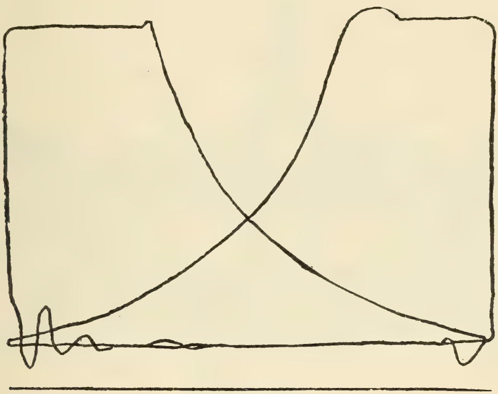


FIGURE 169.
Diagram from De Lavergne Compressor.

The various parts are clearly indicated in Fig. 168—and the routes taken by the ammonia, the sealing oil, the lubricating and cooling oil, and the steam are shown by the arrows.

Fig. 170 is a sectional view of the Triumph Ice Machine Company, Cincinnati, O., horizontal pattern double-acting ammonia compressor. It will be seen from the illustration that the compressor is provided with five valves, viz., three suction valves and two discharge valves, the third, or auxiliary suction valve, being much lighter than the main valves, and perfectly balanced, and it being claimed by the makers tending greatly to increase the economy of the machine.

Obviously the main suction valves must necessarily be of sufficient dimensions to admit the charge quickly at the commencement of each stroke, and the springs con-

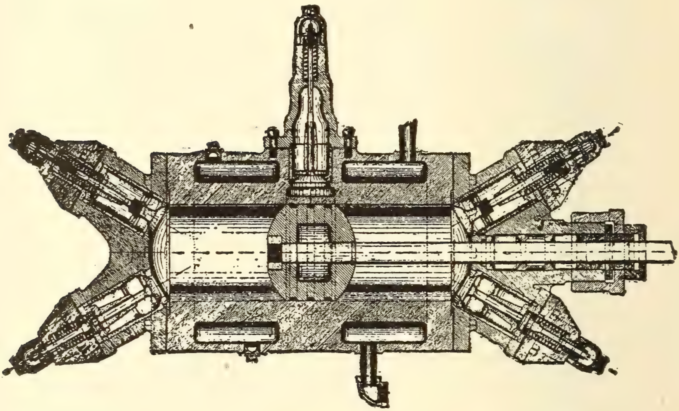


FIGURE 170.
Double-action horizontal type of Triumph ammonia compressor.

trolling them must consequently have an appreciable tension. It will be readily seen that owing to this fact the pressure of the gas in the cylinder, during admission, must be less than it is in the suction pipe by an amount equal to the tension of these springs. By the use of the above mentioned third, or auxiliary suction valve, which is comparatively light, and is consequently operated with a very light spring, the pressures in the compressor pump are equalised, and a fuller charge is obtained at each stroke, thereby increasing the efficiency of the machine.

The valves comprise each a guard screwed on to the stem, fitted inside a cage, and so ribbed as to reduce the port area, the bottom of the stem being enlarged for that reason. Stems extending from both the suction and discharge valves to the exterior, and passing through stuffing boxes, admit of their being adjusted from the outside, and any desired degree of tension being put upon the springs. The object of this arrangement is to adjust the machine for working at different pressures, and the relative temperatures thereof.

There are three packing compartments in the piston-rod stuffing box, and it is fitted with a suitable relief valve communicating with the suction. The heads are formed concave, and of a radius which enables a larger valve area to be secured. The principal shut-off valves are of such a form of construction as to admit of their being packed whilst the machine is working, and a feature in the design of this machine which is of by no means inconsiderable advantage, is that every portion of the compressor is easily accessible.

Besides ammonia, there are various other refrigerating agents employed in the compression system, among which may be mentioned Ether, Methyl-chloride, sulphurous acid, and carbonic acid, but space will not permit a further discussion of the compression system, and the absorption process will now be taken up.

The principle involved in the operation of apparatus for the abstraction of heat by the evaporation of a separate refrigerating agent of a volatile nature under the direct action of heat, and without the use of power, which agent again enters into solution with a liquid, is, more a chemical or physical action than a mechanical one. It is founded upon the fact of the great capacity possessed by water for absorbing a number of vapors having low boiling points, and of their being readily separable therefrom again, by heating the combined liquid; hence it is commonly known as the absorption process.

The absorption process was invented by Ferdinand Carré about the year 1850. This system involves the continuous distillation of ammoniacal liquor, and requires the use of three distinct sets of appliances, viz:—

First, for distilling, condensing, and liquefying the ammonia. Second, for producing cold, by means of a refrigerator, and absorber, a condenser, a concentrator, and a rectifier. Third, pumps for forcing the liquor from the condenser into the generator for redistillation. The three operations are each distinct from the other, but when the apparatus is in actual work they must be continuous, and are dependent upon one another, forming separate stages of a closed cycle.

An advantage of the absorption process is that the bulk of the heat required for performing the work is applied direct without being transformed into mechanical power. The first machines, however, constructed upon this principle were very imperfect in operation, by reason of the impossibility of securing an anhydrous product of distillation, and as the ammonia distilled over contained as much as 25 per cent of water, a very large expenditure of heat was required for evaporation, and the working of the apparatus, moreover, was rendered intermittent. This was owing to the distillation, which is the most important operation, and has of necessity to be executed in a rapid manner, being, in the first machines, very imperfectly effected, and the liquor resulting therefrom being naturally much diluted with water. Another serious result of the above defect was the accumulation of weak liquor in the refrigerator, and the consequent necessity for constant additions of ammonia.

Fig. 171 illustrates an ammonia absorption, refrigerating device, one of a leading American type, and will give a clear idea of the operation in general of the system.

A constant pressure of about 150 lbs. per square inch is maintained in the generator, and to prevent this pressure from being exceeded, a safety valve is provided on the dome of the generator. The gas that escapes through this safety valve is led through a suitable pipe to a small water tank, where it is absorbed. The operation is as follows:

The aqua ammonia is first introduced into the generator, the gas or vapor expelled therefrom by heat into the condenser; and so that the process may be carried out continuously and not be arrested by the exhaustion of the solution, the exhausted or impoverished liquor is slowly drawn off at the bottom of the generator, an equal volume of fresh strong solution being constantly inserted at the top thereof. The united effects of the cooling and pressure produce liquefaction of the ammoniacal gas or vapor in the condenser, and the liquid ammonia passes to the refrigerator. It will be seen that the ammoniacal gas or vapor from the tubes of the refrigerator is re-absorbed, and a rich solution is formed to feed the generator, the absorbing water used being that withdrawn exhausted from the latter. Thus the generator and the condenser will keep up a continuous supply of the liquid, and the refrigerator will continue to freeze successive charges of water in the ice-cans or cases, provided, however, that the requisite heat to va-

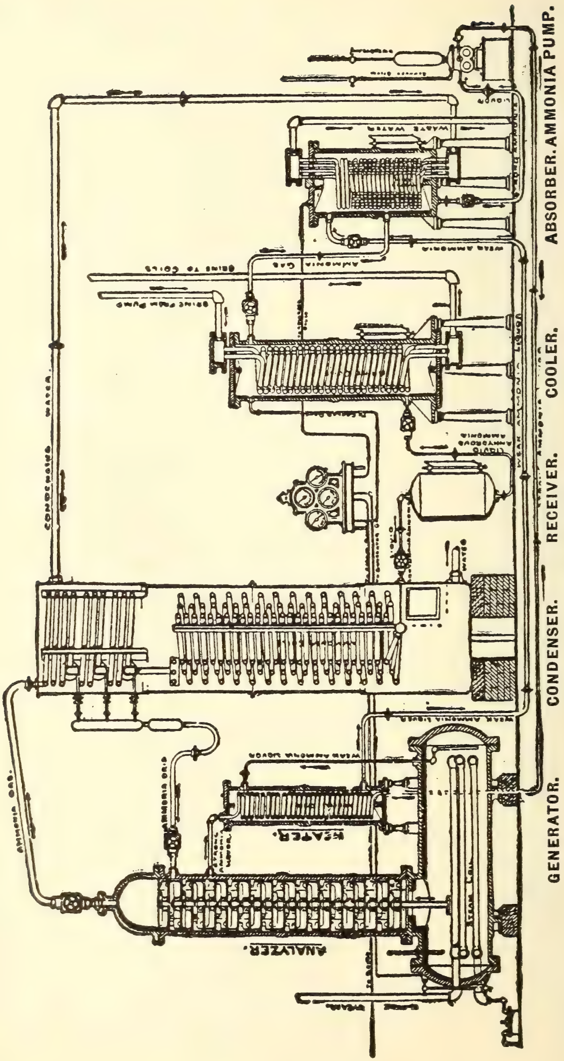


FIGURE 171.

Diagram illustrating leading type of American ammonia absorption machine.

porise or gasify the ammonia is supplied to the generator. If, therefore, the entire apparatus be perfectly fluid-tight, as it is theoretically supposed to be, no escape could take place by leakage or otherwise, and the same materials would go on indefinitely producing the same uniform effect.

In starting a machine constructed on the absorption principle it must be first blown through to expel all the air. In Carré's apparatus the air escaping from the absorber is conducted by a suitable pipe into what is known as a purger, where it is passed below the surface of water to absorb or retain any ammonia that would otherwise escape with the air.

A large amount of water is required for cooling purposes in the condenser or liquefier, and absorber, and a considerable consumption of fuel is also necessary to heat the generator, when this is performed directly by means of a furnace. When, however, this is effected by steam-heated pipes, or, by coils of pipe heated by the exhaust steam from an engine, or even by direct or live steam from a boiler, there is a considerable saving on this head. Steam or other motive power is likewise required for driving the force pump.

The operation of Reece's improved apparatus is briefly as follows:—

The charge of liquid ammonia (the ordinary commercial quality of a density of 26° Beaumé) is vaporised by the application of heat, and the mixed vapor of water and ammonia passed to the vessels called the analyser and the rectifier, wherein the bulk of the water is condensed at a comparatively elevated temperature, and is returned to the generator. The ammoniacal vapor or gas is then passed to the condenser, where it is treated in a substantially similar manner to that in Carré's apparatus, that is to say, it is caused to liquefy under the combined action of the condensation effected by the cooling water circulating around the condenser tubes, and of the pressure maintained in the generator. The liquid ammonia (in this case practically anhydrous) is then used in the refrigerator, and the vapor therefrom, whilst still under considerable tension, is admitted from the refrigerator to a cylinder fitted with a slide valve, and entry and exhaust ports, practically similar to those of a high pressure steam-engine, and is thus utilized to drive the force pump for returning the strong solution to the generator, after which it is passed into the absorber, where it meets, and is taken up by, the weak liquor from the generator, and the strong liquor so formed is forced back into the generator by means of a force pump.

Figure 172 shows the general form of the Consolidated ice-making and refrigerating machine. It is a compression type of machine, having two single-acting, vertical compressors and either a horizontal or a vertical engine, which is connected to a center crank, on either side of which are large journal bearings. Power thus transmitted to the shaft is regulated by two flywheels which are of sufficient weight to carry the engine smoothly over the point of maximum compression and to deliver the power to the compressor.

It is an adavantage to have the crank in the center of the shaft and to place a flywheel between the engine crank and each pump crank, because this construction gives uniformity and steadiness of motion and diminishes torsional strain, vibration and friction of the crank shaft. It also permits the use of a long-stroke Corliss engine, since the stroke of the engine is not limited to the stroke of the ammonia pump, as is the case where the compressor and engine are connected to the same crank pin. In this way, the builders claim to effect a saving of from 10 to 15 per cent in the steam consumption.

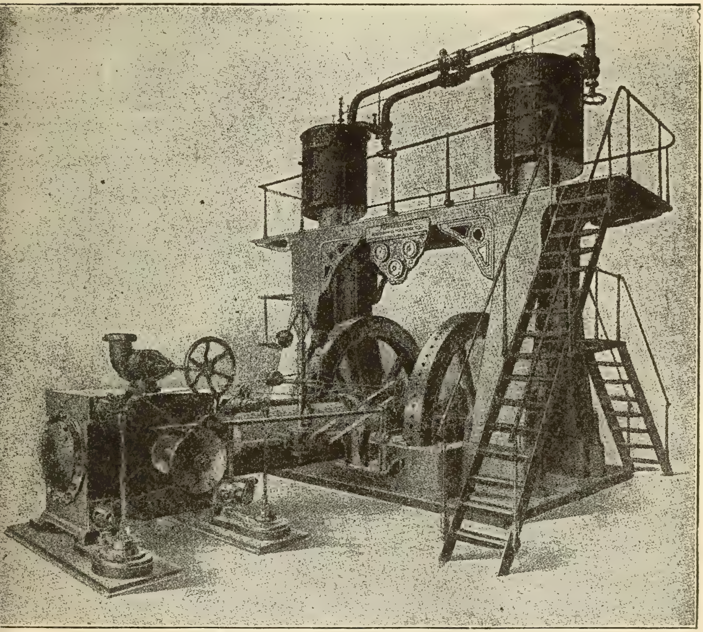


FIGURE 172. VERTICAL CONSOLIDATED REFRIGERATING MACHINE.

Heavy pump columns terminate at the bottom in broad flanges bolted to a substantial foundation plate, cast in one piece and provided with four journal bearings for the crank shaft. Convenient stairways and galleries are provided to furnish access to the upper part of the machine. As seen in Fig. 173 the compressor or ammonia pump is single-acting, compressing only on the up-stroke, and the gas has free entrance to and exit from the cylinder below the piston, thus keeping the pump cylinder and piston cool.

An oil chamber, which effectually seals the stuffing-box around the pump piston rod, is formed in the lower part of the pump. As the pressure on the stuffingbox end of the pump is only the direct evaporator pressure, there is no chance for the escape of ammonia. Equalization of the temperature and cooling of the compressor is effected by encasing it in a copper water jacket.

In the construction of the piston, no bolts or nuts are used, and there are, therefore, no cavities or chambers into which the gas can be comprest. Since the piston travels flush with the pump head, all of the gas is expelled at each stroke. The pistons are fitted with spring rings that are first turned elliptical and afterward returned on a mandrel until they fit the cylinder exactly.

As shown in Fig. 173 the stuffingboxes are operated by a worm-gear device so that, while the machine is running, a turn of the handwheel accurately adjusts the stuffingbox gland and thus makes unnecessary the different and frequently dangerous use of a wrench or spanner and also avoids the possibility of cutting the piston rod by uneven adjustment of the gland.

Connections for the suction and discharge pipes are made outside of the pump head so that, when it is desired to remove the head, neither of these connections need be disturbed. Discharge and suction valves, com-

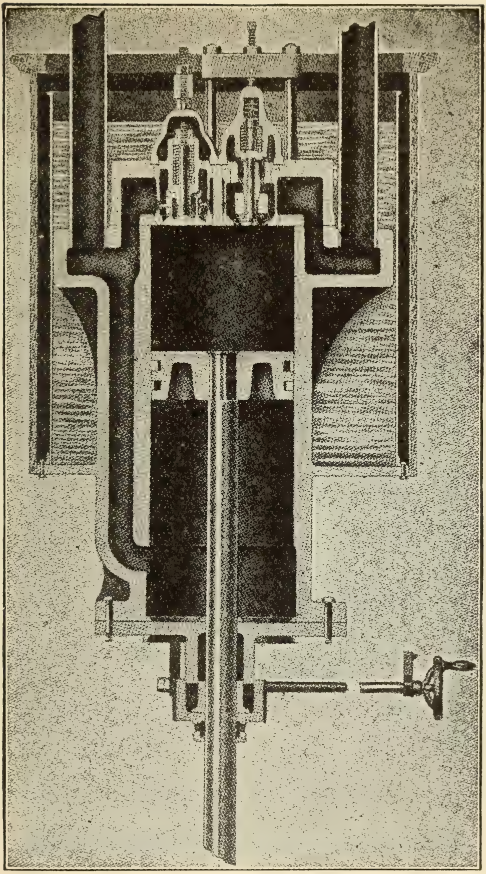


FIGURE 173. CROSS-SECTION OF THE SIMPLE-ACTING AMMONIA COMPRESSOR.

pressor heads, piston and piston rods, all are easily removed without breaking any ammonia connections.

Figure 173 shows the suction and discharge valves which are located in the pump head. The suction valve, Fig. 174, is balanced, thus allowing the pump to fill with expanded gas from the evaporator with no loss of press-

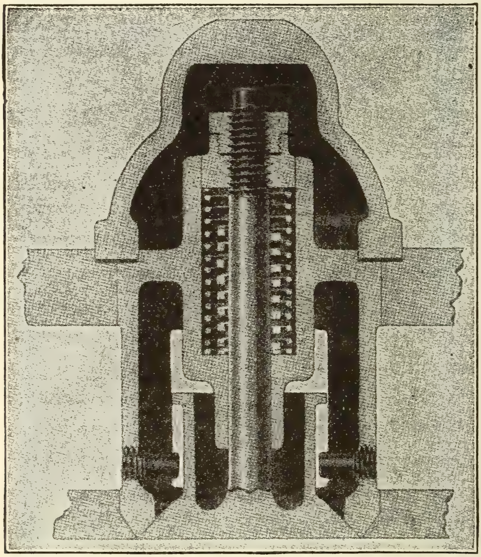


FIGURE 174. SUCTION VALVE SHOWING SAFETY DEVICE.

ure. As shown in Fig. 174, the valves are provided with a safety device which renders it impossible for them to get into the cylinder. Cushioning of the discharge valves ensures noiseless action and, since both suction and discharge valves are set in steel cages and held in position in the pump head by means of yokes and set screws, it is but a moment's work to remove a valve and put a duplicate in place.

As seen in Fig. 172 the machine is driven by a Featherstone Corliss engine resting on substantial base plates which are extended on one side for the dashpots. The valve motion is of the improved Corliss type, having the liberating catches made of hardened steel of such form that eight wearing surfaces are available, by change of position, each new position restoring the valve motion to its original setting.

HORIZONTAL TYPE.

In this form, the Featherstone machine is built with a horizontal engine and a horizontal, double-acting compressor, and has a straight crank shaft with the flywheel placed in the middle between the two main bearings as shown in Fig. 175. These machines are mounted on the heavy-duty Tangye frame which is almost universally used by builders of double-acting compressors. Provision is made for cooling the compressor cylinder by means of a water jacket so that it may be operated as a dry or humid gas machine. As shown in Fig. 175, the machine is driven by a Featherstone-Corliss engine, having a heavy frame similar to that of the compressor, but any type of engine may be used and, if necessary, the compressor can be driven by belt.

Figure 176 shows the manner in which the compressor cylinders are pressed into the frame so as to form a water jacket. The valves are placed in the compressor head in a way that will permit of their easy removal and,

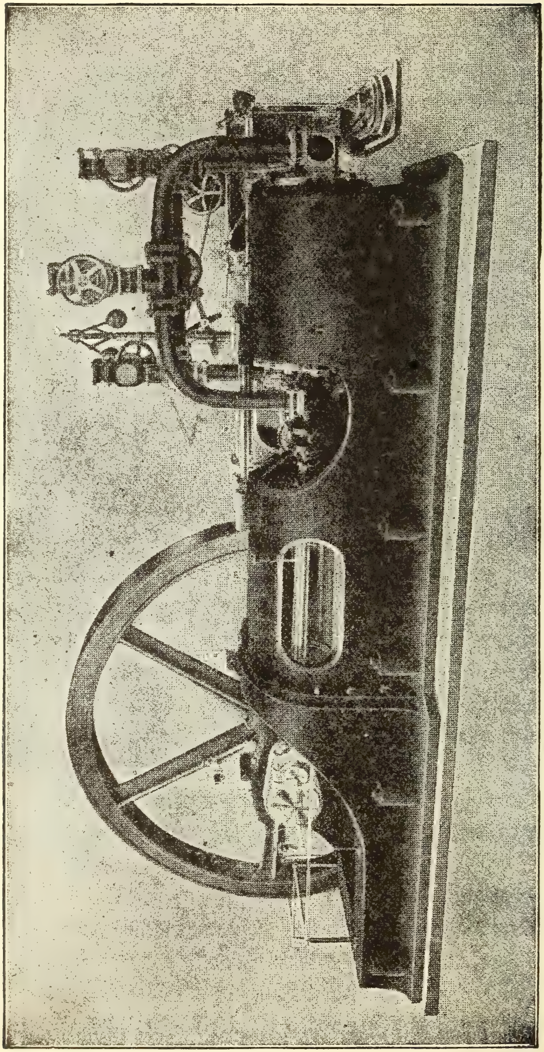


FIGURE 175. HORIZONTAL DOUBLE-ACTING MACHINE.

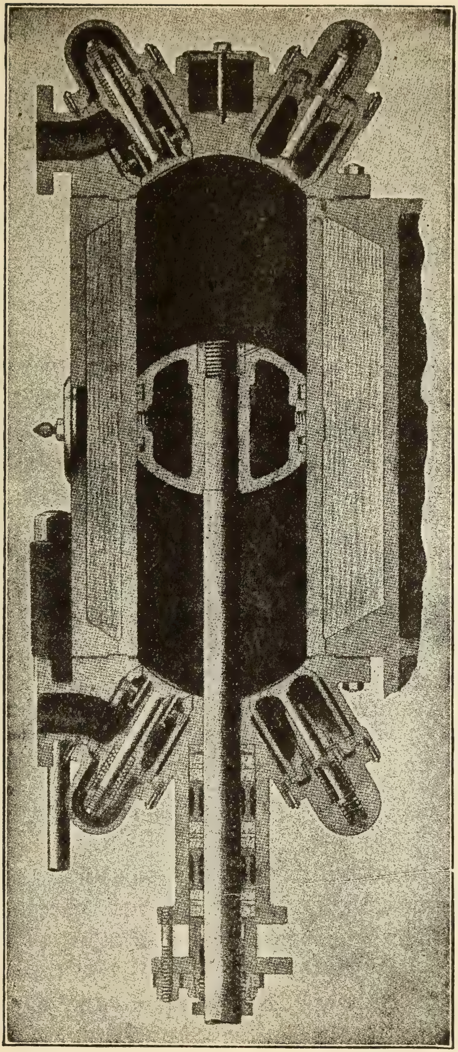


FIGURE 176. SECTION OF COMPRESSOR SHOWING WATER JACKET.

since the discharge valves are located at the lowest part of the cylinder, perfect draining at the end of the compression period is assured. This makes it impossible for the machine to be wrecked by the piston coming in contact with an incompressible liquid at the end of the stroke. The clearance is less than 1-32 inch, thus giving good efficiency by permitting the piston to discharge all of the gas at each stroke, so that on commencing a new stroke, gas is immediately drawn into the cylinder.

In the horizontal machine, the valves are like those used in the consolidated compressors, the stems and disks being of forged steel set in cast-steel housings. Lift of the valves is given by cushion springs and controlled by compression springs and the suction valves are of the Featherstone safety type so that it is impossible for them to fall into the cylinder. The piston is screwed to the piston rod by a jam nut, and the connecting rod is provided with adjustable wedges for taking up the wear of the boxes.

In a double-acting, ammonia compressor, the stuffiing-box is one of the most vital parts. Referring to Fig. 177, letters *A, B, C, D, E* and *F* indicate composition split packing rings and letters *Q, R, S, U, V* and *W* denote pure tin rings of an inside diameter 1-16 inch larger note that of the piston rod. These rings should never be split.

J is a lantern which forms an oil storage reservoir in the stuffingbox, the oil being taken in at the point marked *K* from a pipe connected to the oil trap. This passage being always open, the oil is forced into the stuffingbox by the high pressure of the gas in the oil trap, thus keeping the lantern full and instantly replacing what

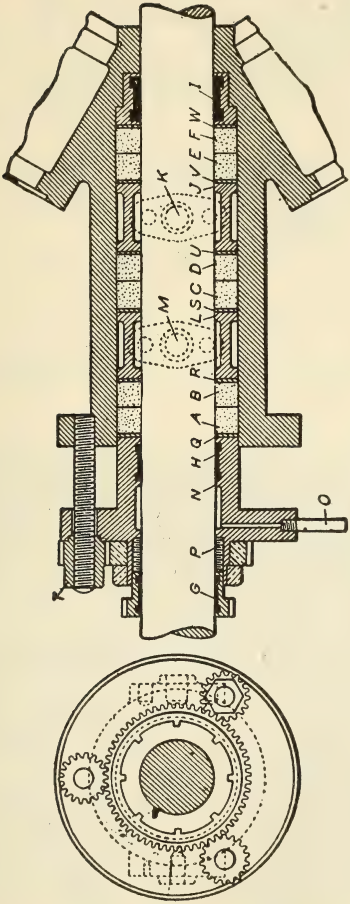


FIGURE 177. STUFFING-BOX OF THE DOUBLE-ACTING COMPRESSOR.

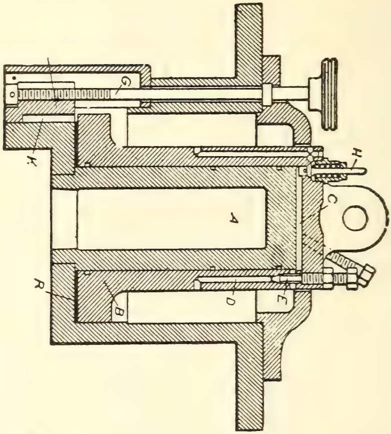


FIGURE 178. SECTION OF THE DASHPOT.

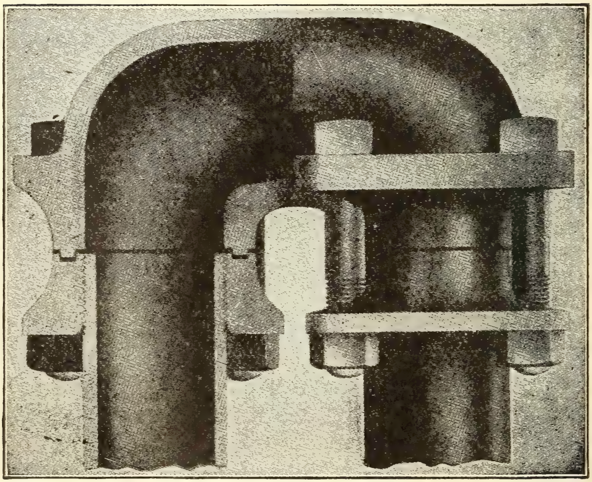


FIGURE 179. RETURN BEND FOR THE ATMOSPHERIC CONDENSER.

little oil is carried into the cylinder by the rod. *L* is a lantern which at the point marked *M* has a pipe connection to the suction line so that any ammonia gas which may have escaped the packing rings, *C, D, E* and *F* is drawn back. By this device, packing rings *A* and *B* have to withstand only the suction pressure. *N* is the stuffing-box gland which has a chamber supplied with oil through *O* from a small rotary oil pump operated from the main shaft. *P* is the oil gland which should be kept just tight enough to keep the oil in the stuffingbox gland.

Points of contact with the rod are *G, H* and *I* and they are made an exact fit. If the rod becomes scored and is turned down, these parts must be rebabbitted. To tighten the stuffingbox gland it is only necessary to adjust the nut *T,* which is a pinion nut and is in mesh with the inside gear and the other two pinion nuts.

As shown in Fig. 178, the dashpot is of a special design and allows for the adjustment of both vacuum and cushion. It is placed on an extension of the cylinder foot and connected by the usual vertical link rod to the crank on the valve stem. The central cylinder *A* acts as a guide and piston while the pot *B* rises and falls and by so doing draws air into the chamber *C* through the passage *D,* the vacuum *C* being regulated by the position of the needle valve *E.* As the pot falls, air escapes from *C* through valve *H* and the fall is free until the lower end of the pot cushions into a chamber *K* formed by drawing up the ring *F* by means of the screw *G.* The position of *F* determines the amount of the cushioning and the leather washer *R* prevents hammering at the end of the fall.

DOUBLE-PIPE AMMONIA CONDENSER.

This type of condenser consists of two series of coils, one within the other, and is usually built in four different forms having 2-inch and 1.25-inch, 2.5-inch and 1.25-inch, 3-inch and 2-inch pipes or, having the upper outside pipes 2.5 inches and the lower pipes with all of the inner pipes 1.25 inch. Of these forms, the first is used most extensively, but the second is used whenever extra strong pipe is required and the third when extremely dirty water is to be handled. The ammonia circulates downwards through the annular space between the two

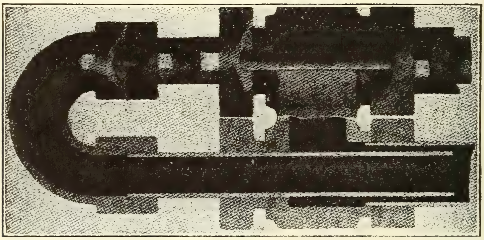


FIGURE 180. DOUBLE-PIPE RETURN BEND.

sets of pipe coils. By this arrangement a comparatively small charge of ammonia is required, owing to the narrowness of the space between the pipes.

Occupying small space, the condenser can be placed in a basement or other convenient place. Since the flow of ammonia gas and the cooling water are in opposite directions, the hottest gas comes in contact with the hottest water and thus fully utilizes the cooling effect of the water.

Figure 179 shows a sectional view of the atmospheric condenser return bend and Fig. 180 a view of the return

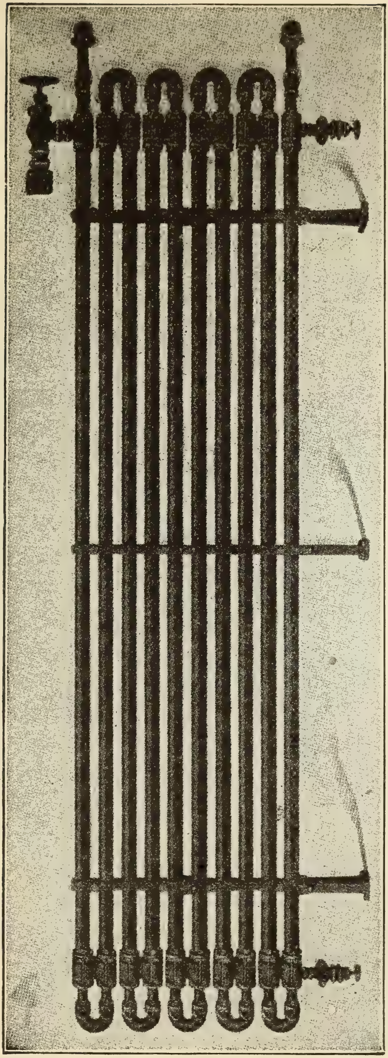


FIGURE 181. DOUBLE-PIPE AMMONIA CONDENSER.

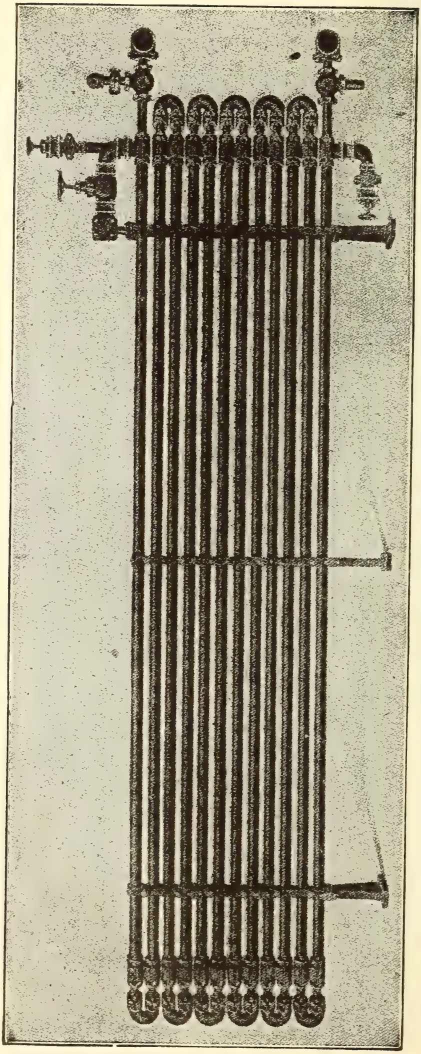


FIGURE 182. DOUBLE-PIPE BRINE COOLER.

bend which is used for the double-pipe ammonia condenser and also for the brine cooler. Figure 181 shows the double-pipe condenser in which, owing to the construction of the return bend, it is possible to remove and replace any length of pipe without tearing down the whole coil as is necessary where double-pipe connections are made with screwed bends.

Condensers are furnished complete with gas, liquid, pump out, and water headers and one of the special features is the construction of the liquid and purge headers which are made with special tee valves. Owing to the design, additional sections can be added at any time as enlargement of the plant may require.

Figure 182 shows a double-pipe brine cooler which is built on the same general plan as the ammonia condenser, but is made of 2 and 3-inch pipes. Liquid ammonia enters and is expanded in the bottom pipe and the gas is drawn off at the top, while the brine is pumped into the top and circulates downward, through the annular space between the two pipes.

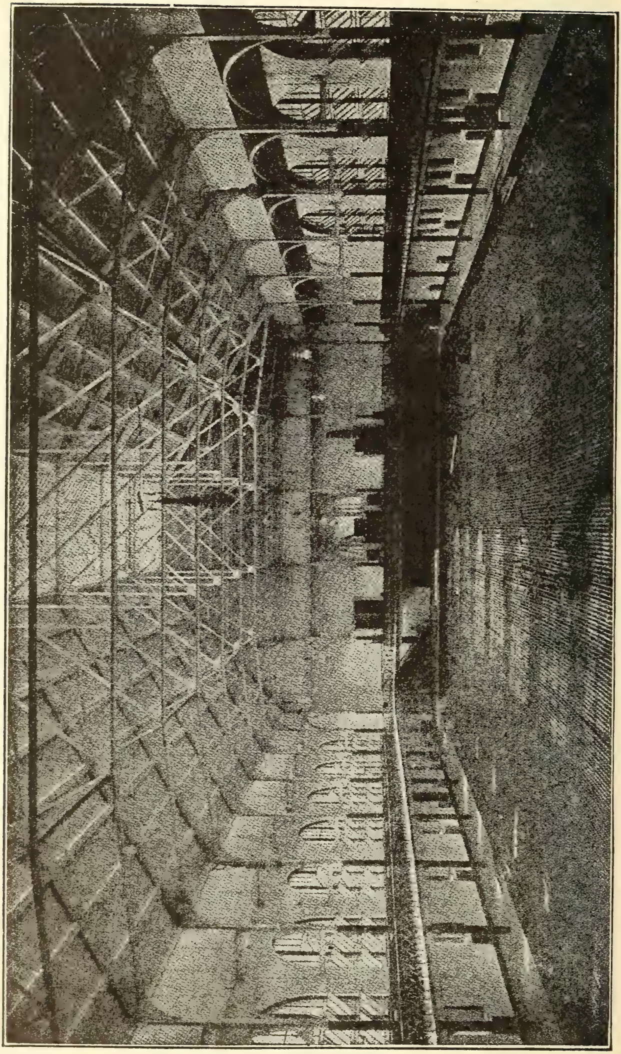


FIG. 183. SKATING RINK FLOOR BEFORE FLOODING, SHOWING BRINE PIPES.

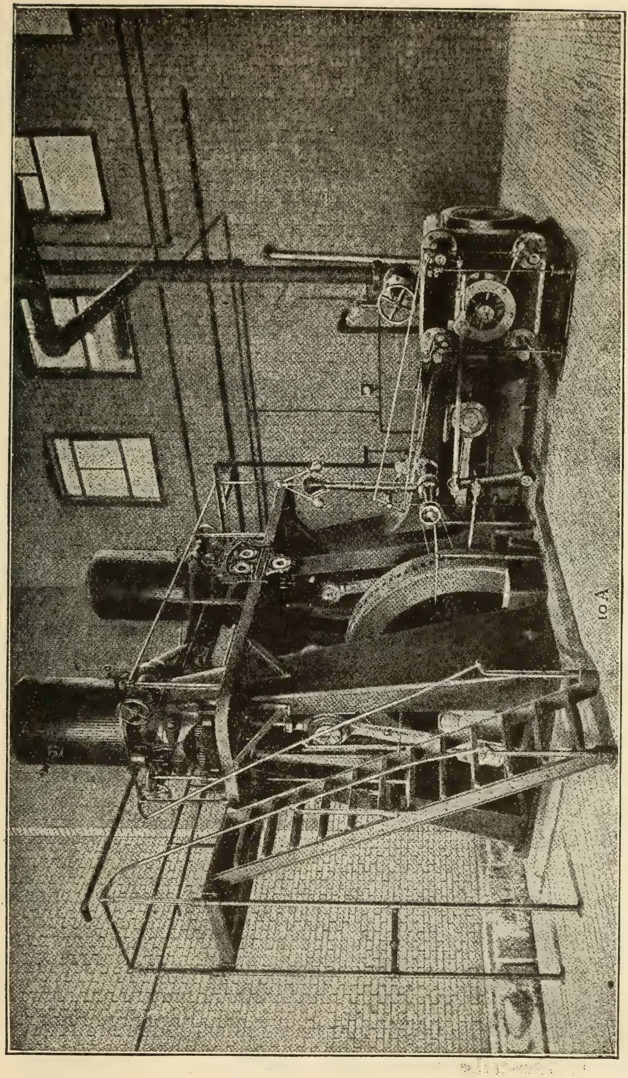


FIG. 184. FRICK ICE MACHINE, DIRECT-CONNECTED WITH CORLISS ENGINE.

1. Of what does the process of refrigeration consist?

2. Describe a freezing mixture that will give a temperature of 67° below zero.

3. Upon what are the theory and practice of mechanical refrigeration based?

4. What are the two first laws of thermo-dynamics?

5. Can the quantity of heat in the universe be increased or diminished?

6. What is the result of compressing a pound of air at 70° temperature, and atmospheric pressure, to one-half its original volume?

7. In order that the higher pressure may be maintained as the temperature is reduced, what is necessary?

8. If the pound of compressed air be allowed to expand in a cylinder what will be the result?

9. What can be said of the mechanical work done by this air in its expansion?

10. What can be said of the distribution of heat throughout the universe?

11. How is the temperature of a body or substance reduced?

12. What work is demanded of a refrigerating machine?

13. How may a refrigerating machine be defined, and what is its main function?

14. How may the various devices for refrigeration and ice making be classified?

15. How is refrigeration accomplished in apparatus belonging to the first class?

16. Describe the vacuum system.

17. How is refrigeration effected in machines belonging to the third class?

18. Describe the absorption system.

19. How is refrigeration effected in machines belonging to the fifth class?

20. What two systems have come into general use in this country?

21. What are the three distinct stages, in the compression system?

22. What is the refrigerating medium used in this process or system?

23. Of what does ammonia consist, and what is its chemical formula?

24. Under what two conditions may gaseous ammonia be liquefied?

25. To what pressure is the gaseous ammonia usually compressed?

26. In order to liquefy gaseous ammonia by cold, what temperature is required?

27. What takes place during compression?

28. How is the vapor condensed and liquefied?

29. How are the refrigerating qualities of the ammonia in its liquefied state utilized?

30. After being expanded into vapor what becomes of it?

31. How many, and what are the systems of refrigeration by compression?

32. Describe the theory of the "wet" system as effected in the action of the Linde machine.

33. Upon what does the pressure of steam in a boiler depend?

34. What are the relations of the temperatures of the steam, and the water from which it was generated, so long as they are in contact?

35. What is the result if the steam be superheated?

36. What results from the compression of a dry gas without cooling?

37. What does the Adiabatic curve as traced by the indicator represent?

38. How is the cooling of the vapor accomplished in the Linde compressor?

39. Describe in brief the construction of the cylinder heads, piston, and valves of the Linde ice machine.

40. What is the clearance between piston and cylinder head?

41. How is the piston lubricated?

42. What may be said of the area of the valves in the Linde machine?

43. Describe briefly the stuffing box of the Linde machine.

44. How many methods are there of utilizing refrigeration?

45. Describe the Brine system.

46. Describe the direct expansion system.

47. Which one of the two systems is the more efficient?

48. Mention a few of the advantages that the direct expansion system has over the Brine system.

49. By what two systems is ice made, or manufactured?

50. Describe in general terms the can system of ice making.

51. In the De La Vergne refrigerating machine how is the heated gas cooled?

52. Mention a characteristic feature of this machine.

53. What are some of the advantages claimed for the De La Vergne machine?

54. Describe the action of the valves in the De La Vergne machine.

55. Describe in general terms the course of the ammonia in this machine and apparatus connected with it.

56. Describe briefly the course of the oil used for sealing, and other purposes, in the De La Vergne machine.

57. How many valves has the Triumph ammonia compressor?

58. What advantage is gained by the use of the third or auxiliary suction valve?

59. Describe in brief the construction and action of the valves in this machine.

60. What other agents besides ammonia are employed in the compression system of refrigeration?

61. By whom was the absorption system of refrigeration invented?

62. What chemical action is involved in this process?

63. How many distinct sets of appliances are required?

64. Mention the functions of each.

65. What advantage appertains to the absorption system of refrigeration?

66. What pressure is maintained in the generator?

67. Describe in general terms the operation of an absorption device.

68. Is power required in its operation?

69. What is done with the air escaping from the absorber in Carre's apparatus?

70. Describe the operation of Reece's device for refrigeration by absorption.

CHAPTER X.

CORLISS ENGINE VALVE GEAR.

Fig. 185 shows the valve gear of a Corliss Engine. A′ shows the connection of the steam pipe with the steam

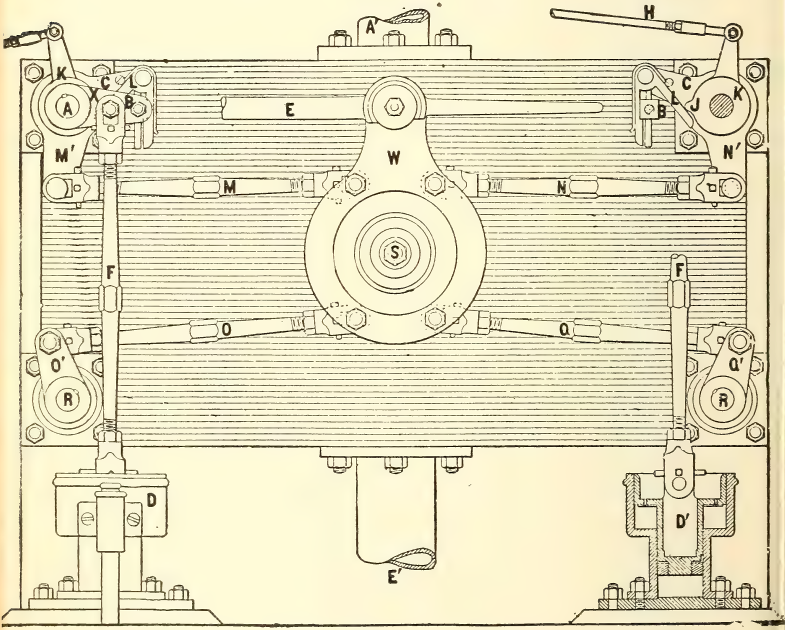


FIG. 185. VALVE GEAR OF A CORLISS ENGINE.

chest on top of the cylinder, and E′ is the exhaust pipe underneath. There are four valves, two steam admission valves above, and two exhaust valves beneath. These valves are all of the rotative type, extending across the entire width of the steam chest on top, and the exhaust chest directly under the cylinder. The working face of a Corliss valve is turned to a true circle, and the seat in which the valve works is bored to a true circle also, and is fitted with ports. The valves are rotated part of a revolution at each stroke of the piston, motion being transmitted to them through the medium of the wrist plate W, and the rods M-N-O-Q. The wrist plate receives its vibratory motion from the eccentric by means of the rod E. The valves are fitted with cranks M′-N′-O′-Q′ to which the rods M-N-O-Q are connected. These rods are threaded on the ends in order that their lengths may be varied, when necessary in adjusting the valves.

The connections of the exhaust valves to the wrist plate are positive, the travel of these valves being a fixed quantity.

The connections of the steam valves with the motion of the wrist plate are detachable, the travel of these valves being under the control of the governor, when the engine is running up to speed. R-R are the ends of the exhaust valves, to which the cranks O′ and Q′ are keyed. A shows the end of one of the steam valves. X is a crank arm that is keyed to the valve spindle or stem. D and D′ are the dash pots. F-F are the dash pot rods that connect the arms X-X of the valves with the dash pots. The Cranks M′-N′ rotate loose upon the valve spindles, in fact they are loose sleeves, carrying arms C-C at right angles to M′N′. These arms C-C also carry at their free ends trip hooks L-L that engage the blocks B when the arms

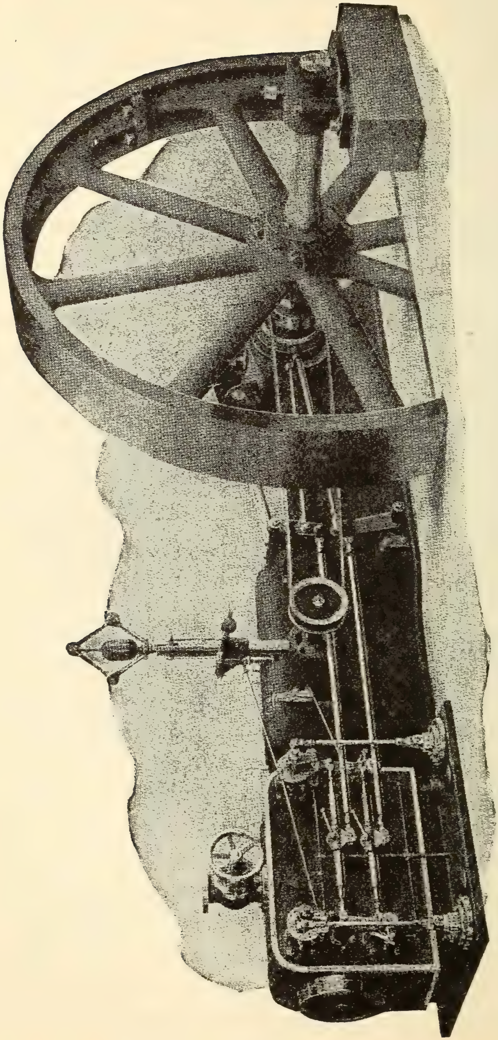


FIG. 186. DOUBLE ECCENTRIC CORLISS ENGINE.

are at the lowest point of their travel. The engagement of the trip hook with the block B, and the lifting of the arm C, causes the steam valve to rotate upon its seat and uncover the steam port for the admission of steam to that end of the cylinder. The steam valve does not open wide only when the engine is being started, or before full speed has been attained. This is owing to the fact that the governor controls the position of the trip mechanism J-K,

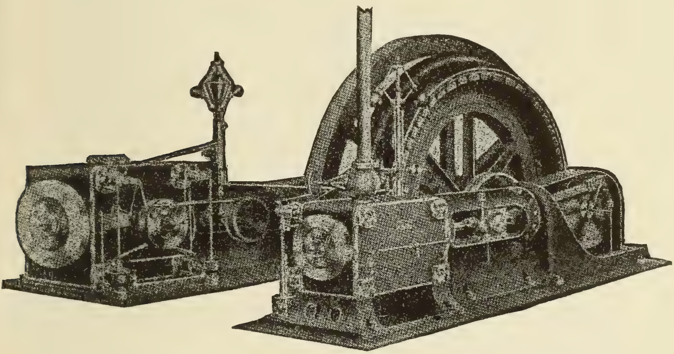


FIG. 187. CROSS COMPOUND CORLISS ENGINE.

which also turns freely on the stem or spindle of the valve. The point J of this mechanism is brought to bear upon the arm of the trip hook L by the governor through the arm K and rod H thus causing the hook to become disengaged from the block B, allowing the arm X to drop and close the valve. This closure of the valves is accomplished quickly, owing to the constant pull downwards of the dash pots on the arms XX. The dash pots are simple cast iron cylinders, open at the top, and fitted with air tight pistons to which the rods F-F are connected. The lifting of these pistons by the arms XX

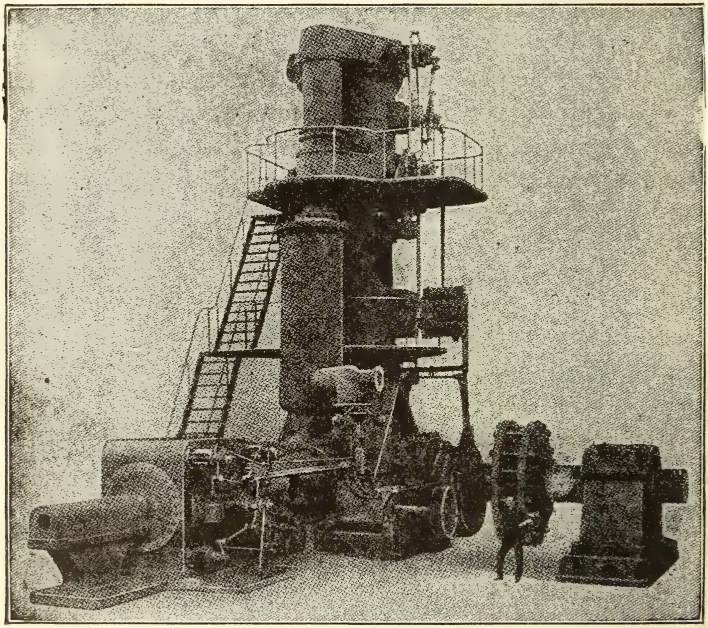


FIG. 188. HORIZONTAL-VERTICAL CORLISS ENGINE.

causes a vacuum under the pistons, and the pressure of the atmosphere upon the top surface of the pistons causes them to drop quickly.

HIGH SPEED, HORIZONTAL, PISTON-VALVE ENGINE

In Fig. 189 is shown the latest type of horizontal engine manufactured for direct connection to electric generators. With slight modifications these engines can be operated independently.

An automatic governor effects close regulation and large bearing surfaces, together with forced lubrication and light parts, adapt the engine for high speed operation. An oil pump operated by the crank shaft draws oil from the reservoir in the base of the engine and forces it through pipes and internal passages in the moving parts to the main bearings, the crank pin, the crosshead pin and the guides, valve slide and eccentric.

Oil is thus supplied at a pressure of 15 pounds per square inch, so that a thin film of lubricant is maintained between the metal surfaces, and by preventing contact reduces friction and wear. This system of lubrication, together with the complete enclosing of the parts, results in a mechanical efficiency of something over 90 per cent and permits the engine to be run continuously with little or no supervision.

To prevent oil entering the cylinder on the piston rod and at the same time to make it impossible for water formed in the stuffingbox to get inside of the casing, a water-shed partition with a bronze stuffingbox is inserted in the frame a few inches from the cylinder and is so constructed as to leave the cylinder stuffingbox easily accessible.

Although enclosed for protection from dust and dirt, the moving parts can be examined by means of openings

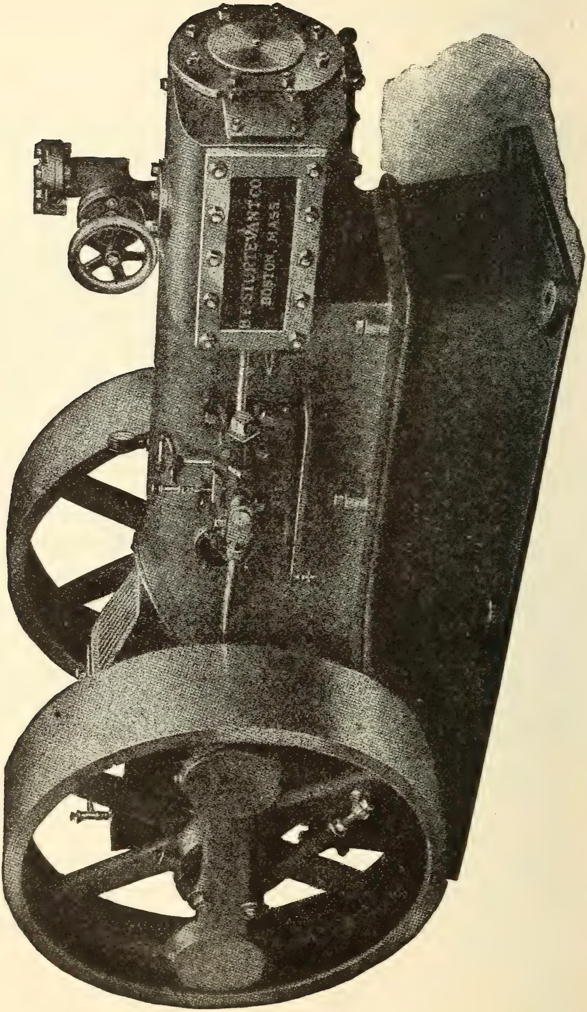


FIG. 189. HIGH SPEED, HORIZONTAL, PISTON-VALVE ENGINE.

in the crank case which are covered with oil-tight plates. If necessary or desirable, the entire case can be removed.

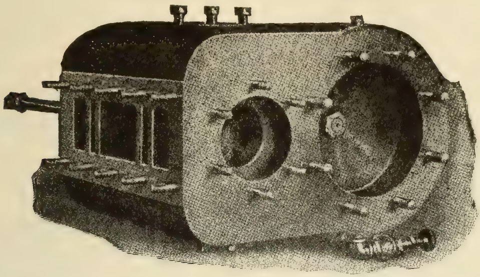


FIG. 190. VALVE CHEST WITH COVER REMOVED.

To minimize power expended for operation, the steam valve, which is of the double-ported piston type, is balanced, and since it works in a renewable bushing and has

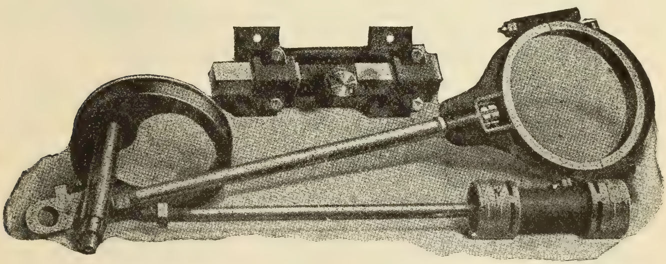


FIG. 191. PARTS OF THE ECCENTRIC AND THE VALVE.

cast-iron packing rings turned to an exact fit, the valve is easily kept steam tight. Figure 190 shows the valve casing with the outside plates removed.

In the flywheel is an automatic Rites governor to which an eccentric is attached and connected by a rod to the steam valve, thus giving the motion for correct steam distribution. Figure 191 shows the eccentric and its connecting rod, as well as the piston valve and rod.

Cutoff ranges from 0 to three-fourths stroke and the speed is so regulated, by automatically altering the point of cutoff, that the variation from no load to full load is not more than 1.5 per cent. To reduce condensation, the casting forming the cylinder and valve chest is heavily lagged with magnesia and asbestos of good quality, held in place by a cast-iron casing of neat design. At each end of the cylinder is a relief valve to guard against damage from water in the cylinder and adjustable to open at any desired pressure.

Taps for connections of indicator piping are made in the cylinder. To secure lightness and strength, the cast-iron piston is cored out and provided with internal ribs, being fastened to the piston rod, which is forged from open-hearth steel, by forcing it on a taper and securing it with a nut and pin.

Moving in guides cast in one piece with the engine frame, the crosshead is equipped with adjustable cast-iron slippers to allow for wear and is provided with a steel crosshead pin flattened on two sides. At the crank-pin end the connecting rod of forged steel has a cast-iron box lined with white metal, which is hammered in and accurately bored. At the crosshead end it is provided with a steel strap, an adjustable key, and a bronze box. Counterweights are secured to the webs of the crank shaft and the engine is finished in a thorough manner.

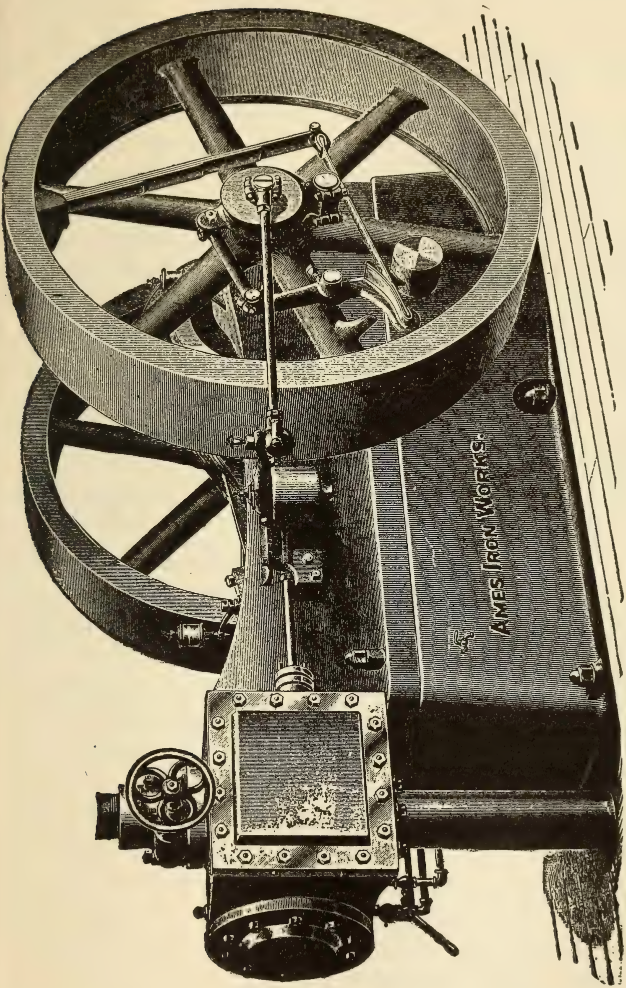


FIG. 192. HIGH SPEED HORIZONTAL SLIDE VALVE ENGINE.

AIR COMPRESSORS.

COMPOUND AND MULTIPLE STAGE AIR COMPRESSION.

Compression of gas is accomplished generally by one of the two methods technically termed adiabatic, without transference of heat, no heat is removed from the gas, and a consequent rise of temperature attends the operation, a diagram indicating the line of compression will demonstrate the resulting loss of power due to not extracting the heat generated by compression, as the volume is greatest in adiabatic compression, and in ratio increasing with pressure, and isothermal, wherein the heat developed by compression is carried away as fast as generated.

Water jacketed air or gas cylinders are provided for both compressions mentioned above, but contact between the vapor and cooling medium is transient, resulting in inconsiderable benefit, referring to abstraction of heat, and mainly effective in reducing temperature of cylinder walls, therefore, most economical operation will follow multiple stage compression and by withdrawing the heat thereof by a suitable cooling medium and apparatus, and, as fast as developed, in compounding, compression is carried forward in the first cylinder adiabatically or without the abstraction of heat, practically, the cylinder walls being cooled by a circulating fluid, compression is not accomplished in the initial cylinder to a high pressure, and a device intervenes between the first and second cylinders, through which the vapor passes to final compression, termed an inter-cooler, and, provided this device is properly designed and constructed, and furnished with a cooling medium adequate in quantity and of sufficiently low temperature, heat of compression is withdrawn until approximately the initial temperature is had and the volume reduced.

An after-cooler may be employed with profit in effecting a reduction of heat after final compression, and in abstracting moisture from the air or gas, furthermore an advantage accrues therefrom during operation in cold weather, especially where the air discharge line is exposed, by preventing an accumulation of frost upon the inside walls thereof.

Lubrication is more easily accomplished in two-stage than in single stage compression, vaporizing of the lubricant is not so rapid, resulting in more effective service and less deterioration of the wearing parts. The danger of explosion, while rarely attending adiabitic compression of air, is further removed under two-stage operation.

The volumetric efficiency of the machine is improved in that the terminal pressure in the first cylinder is lower than the final pressure under single stage compression, and the inflow of air begins at an earlier period of the return movement of the piston by reason of the fact that the expansion of the air or gas in clearance space occupies a reduced space in the cylinder.

Compressors of special type for a maximum of 3,000 pounds per square inch are furnished.

For pressures exceeding 100 pounds per square inch, for economy and safety compounding is recommended, for pressures exceeding say 400 pounds per square inch, multi-stage compression.

For pressures under 100 pounds per square inch, factors must enter into consideration upon which local conditions have a bearing, first cost, comparing cost of installation of single and two-stage machines, cost of fuel, horse power developed.

The table of horse powers developed under multi-stage compression is upon the following basis: Water-jacketed cylinders with temperature of air reduced to 60 degrees Fahrenheit in the inter-coolers. Atmosphere at 60 degrees. Three per cent approximately allowed for friction of piston for each cylinder.

ELECTRIC COMPRESSORS

SINGLE AND MULTIPLE STAGE

A special design of compressor, suitable for motor drive, is shown in Fig. 193 or may be modified into a steam actuated unit and for air pressures ranging from eighty tc twenty-five hundred pounds per square inch. The unit here shown is as constructed for a working pressure of 2,500 pounds per square inch, and tested to 3,000 pounds per square inch, operating at 560 revolutions per minute.

Its compactness will render its installation possible in a space entirely too small for regular types, space reserved in high buildings for the power plant, mines, shipboard; the speed of operation is favorable in many instances to direct connection to motors.

For developing a pressure of eighty pounds or less, and in instances where multi-stage compression is not desired, four air cylinders of equal diameter may be installed, if multi-stage is desired, one or more initial air cylinders are employed and compounding or multi-staging provided for, and up to a terminal pressure of 2,500 pounds, with inter- and after-coolers.

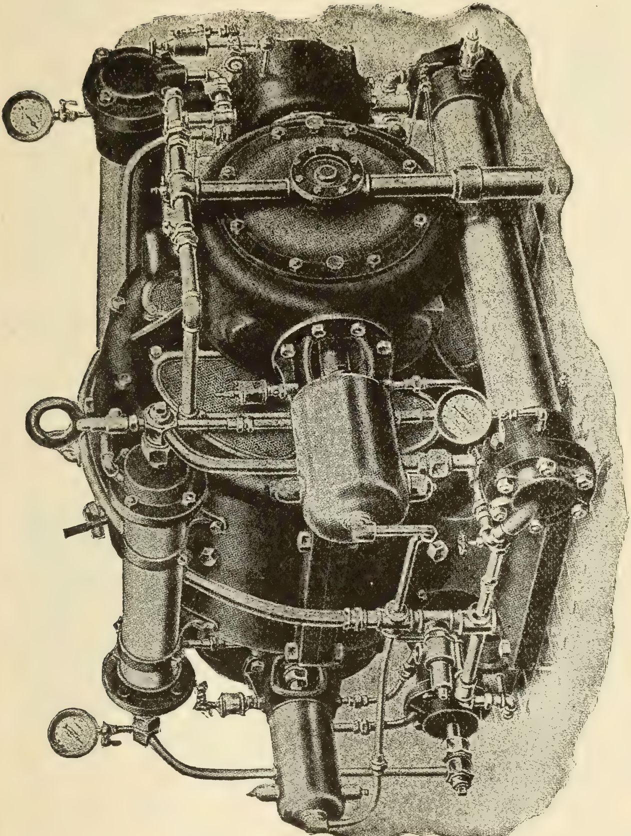


FIG. 193. ELECTRIC AIR COMPRESSOR.

In the selection of material entering into the construction thereof, great care has been taken to provide metals of uniform texture, of great strength, and of kinds best adapted for service imposed, and without regard to cost. For the maximum pressure, second, third, and fourth stage air cylinders are provided, with inter-coolers of very liberal cooling surfaces, and an after-cooler. The main bearings are automatically lubricated, the oil pump therefor being actuated by a reciprocating part of the machine and a device provided for automatically cooling and screening the lubricant. A cooling water pump is also attached, providing circulating water for air cylinders and inter-coolers.

Air valves are of special design permitting of the speed mentioned above, and quiet operation.

Special lubricators are provided.

AIR COMPRESSOR GOVERNOR

Where a steam driven single air compressor, or a compressor driven by a constant speed motor, is used to furnish air in varying quantities, some method other than the extremely wasteful one of allowing the surplus air to escape through a safety valve should be used. By preventing the atmosphere from entering the cylinder the compressor cannot do any work, consequently cannot consume power, although running at full speed, beyond that required to keep the machine alive, or rather to overcome the unloaded frictional resistance. An automatic valve for accomplishing this is shown in cut. It is simply a balanced governor valve controlled by a pilot valve. A small pipe leads from the air receiver to the pilot valve. The weight or spring, or both, may be regulated to allow the valve to unload at any pressure desired. With a slight fall in the receiver pressure it will gradually allow the air to enter the cylinder, thereby giving the compressor its load again.

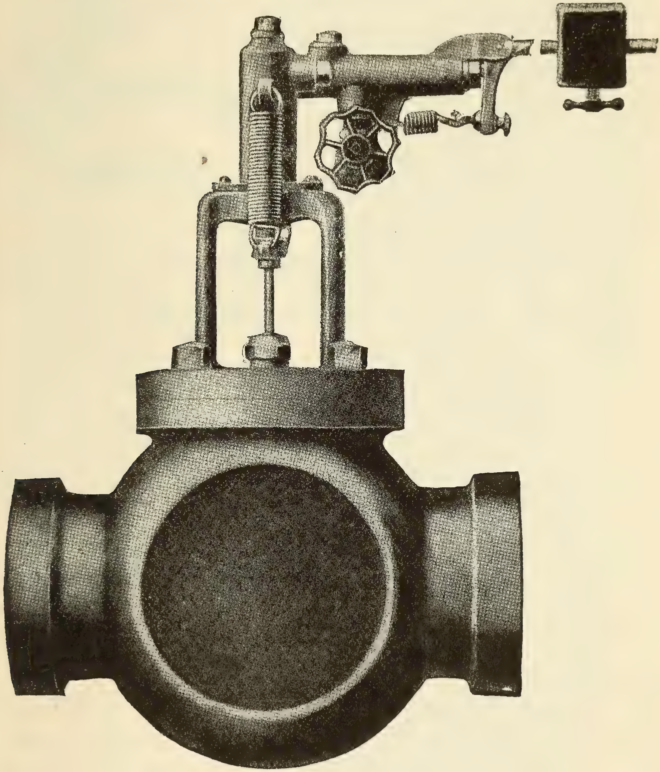


FIG. 194. AIR COMPRESSOR GOVERNOR.

This device loads and unloads very gradually, giving the compressor time to receive its load without shock; is noiseless in its operation, and is very close in its regulation.

DIRECTIONS FOR SETTING AND OPERATING AIR COMPRESSORS

Foundation. It should be the first care in installing an Air Compressor to provide it with a suitable foundation. The Compressors are self-contained and need foundations only of such design and strength as will insure the compressor remaining rigidly in place, a poor foundation costs almost as much as a good one, and as a compressor is usually a permanent fixture, it is advisable to put in a good foundation.

Blue prints are usually furnished showing location and proper size of foundation bolts for each machine, from which a template can be made by which the foundation bolts can be accurately located. It is of great importance that space should be left around foundation bolts so that they may be left free to move. The setting of the compressor is rendered much easier by taking this precaution. A good way to do is to put a short piece of pipe around each foundation bolt, carrying it up with the foundation, thus leaving the desired space behind it. In case a concrete foundation is installed, the pipe should be full length around each rod.

Setting Compressor. After the compressor has been placed in position, block the compressor off the foundation about ¼ inch by means of iron wedges, upon which the compressor should set level. Then the cement should be run into the bolt holes and also between the base of the compressor and foundation to insure true bearing all around.

Pipe Connections. The steam and exhaust pipes should be as free from L's as possible, and only should be

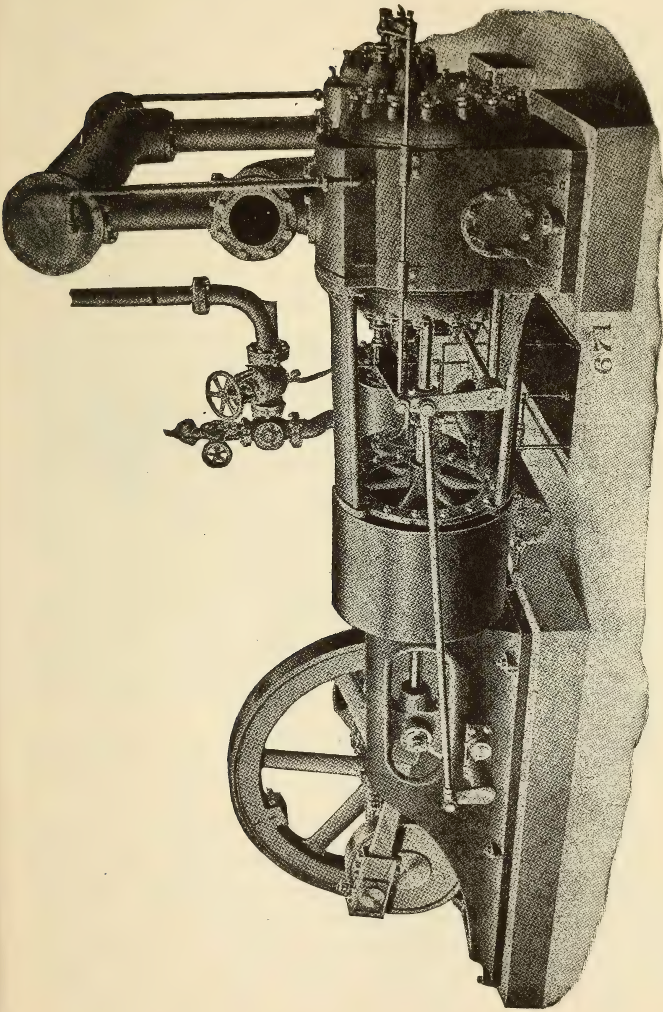


FIG. 195. AIR COMPRESSOR WITH COMPOUND STEAM AND AIR CYLINDERS.

used in so far as is demanded by expansion of pipes. All pipes should be thoroughly cleaned before starting the compressor, so that metal chips from cutting pipes may not be carried into the steam chest and score the valves and seats.

Proper allowance should be made for the expansion of the steam pipes in connecting same up.

A drain pipe or bleeder should be provided for live steam, connection being made directly above throttle valve and with the drain, so that the water of condensation may not have to pass through the steam cylinders. If steam connection for compressor is taken from main steam line instead of direct from boilers, the connection should be taken from the top of the steam pipe, thus avoiding the carrying of condensation.

The cocks and drains provided for both steam and air ends should be opened after the pump ceases operation, so that the water may be thoroughly drained, thereby avoiding any possibility of freezing.

In connecting water pipe to jacket around air cylinder care should be exercised to allow for proper drainage of cooling surface and pipes. In cold weather the water should be drained or breakage from freezing might occur in cylinder or jacket.

In piping air discharge pipe use lead in all joints and screw up tight, as air leaks are expensive.

Packing. After all connections are made and compressor is ready to start, fill the rod and steam valve stem stuffing boxes with a good grade of packing. Cut the packing so that it will fit easily in stuffing boxes. Do not pound it in and be careful that no grit is carried in with it, so as to mar the piston rod. When tightening the gland, remember that a gland should only be tight enough to

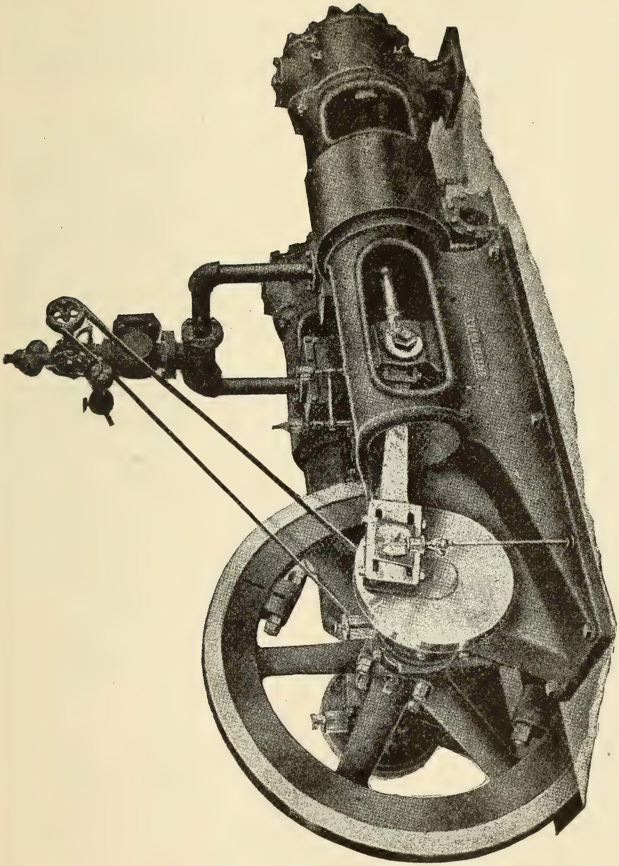


FIG. 196. DUPLEX AIR COMPRESSOR.

prevent leakage. If the gland is too tight it will cause undue friction and also may score and cut the rod.

Receiver. The air receiver should be so constructed so that the discharge pipe from the air compressor enters at top and goes to within six inches of the bottom of the receiver. The outlet pipe from the receiver should be on the side near the top.

General Precautions. Before starting the compressor, clean out all oil holes and grooves and see that all bearings are properly adjusted. Go over the compressor and see that all bolts and screws and nuts are thoroughly tightened, and it is advisable after the machine has been in operation for several hours to repeat the above operation in order to insure that nothing has worked loose.

When locating the compressor place it in a position or so locate the air induction pipe that it will have plenty of clean air. If the machine is placed in a position where fine particles of dust are floating in the air, the air valves are liable to become choked up and stick. Other parts of the compressor, such as slides, valves, stems, etc., are liable to undue wear when subjected to grit from the surrounding air.

Contents of Cylinder in Cubic Feet for Each Foot in Length.

Diameter in Inches.	Cubic Contents.	Diameter in Inches.	Cubic Contents.	Diameter in Inches.	Cubic Contents.
1	.0055	8¾	.4175	21	2.405
1¼	.0085	9	.4418	21½	2.521
1½	.0123	9¼	.4668	22	2.640
1¾	.0168	9½	.4923	22½	2.761
2	.0218	9¾	.5185	23	2.885
2¼	.0276	10	.5455	23½	3.012
2½	.0341	10¼	.5730	24	3.142
2¾	.0413	10½	.6013	25	3.409
3	.0491	10¾	.6303	26	3.687
3¼	.0576	11	.6600	27	3.976
3½	.0668	11¼	.6903	28	4.276
3¾	.0767	11½	.7213	29	4.587
4	.0873	11¾	.7530	30	4.909
4¼	.0985	12	.7854	31	5.241
4½	.1105	12½	.8523	32	5.585
4¾	.1231	13	.9218	33	5.940
5	.1364	13½	.9940	34	6.305
5¼	.2503	14	1.069	35	6.681
5½	.1650	14½	1.147	36	7.069
5¾	.1803	15	1.227	37	7.468
6	.1963	15½	1.310	38	7.886
6¼	.2130	16	1.396	39	8.296
6½	.2305	16½	1.485	40	8.728
6¾	.2485	17	1.576	41	9.168
7	.2673	17½	1.670	42	9.620
7¼	.2868	18	1.767	43	10.084
7½	.3068	18½	1.867	44	10.560
7¾	.3275	19	1.969	45	11.044
8	.3490	19½	2.074	46	11.540
8¼	.3713	20	2.182	47	12.048
8½	.3940	20½	2.292	48	12.566

Horse-Power Developed—To Compress 100 Cubic Feet Free Air From Atmosphere to Various Pressures.

Gauge Pressure Pounds.	One-Stage Compression D. H. P.	Gauge Pressure Pounds.	Two-Stage Compression D. H. P.	Four-Stage Compression D. H. P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.67	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1000	37.80	31.80
80	15.94	1200	39.70	33.30
90	17.06	1600	43.00	35.65
100	18.15	2000	45.50	37.80
		2500		39.06
		3000		40.15

TABLE OF EFFICIENCIES AT DIFFERENT ALTITUDES.

Altitude in Feet.	BAROMETRIC PRESSURE.		Volumetric Efficiency of Compressor, Per Cent.	Loss of Capacity, Per Cent.	Decreased Power Required, Per Cent.
	Inches Mercury.	Pounds per Sq. In.			
0	30.00	14.75	100	0	0
1000	28.88	14.20	97	3	1.8
2000	27.80	13.67	93	7	3.5
3000	26.76	13.16	90	10	5.2
4000	25.76	12.67	87	13	6.9
5000	24.79	12.20	84	16	8.5
6000	23.86	11.73	81	19	10.1
7000	22.97	11.30	78	22	11.6
8000	22.11	10.87	76	24	13.1
9000	21.29	10.46	73	27	14.6
10000	20.49	10.07	70	30	16.1
11000	19.72	9.70	68	32	17.6
12000	18.98	9.34	65	35	19.1
13000	18.27	8.98	63	37	20.6
14000	17.59	8.65	60	40	22.1
15000	16.93	8.32	58	42	23.5

Flow of Air Through an Orifice in Cubic Feet of Free Air Per Minute.

Flowing from a Round Hole in Receiver into the Atmosphere.

Diam. of Orifice in Inches.	Receiver Gauge Pressure							
	2 Pounds.	5 Pounds.	10 Pounds.	15 Pounds.	20 Pounds.	25 Pounds.	30 Pounds.	35 Pounds.
1/64	.038	.0597	.0842	.103	.119	.133	.156	.173
1/32	.153	.242	.342	.418	.485	.54	.632	.71
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80
1/8	2.435	3.86	5.45	6.65	7.7	8.6	10.00	11.2
1/4	9.74	15.40	21.8	26.70	30.8	34.5	40.	44.7
3/8	21.95	34.60	49.0	60.	69.	77.	90.	100.
1/2	39.0	61.60	87.0	107.	123.	138.	161.	179.
5/8	61.0	96.50	136.	167.	193.	216.	252.	280.
3/4	87.6	133.	196.	240.	277.	310.	362.	400.
7/8	119.5	189.	267.	326.	378.	422.	493.	550.
1	156.	247.	350.	427.	494.	550.	645.	715.
1 1/4	242.	384.	513.	665.	770.	830.	1000.	
1 1/2	350.	550.	780.	960.				
2	625.	985.						

FLOW OF AIR THROUGH AN ORIFICE IN CUBIC FEET OF FREE AIR PER MINUTE.

Flowing from a Round Hole in Reciever into the Atmosphere.—Continued.

Diam. of Orifice in Inches.	RECEIVER GAUGE PRESSURE.							
	40 Pounds.	45 Pounds.	50 Pounds.	60 Pounds.	70 Pounds.	80 Pounds.	90 Pounds.	100 Pounds.
1/64	19	.208	.225	.26	.295	.33	.364	.40
1/32	.77	.843	.914	1.05	1.19	1.33	1.47	1.61
1/16	3.07	3.36	3.64	4.2	4.76	5.32	5.87	6.45
1/8	12.27	13.4	14.50	16.8	19.0	21.2	23.50	25.8
1/4	49.09	53.8	58.2	67.	76.	85.	94.	103.
3/8	110.45	121.	130.	151.	171.	191.	211.	231.
1/2	196.35	215.	232.	268.	304.	340.	376.	412.
5/8	306.80	336.	364.	420.	476.	532.	587.	645.
3/4	441.79	482.	522.	604.	685.	765.	843.	925.
7/8	601.32	658.	710.	622.	930.	1004.		
1	785.40	860.	930.					
1 1/4								
1 1/2								
2								

Loss of Pressure Through Friction of Air in Pipes for Every One Hundred Feet Length of Pipe. Initial Gauge Pressure, 80 Pounds at Receiver.

Equivalent Volume of Free Air Discharge per Minute.	SIZE OF PIPE.													
	1 Inch	1¼ Inch	1½ Inch	2 Inch	2½ Inch	3 Inch	4 Inch	5 Inch	6 Inch	7 Inch	8 Inch	10 Inch	12 Inch	14 Inch
25	.24	.12												
50	1.00	.45	.18											
75	2.4	1.0	.4											
100	....	1.7	.7	.13										
200	....	....	3.0	.5	.175									
300	....	....	....	1.2	.38	.15								
400	....	....	....	2.15	.67	.27	.06							
500	....	....	....	3.3	1.1	.40	.10	.03	.012					
750	....	....	....	....	2.5	.91	.22	.07	.03	.013				
1000	....	....	....	....	....	1.8	.40	.12	.05	.023	.012			
1500	....	....	....	....	....	4.0	1.00	.30	.12	.052	.027			
2000	....	....	....	....	....	....	1.60	.50	.20	.095	.048	.017		
3000	....	....	....	....	....	....	3.70	1.20	.45	.22	.115	.036	.015	
4000	....	....	....	....	....	....	....	2.00	.80	.39	.20	.07	.026	.012
5000	....	....	....	....	....	....	....	....	1.30	.60	.30	10	.041	.018
6000	....	....	....	....	....	....	....	....	1.9	.85	.43	.15	.06	.028
7500	....	....	....	....	....	....	....	....	3.	1.40	.68	.22	.09	.04
10000	....	....	....	....	....	....	....	....	....	2.5	1.25	.40	.17	.075

Mean Effective Pressures.*

For the Compression Part only of the Stroke when Compressing and Delivering Air from One Atmosphere to Given Gauge-Pressure in a Single Cylinder.

Gauge Pressure.	Adiabatic Compression.	Isothermal Compression.
1	.44	.43
2	.96	.95
3	1.41	1.4
4	1.86	1.84
5	2.26	2.22
10	4.26	4.14
15	5.99	5.77
20	7.58	7.2
25	9.05	8.49
30	10.39	9.66
35	11.59	10.72
40	12.8	11.7
45	13.95	12.62
50	15.05	13.48
55	15.98	14.3
60	16.89	15.05
65	17.88	15.76
70	18.74	16.43
75	19.54	17.09
80	20.5	17.7
85	21.22	18.3
90	22.	18.87
95	22.27	19.4
100	23.43	19.92

*The Mean Effective Pressure for compression only is always lower than the Mean Effective Pressure for the whole work.

Approximate Amount of Air Required at Sea Level for Specific Sizes Rock Drills.

Size of Cylinder.......	2	2¼	2½	2¾	3	3⅛	3¼	3½
Diam. of Hole Drilled...	1-1½	1⅛-1½	1-2	1¼-2½	1½-3	1½-3	1½-3	1¾-3
Air Pressure.	Air Compression at Sea Level of one Drill—Cubic feet per minute of free air,							
60	60	65	70	80	90	100	110	120
70	70	75	80	90	105	115	125	135
80	80	85	90	100	115	130	140	150
90	85	90	95	115	130	140	150	170
100	95	100	110	125	140	155	170	185

FACTORS FOR COMPUTING REQUIREMENTS FOR DRILLS AT VARIOUS ALTITUDES.

Altitude in Feet Above Sea Level.	Atmospheric Pressure Pounds Per Square Inch.	FACTOR OF MULTIPLICATION. Pressure At Drill.				
		60 Pounds.	70 Pounds.	80 Pounds.	90 Pounds.	100 Pounds.
....	14.7	1.00	1.133	1.26	1.40	1.535
500	14.45	1.015	1.15	1.28	1.425	1.563
1,000	14.12	1.03	1.17	1.31	1.45	1.59
1,500	13.92	1.048	1.19	1.33	1.48	1.62
2,000	13.61	1.06	1.21	1.35	1.50	1.645
3,000	13.10	1.10	1.25	1.40	1.55	1.70
4,000	12.61	1.131	1.287	1.443	1.60	1.755
5,000	12.15	1.17	1.33	1.495	1.652	1.81
6,000	11.75	1.20	1.37	1.537	1.705	1.87
7,000	11.27	1.24	1.42	1.59	1.76	1.935
8,000	10.85	1.282	1.465	1.645	1.825	2.00
9,000	10.45	1.32	1.51	1.70	1.90	2.07
10,000	10.10	1.365	1.56	1.755	1.968	2.143

QUESTIONS ON COMPOUND AND MULTIPLE STAGE AIR COMPRESSION.

1. How many systems of gas compression are usually employed?

2. How are they designated?

3. Explain the principles underlying the Adiabatic system.

4. What is the leading characteristic of the Isothermal method?

5. How are the compressor cylinders cooled?

6. What is the most economical system of compression?

7. Describe it briefly.

8. Mention several advantages possessed by multiple stage over single stage compression.

9. Upon what basis is the table of horse-powers developed under multiple stage compression computed?

10. How many pounds pressure per square inch may a motor driven high speed air compressor be safely operated at?

11. How many stages of compression are usually provided for the very high pressures?

12. How is lubrication of the apparatus accomplished?

13. Describe the method of controlling the quantity of air compressed.

14. What is an air compressor governor?

15. What should be the first care in setting up an air compressor?

16. Describe the best method to pursue in regard to foundation bolts.

17. Describe the proper method of setting a compressor.

18. What rule should be followed regarding the piping?

19. Where should the drain pipe for live steam be located?

20. What rule should be observed regarding the steam connection for the compressor?

21. What regulations should be adhered to in connecting the water pipes?

22. Describe the proper method of packing the piston rods of an air compressor.

23. How should the air receiver be constructed?

24. What are some general precautions to be observed?

25. What special precaution should be taken regarding the air induction pipe?

CHAPTER XII.

PUMPS.

All engineers have more or less dealing with pumps of some type, and it is proper that a short space be devoted to a study of the principles governing the action of a pump, and especially that law of nature which makes it possible to raise water from a lower level to a higher plane, by the pressure of the atmosphere upon the surface of the water to be raised. A pump may be described in general terms, as a device for lifting liquids, and also for causing them to flow through pipes in such a manner that they will not return, therefore there must be a system of valves that will allow the passage of the liquid only in one direction. Water is the liquid with which we will deal, and the valves will all be required to act under the influence of the currents passing through them without the assistance of outside rods or other appliances. In other words they must be automatic. In Figure 198 three kinds of non return valves are shown, and a short description of each will serve to give the student a fair idea of their action; a a is a section of a vertical pipe in which there is fitted a cross diaphragm with a hole in it. This forms the "seat" of the valve b, which is hinged at c. The hole in the diaphragm may be circular, rectangular, or any other shape, but the plate, or valve b must be large enough to cover it, and its under surface, and the raised rim or seat upon which it rests must be trued up to fit each other water tight. It is evident that if water is forced up through the pipe, it will push the valve b open, and pass through the hole, but will not be able to return, for the reason that just as soon as the upward current ceases, the valve will close by its own weight, and thus retain the water that has passed through it. In the second form of valve, d d is a section of vertical pipe, having a diaphragm,

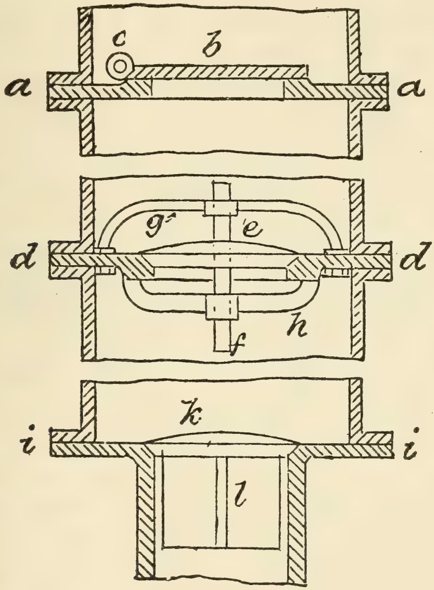


FIGURE 198.

in which a circular conical hole is bored. A conical disk e which is the valve, is turned to fit this opening or seat, and contact between the valve and seat is made water tight by grinding the valve in the seat with very fine flour of emery, followed up by "crocus," which is chemically prepared oxide of iron. This form of valve is fitted with a stem f, which passes above and below through holes in guide frames g and h, thus serving to always keep the valve in its proper axial position. The action of this valve is similar to valve b, in that it is opened by the rising current of water, and closed by its own weight, but its operation is much more satisfactory, being quicker and more delicate, as the water in rising passes up all around the valve, and in closing less water will pass the valve in the return direction for the reason that the valve closes more promptly. A third form of metal valve is shown at i i which is a section of pipe, with diaphragm, and valve seat. This type of valve is guided and held in its proper position by ribs l extending downwards, and having a loose fit against the sides of the circular passage below the seat. It is necessary that a stop be placed above the valve k to prevent its rising too high. The valves hitherto described are metallic. India rubber in various forms is more largely used for pump valves, than any other material. When a large volume of water at a high pressure is to be handled, the types of valves shown in Fig. 198 are not suitable, as their action is not quick enough, and the concussion caused by their closing is too severe. Many other types of metal valves have been designed, to obviate this shock, some consisting of a number of balls falling into spherical seats, others formed of rings of increasing diameter, each ring fitting as a valve to that beneath it, and forming a seat for the one above, while the top ring is closed by a small disk valve. Probably the best metal valve that has been brought out for this purpose is the double beat valve, shown in vertical section in Figure 199. This valve is crown shaped in section, and has two faces, and two seats, an upper and a lower as shown, and over these the water passes, when the valve is open, in the directions indicated by the arrows a a and b b. The valve is guided in its movement by inside ribs, and a central stem. Under the collar of the latter, at c a leather washer is fitted to prevent concussion when the valve opens. The surface of the valve acted upon by the water, or acting upon it is the annular area comprised between the two valve seats. Hence in proportion to the

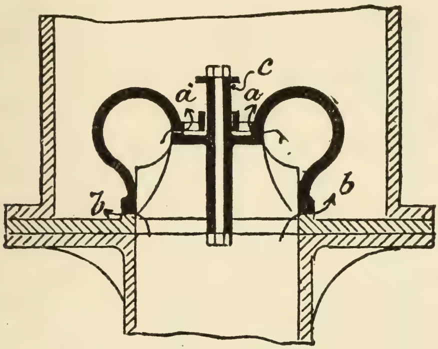


FIGURE 199.

area of opening, a much greater pressure is exerted to overcome the resistance of the water in closing, than with any of the single seated valves. This force can, in fact, be made anything that is desired, for there is no limit to the ratios of the valve seats, until their diameters become equal, when the valve will be an equilibrium valve, and will not open to any internal pressure. The action of the valves being understood, the action of the various types of pumps may be easily comprehended. In Figure 200 A is a vertical sectional view of the most simple form of lift pump. a is a pipe called the suction pipe, rising from a well or other source of supply, and connected to the diaphragm which constitutes the bottom of the pump, and also forms the seating for the valve b, termed the suction valve. Above this valve is seen the pump cylinder or barrel, which is properly bored out, and in which moves the piston, or plunger c, having an opening through it guarded by the valve d. Both of these valves b and d open upwards, consequently the water can pass up through them, but cannot return. The plunger or piston c is connected to the forked end e of the pump rod f, and is packed with leather or other packing so that it moves water tight in the cylinder. In order to thoroughly understand the principle governing the action of the pump it will be necessary to revert to the natural law referred to at the beginning of this chapter. This law is, that the atmosphere exerts a pressure of 15 pounds (14.7 lbs. to be exact), per square inch upon all surfaces with which it comes in contact, therefore it will sustain a vertical column of water one square inch in area, and of such a height as to weigh 15 pounds. Now water at a temperature of 39.1° weighs 62.5 pounds per cubic foot, therefore a column of water one inch square and one foot high would weigh $\frac{62.5}{144}=0.434$ pounds. As the atmospheric pressure is 15 pounds per square inch, it follows that the column of water balanced by the atmosphere will be $\frac{15}{0.434} = 34.5$ in height. These conditions assume that a perfect vacuum is created in the pump cylinder by the upward motion of the piston, but a perfect vacuum is practically impossible, at least in the pumping of water, owing to the fact that there is always air in water, which is released when the atmospheric pressure is removed from the surface of the water.

The action is as follows, referring to Fig. 200. Suppose the pump piston c is at the bottom of the cylinder and just beginning the upward stroke. As it rises a partial vacuum will be created beneath it, as the air cannot pass down through the valve d, or past the packing that

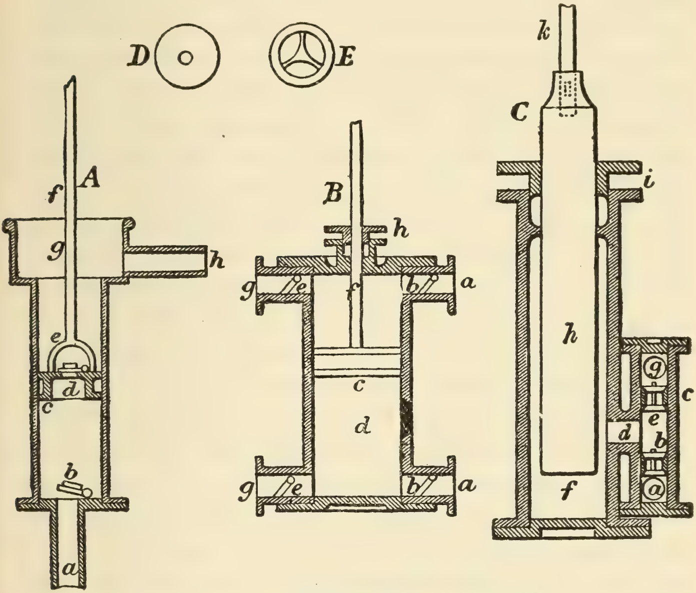


FIGURE 200.

is placed around the piston causing it to fit the cylinder water tight.

Consequently the atmospheric pressure on the surface of the water in the well, being unbalanced by an equal pressure in the pump cylinder, forces water up through the suction pipe a, past the valve b, and into the pump cylinder, where it is retained by valve b. As the pump piston returns on the downward stroke, the valve d opens thus permitting the water in the cylinder to pass up through the piston, and on the next upward stroke, the valve d closes, and this water is lifted into the head g, of the pump, from whence it flows away through the pipe h. At the same time more water rises from the suction pipe a, through valve b, and fills the pump cylinder underneath the piston. The height to which the pump will lift the water from the well, or rather to which the atmospheric pressure will force the water, depends upon the character of the vacuum that is created in the cylinder by the up stroke of the piston. If there are no air leaks in the suction pipe, and the valves, piston, and cylinder are all properly fitted, a pump may be made to lift water 28 feet. As before stated the atmosphere will, from a theoretical standpoint, sustain a column of water 34.5 feet in height, but in pumping water there are certain unavoidable drawbacks to overcome, such for instance as the weight of the suction valve, or valves, the friction of the water in passing through the pipes, and the force required to raise the piston or plunger. This latter force will be equal to the weight of a column of water equal in diameter to the diameter of the pump piston, and in height to the distance from the surface of the water, to the underside of the pump piston. Therefore as the piston rises, an increasing force is required, the mean being that corresponding to the position of the bucket or piston at half stroke. Let P equal this force in pounds, d equal diameter of piston in inches, and h equal lift of water in feet, then $P = .7854d^2 \times h \times .434 = .34d^2h$.

Referring again to Fig. 200, B is a vertical section of a double acting force pump, in which d is the cylinder, c is a solid piston properly packed to fit the cylinder, f is the piston rod, working through the stuffing box h. There are two suction inlets a a, guarded by valves b b, opening inwards, and g g are the discharge outlets, guarded by valves e e opening outwards. The action of this type of pump is as follows: When the piston moves downwards, water enters the cylinder through valve b at the top, and the water below the piston is forcibly discharged through valve e, at the bottom. During the upward stroke of the piston, water is admitted through bottom valve b, and discharged through top valve e. When this type of pump is used for water, the force necessary to operate it may be found by the above formula, but h should equal the height in feet from the surface of the water at the source of supply, to the level to which it is forced. When the pump is used for air, the force to work it will be the pressure of air per square inch multiplied by the area of the piston.

A form of pump that is largely used for forcing water against high pressures, is shown in vertical section at C Fig. 200 in which f is the pump cylinder, within which moves the plunger h, which works water-tight through the stuffing-box i.

Into the upper end of plunger h, the pump rod k is secured. The pump here shown is single acting. C is the valve box or chamber, communicating with the pump cylinder through the passage d, a is the inlet, and b is the suction valve, through which the water passes as the plunger rises on the upstroke. When the plunger starts on the downward stroke, valve b closes, and the water is forced out through passage d, and discharge valve e into the delivery pipe g. In order that a water valve may be efficient it should be allowed sufficient lift, that is it should rise high enough to cause the area between the valve and the edges of the seat, to equal the area of the opening through the seat. For a circular valve the area of opening will be $3.1416\ r^2$ if r=the ra-

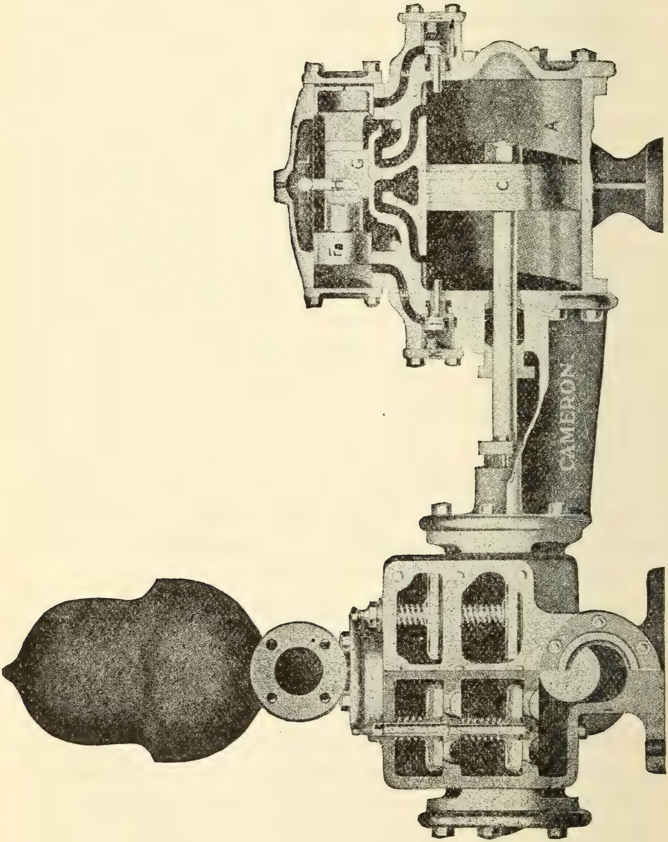


FIGURE 201. VERTICAL SECTION THROUGH CAMERON STEAM PUMP.

dius. If h=the height of lift, the waterway between the valve and its seat will be $6.2832\ r\ h$.

Hence if the valve is properly adjusted, its lift should be not less than one-half the radius, thus $3.1416\ r^2 = 6.2832\ r\ h$, $r = 2\ h$.

In a double beat valve, if r=the less, and r′ the greater diameter, the effective area of the opening is $3.1416\ r'^2$, and the area of waterway given by the lift of the valve equals $6.2832\ h\ (r+r')$, therefore $h = \frac{r'^2}{2(r+r')}$. A valve hinged on one side must be allowed to rise twice as high as one of the same size rising vertically, to give the same area of outlet.

While there are various methods of actuating the water piston of a pump, it will hardly be necessary to devote much time, or space to any of these methods, except the two in which engineers are mainly interested, viz., steam pumps and power pumps. There is a large number of various types of steam pumps, each type having its own particular kind of steam valve, but only a few of the leading types will be noticed in this connection.

Figure 201 is a sectional view of the Cameron steam pump, showing both the water end, and steam end. One of the leading features of this pump is, that there is no outside valve gear connected with the steam valve, this valve being operated entirely by internal appliances as will be understood by reference to Figure 202 which gives an enlarged sectional view of the steam end.

A is the steam cylinder; *C,* the piston; *L,* the steam chest; *F,* the chest plunger, the right-hand end of which is shown in section; *G,* the slide valve; *H,* a lever, by means of which the steam-chest plunger *F* may be reversed by hand when expedient; *II* are reversing valves; *KK* are the reversing valve chamber bonnets, and *EE* are exhaust ports leading from the ends of steam chest direct to the main exhaust and closed by the reversing valves *II*.

The operation is as follows:

C, the piston, is driven by steam admitted under the slide valve *G*, which, as it is shifted backward and forward, alternately connects opposite ends of the cylinder *A* with the live steam pipe and exhaust. This slide valve *G* is shifted by the auxiliary plunger *F; F* is hollow at the ends, which are filled with steam, and this, issuing through a hole in each end, fills the spaces between it and the heads of the steam chest in which it works. Pres-

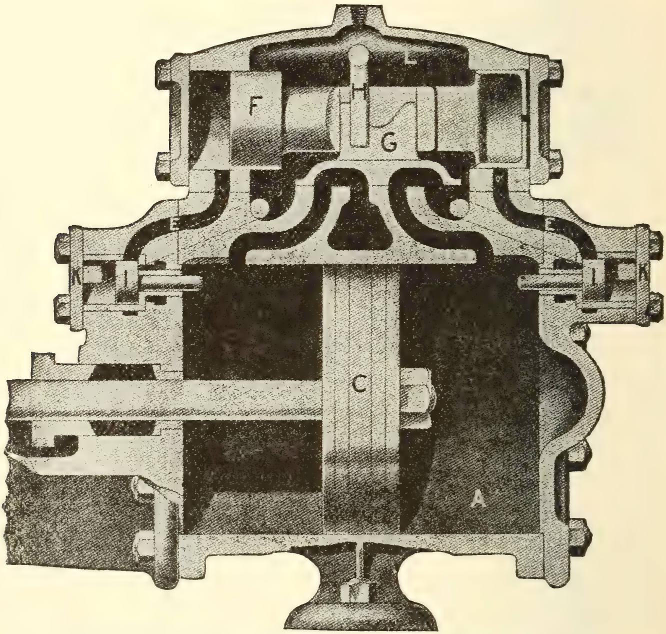


FIGURE 202. STEAM END OF CAMERON STEAM PUMP.

sure being equal at each end, this plunger *F*, under ordinary conditions, is balanced and motionless, but when the main piston *C* has traveled far enough to strike and open the reverse valve *I*, the steam exhausts through the port *E* from behind that end of the plunger *F*, which immediately shifts accordingly and carries with it the slide valve *G*, thus reversing the pump. No matter how fast the piston may be traveling, it must instantly reverse on touching the valve *I*. In its movement the plunger *F* acts as a slide valve to close the port *E*, and is cushioned on the confined steam between the ports and steam-chest cover. The reverse valves *II* are closed as soon as the piston *C* leaves them, by a constant pressure of steam behind them conveyed direct from steam chest through the ports shown by dotted lines.

The arrangement of valves in the water end of this pump is shown in section in Figure 201. The right hand side is shown in full as it appears when the bonnet is removed, and the left hand side in section.

By simply removing one bonnet or cover, the whole interior with every valve is plainly visible, turned inside out so to speak, and not a speck of anything that may have lodged there can escape detection. The shelves or decks are bored out tapering, and the brass seats forced in. They can thus be readily taken out and renewed at any time. Each stem holds two valves, with their springs one above the other, so that by simply unscrewing one plug, and pulling up the stem, both are released. It will be noticed that the Cameron valve chest is placed close to the ground and beside the water piston, instead of above it as in other makes. The valves are therefore just so much nearer the water, and the suction lift is reduced accordingly. Every pump has two suction open-

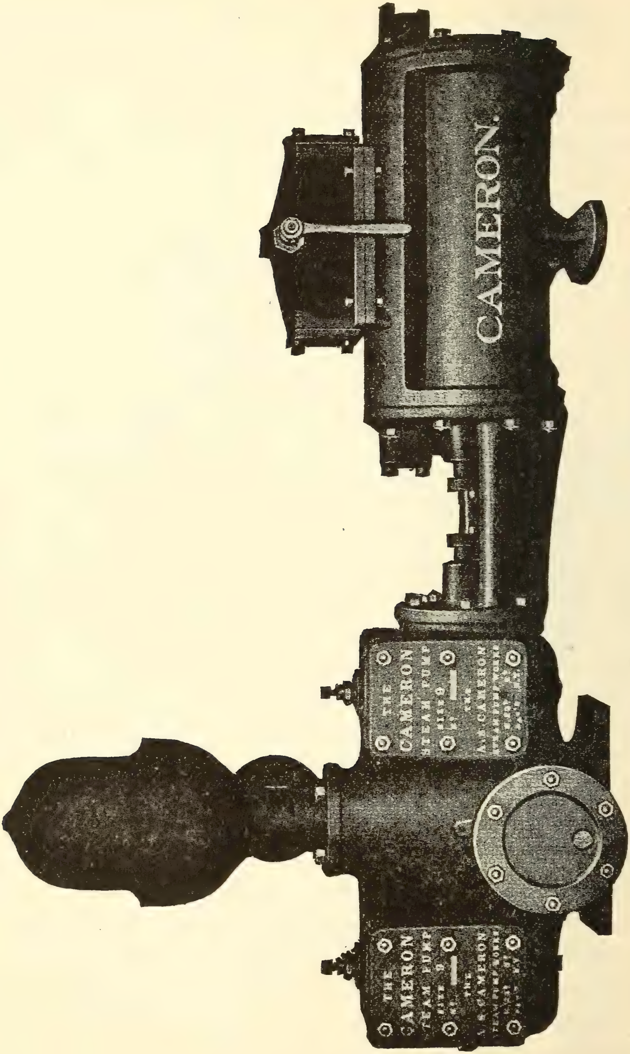


FIGURE 203. OUTSIDE VIEW OF CAMERON STEAM PUMP.

ings, one on each side, and the discharge opening can be turned in any direction desired.

Figure 203 is a full view of the Cameron pump as it appears when in operation. Figure 204 is a sectional view of the Dean steam pump. It will be noticed that there is an outside valve gear actuated by the piston rod. Also that the water valves are above the water pis-

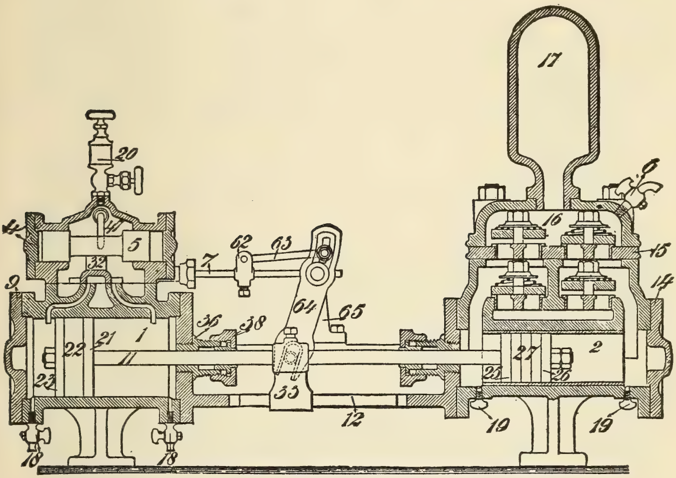


FIGURE 204. DEAN STEAM PUMP—SECTIONAL VIEW.

ton. Figure 205 is a plan view of the Dean steam valve motion, the action of which is as follows:

The auxiliary valve F slides on the valve seat E^2, and is provided on its under side with diagonal exhaust cavities d d^1. The ports b b^1 and exhaust port c are arranged in the shape of a triangle, the diagonal cavities diverge from each other, whereby the cavity d connects the ports b and c, and cavity d^1 connects the ports b^1 and c when the valve F is in extreme positions.

The operation is as follows: When the main piston moves from left to right the valve F is moved in an opposite direction, opening the port b¹, admitting steam to the sub-cylinder E¹ at the moment the main piston has reached the limit of its stroke, whereby the auxiliary piston E is forced to the left, opening the main port and admitting steam to the steam cylinder, consequently reversing the movement of the main piston. On the return stroke of the main piston the movement of the auxiliary valve is reversed, whereby the port b¹ is closed, and at the moment the main piston has reached the limit of its

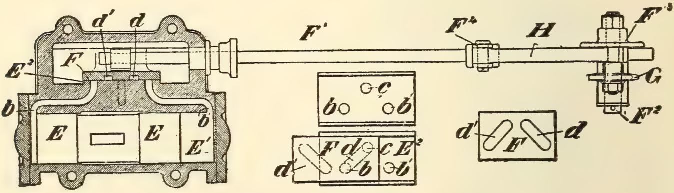


FIGURE 205. PLAN VIEW OF DEAN STEAM VALVE.

outer stroke, the port b is opened by the valve F, causing the auxiliary piston E to reverse its motion, opening the main port and reversing the motion of the main piston.

Figure 206 is a full view of the Dean steam pump, showing outside valve gear connections.

The steam pumps hitherto described are what are termed single cylinder direct acting, that is, each pump has one steam cylinder and one water cylinder.

A duplex steam pump consists of two water cylinders, and two steam cylinders, the steam valve of one side being actuated by the steam piston of the other, and vice versa. Figure 207 is a view of the Buffalo Duplex steam pump, and Figure 208 is a sectional view. The steam valves, of which there are two, are simple slide valves, each receiving its motion through the medium of a rocker arm, connected with the piston rod of the opposite side.

The Worthington type of duplex steam pumps, and many others of the same class, have steam slide valves, actuated in practically the same manner.

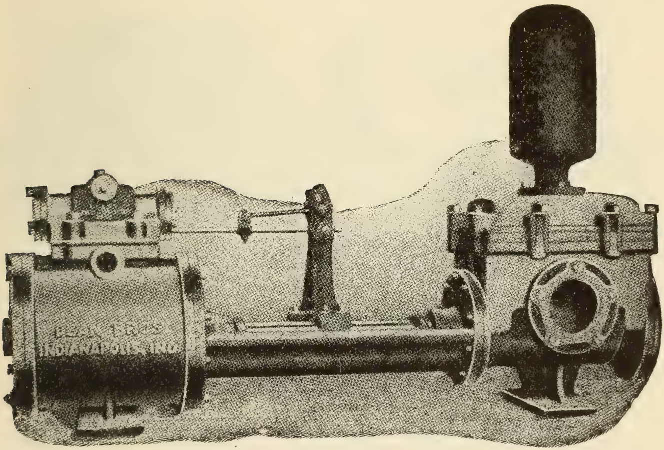


FIGURE 206. DEAN STEAM PUMP.

The Epping Carpenter steam pump, of which Figure 209 is an exterior view, is of the duplex pattern, and is fitted with piston steam valves. Figure 210 shows the construction of this type of valve, described as follows:

The valve is composed of the following parts: Body (A), Followers (B), Solid Rings (C), Self-adjusting Rings (D), Springs (E), Tongue Pieces (F), Valve Rod (G), Valve Rod Nuts (H), and Valve Rod Head (I).

The self-adjusting rings (D) are split as shown, and the tongue piece (F) fitted into them, making them positively steam tight in whatever position of travel.

The rings (D) are made somewhat wider than the port openings in the lining, to prevent any gouging action when moving over the bridges, one side of the ring being always held around its entire circumference until the other side has passed the port opening.

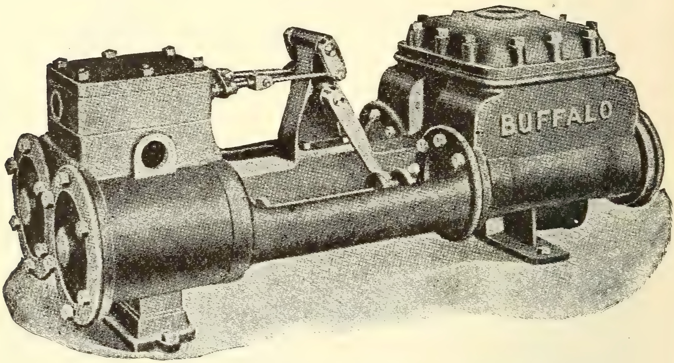


FIGURE 207. BUFFALO DUPLEX PISTON PATTERN PUMP.

The rings (C) are made to a sliding fit and as they are solid will not compress under any pressure, making them of great value to stop momentum of steam pistons when cushioning.

The outside adjustable valve motion, also illustrated in Figure 210, is made up of the following parts:

Lost motion block link (K), Valve rod link head (L), Valve rod head pin (M), Lost motion block (N), Lost motion adjusting nuts (O), and Lost motion lock nuts (P).

The lost motion block (N) is moved back and forth on the lost motion block link (K) by means of a pin (R) attached to the crank on rock shaft, until it strikes the lost motion adjusting nuts (O), thus imparting motion to piston valve.

Figure 211 shows a sectional view of the Epping Carpenter steam pump. It will be noticed that the water valves are above the water piston, thus keeping it continually submerged.

There are many other styles of steam pumps for the engineer to choose from, but space will not permit of their being described in this connection.

A power pump is a pump, either horizontal, or vertical, in which the water piston is given a reciprocating motion, through the medium of a connecting rod, and crank driven by a belt, and gear wheels.

Figure 212 shows a view of a duplex power pump. Power pumps are also driven by electric motors. Such a pump is illustrated in Figure 213 which is a view of the Smith Vaile power pump.

The elastic attribute of steam available to withstand sudden vibrations and jars in the case of direct acting steam pumps cannot be taken advantage of by power pumps. The problem of providing for the strains, therefore, is a serious one, and necessitates a heavier machine.

A sinking pump is a pump used for pumping the water out of excavations, mines, coffer dams, etc., and the duty is generally very hard, as the water to be pumped is usually muddy and full of grit.

Therefore a pump in which the water does not come in contact with a water piston, or the interior of a bored out water cylinder, and yet will raise the water, would seem to be the kind of pump required in this service. The Emerson steam pump, made by the Emerson Pump

Co. of Alexandria, Va., is built along these lines and consists of two simple hollow chambers with inlet and outlet valves for water. A plain circular slide valve for admitting steam alternately to each chamber. A small three cylinder engine for actuating this valve. A small condenser nozzle at the middle of each chamber, connected by pipes to the bottom of the opposite chamber and two small air check valves at the top of each chamber. The water is forced from the chamber to a height corresponding with the boiler pressure available, by the direct pressure of steam, then the steam is condensed to

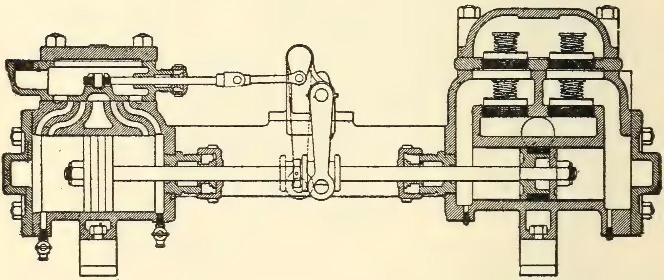


FIGURE 208. SECTIONAL VIEW BUFFALO DUPLEX PISTON PATTERN PUMP.

form a vacuum and cause the chamber to fill again; one chamber fills while the other is discharging.

Figure 215 shows a sectional view of this pump and the following description will serve to make its construction plain:

It consists in common of two vertical chambers B and C cast together at the bottom end; each chamber having suction valves L at the bottom, opening upward from the common chamber into which the suction pipe A enters; and discharge valves R opening upward into the common chamber from which the discharge or delivery

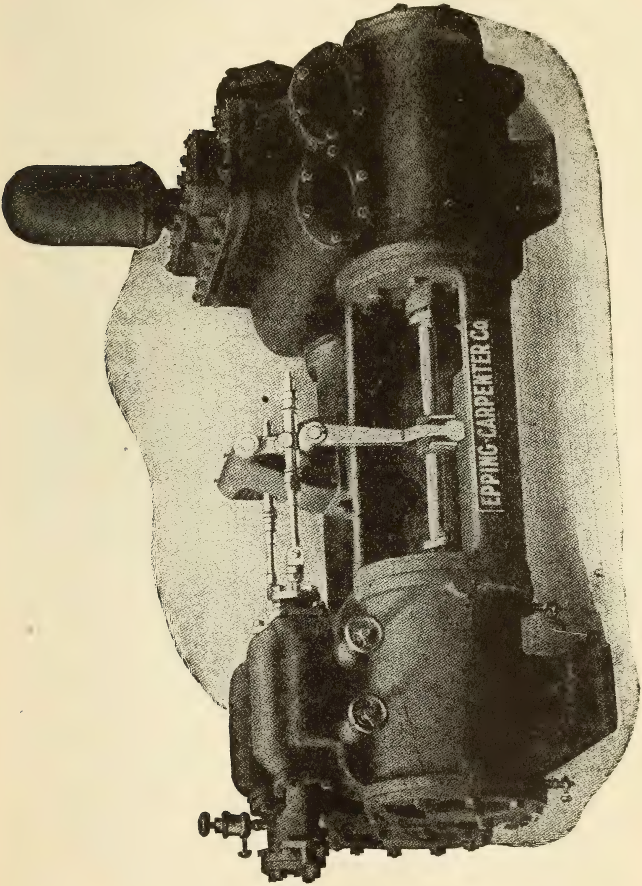


FIGURE 209. EPPING-CARPENTER STEAM PUMP.

pipe U extends. The seats for these valves are of gun metal bronze, and very heavy and substantial. They are held in position by heavy bolts, which are screwed in from the outside, and copper washers under their heads to prevent their leaking. The valve stems are also of gun metal bronze and very heavy. The valves are of medium hard rubber. The openings through the seats are large and the combined areas of the valve openings largely exceed the areas of the suction and discharge pipes with which they connect, the design being such as to admit of large openings with a small lift or movement of the valve. The valves L and R are easy of access through openings which are closed by substantial cover plates which are shown at D.D. On the top end of each chamber is a flange, having cast to its lower or inside face a baffle plate G, located opposite the steam port which enters through this flange. The purpose of this baffle plate is to distribute the steam evenly and prevent it from agitating the surface of the water in the chambers. The top side of this flange has a ground ball joint to which the main steam chest connects. The condenser nozzles F are of gun metal bronze, and are screwed firmly into the walls of each chamber from the outside, and are each connected with the bottom of the opposite chamber by an extra heavy pipe into which is a check valve opening upward. As the pressure in the chambers alternates, sufficient water will be injected through nozzles F into the opposite chamber for condensing the steam therein and forming a vacuum promptly. A small air check valve P, opening inwardly, attached to each chamber at the top end, admits a small quantity of air while the chamber is filling, which cushions the ram action of the water, prevents shocks, fills the clearance space at the top with air under pressure and places a stratum of air between the steam and water, effectively preventing con-

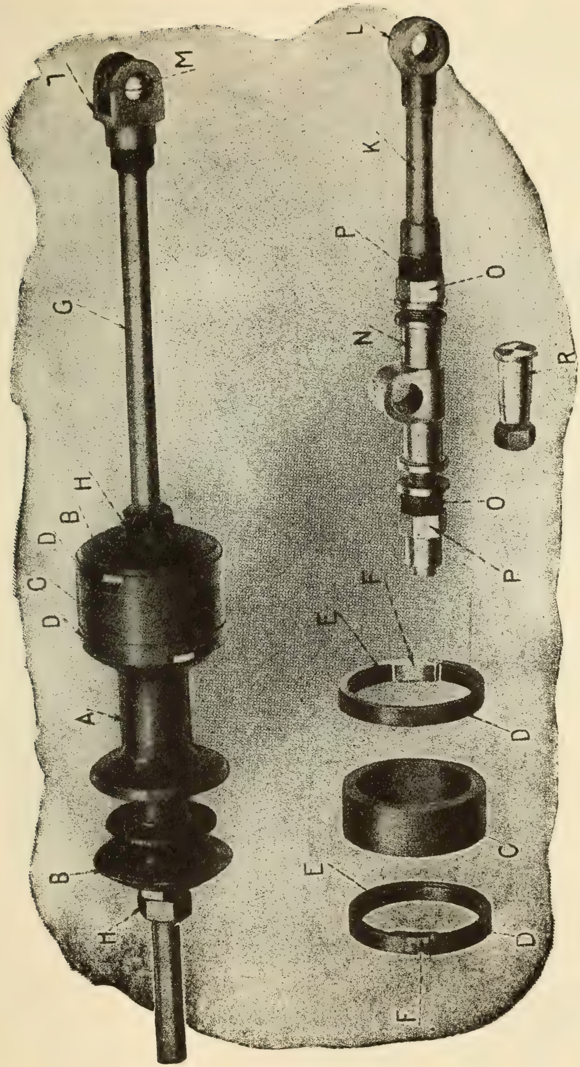


FIGURE 210. EPPING-CARPENTER STEAM VALVE AND FITTINGS.

densation. The specific gravity of air being greater than that of steam, the air pocket remains below the steam and prevents its contact with the water; forms an elastic

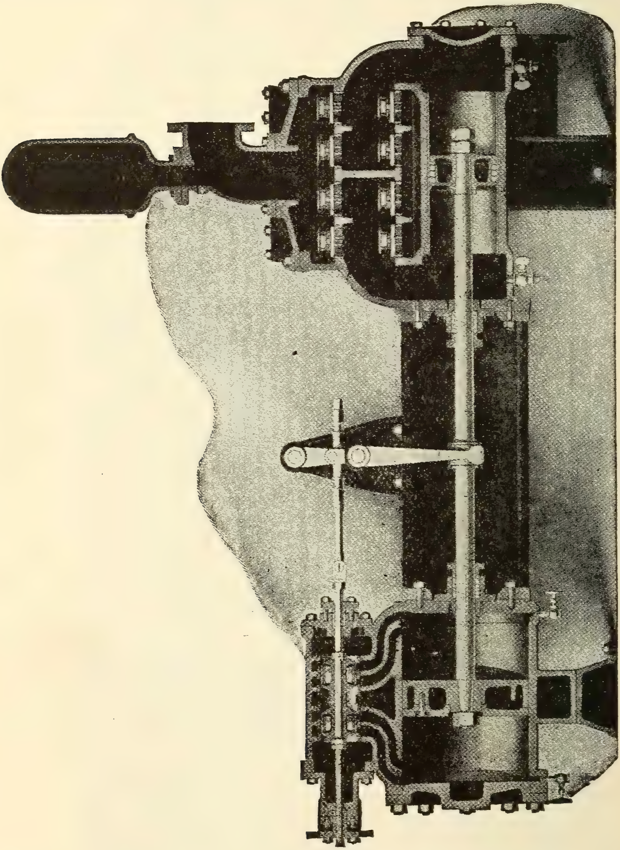


FIGURE 211 SECTIONAL VIEW—EPPING-CARPENTER STEAM PUMP.

cushion which receives the excess of inflow without noise or shock, and gives it out again silently at each impulse. From the steam chest there is a port leading to each chamber. Steam is admitted to, and cut off from them alternately, by a flat rotary slide valve which is located within the steam chest, and so designed that when steam is being admitted to one chamber it is cut off from the other. One chamber is filled while the other is discharging. The motion of this valve is continuous and slow. Both chambers fill and empty while the valve is making one revolution. This valve is driven by a small three cylinder engine E Figure 215 which is rigidly attached to the under side of the steam chest. The engine crank shaft extends into the steam chest in the center of the bearing around which the valve rotates, and a positive geared connection is made between the engine and valve, by cut gears of steel and bronze, so arranged that the engine runs faster than the valve.

Steam is admitted into the central chamber of the engine through a small pipe that connects with the main steam supply pipe, as shown, and presses alike on the inner side of the three pistons, but a small circular slide valve which is driven by the end of the crank pin, opens ports which connects with the outer end of one piston, throwing that piston into equilibrium, but the three pistons collectively out of equilibrium, causing a rotary motion of the crank shaft and slide valve. The motion of the engine is controlled by a small globe valve N in its exhaust pipe just below the engine, after leaving which the exhaust pipe passes down between the chambers and into the common suction chamber where the exhaust steam from the engine is condensed. There is also a branch valve in the exhaust pipe of the engine opening outside, which can be used for controlling the motion of the engine instead of the one just named, if desired. Above the main steam chest S is a globe valve O for regulating the amount of steam that enters the pump to suit conditions.

Lugs H are cast into each chamber for suspending the pump when it is necessary. When it is desirable to set the pump on a foundation a base is furnished with it.

In the type of pump shown in Fig. 217 a hard iron

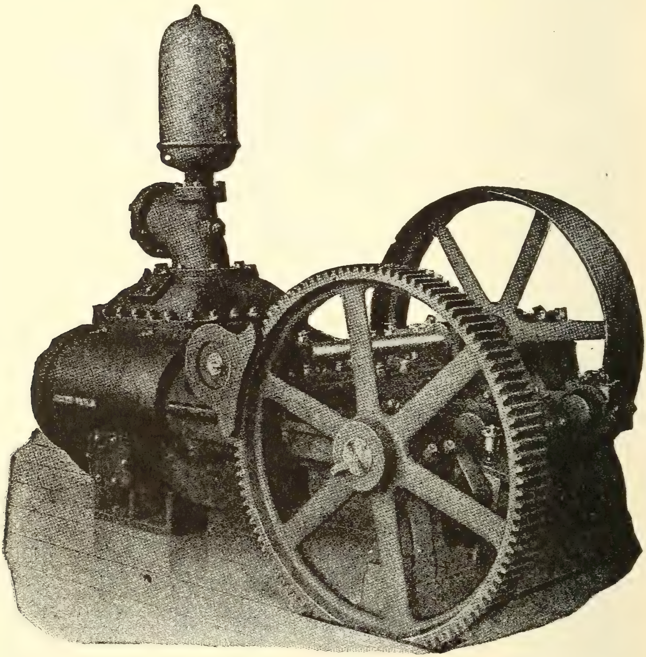


FIGURE 212. DUPLEX POWER PUMP.

plunger moves in two working-barrels having stuffing boxes and glands fitted with swing bolts for convenience in packing. The valves are of medium hard rubber, with brass seats, bolts and springs, the valve chamber being

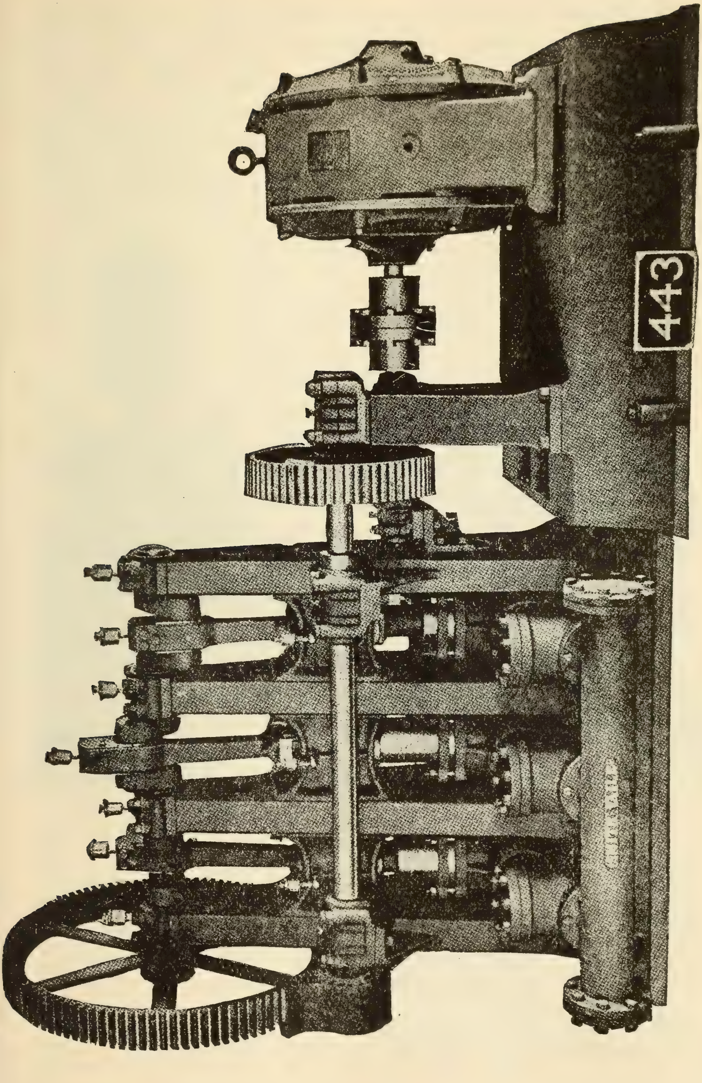


FIGURE 213. TRIPLEX ELECTRIC BOILER FEED PUMP.

independent and easily removable for inspection or repairs. The suction valve chamber is fitted with automatic air valves for relieving the pump of air, and the discharge air chamber has a cock for the same purpose. The discharge elbow is fitted with a standard flange and has a cock for drawing off the water in discharge pipe

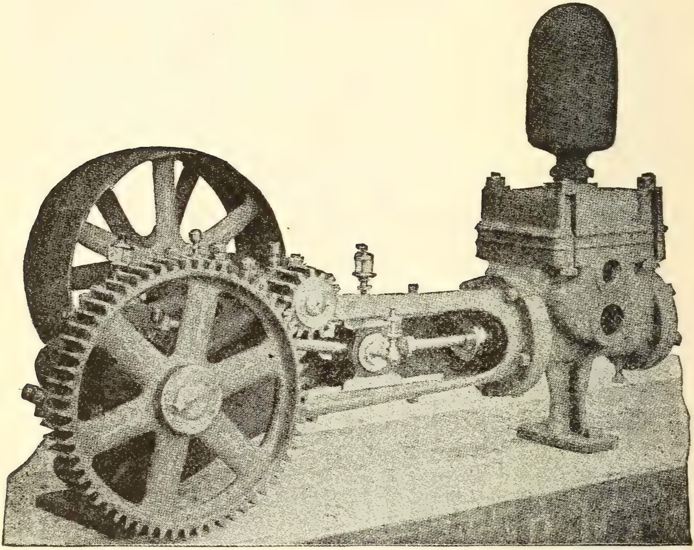


FIGURE 214. DEAN SINGLE CYLINDER POWER PUMP.

when desired. The bottom flange of the lower working barrel has swing bolts for convenience of removal in order to take out sand or gravel, and the discharge air chamber is in one piece, securing compactness and minimum weight.

The steam cylinder has a recently improved valve gear, without external moving parts, thus reducing the liability to injury from accident or rough usage.

The combined Automatic Receiver and Feed Pump illustrated in Fig. 218 is designed primarily to drain heating systems and automatically deliver to the boilers the water of condensation in its hottest condition. It is, therefore, a necessary and economical apparatus for office buildings, hotels, apartment houses, factories, etc. It is also a valuable auxiliary in connection with oil refineries, brick yards, chemical laboratories, etc.

Its operation is entirely automatic, being placed in a position to receive by gravity the condensed water from the entire system for which it is operating, and as the returns accumulate in the receiver, the float located therein gradually rises and opens a special valve, admitting live steam to the steam chest of pump. As soon as the receiver is relieved of its condensed water, the pump stops and does not resume action until water again accumulates.

Both receiver and pump are mounted on a cast iron base, the height of receiver being restricted so that it affords a drain for the lowest pipe or radiator.

Should the pump be desired as the sole means of feeding the boilers, a sufficient quantity of cold water may be introduced directly into the receiver to supply the deficiency occasioned by leakage, etc.

It will be observed, therefore, that this apparatus is desirable and economical in the highest degree, not only on account of the direct saving effected, but it relieves the system of ever accumulating condensation, returning it directly to the boilers at a temperature closely approximating the boiling point, and also relieves the radiators, coils, etc., of that objectionable hammer due to the presence of entrained water.

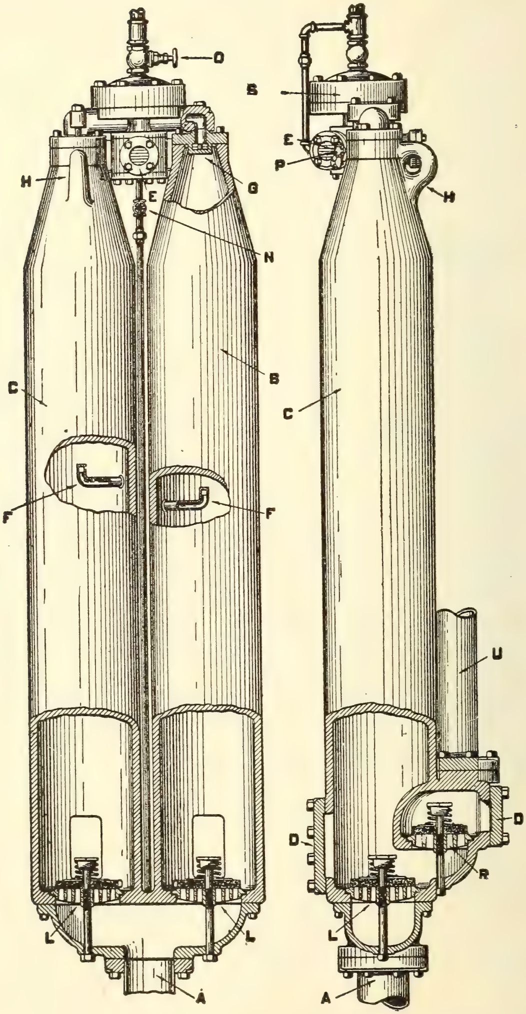


FIGURE 215. SECTIONAL VIEWS OF THE EMERSON STEAM PUMP.

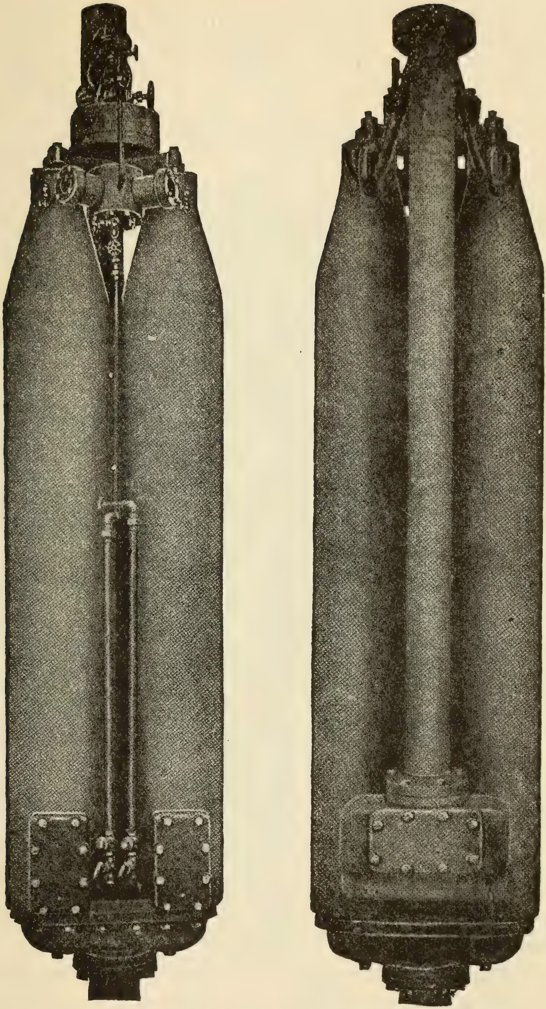


FIGURE 216. FRONT AND REAR VIEWS OF THE EMERSON STEAM PUMP.

QUESTIONS.

1. What is a pump?
2. What is a necessary part of a pump?
3. What is the seat of a valve?
4. Describe three different types of valves.
5. What kind of material is generally used in making pump valves?
6. Describe the double beat valve.
7. Describe in general terms the most simple form of pump.
8. How much pressure per square inch does the atmosphere exert upon all surfaces that come in contact with it?
9. Give the weight of a cubic foot of water at a temperature of 39°.
10. What is the height of a column of water balanced by the atmosphere?
11. Suppose a pump piston is at the end of the stroke and it starts and moves towards the other end, what occurs behind it?
12. Then when a vacuum is created behind the pump piston what effect does the atmospheric pressure have upon the water?
13. When the pump piston starts on the return stroke, what becomes of the water?
14. If the suction pipe is air tight, and the pump in good condition how high may the water be lifted by suction?

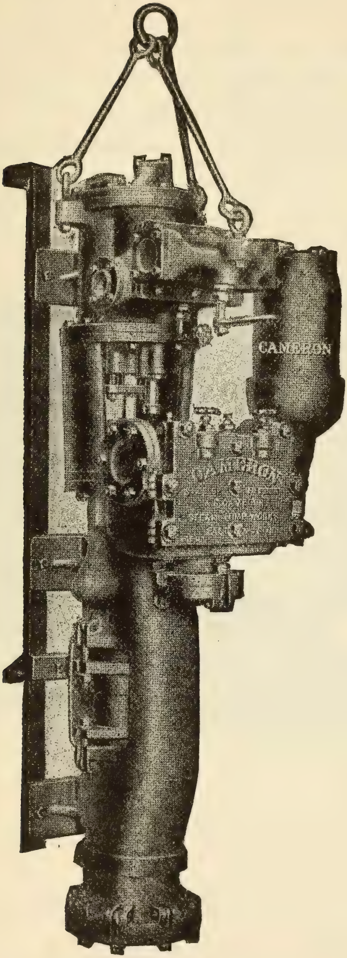


FIGURE 217. THE CAMERON MINE SINKING PUMP.

15. In pumping water, what unavoidable drawbacks are there to overcome?

16. Describe the operation of a double acting pump.

17. How high should the valves of a pump lift, in order to perform efficient service?

18. How high should a hinged valve rise?

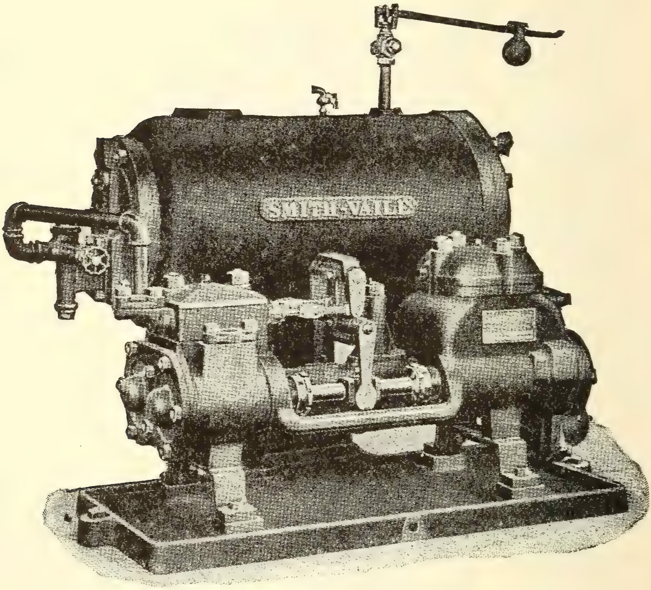


FIGURE 218. AUTOMATIC PUMP AND RECEIVER.

19. How are the water pistons of pumps usually actuated in steam plants?

20. What is one of the leading features of the Cameron steam pump?

21. How are the water valves arranged?

22. What kind of a valve gear has the Dean steam pump?

23. Describe briefly a duplex steam pump.

24. What type of steam valves do the Buffalo, Worthington and many other duplex pumps have?

25. What kind of a steam valve has the Epping Carpenter steam pump?

26. What is a power pump?

27. What is a sinking pump, and for what purpose is it used?

28. Describe briefly the construction of the Emerson sinking pump.

29. Has this pump a water piston?

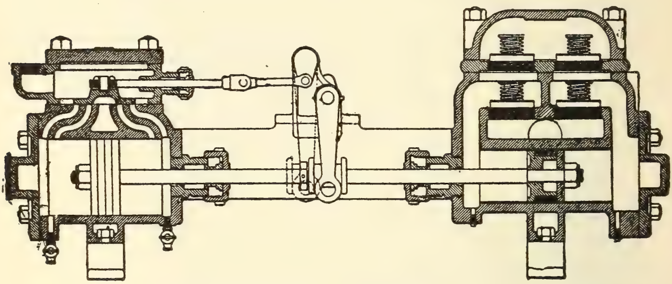
30. Then how is a vacuum created in the water chamber?

31. Describe the construction of the Cameron sinking pump.

32. Describe the construction and operation of an automatic receiver and feed pump?

SETTING THE STEAM VALVES OF DUPLEX PUMPS.

The duplex steam pump consists of two steam pumps placed side by side, and so combined that one piston acts to give steam to the other, after which it finishes its own stroke and waits for its steam valve to be acted upon by the other piston before it can start on the return stroke. This slight pause of the pistons at each end of the stroke allows the water valves to seat quietly, thus preventing any shock or jar.



Valve-operating gear—Duplex steam pump.

In setting the steam valves the pistons are so placed relatively to each other, that when one is at mid stroke, the other one is just about to finish its stroke. This arrangement effectually prevents there being a dead point, because one or the other of the steam valves is always open.

These valves are always adjusted by the builders before the pumps are sent from the shops, but if owing to a breakdown, it should become necessary to re-set the steam valves the following rules should be observed.

Place one of the pistons at mid stroke. This may be accomplished by removing the cylinder head, and then by means of a small jack placed against the piston move it gradually along until the rocker arm connected to the piston rod stands vertical as shown by a plumb bob.

Then place the other piston at four-fifths of the completion of its stroke. The steam valves, which with this type of pumps have no lap should then be adjusted in such manner that the one for the piston at mid stroke just covers both the steam ports, while that one for the piston at four-fifths stroke should be in such a position that, being acted upon by the motion of the opposite piston through the medium of the rocker arms it will have a slight lead when its piston has finished its stroke.

QUESTIONS.

1. Describe the construction of a duplex steam pump.
2. How are the steam valves of this type of pump actuated?
3. How are the pistons placed relatively to each other?
4. Is there a dead point in the strokes of the pistons?
5. Have the steam valves lap?
6. Describe the process of adjusting the steam valves.

CHAPTER XIII.

LUBRICATION

Next to the all important problems of keeping the water in the boilers at the proper level, and maintaining a sufficient supply of steam, comes the proper lubrication of the bearings, and other rubbing surfaces on the engine. If these are not oiled as they should be, the efficiency of the engine will be reduced, and besides there is a constant danger of some one of the heavy bearings becoming heated, and most likely cause a shut-down.

In discussing the problem of lubrication it is well to first study the laws of friction of plane surfaces in contact.

There are five of these laws which are commonly accepted relative to this subject.

Friction is the resistance caused by the motion of a body when in contact with another body that does not partake of its motion, and the laws that control this resistance are as follows:

First—Friction will vary in proportion to the pressure on the surfaces, that is if the pressure increases, the friction will be increased and vice versa.

Second—Friction is independent of the areas of the surfaces in contact, but if the pressure or friction be distributed over a larger area, the liability of heating and abrasion becomes less than it would be if the friction is concentrated on a smaller area.

Third—Friction increases with the roughness of the surfaces, and decreases as the surfaces become smoother.

Fourth—Friction is greatest at the beginning of motion. Greater force is required to overcome the friction at the instant of starting to move a body, than is required after motion has commenced.

Fifth—Friction is greater between soft bodies than it is between hard bodies.

These five laws were formulated in the years 1831-33 by Gen. Arthur Morin, a French engineer, who made many experiments relating to the friction of plane surfaces in contact, but numerous experiments in later years by many eminent engineers have demonstrated that these laws are not altogether rigid, and that they can only be accepted in so far as they relate to the friction of dry surfaces in contact, or lubricated surfaces moving under light pressures, and at slow speed. As friction is always a resisting, and retarding factor, its tendency is to bring everything in motion to a state of rest. With machinery in motion the friction between the surfaces of the parts moving in contact tends to cause them to adhere to each other.

Therefore in order to successfully and economically operate the machinery, it is absolutely necessary that a lubricant be used that will distribute itself over these surfaces, and thus prevent them from coming in direct contact with each other.

Friction, however, is useful in many ways, as for instance, the friction of the belt in contact with the rim of the pulley causes power to be transmitted from the engine to the machines throughout the shop. Then also the friction or adhesion of the driving wheels of the locomotive makes it possible for the engine to start a heavy train and keep it moving.

The friction of the brake shoes on the car wheels makes it possible to stop a train in much less time than if it were allowed to stop of its own accord.

There are two kinds of friction in mechanics, viz., the friction of solids, and the friction of liquids. It is the friction of solids that the engineer has to deal with mainly, and this kind of friction for convenience may be again divided into two classes, viz., rolling friction, as for instance a journal revolving in its bearings, or a crank pin in its brasses, and second, sliding friction, as

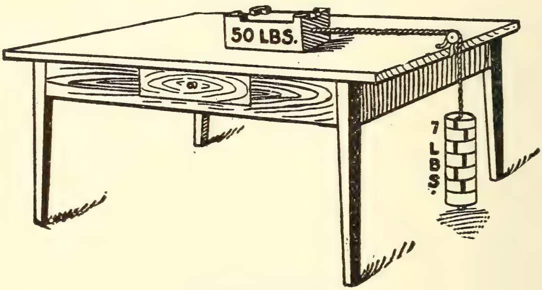


FIGURE 219.

the cross head on the guides, or the piston travelling back and forth in the cylinder.

CO-EFFICIENT OF FRICTION.

By this term is meant the relation that the power required to move a body, bears to the weight or pressure on that body.

This definition may be expressed in another, and perhaps plainer form, as follows:

The co-efficient of friction is the ratio between the resistance to motion, and the perpendicular pressure, and is determined by dividing the amount of the former by the latter. Figures 219 and 220 will serve to illustrate in a graphic manner the second law of friction and also explain one method of determining the co-efficient of friction.

A block of iron or other metal is drawn across the surface of the table top by means of weights suspended from a cord attached to one end of the block, and passing over a small pulley or roller at one end of the table. The block has a flat surface on one side, while on the opposite side there are four small projections or legs, one on each corner, and each leg has a sectional area of one square inch. The size of the block may be assumed to be 8 inches wide, 12 inches long and 2 inches thick, and its weight may be taken at 50 pounds. In Figure 219 the block is placed upon the table with its flat or largest bearing surface down. This surface has an area of 8 inches by 12 inches=96 square inches in contact with the surface of the table, and it is found that by placing weights on the cord until the block begins to move, and keep moving requires a weight of 7 pounds. Now it might be supposed that if the block were reversed so that it would rest on its four legs it could be moved across the table with much less weight on the cord than was required in the position shown in Figure 219, but such is not the case, as shown by Figure 220 and which can also be mathematically demonstrated.

In the experiment illustrated in Figure 219 the co-efficient of friction is resistance 7 pounds divided by weight or pressure 50 pounds=.14; that is it requires a force of .14 pounds to move one pound of weight. The pressure per square inch of area=weight 50 pounds divided by area 96 square inches=.52 pounds. The co-efficient being .14 pounds, the pull per square inch of surface required to move the block is $.52\times.14=.0729$ pounds, which multiplied by the total area 96 square inches equals 6.9888 or practically 7 pounds. Referring to Figure 220 where the block is reversed, and stands on four legs, each leg having an area of one square inch in contact with the surface of the table, the total contact is four square inches, but the pressure remains the same, viz., 50 pounds. Therefore the pressure per square inch of area=50÷4=12.5 pounds, which when multiplied by the co-efficient .14 equals 1.75, which is the pull per square inch of surface, and there being 4 square inches, the total

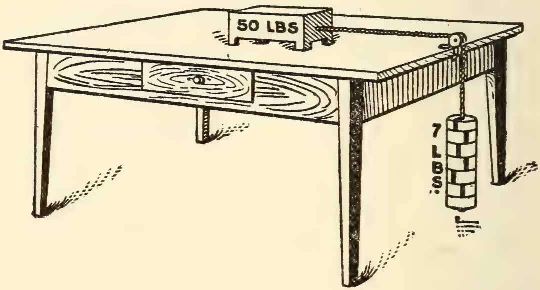


FIGURE 220.

pull=1.75×4=7 pounds. It will thus be seen that the extent of surface in contact does not affect the friction so long as the weight or pressure remains constant, but by allowing the larger area of surface to come into contact with the table surface thus distributing the pressure over a greater area, reduces the liability of heating and abrasion because the pressure per square inch is so much less.

In machine design, especially engine bearings, and crank pins, the object should be to obtain as large a surface as possible in order that the pressure per square inch may be reduced. By making the bearings of proper proportions, by using bearing metals having the greatest anti-friction value, by keeping the shafting in line, and by the use of the best and most suitable lubricants, and lubricating devices, or by using self-oiling bearings

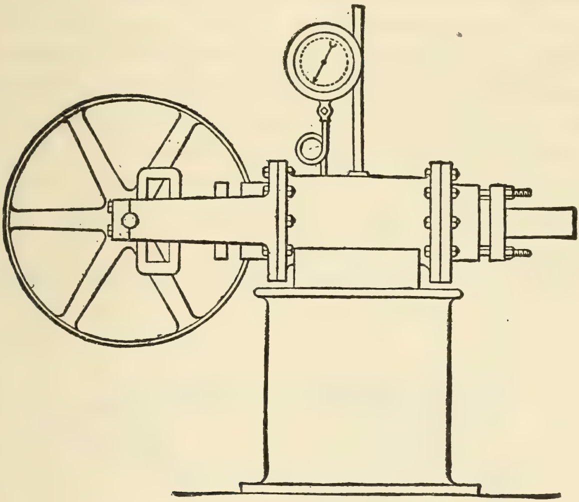


FIGURE 221.

wherever possible, the friction losses may be reduced to a very small percentage of the total power developed by the engine. Modern engine construction, and methods of lubrication have in recent years been brought to such a degree of mechanical refinement that the friction loss per horse power is only 2 or 3 per cent. This low per cent of friction loss has been brought about in the case of high speed engines by properly proportioning, and balancing the rotating parts, and by the use of lubricating apparatus that keeps the bearing continuously flooded in a bath of oil.

Great care should be exercised by the engineer in the selection of piston rod, and valve stem packing, and in its application and adjustment, as otherwise there will be considerable friction loss, especially if the packing is unsuitable or becomes hard from too long service, or has been screwed up too tightly.

Prof. Chas. H. Benjamin, in a paper presented at the meeting of the A. S. M. E. December, 1900, gives the results of a series of tests made by himself, at the Case School of Applied Science, in Cleveland, Ohio, to determine the amount of friction caused by various kinds of piston packing. Figure 221 shows the device used by Prof. Benjamin in making the tests.

Figure 222 is a sectional view of the same machine,

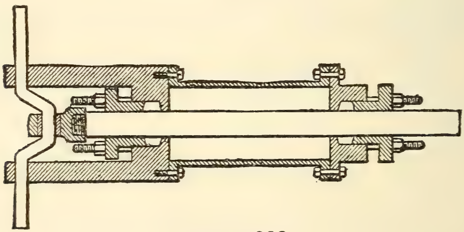


FIGURE 222.

which consisted of a cast iron cylinder 6x12 inches, fitted at each end with a suitable head, and stuffing box and gland arranged for a two-inch piston rod. The rod was given a reciprocating motion, through the medium of a slotted cross head, and crank, and a pulley on the crank shaft was connected by a belt to a dynamometer. Steam was admitted to the cylinder through the pipe shown in Figure 221 and the water condensation was drawn off at the bottom, while a steam gauge showed the pressure in the cylinder. The gland nuts were usually tightened with the fingers only, but when a wrench was used, a spring balance was attached, and the turning moment was noted. The stroke of the rod was 4.25 inches, and the revolutions were 200 per minute, giving a piston speed of 141 feet per minute. Seventeen different kinds of packing were used, the materials of which were rubber, cotton, asbestos, hemp, lead, and flax.

Some of these packings were combined with mica, graphite, and paraffine. The various packings were fitted according to the directions of the makers, and the routine of the tests as they were conducted was as follows:

The machine was first run without packing, in order to determine the friction of the empty apparatus. The packing was then inserted, and steam turned on, the gland nuts being tightened just sufficient to prevent leakage, and the packing was then tested under various pressures, each test lasting from 15 to 40 minutes. The gland nuts were then tightened with the wrench, and spring balance to various pressures, and other sets of readings taken, after which cylinder oil was applied to the rod, and the difference in friction noted. These tests were measured by means of a Flather recording dynamometer, and a Weber box gear dynamometer, the readings being taken at short intervals and averaged. The results of these tests are summed up in tables 20 and 21. Table 20 gives a summary of the results, showing the average horse-power absorbed by each packing at various pressures, and for purpose of comparison, the power at 50 pounds of steam pressure. Table 21 shows the increased friction caused by tightening the gland nuts, and also the beneficial effect of oiling the rod. The different packings are numbered.

The general conclusions arrived at from this series of tests are as follows:

First—That the softer rubber, and graphite packings absorb less power in friction than the harder kinds do.

Table 20.

Kind of Packing.	No. of Trials.	Total Time of Run in Minutes.	Average H. P. Consumed by Each Box.	H. P. Consumed at 50 lbs. Pressure.	Remarks on Leakage, etc.
1	5	22	.091	.085	Moderate leakage.
2	8	40	.049	.048	Easily adjusted; slight leakage.
3	5	25	.037	.036	Considerable leakage.
4	5	25	.159	.176	Leaked badly.
5	5	25	.095	.081	Oiling necessary; leaked badly.
6	5	25	.368	.400	Moderate leakage.
7	5	25	.067	.067	Easily adjusted and no leakage.
8	5	25	.082	.082	Very satisfactory; slight leakage.
9	3	15	.200	.182	Moderate leakage.
10	3	....	.275	....	Excessive leakage.
11	5	25	.157	.172	Moderate leakage.
12	5	25	.266	.330	Moderate leakage.
13	5	25	.162	.230	No leakage; oiling necessary.
14	5	25	.176	.276	Moderate leakage; oiling necessary.
15	5	25	.233	.255	Difficult to adjust; no leakage.
16	5	25	.292	.210	Oiling necessary; no leakage.
17	5	25	.128	.084	No leakage.

Second—That oiling the piston rod will reduce the friction of any kind of packing.

Third—That there is almost no limit to the friction loss that can be caused by the injudicious use of the wrench.

Variations of friction of lubricated surfaces occur with every change of condition of either the bearing or journal surfaces, or of the lubricant applied to them. The conditions that produce the greatest differences in ordinary lubrication are, the nature and quality of the lubricant,

Table 21.

Kind of Packing.	Horse-power Consumed by Each Box, when Pressure was Applied to Gland Nuts by a Seven-inch Wrench.						H. P. Before and After Oiling Rod.	
	5 Lbs.	8 Lbs.	10 Lbs.	12 Lbs.	14 Lbs.	16 Lbs.	Dry.	Oiled.
1	.120	....	.136					
3	....	....	....	....	....	....	.055	.021
4	....	.248	....	.303	....	.390	.154	.123
5	....	.220						
6	....	.348	.430	....	....	....	.323	.194
7	....	.126	.228	.260	.330	.340	.067	.053
8	....	.363	.500	.535	.520	.533	.533	.236
9	....	.666	....	....	....	....	.666	.636
11	....	.405	.454	....	....	....	.454	.176
12	....	.161	.242	.359	.454	....	.454	.122
13	....	.317	.394	.582				
15	....	.526						
16	....	.327	.860					
17	....	.198	.277	.380				

the nature and condition of the wearing surfaces, and the speed, pressure, and temperature.

LUBRICATING OILS.

The engineer in charge of a plant will always find on the market a wide range of petroleum products to choose from to meet the various conditions that will show up in the proper lubrication of the machinery under his charge. The ordinary facilities of the engine room do not usually afford means to make elaborate tests of oils, and other lubricants, but an engineer can make valuable comparative tests of different grades of oil on his engine, or other machinery.

For instance by means of a thermometer placed in the bearing, with the bulb resting on the shaft, or immersed in the oil chamber, the temperature of the bearing may be noted, while it is being lubricated with various grades of oils, and their qualities thus determined. Of course in tests of this kind, care should be taken that the rate of oil feed, the belt tension, the pressure on the bearings, and the speed remain as near constant as possible, and an allowance should also be made for any difference in the temperature of the room during the tests. A good and efficient lubricant should possess the following characteristics:

First, sufficient "body" to keep the surfaces apart, but the greatest possible fluidity consistent with this.

Second, a minimum coefficient of "internal" friction in actual service.

Third, must not dry or "gum" and must not contain free acids or other corrosive ingredients.

Fourth, must not be readily thinned, vaporized or ignited by heat or stiffened by the cold encountered in the service to be performed.

Fifth, must be absolutely free from all gritty foreign substances.

Sixth, it must be especially adapted to the conditions for which it is chosen.

Experience has proved that in lubrication the best is nearly always the cheapest in the end and that the consumer can better afford to use the highest priced lubricants the market affords than accept those of lower value as a gift.

The cost of lubrication is not merely the market price of lubricants but their cost *plus the cost of the friction accompanying their use.* The *value,* not the *cost,* of the lubricant, is the point worthy of greatest consideration. What it will *do, not what it costs* per pound or per gallon. No greater error can be made than to economize upon the *quality* of lubricants, for even under the most extravagant conditions the cost of lubricants represents but a very small fraction of the cost of fuel and repairs and depreciation of poorly lubricated engines and machinery.

The best lubricant for a bearing under normal conditions may not do so well after heating commences, a thick viscous oil which under ordinary conditions on high speed machinery would be comparatively wasteful of power is often an excellent lubricant for a hot bearing, and for the following reason: an engineer on finding a bearing heating up will apply the ordinary oil freely and at the same time loosen up the bolts so as to allow for increased expansion and free flow of oil; if the heating continues, and the engine or machinery must be kept in operation at all hazards, he will turn to his cylinder oil, apply it freely, and often with good results. The reason of this is that the cylinder oil, owing to its high fire test (from 550 to 600) became thin and limpid without burning, and flowed freely between the close-fitting surfaces and kept them apart, and at the same time, absorbed the heat that would otherwise have gone into the metal and carried it away, while the engine oil, being of lower flash test, vaporized, and if the bearing got hot enough, caught fire.

In many cases the use of pure graphite or plumbago, as it is sometimes called, will prove to be beneficial especially on heavy bearings that are inclined to heat.

The essential function of graphite is that of an auxiliary or accessory lubricant, with which to perfect and maintain the working surfaces in a condition of high polish and great smoothness, so that the oils and greases used as the actual lubricating film may the more successfully perform their particular service. They have only to separate two highly-polished and perfectly fitted surfaces and to reduce friction to the lowest possible point.

Graphite allows the safe and satisfactory use of less oil or grease than would otherwise be necessary because there is far less actual wearing out of the oil between the smooth surfaces.

Inasmuch as metallic wear is nearly eliminated, the oil does not become rapidly charged with fine metal particles and lose its lubricating value.

Thinner lubricants can generally be used. Graphite increases the endurance and efficiency of oil and grease lubricants because it relieves them of a very great part of the duty they otherwise have to perform.

Whether graphite is fed at regular intervals or only occasionally the results are much the same, inasmuch as the coating of graphite persists for a considerable period after application.

In 1902 Professor W. F. M. Goss of Purdue University conducted a long series of tests to determine the value of Dixon's Flake Graphite as a general lubricant for bearings, and as applied to railroad air brake equipment.

The tests extended over a period of many months and were made, not to create arguments in favor of Dixon's Graphite but to enlarge the sum of information on the subject of graphite lubrication.

The following extracts are taken from the report:

"From the earlier and rather limited uses of graphite in lubrication, the field has gradually widened to include its use with light oils, with water, and, in some cases, unmixed with other materials. It is no longer regarded merely as a material for an emergency, but now has a place in the ordinary and usual routine of the engineer's day. . . .

"The demand for graphite has come because men charged with the responsibility of keeping machinery moving have found it beneficial in their work, and not because manufacturers and plant owners pressed its use upon them.

"It is not to be presumed that because a material is sold as graphite it will give good results in lubrication; it must be free from grit and other impurities and properly graded for the work. . . .

"Graphite does not behave like oil, but associates itself with one or the other of the rubbing surfaces. It is worked into every crack and pore in the surfaces and fills them, and if the surfaces are ill-shaped or irregularly worn, the graphite fills in and overlays until a new surface or more regular outline is produced. When applied to a well fitted journal the rubbing surfaces are coated with a layer so thin as to appear hardly more than a slight discoloration. If, on the other hand, the parts are poorly fitted, a veneering of graphite of varying thickness, which in the case of a certain experiment was found as great as 1-16 inch, will result. The character of this veneering is always the same, dense in structure, capable of resisting enormous pressure, continuous in service without apparent pore or crack, and presenting a superficial finish that is wonderfully smooth and delicate to the touch."

In the lubrication of the interior wearing surfaces of the valves and cylinders of steam engines conditions will be met which are altogether different from those encountered in the lubrication of bearings and journals.

In the latter case, the working and comparing of one oil with another, and the results obtained can be easily determined by noting the changes of temperature, etc., but in internal lubrication the conditions are altogether different.

In the case of journals and bearings, the oil can be applied directly to the surface to be lubricated; in cylinder lubrication one must depend upon the flow of steam to convey the oil to the parts or wearing surfaces requiring lubrication.

The points that govern the conditions of interior lubrication are: The conditions of the surfaces, the steam pressure, the amount of moisture in the steam, the piston speed, weight and fit of the moving parts, and the make or type of the engine.

An automatic cut-off engine with balanced or piston valves will usually require less oil than an engine with a heavy unbalanced valve.

A large cylinder whose piston is supported by a "tail-rod" is more easily lubricated than one whose heavy piston drags back and forth over the bottom of the cylinder.

An oil to be used as a cylinder lubricant in order to give good results must possess certain essential properties.

It must be of high flash test, so that it will not volatilize or vaporize when in contact with the hot steam; it must have good viscosity or body when in contact with the hot surfaces, and should adhere to, and form a coating of oil so as to prevent wear and reduce as much as possible the friction of the moving parts.

While the quality of a cylinder oil as shown by the use of testing instruments will give one a general idea of its lubricating value, the engineer who is studying the question of cylinder lubrication can determine more accurately its exact value by experimenting on his engines and pumps and under the conditions peculiar to his own plant.

LUBRICATING APPLIANCES.

The successful lubrication of an engine depends in a large measure upon the character of the appliances that are used to convey the lubricant to the wearing surfaces.

For steam cylinder lubrication the hydrostatic or sight feed type of lubricator is in most general use; this type of lubricator depends for its operation upon the displacement of the oil by a body of water which is formed by the condensing of the steam in the condensing chamber of the lubricator, the water in passing into the oil chambers displaces the oil, forcing it up through the sight-feed glass, whence it flows through the discharge pipe to the cylinder.

The construction and operation of this class of lubricators will be better understood by reference to Figures 223 and 224. Figure 223 is an exterior view of the well-known Detroit sight-feed lubricator, while Figure 224 is a sectional view showing the interior construction. The pipe P shown in Figure 224 connects with a passage from the condenser A-2 Figure 223 and when the water feed valve A-4 Figure 223 is opened, the water in the condenser will pass down the pipe P to the bottom of the lubricator, and, being heavier than oil, will stay at the bottom, the oil floating above it. The pipe S Figure 224 leads from the lower sight-feed arm to the upper part of the body of the lubricator. The action of the lubricator is as follows:

The body A-1 is filled with oil. Steam from the main steampipe passes in the connecting pipes above the lubri-

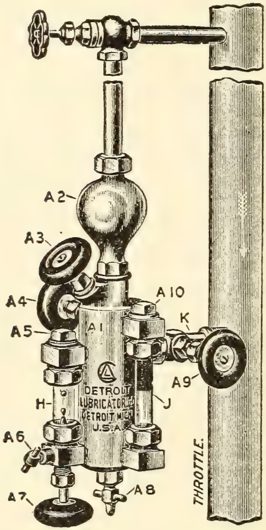


FIGURE 223. EXTERIOR VIEW DETROIT LUBRICATOR.

cator, and condenses, filling the condenser A-2 and part of the pipe above it with water. The steam also passes into the support arm and through the internal tube T into the sight-feed glass, where it condenses, filling the glass with water.

As soon as the valve A-4 is opened, the oil in the body of the lubricator is subjected to the pressure of the column of water extending through the pipe P, the condenser and part of the pipe above it, amounting to about 2 lbs. to the square inch, and in addition to the pressure of the steam above the water, amounting to say 100 lbs. to the square inch, or a total pressure of about 102 lbs. to the square inch. This we may call the positive pressure. Liquids communicate pressure equally in all direc-

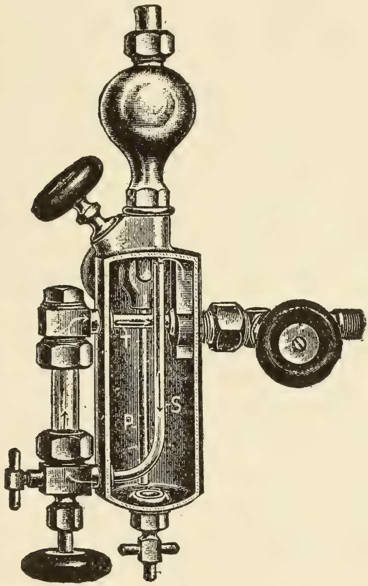


FIGURE 224. INTERIOR VIEW DETROIT LUBRICATOR.

tions, so the oil in the body of the lubricator will press in every direction with a force of about 102 lbs. to the square inch. It will therefore press down through the tube S with this force of 102 lbs. to the square inch. Then, if the valve A-7 is opened, a force acting in the opposite direction is encountered, which we may call the back pressure. When the lubricator is connected as shown, this back pressure will consist of the column of water in the sight-feed glass, and in addition, the steam pressure back of this column entering through the support arm, and amounting to 100 lbs. to the square inch.

The positive steam pressure being just the same as the back steam pressure, these two forces will neutralize each other, and we have left, the positive pressure of the column of water extending through the pipe P, the condenser and part of the pipe above it, and the back pressure of the column of water in the sight-feed glass. As the latter is much less than the positive pressure, the drop of oil is forced through the nozzle. As soon as it leaves the nozzle it is no longer acted upon by the positive pressure, and it rises through the water in the glass from the force of gravity, it being lighter than the water. After rising through the sight-feed glass it floats through the tube T, Figure 224, and through the support arm into the main steampipe and goes with the current of steam to the steam chest and cylinder. The positive pressure must always be greater than the back pressure, or the lubricator will not work. For instance, if a lubricator be connected to a horizontal steampipe by being suspended below it, the back pressure would be greatly increased, and in order to get sufficient positive pressure the condensing pipe should rise 18 in. to 24 in. above the horizontal steampipe and then descend to the condenser. This will give a column of water for positive pressure higher than the column of water which acts as back pressure.

TO RE-FILL AND OPERATE.

Close valves A-4 and A-7. Open drain valve A-8, then remove filler plug A-3 and the water will drain out rapidly. When water is all out, close valve A-8, fill with oil, and replace filler plug A-3. Then open valve A-4, and regulate the flow of oil with valve A-7. The valve A-9 is to be closed only when desiring to shut off steam from the lubricator in case of accidental breakage of the glass, or when there is danger from freezing. Before starting the lubricator, time should be allowed for the sight-feed glass and condensing chamber to fill with water from condensation. When there is danger from freezing when lubricator is not in use, empty the lubricator, and leave open valves A-4, A-8 and A-6. Then close valve A-9 and the small angle valve in condensing pipe above the lubricator.

Figure 225 shows an external view of the Powell lubricator "Class A," for single cylinder engines, and Figures 226 and 227 show exterior and sectional views of the Powell duplex condenser and double up-feed lubricator for use on compound and triple expansion engines. In this lubricator there may be two or three sight-feeds combined with one oil chamber. The letters designate the different parts, and the operation of this lubricator will be easily understood by a study of Figure 227.

The force feed, or mechanically operated lubricator, has come into favor largely within recent years, and it certainly has the merit of being positive, while at the same time it is not wasteful of oil, being governed by the speed of the engine or pump that it is lubricating. This type of lubricator is made in single, double, triple, and quadruple style, and is operated by attaching the connecting rod of the oil pump to any movable part of the engine that will give it a reciprocating motion.

Figure 228 shows the Manzel quadruple feed oil pump. These pumps are also made with five and six feeds. Manzel Brothers Co. also make an agitating force and

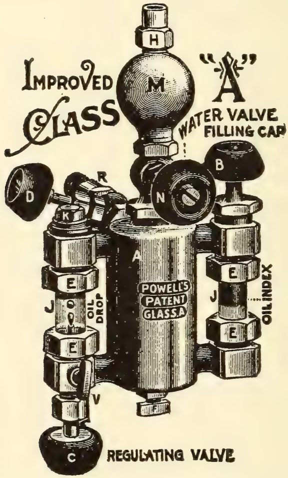


FIGURE 225. POWELL LUBRICATOR.

A—Oil Reservoir.
B—Filling Cup.
C—Valve to Regulate Oil Drops.
D—Shut-off Valve.
E—Packing Nuts.
F—Drain Valve.
H—Coupling for Condensing Pipe.
JJ—Sight Feed and Index Glasses.
K—Plug for Removing and Inserting Glasses.
M—Condensing Chamber.
N—Valve to Regulate Water from the Condenser.
V—Valve to Drain Sight Feed Glass.
R—Attaching Shank and Valve.

sight-feed oil pump for the purpose of feeding graphite mixed with the oil. Graphite being a mineral and not easily suspended in oil it has always been a rather difficult problem to feed it properly along with the oil, but the device illustrated in Figure 229 has proved to be very successful in feeding the mixture of oil and graphite. The action of this appliance will be easily comprehended

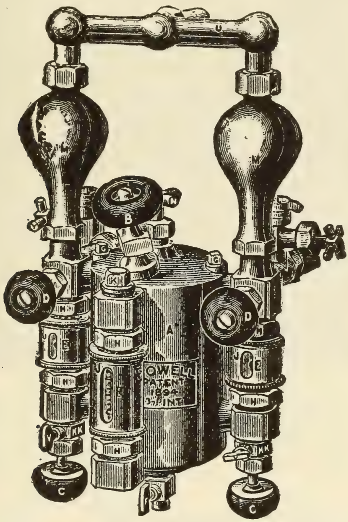


FIGURE 226. POWELL'S DUPLEX CONDENSOR LOCOMOTIVE LUBRICATOR.

by a reference to Figure 229. The spiral agitating device that revolves in the cup is operated by means of the belt-drive on the wheel, and bevel gears on the cup. The construction is simple and durable. Two fillers are used, one for oil and one for graphite. No fixed rule can be laid down for the amount of graphite to be used, as some engines require more than others. Two or three good teaspoonfuls to a pint of valve oil, would be a good rule

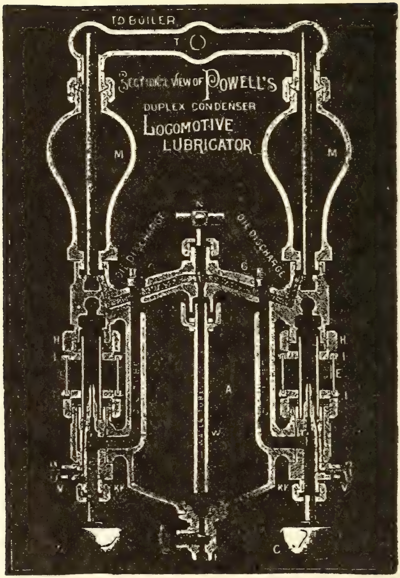


FIGURE 227. DESCRIPTION OF INTERNAL PARTS.

A—Oil Chamber.
CC—Oil Drop Regulating Valves.
EE—Brass Protecting Shields.
F—Drain Valve.
GG—Removable Plugs to Clean Oil Tubes.
HH—Packing Nuts.
II—Adjustable Rings.
JJ—Sight Glasses.
KK—Removable Cages to Replace Glasses.
MM—Condensers.
N—Water Valve.
T—Connecting Coupling to Boiler.
VV—Cleaning Valves for Sight Glasses.
W—Water Tube.
X—Water and Oil Trap.

to start on, and the engineer can then watch results and ascertain for himself the proper quantity to use.

Another rule might be, three teaspoonfuls of graphite per day for a 150 horse-power engine.

INSTRUCTIONS HOW TO ATTACH MANZEL OIL PUMPS.

Place the pump on the frame of an engine or pump where it is most convenient to get motion. It can be

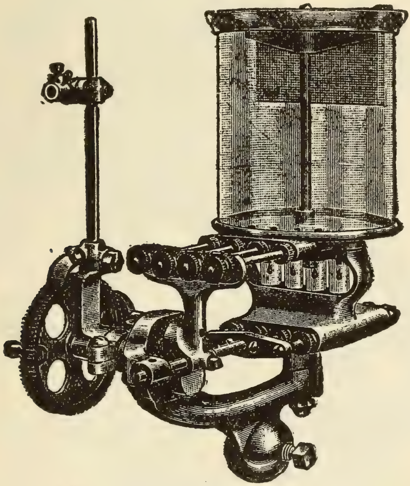


FIGURE 228. MANZEL QUADRUPLE FEED, OIL PUMP.

bolted to a stud or stand. Attach connecting rod of the pump to any movable part that travels back and forth such as a valve rod to an engine or rocker arm of a pump. (See illustrations on the following pages.) Connect the pipe to the pump cylinder. Use ⅛ in. pipe for ½ pint and pint pumps, and ¼ in. pipe for all other sizes; the end of pumps and check valves are threaded for these sizes, and run to and enter the steam line or steam chest above or below the throttle, as desired. Equip the oil pipes as near as possible to the steam line with check valve; the end marked "S" toward the steam line. By using a reducer, 1/8 in. pipe can be used on the larger size pump.

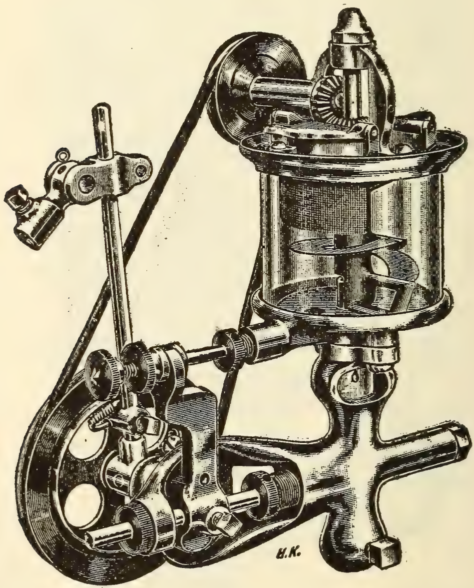


FIGURE 229. THE MANZEL AGITATING, FORCE AND SIGHT FEED OIL PUMP.

The feed on the "MANZEL IMPROVED" Pump is regulated while in operation on the engine, on the upper plungers. To increase the feed screw plunger inward, to decrease the feed screw plunger outward, then tighten lock-nut. Particular attention is called to the regularity of the feed that is obtained on these pumps, under all conditions. They can be regulated to feed from nothing or one drop to a stream of oil with every stroke of the plunger.

Another good force feed lubricator is the Dietz high pressure force feed lubricator made by the Pearl Manufacturing Co. of Buffalo, New York. This device is made either single or double acting, and with from one to six feeds.

Figure 230 shows a double acting three-feed Dietz

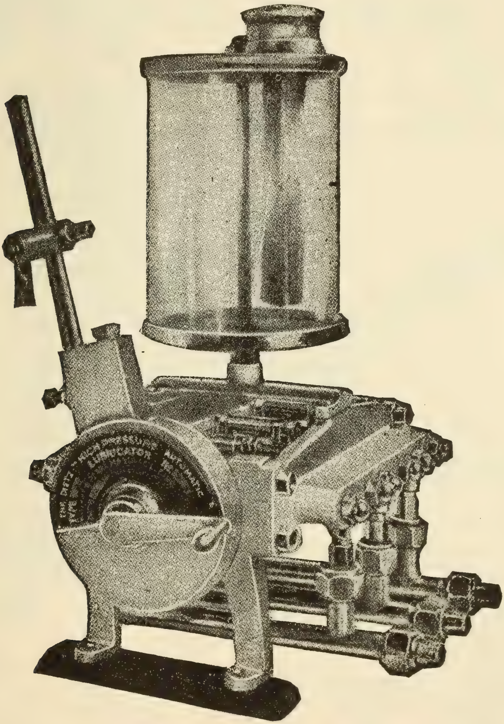
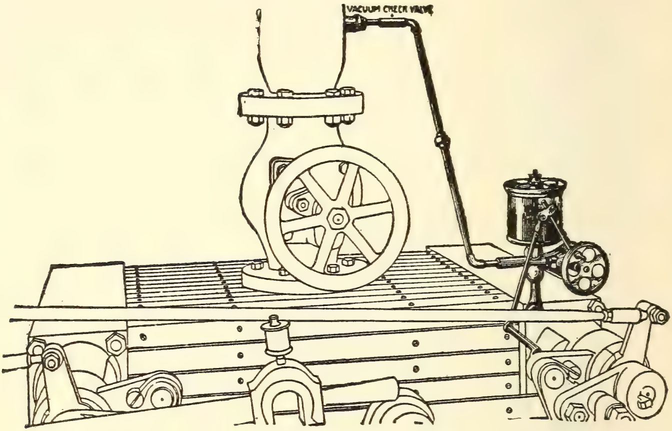
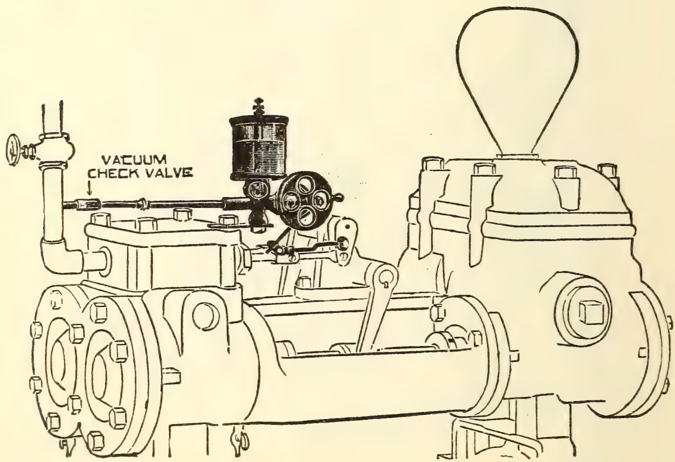


FIGURE 230. DIETZ HIGH PRESSURE FORCE FEED LUBRICATOR.



MANZEL OIL PUMP APPLIED TO CORLISS ENGINE.



MANZEL OIL PUMP APPLIED TO STEAM PUMP.

high pressure lubricator, and it is claimed by the manufacturers that it will feed any mixture of oil and graphite without becoming clogged, owing to the fact that the

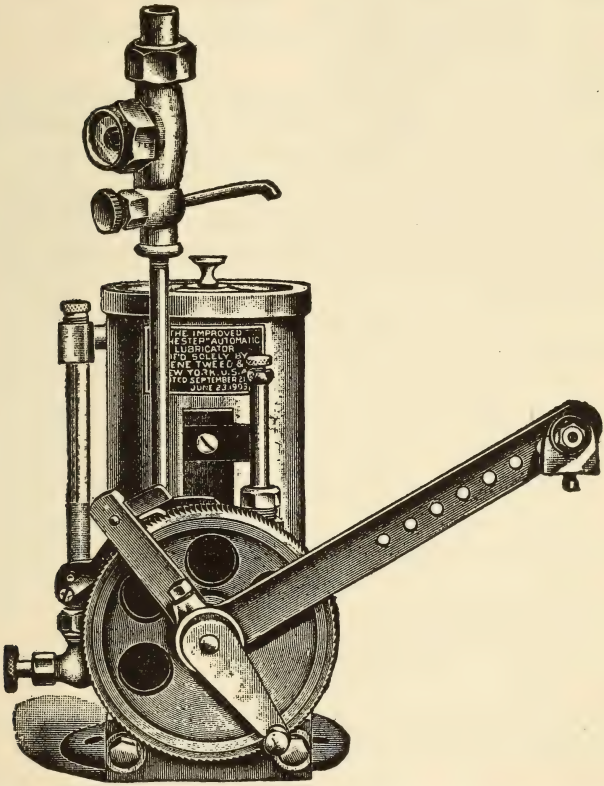


FIGURE 231. ROCHESTER FORCE FEED LUBRICATOR WITH MONITOR SIGHT FEED APPLIANCE.

valves are of the poppet type, and made of steel, and when not opened by the cams, are held to their seats by a strong spiral spring in addition to the pressure. This oil pump is fitted with a crank, by means of which it may be worked by hand, in starting, or should an extra amount of oil be required at any time. The pump is driven in the usual way by connecting to the valve rod of the engine and the feed is regulated by varying the travel of the rocker arm.

Figure 231 shows the Rochester force feed lubricator, as it appears with the Monitor sight-feed attachment screwed onto the delivery pipe, by means of which the engineer is enabled to see the drops of oil as they are being fed to the cylinder or bearings. The number and size of the drops can be regulated to suit the requirements of the engine.

QUESTIONS ON LUBRICATION.

1. What is one of the most important problems connected with the operation of the engine?

2. What is friction?

3. What is the first law of friction?

4. Define the second law of friction.

5. What is the third law regarding friction?

6. Give a definition of the fourth law of friction.

7. Define the fifth law of friction.

8. When and by whom were these laws first formulated?

9. What is the tendency of friction with machinery in operation?

10. How may this friction be largely obviated?

11. Does friction serve any good purpose?

12. How many kinds of friction are there in connection with machinery in motion?

13. What is meant by the term coefficient of friction?

14. What should be the object sought in the design of engine bearings?

15. What is the friction loss in a correctly designed, properly balanced high speed engine, if kept well lubricated?

16. Mention some of the qualities that a good lubricating oil should possess.

17. What is the proper kind of oil to use on a bearing that has started to heat?

18. Is graphite a good lubricant?

19. What is the essential function of graphite?
20. Mention some of the points that govern interior lubrication.
21. What properties should a good cylinder oil possess?
22. Upon what does the successful lubrication of an engine depend?
23. What system of lubrication for cylinders and valves is probably most largely used?
24. What other system is also largely used?

Electricity for Engineers

CHAPTER I

The Electric Current—The Ampere—The Volt—The Ohm—The Watt—Divided Circuits.

The Electric Current. All electrical phenomena with which we have to deal are produced through the medium of the electric current. This current flows only in a conductor of electricity. Among the most noteworthy of the conductors are the various metals; the most useful, and in fact the only one in general use for light and power purposes, being copper.

Every conductor offers some resistance to the flow of current, just as every pipe offers resistance to the flow of steam or water. Just how this resistance varies we shall see later on. In order to familiarize ourselves with the most important electrical phenomena let us consider Fig. 1. The current is assumed to leave the battery at the +, or positive, pole and flow along the wires, etc., to the negative, or – pole, and as it passes through the coils of wire wound about the iron bar it produces magnetism in the bar. If the bar is of soft iron the magnetism lasts only while the current is flowing, but a bar of hardened steel will permanently retain its magnetism. The current will also heat the incandescent lamp until it emits light, and the fine wire, *R*, to the melting point, if desired. In passing through the water in the jar, it will decompose it, forming oxygen and hydrogen gas. If, instead of water, the jar is filled with a proper solution, one of the copper plates in the solution will be gradually eaten away and the other added to. If we now disconnect our wires from the battery and connect 1 at 2, and 2 at 1, the chemical action in the jar will be reversed, the lamp and fine wire, *R*, will heat as before, no difference being noticeable. The iron bar will also be a magnet as before, but the end that before attracted the north seeking end of a compass needle will now repel it and attract the south seeking end of the same

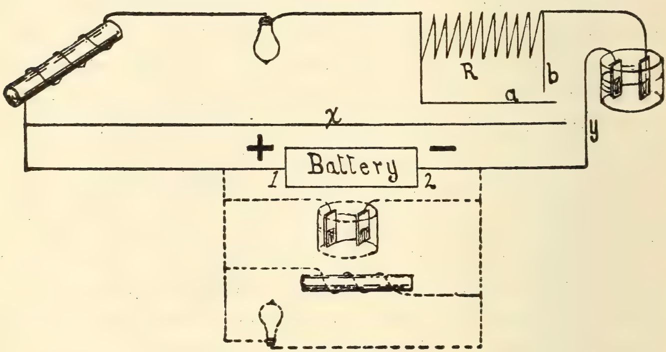


FIGURE 1.

needle. The wire which connects the various devices, and the devices themselves, constitutes an electric circuit, and the current is said to flow in such a circuit along the wire, just as water flows in a pipe. The solid lines form what is known as a series circuit, while the dotted lines form a multiple circuit. In the latter case, each piece of apparatus receives current independent of the others. In the series circuit the same current passes through all. If the small wire *a* is connected to *b*, no current will flow through R; it will all flow through *a* and *b*. If the wire X be connected to Y, all current will flow through it and none through any other part of the circuit. The current obeys the same law as does water; it takes the path which offers the least resistance to its flow.

Such substances as effectually prevent current from flowing through them are known as insulators. Some of them are

Dry Air,	Mica,
Glass,	Shellac,
Silk,	Oil,
Asbestos,	Paraffine,
Porcelain,	Wool,
Cotton,	Paper,
Rubber,	Gutta Percha,

and because the following substances have a low resistance they are known as conductors of electricity. Their relative conductivity is in the following order, silver being the best:

Silver,
Copper,
Gold,
Platinum
Iron,
Tin,
Lead, etc.

The Ampere. The ampere is the unit of volume or rate of flow, and in speaking of a flow of so many amperes, we mean substantially the same thing, electrically speaking, as though we referred to so many gallons of water, mechanically speaking. The number of amperes flowing over a wire deliver power, much or little, proportional to the electromotive force or pressure under which they flow; just as the number of gallons of water flowing through a pipe toward a water wheel deliver a large or small quantity of power to the wheel, proportional to the pressure under which the water flows. If 100 amperes were flowing at a pressure of 10 volts they would produce the same power as though there were 10 amperes flowing at 100 volts, exactly as 100 gals. of water flowing at a pressure of 10 lbs. to the square inch would produce the same power as 10 gals. flowing at a pressure of 100 lbs. to the square inch. In both cases, however, for convenience, we have not considered the size of either wire or pipe, but with the wire, as with the pipe, as we increase the diameter we decrease the friction or resistance. In speaking of the gallon we, of course, have something material on which we can base the unit gallon. We may take a vessel 1 ft. wide, 1 ft. long and 1 ft. high, and this vessel will hold 1 cu. ft. of water. This cubic foot would contain 7½ gals.; but in the case of the ampere we must adopt another method. We shall take an earthenware tank in which is contained a solution of copper sulphate and add one-tenth of one per cent. sulphuric acid. We shall next take two copper plates and hang them into this solution, keeping them spaced one inch apart, vertically. Having washed these plates in clear water, rounded off the corners and dried them thoroughly, we must next weigh them very carefully before submerging them in the liquid. We may now connect both plates to a source from which we can obtain a current of electricity and allow the current to flow from one plate to another, through the liquid, for a period of time which we must measure by a watch or clock. After current has flowed for several hours we will remove the plates, wash them in clean water, and then dip in a bath of water containing a very small amount of sulphuric acid to prevent oxidization, dry them and carefully weigh them again. It will be found that the negative plate has increased in weight by what is called electrolytic action. Now weigh the negative plate and ascertain the exact number of grammes of copper deposited on its surface, or, in other words, find how many grammes heavier the plate is now than it was before it went into the bath. With these data in our possession we will multiply the time in seconds that current was passing through the plates by .000329 and divide the number of grammes deposited on the plate by the result. The quotient will be the number of amperes that passed from plate to plate. This I give simply to show you the manner in which the ampere can be ascertained. It is that current which will deposit .000329 gramme per second on one of the plates of a voltameter, as above described. It is also the current produced by one volt acting through a resistance of one ohm.

In other words, the ampere is that current which would be forced over a wire having a resistance of one ohm by a pressure of one volt.

The ampere-hour is the unit of electrical quantity in general use. It is the quantity of electricity conveyed by one ampere flowing for one hour, or one-half ampere flowing for two hours; or again, one-fourth ampere flowing for four hours. In each case the sum total would be one ampere-hour. It must, however, be noted that an ampere-hour with the pressure at 110 volts would deliver just one-half as much power as an ampere-hour at 220 volts.

An ordinary 16 candle-power 110 volt incandescent lamp requires a current of about one-half an ampere, while a lamp of the same candle-power at 220 volts requires but one-fourth of an ampere, and a 52 volt lamp about one ampere.

A milli-ampere is the one-thousandth ($\frac{1}{1000}$) part of an ampere.

The Coulomb. The Coulomb is the unit of quantity. It is the quantity of current delivered by one ampere flowing for one second.

The Volt. By electromotive force, volts, or potential, we mean electrically about the same as we do when speaking of pounds pressure as indicated on a steam gauge. If we connect a volt-meter between a positive and a negative wire we find that it indicates a certain number of volts; the volt-meter then indicates electrical pressure just as a steam gauge indicates steam pressure. The difference in potential or pressure between two wires we will assume to be 100 volts, and the difference of potential between the inside of a pipe and the atmosphere also at 100 lbs. to the square inch. The steam gauge is closed at one end of the tube which operates it, and hence, the pressure from the interior of the pipe does not flow into the atmosphere; in other words, the resistance offered to the pressure prevents the water from escaping into the atmosphere. In the case of the volt-meter the resistance of the wires used in its construction prevents any great quantity of electricity from flowing out of the positive wire and into the negative through the volt-meter coil. If the gauge were accidentally broken off the pipe, the resistance to the pressure on the inside of the pipe would be greatly lowered and allow the water to flow into the atmosphere. If a piece of ordinary wire were connected to the positive and negative wires, where we have just connected our volt-meter, it would form a path of such low resistance and allow all the current to flow through it, so there would be no pressure indicated in the volt-meter. This would be called a "short circuit." With a volt-meter there is always a small amount of current flowing from a positive to a negative wire through the coil in the meter. This current is neccesary to produce the reading on the meter, but we need not consider this current at present, the quantity being very small.

One volt (unit of pressure) will force one ampere (unit of current) over one ohm (unit of resistance).

Potential is a term quite frequently used to express the same idea as voltage or electromotive force, but its meaning is somewhat different. Suppose that a steam engine is working with 100 lbs. of pressure at the throttle valve, and exhausting into a heating system or system of piping that offers a back pressure of 5 lbs. to the square inch; in other words, the resistance to the flow of steam out of the exhaust pipes of this engine is such that the remaining pressure, when the engine has exhausted, is 5 lbs. Now it will readily be seen that the total pressure utilized to do the work would be 100 lbs. less 5 lbs., or 95 lbs., and therefore the potential would be 95 lbs. Now, if we are using electricity at 100 volts pressure, and lose 5 volts in overcoming resistance, we have a potential of 95 volts left. Whenever work is done by a steam engine a certain amount of pressure is lost by condensation, doing work and by overcoming friction. This loss may be considered the same as a loss of potential, for in the use of electricity any loss in pressure of volts that may occur from doing work or overcoming resistance is called a loss of potential.

In open arc lamps the loss of potential across the terminals or binding posts is about 50 volts; that is, 50 volts have been absorbed or used in producing light. You can now readily understand that electromotive force means force, pressure, energy, and that by potential we mean the capacity to do work or the effective pressure to do work. While we are speaking of electromotive force we may consider some of the advantages of high and low electromotive forces. High electromotive force, like steam at high pressure, is far more economical in transmission or utilization because the quantity may be that much smaller.

When transmitted to great distances, high electromotive forces, like high water or steam pressures, are far more desirable on account of the reduction in friction losses; but this is partially offset by the necessity of using, in water transmission, a much stronger pipe for the high pressure than would be necessary for the low pressure, and in the transmission of current at a high electromotive force or pressure it becomes necessary to use wires with far better insulating material than would be required for the transmission of electricity at low pressure. Increasing the pressure or electromotive force always means more danger, even if you know the pipes are extra strong or the insulation of the wire is of unusually high resistance; for if anything should happen the consequences would be far more serious with high than with low pressures. But notwithstanding all this, engineers are continually increasing the pressures of electrical machinery.

Static electricity is a term applied to electricity produced by friction, and a static discharge of electricity usually consists of an infinitely small quantity but a very high electromotive force or pressure. Discharges of lightning are extremely high in voltage, but the quantity of current that flows is very small.

The Ohm. The ohm is the unit of resistance. Resistance, electrically speaking, is much the same thing as friction in mechanics. If a wire or pipe of a certain length is delivering 10 gals. or 10 amperes at a pressure of 100 lbs. or 100 volts, and we propose to double the flow without increasing the pressure, it will be necessary for us to increase the diameter of the pipe and wire in order to lower the resistance of the wire and the friction of the pipe to one-half of what it was before. If we desire the best results from the pipe, we lower its friction by reaming out all burrs and avoiding all unnecessary bends and turns; likewise if we desire the best results from the wire we will have the copper of which it is constructed as nearly pure as possible, and we will install the wire where its temperature will not be unnecessarily high, avoiding boiler rooms and other hot places. Resistance of the wire increases slightly with an increase in temperature.

For every additional degree centigrade the resistance of copper wire increases about 0.4 per cent., or for every additional degree Fahrenheit about 0.222 per cent. Thus a piece of copper wire having a resistance of 10 ohms at 32° F. would have a resistance of 11.10 ohms at 82° F. An annealed wire is also of lower resistance than a hard drawn wire of the same size. A good idea of the value of an ohm may be had from the following table, which gives the length of different wires required to make one ohm resistance.

FEET PER OHM OF WIRE (B. & S.).

94	feet of No.	20	605	feet of No.	12
150	"	18	961	"	10
239	"	16	1529	"	8
380	"	14	2432	"	6

3867 feet of No. 4

We have not as yet established a unit of mechanical friction, therefore when we speak of mechanical friction we refer to it as requiring a certain quantity of power to overcome it. When, however, resistance to the flow of electricity is spoken of it is referred to as so many ohms. It can be measured in several ways, the most reliable and convenient being by an instrument called the Wheatstone Bridge. It can also be calculated if the length and diameter of the wire or conductor is known, as will be shown later on.

The basis of all electrical calculation is Ohm's law. This law reads:

"The strength of a continuous current in a circuit is directly proportional to the electromotive force acting on that circuit, and inversely proportional to the resistance of the circuit." In other words, the current is equal to the volts divided by the ohms. Expressed in symbols, $C = E/R$; C being current, E voltage, and R resistance. If an incandescent lamp having a resistance of 200 ohms be placed in a socket where the pressure is 115 volts, the resulting current through such a lamp would be 115 divided by 200, or .575 of an ampere.

From the formula $C = E/R$, two others are deduced. The volts divided by the amperes equal the ohms, $E/C = R$.

The amperes multiplied by the ohms equal the volts, $C \times R = E$.

The Watt. The watt is the unit of power. It is an ampere multiplied by a volt; just as the unit of mechanical power, called the foot pound, is the result of the pound multiplied by the space in feet through which it moves. If a current of say 100 amperes, flows over a wire at a pressure of 10 volts, the power delivered will equal

100 amperes × 10 volts = 1,000 watts. If a current of 10 amperes flows over a wire at a pressure of 100 volts, the power would be exactly the same, 10 amperes × 100 volts, or 1,000 watts. But, of course, in the first case it would require a wire ten times as large to deliver the 1,000 watts as would be necessary in the latter case. If a weight of 10 pounds were being elevated through space at the rate of 100 ft. per minute the power equivalent would be 10 lbs. × 100 ft., or 1,000 ft. lbs. If an arc lamp consumes 10 amperes at a pressure of 70 volts, its power consumption is 10 × 70, or 700 watts. One watt is the power developed when 44.25 ft. lbs. of work are done per minute. Seven hundred forty-six watts equal one horse power. The watt-hour is the unit of electric work, and is a term employed to indicate the expenditure of one watt for one hour. The kilo watt-hour is the term employed to indicate the expenditure of an electric power of 1,000 watts for one hour.

The work done per second when a power of one watt is being developed is called the joule, and a joule is equal to .7375 ft. lbs.

Electromotive force times current equals watts. The square of the current multiplied by the resistance equals watts; and the voltage multiplied by itself and divided by the resistance equals watts. Expressed in symbols, these explanations would look like this:

$$W = E \times C. \qquad W = C^2 \times R. \qquad W = E^2 \div R.$$

First. If we have an electromotive force or voltage of 10 volts and a current of 20 amperes, we have 10 × 20 = 200 watts.

Second. If we have a current of 10 amperes and a resistance of 30 ohms, we would have 10 × 10 × 30 = 3,000 watts.

Third. If we have an electromotive force or voltage of 10 volts and a resistance of 20 ohms, we would have 10 × 10, or 100 ÷ 20, or 5 watts.

In the above formulas E stands for voltage, C for current, R for resistance and W for watts.

Divided Circuits. Currents of electricity, although they have no such material existence as water or steam, still obey the same general law; that is, they flow and act along the lines of least resistance. If a pipe extending to the top of a ten story building had a very large opening at the first floor, it would be impossible to force water to the top floor. All the water would run out at the first floor. If the opening at the first floor were small only a part of the water would escape through it, some would reach the top of the building. The flow of water in each case is inversely proportional to the resistance offered to it by the different openings.

The same thing is true of currents of electricity. Where several paths are open to a current of electricity the flow through them will be in proportion to their conductivities, which is the inverse ratio of their resistances. As an illustration, the current flow through all of the lamps, Fig. 2, is the same, because

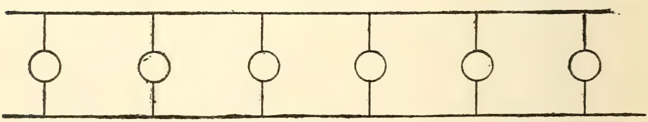


FIGURE 2.

each lamp offers the same resistance. But if we arrange a number of lamps as in Fig. 3, the lamps in series will offer twice as much resistance as the single

FIGURE 3.

lamps, and will receive but half the current of the single lamp. In Fig. 4 we have still another arrangement. The lamp A limits the current which can flow through B and C, and that current which does flow

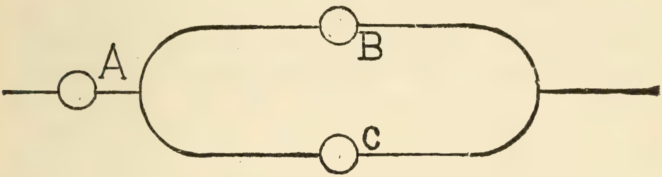


FIGURE 4.

divides between B and C in proportion to their conductivities. If B has a resistance of 110 ohms and C 220 ohms, then B will carry two parts of the current and C only one. The combined resistance of all lamps, Fig. 2, equals the resistance of one lamp divided by the number of lamps. The combined resistance, Fig. 3, equals the sum of the resistances of the two lamps at A multiplied by the resistance of B and divided by the sum of all the resistances. If the resistance of each of the lamps were 110 ohms, the problem would work out thus: $\frac{110+110\times110}{110+110+110}=73\frac{1}{3}$.

In Fig. 4 the total resistance is $\frac{110\times220}{110+220}+110=183\frac{1}{3}$.

One practical illustration of the above law may be found in the method of switching series arc lamps,

Fig. 5. As long as the switch S is open the arc lamp burns, but as soon as the switch is closed the lamp is

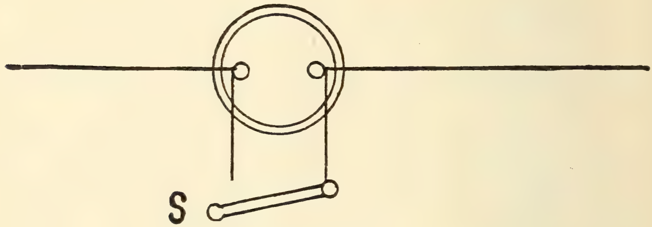


FIGURE 5.

extinguished because the resistance of the short wire and the switch S is so much less than that of the arc lamp that practically all the current flows through S.

CHAPTER II

WIRING SYSTEMS — CALCULATION OF WIRES — WIRING TABLES.

Wiring Systems. The system of wiring which is most generally used for incandescent lighting and ordinary power purposes is called the two wire parallel system. In this system of wiring the two wires run side by side, one of them being the positive and one the negative. The lamps, motors and other devices are then connected from one wire to the other. A constant pressure of electricity is maintained between the two wires, and the number and size of lamps, or other apparatus, connected to these two wires, determine how many amperes are required. Each lamp or motor is independent of the others and may be turned on or off without disturbing the others.

A diagram of such a system is shown in Fig. 6.

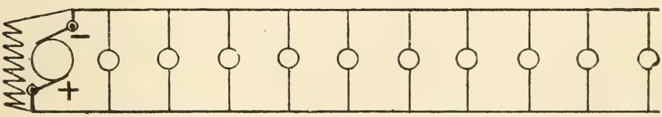


FIGURE 6.

In this system the quantity of current varies in proportion to the number of devices connected to it. Suppose that we are maintaining a pressure or potential or electromotive force of 110 volts on such a system, and that we have connected to the system ten 16 candle power incandescent lamps, consuming one-half ampere each. The total quantity of current to supply these lamps would be 5 amperes. If we should now switch on ten more lamps the quantity of current would be 10 amperes, and the pressure would remain 110 volts. This system is also known as the "constant potential system," or multiple arc system, and among the numerous devices used in connection with it are the constant potential arc lamp, the shunt motor, the compound wound motor, the series motor, incandescent lamps, etc. Electric street railways are also operated on this system. The electricity supplied through this system of wiring may be either direct or alternating current.

The series arc system, Fig. 7, is a loop; the greatest electrical pressure being at the terminal or terminal ends

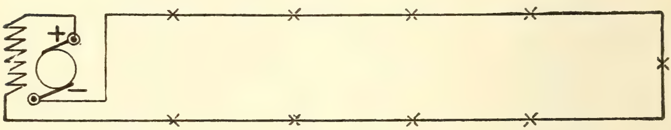


FIGURE 7.

of the loop. The current in such a system of wiring is constant, and the pressure varies as the lamps or other apparatus are inserted in or cut out of the circuit. This system is also called the constant current system. The same current passes through all of the lamps, and the different lamps are also independent of each other.

At the present time the series system is used mostly for operating high tension series arc lamps. The use of motors with it has been almost entirely abandoned.

The series multiple system, Fig. 8, is simply a number of multiple systems placed in series. This method of wiring was at one time employed to run incandescent lights from a high tension series arc light circuit, but on account of the danger connected with the use

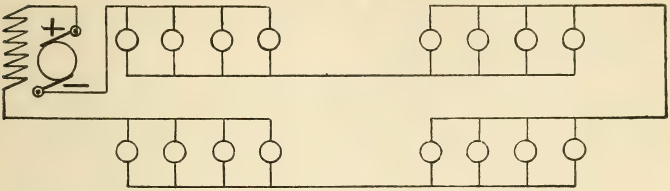


FIGURE 8.

of incandescent lamps, operated from a high tension arc lamp circuit, the system has been abandoned. It is not approved by insurance companies, and consequently is not often used.

The multiple series system consists of a number of small series circuits, connected in multiple, as shown in Fig. 9. This system of wiring is used on constant

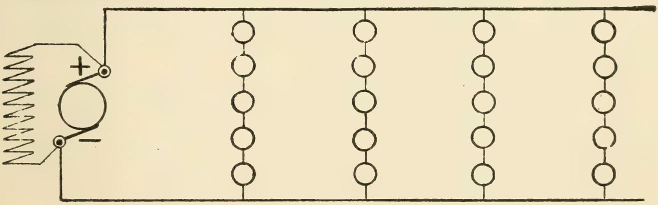


FIGURE 9.

potential systems, where the voltage is much greater than is required by the apparatus to be used, as, for instance, connecting eleven miniature lamps, whose individual pressure required is 10 volts, into a series, and then connecting the extreme ends of such a series to a multiple circuit whose pressure is 110 volts. In electric street cars, where the pressure between the trolley wire and the running rail is 500 volts, it will be noticed that the lighting circuits in the car consist of five 100 volt lamps in series, and one end of this series is connected to the trolley line, the other end being grounded on the trucks.

The three wire system, Fig. 10, is a system of multiple series. In this system, as its name implies, three wires are used, connected up to the machines in

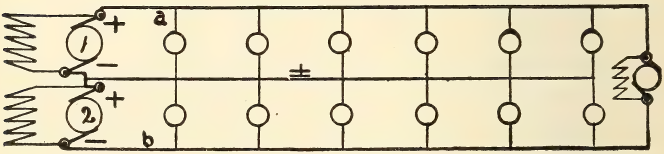


FIGURE 10.

the manner shown in the diagram. Both machines are in series when all lights are turned on, but should all lights on one side of the neutral or center wire be turned off the machine on the other side alone would run the other lights.

One of these wires is positive, the other is negative, and the remaining one or center wire is neutral. In ordinary practice from positive to negative wire, a potential of 220 volts is maintained, while from the neutral wire to either of the outside wires a potential of 110 volts exists. The advantages of such a system are many, principally among them is the use of double the voltage of the two wire system; this reduces the current one-half and allows the use of smaller wires. This system only requires three wires for the same amount of current that would require four in the other system. Motors are supplied at 220 volts, while lights operate at 110. Incandescent lighting circuits can be maintained from either outside wire to the neutral wire. The saving in copper by dispensing with the fourth wire is not the only advantage in the saving of conductors. The neutral wire may be much smaller than the outside wires because it will seldom be called upon to carry much current.

Inside of buildings, however, where overheating of a wire is always dangerous, the neutral wire should be of the same size as the others. By tracing out the circuits in Fig. 10, it will readily be seen that, so long as all lamps are burning, the current passes out of dynamo 1 into the positive wire and from there through the lamps (always two in series) to the negative or – wire, returning over it to the – pole of dynamo 2. So long as an equal number of lamps is burning on each side of the neutral, no current passes over the neutral wire in either direction. But if the positive or + wire should be broken, say at *a*, dynamo 1 will no longer send current and the lamps between the positive and neutral wire will be out.

Dynamo 2 will now supply the lamps between the neutral and the negative wire and for the time being the neutral wire will become positive. Should the negative wire break at *b*, the lamps connected to it would be out and dynamo 1 would supply the lights on its side, the neutral wire becoming negative. When motors of one or more H. P. are used on this system, it is usual to connect them to the outside wires using 220 volts. It is important also to arrange the wiring so that an equal number of lights are installed on each side of the neutral. When the lights and motors are so arranged, the system is said to be "balanced." It is also very important to arrange so that the neutral wire cannot readily be broken. Should the neutral wire be opened while, for instance, fifty lamps were burning on one side and say ten or twenty on the other, the ten or twenty would be broken by the excess voltage. Grounded wires ordinarily cause more trouble than anything else on electric light or power circuits, but with the three wire system, the neutral wire is often grounded. Grounds on this wire are less objectionable than on other wires, because it carries very little current, and that current is constantly varying in direction, so that no great amount of electrolysis can occur at any one place. For full descriptions and drawings of methods of wiring, see *Wiring Diagrams and Descriptions* by Horstmann and Tousley, published by Frederick J. Drake & Co., Chicago.

Feeders (see Fig. 11), as the name implies, is a term used to designate wires which convey the current to

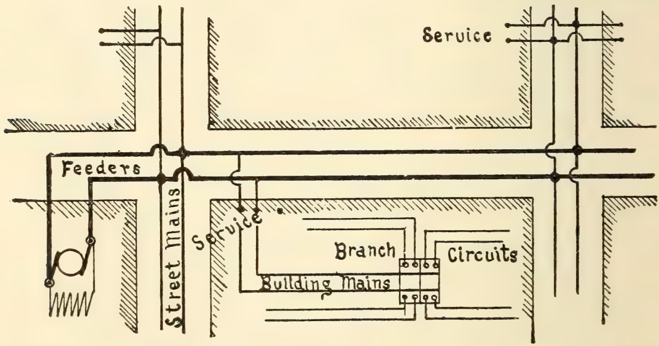


FIGURE 11.

any number of other wires, and the feeders become a part of the multiple series, multiple and three wire systems.

Distributing mains are the wires from which the wires entering buildings receive their supply.

Service wires are the wires that enter the buildings.

The center of distribution is a term used for that part of the wiring system from which a number of branch circuits are fed by feeder wires. In most buildings the tap lines are all brought to one point, and terminate in cut-out boxes. These cut-out boxes are supplied by the main. Each floor of the building may have a cut-out box, or each floor of the building may have several cut-out boxes of the above description.

Calculation of Wires. If we desire to transmit or deliver a certain quantity of liquid through a pipe, we estimate the size of the pipe and the comparison of sizes in the pipes by squaring the diameter, in inches, and multiplying the result by the standard fraction .7854. By way of explanation we will dwell upon the above method for a short time. In Fig. 12 we have a surface which measures one inch on all four sides, and which has an area of one square inch.

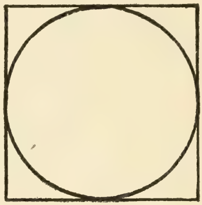


FIGURE 12.

Now in a circle which is contained in this figure, and which touches all four sides of the square, we would only have .7854 of a square inch. If the diameter of this circle is 2 in., instead of 1, you can readily see by Fig. 13 that its area is four times as great or $2 \times 2 = 4$. We then multiply by the standard number .7854 in order to find the area contained in the two-inch circle; and if the diameter were 3 in., then $3 \times 3 = 9$, and $9 \times .7854$ would be the area in square inches contained in the three-inch circle.

Again, if we had a square one inch in area, like Fig. 14, and we took one leg of a carpenter's compass and placed it on one corner of this square, striking a quarter-circle from one adjacent corner to the other adjacent corner, the area inscribed by the compass would again be .7854 of a square inch.

The above will explain to the reader the relation

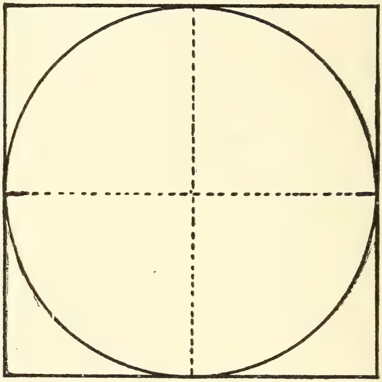


FIGURE 13.

between the circular and square mil. The circular mil is a circle one mil ($\frac{1}{1000}$ of an inch) in diameter. The square mil is a square one mil long on each side. In the calculation of wires for electrical purposes, the circular mil is generally used, because we need only multiply the diameter of a wire by itself to obtain its area in circular mils. If we used square mils we should have to multiply by .7854.

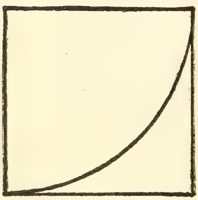


FIGURE 14.

The resistance of a conductor (wire) increases directly as its length, and decreases directly as its diameter is increased. A wire having a diameter of one mil and being one foot long has a resistance at ordinary temperature of 10.7 ohms. If this wire were two feet long, it would have a resistance of 21.4 ohms, but if it were two mils in diameter and one foot long, it would have a resistance one-fourth of 10.7, or about 2.67.

Every transmission of electrical energy is accompanied by a certain loss. We can never entirely prevent this loss any more than we can entirely avoid friction. But we can reduce our loss to a very small quantity simply by selecting a very large wire to carry the current. This would be the proper thing to do if it were not for the cost of copper, which would make such an installation very expensive. As it is, wires are usually figured at a loss of from 2 to 5 per cent.

The greater the loss of energy we allow in the wires the smaller will be the cost of wire, since we can use smaller wires with the greater loss.

In long distance transmission and where the quality of light is not very important, a loss of 10 or 20 per cent. is sometimes allowed, but in stores, residences, etc., the loss should not exceed 2 or 3 per cent., otherwise the candle power of the lamps will vary too much.

Where the cost of fuel is high the saving in first cost of copper is soon offset by the continuous extra cost of fuel to make up for the losses in the wires.

To determine the size of wire necessary to carry a certain current at a given number of volts loss, we may proceed in the following manner: Multiply the number of feet of wire in the circuit by the constant 10.7, and it will give the circular mils necessary for one ohm of resistance. Multiply this by the amperes, and this will give the circular mils for a loss of one volt. Divide this last result by the volts to be lost, and the answer will be the number of circular mils diameter that a copper wire must have to carry the current with such a loss. After obtaining the number of circular mils required, refer to the table of circular mils, and select the wire having such a number of circular mils.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Volts lost}} = \text{circular mils.}$$

By simply transposing the above terms we obtain another formula, which can be used to determine the volts lost in a given length of wire of a certain size, carrying a certain number of amperes.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Circular mils}} = \text{Volts lost.}$$

And again, by another change in the terms we obtain a formula which shows the number of amperes that a wire of given size and length will carry at a given number of volts lost:

$$\frac{\text{Circular mils} \times \text{volts lost}}{\text{Feet of wire} \times 10.7} = \text{Amperes.}$$

In computing the necessary size of a service or main wire, to supply current for either lamps or motors, it is necessary to know the exact number of feet from the source of supply to the center of distribution. When the distance of center of distribution is given it is well to ascertain whether it is the true center or not. It may be only the distance from a cut-out box that has been given, when it should have been the distance from the point at which the service enters the building or, perhaps, from the point at which the service is connected to the street mains. For when the size is determined it is for a certain loss which is distributed over the entire length of the wire to be installed. The transmission of additional current on the mains in the building increases the drop in volts in the main, and likewise in the service. Most buildings are wired for a certain per cent loss in voltage, estimated from the point where the service enters the building. All additions should be estimated from that point.

In using the formula for finding the proper size wire to carry current, the first thing to be determined is the length of the wire; remember that the two wires are in parallel, and therefore the total length of the wire is twice the total distance from the commencement to the end of the circuit. If the proposed load on this circuit is given in lamps, you may reduce it to amperes, and if the proposed load is given in horsepower, you may reduce it to amperes. The voltage on the circuit is known in either case. You take the loss of the voltage and divide the product of amperes, multiplied by the length, as found, and 10.7 by it; this answer will be the size in circular mils of a wire necessary to carry the amperes.

Example: What is the size of wire required for a 50 volt system, having 100 lamps at a distance of 100 ft., with a 4 per cent loss?

Answer: The load of 100 lamps on a 50 volt system is 100 amperes, and a 4 per cent loss of 50 volts is 2 volts. Multiply the total length of the wire, which is twice the distance, or 200 ft., by the 100 amperes of current; this gives us 20,000. Then muitiply this by the constant, which is 10.7; this gives us 214,000. Divide this by 2, which is the loss in volts, and you have 107,000 circular mils diameter of wire required

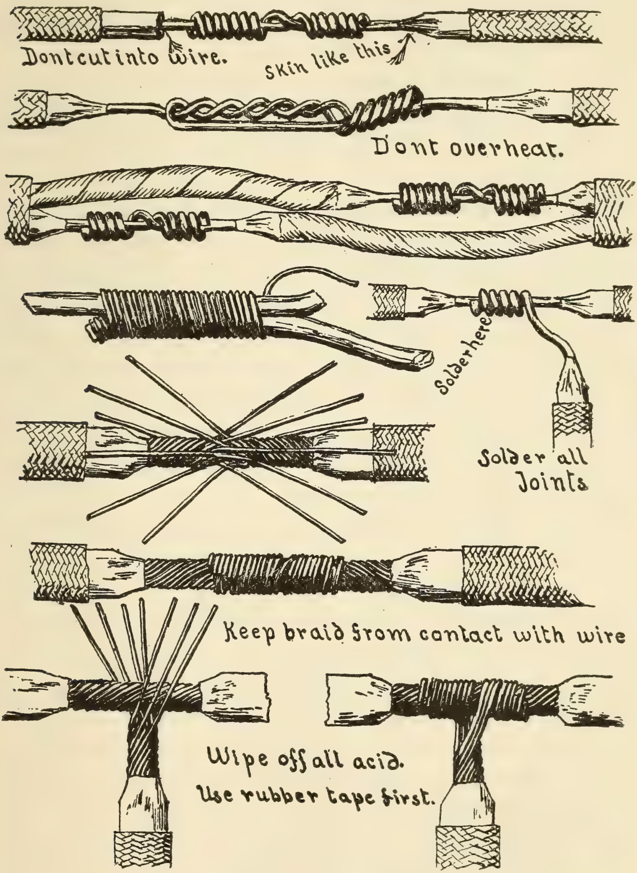
When determining the size of wire to be used it is always necessary to consult the table of carrying capacities, and this will very often indicate a wire much larger than that determined by the wiring formula, especially if a somewhat high loss is figured on.

When estimating the distance it is not always correct to take the total distance.

To illustrate: Suppose one lamp is 100 ft. from the point at which the distance is determined, and the farthest lamp is 400 ft., the remaining lamps being distributed evenly between these two points; we would average the distances between the first and last lamp, which would be 200 ft. It is necessary to use judgment in estimating the mean or average distance, as the lamps or motors are bunched differently in each case

In a series system the loss in voltage makes considerable difference to the power, but does not affect the quality of the light as much as in a multiple arc or parallel system. In a parallel system the lamps require a uniform pressure, and this can only be had by keeping the loss low. In a series system the lamps depend upon the constant current and the voltage varies with the resistance, in order to keep the current constant. This is accomplished by a regulator on the dynamo, which is designed to compensate for the changes of resistance in the circuit and to increase or decrease the pressure as required.

In estimating the size of wire for a series system you consider the total length of the loop. There is no average distance as the total current travels over the entire circuit. We will assume that you have an arc light circuit of a No. 6 Brown & Sharp gauge wire and want to find what loss there is in this circuit. You have the area of a No. 6 wire, which is 26,250 circular mils, and the length of the circuit, and from this we will figure the loss in this manner: Assuming the circuit to be 10,000 ft. long, and the current 10 amperes, we will multiply 10,000 ft. by 10 amperes, and this by 1.07, which gives us 1,070,000, and divide this by 26,250. The answer is 40 volts, lost in the circuit.



Such a circuit would operate at perhaps 2,000 or 3,000 volts, and a loss of 40 volts would not be excessive. It would be wasting a little less energy than is required to burn one large arc lamp.

The *multiple series system* is a number of small wires connected in multiple, and is the same as the multiple arc or parallel system. The wire is figured in the same way as for the multiple arc system.

The *series multiple system* is a number of small parallel systems, and these are connected in series by the main wire. The wire is figured the same as for the series system.

The *Edison three-wire system* is a double multiple, and the two outside wires are the ones considered when carrying capacity is figured. When this system is under full load or balanced, the neutral wire does not carry any current, but the blowing of a fuse in one of the outside wires may force the neutral wire to carry as much current as the outside wire and it should, therefore, be of the same size. The amount of copper needed with this system is only three-eighths of that required for a two-wire system.

Wiring Tables. On the following pages are presented wiring tables for 110, 220 and 500 volt work. These tables are used in the following manner: Suppose we wish to transmit 60 amperes a distance of 1,800 ft. at 110 volts and at a loss of 5 per cent. We take the column headed by 60 in the top row and follow it downward until we come to 1,800, or the number nearest to it. From this number we now follow horizontally to the left, and under the column headed by 5 we find the proper size of wire, which is 500,000 c. m. The same current, at a loss of 10, would require only a 0000 wire, as indicated under the column at the left, headed by 10.

Before making selection of wire, always consult the table of carrying capacities, page 38. This table is taken from the rules of the National Board of Fire Underwriters, and is in general use.

The first three of the following tables are wiring tables for the three standard voltages, 110, 220, 500. From these tables can be found the sizes of wire required to carry various amounts of current (in amperes) different distances (in feet) at several percentages of loss, or the distance the different sizes of wire will carry various amounts of current at several percentages of loss can be found.

These tables are figured on safe carrying capacity for the different sizes of wire. The distances in feet are to the center of distribution.

110-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	125	150	200	250	300	350
......	......	......	......	......	500000	127315	63657	42438	25463	16975	12731	10185	8487	6365	5092	4243	3182	2546	2037	1697	1273	1018	849	727
......	......	......	......	500000	400000	101850	50925	33950	20370	13580	10185	8148	6790	5092	4074	3395	2546	2037	1629	1358	1018	815	679	....
......	......	......	500000	400000	300000	76380	38190	25460	15276	10184	7638	6111	5092	3819	3055	2546	1910	1527	1222	1018	763	611	....	....
......	......	500000	400000	300000	0000	53880	26940	17960	10776	7184	5388	4311	3592	2694	2155	1796	1347	1077	862	718	538	....	....	....
......	......	400000	300000	0000	000	40410	20205	13470	8082	5488	4041	3233	2744	2020	1616	1372	1010	808	647	538	....	....	....	....
......	500000	300000	0000	000	00	33885	16942	11295	6777	4517	3388	2711	2258	1694	1355	1129	822	677	542	452	....	....	....	....
......	400000	0000	000	00	0	26880	13440	8960	5377	3584	2688	2151	1792	1344	1075	896	672	537	430	....	....	....	....	....
500000	300000	000	00	0	1	21310	10655	7103	4262	2841	2131	1705	1420	1065	852	710	532	426	341	....	....	....	....	....
400000	0000	00	0	1	2	16900	8450	5633	3380	2253	1690	1352	1126	845	676	563	422	338	....	....	....	....	....	....
300000	000	0	1	2	3	13400	6700	4466	2680	1786	1340	1072	893	670	536	447	335	....	....	....	....	....	....	....
0000	00	1	2	3	4	10605	5302	3535	2121	1413	1060	848	706	530	424	353	....	....	....	....	....	....	....	....
000	0	2	3	4	5	8430	4215	2810	1686	1124	813	675	562	422	337	281	....	....	....	....	....	....	....	....
00	1	3	4	5	6	6685	3342	2228	1337	890	668	535	445	334	267	....	....	....	....	....	....	....	....	....
0	2	4	5	6	7	5300	2650	1766	1060	706	530	424	353	265	212	....	....	....	....	....	....	....	....	....
1	3	5	6	7	8	4220	2110	1406	844	562	422	338	281	211	......	....	....	....	....	....	....	....	....	....
2	4	6	7	8	9	3330	1665	1110	666	444	333	266	222	......	......	....	....	....	....	....	....	....	....	....
3	5	7	8	9	10	2640	1320	880	528	352	264	211	....	......	......	....	....	....	....	....	....	....	....	....
4	6	8	9	10	11	2095	1047	698	419	278	209	......	......	......	......	....	....	....	....	....	....	....	....	....
5	7	9	10	11	12	1660	830	553	333	221	......	......	......	......	......	....	....	....	....	....	....	....	....	....
6	8	10	11	12	13	1320	660	440	264	176	......	......	......	......	......	....	....	....	....	....	....	....	....	....
7	9	11	12	13	14	1045	522	348	209	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
8	10	12	13	14	15	830	415	276	166	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
9	11	13	14	15	16	655	327	218	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
10	12	14	15	16	......	525	263	175	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
11	13	15	16	......	......	412	206	137	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
12	14	16	....	......	......	330	165	111	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
13	15	......	......	......	......	263	131	87	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
14	16	......	......	......	......	206	103	68	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
15	..	......	......	......	......	165	82	55	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
16	......	......	......	......	......	131	65	43	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....

One 16-Candlepower 55 Watt Incandescent Lamp=½ ampere. One Horsepower= 6.78 amperes. One 2000-Candlepower Constant Potential Arc Lamp=5 amperes.

220-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the number of Amperes: Those Below the Distance in Feet.																		
2	**3.15**	**5**	**6.3**	**8**	**10**	**2**	**4**	**6**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**60**	**80**	**100**	**120**	**160**	**200**	**250**	**300**	**350**
......	......	......	......	......	500000	254630	127315	84877	50926	33950	25463	20370	16975	12731	10185	8487	6366	5092	4243	3183	2546	2037	1697	1455
......	......	......	......	500000	400000	203700	101850	67900	40740	27160	20370	16295	13580	10185	8147	6790	5092	4073	3395	2546	2036	1629	1357	...
......	......	......	500000	400000	300000	152775	76387	50924	30550	20370	15275	12222	10183	7637	6111	5091	3819	3055	2546	1910	1528	1222	....	....
......	......	500000	400000	300000	0000	107780	53890	35926	21556	14370	10778	8622	7 85	5389	4311	3592	2695	2155	1796	1348	1077	....	....	....
.....	......	400000	300000	0000	000	85450	42725	28483	17090	11393	8545	6836	5696	4272	3418	2848	2136	1709	1424	1068	....	....	....	....
......	500000	300000	0000	000	00	67745	33872	22581	13549	9032	6774	5420	4516	3387	2710	2258	1679	1355	1129	839	...	....	....	....
......	400000	0000	000	00	0	53770	26885	17923	10754	7170	5377	4302	3585	2688	2151	1792	1344	1075	896	....	....	....	....	....
500000	300000	000	00	0	1	42620	21310	14206	8524	5682	4262	3410	2841	2131	1705	1420	1065	852	710	....	....	....	....	....
400000	0000	00	0	1	2	34055	17027	11351	6811	4540	3405	2724	2270	1702	1362	1135	851	681	....	....	....	....	....	....
300000	000	0	1	2	3	26570	13285	8856	5314	3542	2657	2125	1771	1328	1062	885	664	....	....	....	..	....	....	....
0000	00	1	2	3	4	21255	10627	7085	4251	2834	2125	1700	1417	1062	850	708	....	....	....	....	....	....	....	....
000	0	2	3	4	5	16855	8427	5618	3371	2247	1685	1348	1123	842	614	562	....	....	....	....	....	....	....	....
00	1	3	4	5	6	13365	6682	4455	2673	1782	1336	1050	891	668	525	....	....	....	....	....	....	....	....	....
0	2	4	5	6	7	10560	5280	3520	2112	1413	1060	848	706	530	424	....	....	....	....	....	....	....	....	....
1	3	5	6	7	8	8405	4202	2801	1681	1120	840	672	560	420	......	....	....	....	....	....	....	....	....	....
2	4	6	7	8	9	6665	3332	2221	1333	888	666	533	444	......	......	....	....	....	....	....	....	....	....	....
3	5	7	8	9	10	5275	2637	1758	1055	703	527	422	....	......	......	....	....	....	....	....	....	....	....	....
4	6	8	9	10	11	4190	2095	1396	838	558	419	......	......	......	......	....	....	....	....	....	....	....	....	....
5	7	9	10	11	12	3325	1662	1108	665	443	......	......	......	......	......	....	....	....	....	....	....	....	....	....
6	8	10	11	12	13	2635	1317	878	527	351	......	......	......	......	......	....	....	....	....	....	....	....	....	....
7	9	11	12	13	14	2090	1045	696	418	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
8	10	12	13	14	15	1655	827	551	331	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
9	11	13	14	15	16	1315	657	438	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
10	12	14	15	16	......	1050	525	350	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
11	13	15	16	......	......	828	414	276	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
12	14	16	......	......	......	657	328	219	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
13	15	......	......	......	......	526	263	175	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
14	16	......	......	......	......	414	207	138	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
15	......	......	......	......	......	329	164	109	......	......	......	......	......	......	......	....	....	....	....	....	....	....	....	....
16	......	......	......	......	......	265	132	88		......	......	......	......	......	......	....	....	....	....	....	....	....	....	....

One 16-Candlepower 55 Watt Incandescent Lamp=¼ ampere. One Horsepower=3.39 amperes. One 2000-Candlepower Constant Potential Arc Lamp=2½ amperes.

500-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes: Those Below the Distance in Feet.																
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	150	170	200
......	......	......	......		500000	578700	289350	192900	115740	77160	57870	46296	38580	28935	23148	19290	14467	11574	9645	7716	6800	5787
......	......	......	......	500000	400000	460645	230322	153550	92129	61420	46064	36852	30710	23032	18426	15355	11516	9213	7677	6142	5420	4606
......	......	......	500000	400000	300000	347220	173610	115740	69444	45296	34722	27777	22648	17361	13888	11324	8680	6944	5662	4629	4085	3472
......	......	500000	400000	300000	0000	244950	122475	81650	48990	32660	24495	19595	16330	12247	9797	8165	6123	4898	4082	3266	2882	2449
......	......	400000	300000	0000	000	194215	97107	64738	38843	25895	19421	15537	12947	9710	7768	6473	4855	3884	3236	2589	2285	......
......	500000	300000	0000	000	00	154025	77012	51341	30805	20536	15402	12322	10268	7701	6161	5134	3850	3080	2567	2054	......	......
......	400000	0000	000	00	0	122210	61105	40736	24442	16293	12221	9775	8146	6110	4887	4073	3055	2443	2036	......	......	......
500000	300000	000	00	0	1	96405	48202	32135	19281	12854	9640	7712	6427	4820	3856	3213	2410	1928	1606	......	......	......
400000	0000	00	0	1	2	76565	38282	25521	15313	10208	7656	6125	5104	3828	3062	2552	1914	1531	......	......	......	......
300000	000	0	1	2	3	60915	30457	20305	12183	8122	6091	4873	4061	3045	2436	2030	1522	......	......	......	......	......
0000	00	1	2	3	4	48310	24155	16103	9662	6441	4831	3864	3220	2415	1932	1610	......	......	......	......	......	......
000	0	2	3	4	5	38282	19140	12760	7656	5104	3828	3062	2552	1914	1531	1276	......	......	......	......	......	......
00	1	3	4	5	6	30457	15228	10152	6091	4061	3045	2436	2030	1522	1218	......	......	......	......	......	......	......
0	2	4	5	6	7	24155	12077	8051	4831	3220	2415	1932	1610	1207	966	......	......	......	......	......	......	......
1	3	5	6	7	8	19140	9570	6380	3828	2552	1914	1531	1276	957	......	......	......	......	......	......	......	......
2	4	6	7	8	9	15229	7614	5076	3045	2030	1522	1218	1015	......	......	......	......	......	......	......	......	......
3	5	7	8	9	10	12077	6039	4026	2415	1610	1207	978	......	......	......	......	......	......	......	......	......	......
4	6	8	9	10	11	9570	4785	3190	1914	1276	957	......	......	......	......	......	......	......	......	......	......	......
5	7	9	10	11	12	7639	3819	2546	1527	1018	......	......	......	......	......	......	......	......	......	......	......	......
6	8	10	11	12	13	6039	3019	2013	1207	805	......	......	......	......	......	......	......	......	......	......	......	......
7	9	11	12	13	14	4785	2392	1595	957	......	......	......	......	......	......	......	......	......	......	......	......	......
8	10	12	13	14	15	3819	1910	1273	763	......	......	......	......	......	......	......	......	......	......	......	......	......
9	11	13	14	15	16	3019	1510	1005	......	......	......	......	......	......	......	......	......	......	......	......	......	......
10	12	14	15	16	......	2392	1195	797	......	......	......	......	......	......	......	......	......	......	......	......	......	......
11	13	15	16	......	......	1910	950	636	......	......	......	......	......	......	......	......	......	......	......	......	......	......
12	14	16	......	......	......	1510	755	503	......	......	......	......	......	......	......	......	......	......	......	......	......	......
13	15	......	......	......	......	1195	597	398	......	......	......	......	......	......	......	......	......	......	......	......	......	......
14	16	......	......	......	......	950	475	316	......	......	......	......	......	......	......	......	......	......	......	......	......	......
15	......	......	......	......	......	755	377	252	......	......	......	......	......	......	......	......	......	......	......	......	......	......
16	......	......	......	......	......	597	298	199	......	......	......	......	......	......	......	......	......	......	......	......	......	......

One Horsepower =1.49 amperes. When lights are used the lamps are put in series.

TABLE OF SIZES, MEASUREMENTS, WEIGHTS, ETC., OF COPPER WIRE.

Size B. & S. Gauge	Diam. Mils	Area: Circular Mils	Area: Square Mils	Weather-Proof Wire, Double Braided: Pounds per 1000 feet	Double Braided: Pounds per mile	Double Braided: Feet per Pound	Triple Braided: Pounds per 1000 feet	Triple Braided: Pounds per Mile	Triple Braided: Feet per Pound	Bare Wire: Pounds per 1000 feet	Bare Wire: Pounds per Mile	Bare Wire: Feet per Pound	Resistance at 75° F.: R Ohms per 1000 feet	Ohms per Mile	Feet per Ohm	Ohms per Pound
....	707 160	500000 0	392700	1680	8870	59	1744	9208	57	1562	8247	64	02079	10978	48290	00001322
....	632 455	400000 0	314160	1343	7091	74	1405	7418	76	1209	6489	81	02589	13723	38630	00002063
... ...	547 722	300000 0	235620	1055	5570	94	1112	5873	90	941	4968	1 06	03465	18297	28980	00003656
0000	460 000	211600 0	166190	700	3718	1 42	746	3940	1 34	639 33	3375 7	1 56	04904	25891	20392 9	00007653
000	409 640	167805 0	131790	565	2983	1 77	599	3161	1 67	507 01	2677 0	1 97	06181	32649	16172 1	00012169
00	364 800	133079 0	104520	460	2433	2 17	493	2600	2 03	402 09	2123 0	2 49	07797	41168	12825 4	00019438
0	324 950	105592 5	82887	371	1963	2 69	397	2095	2 52	319 04	1684 6	3 14	09827	51885	10176 4	00030734
1	289 300	83694 5	65733	281	1483	3 56	299	1572	3 35	252 88	1335 2	3 95	12398	65460	8066 0	00048920
2	257 630	66373 2	52130	231	1219	4 33	248	1310	4 03	200 54	1058 8	4 99	15633	82543	6396 7	00077784
3	229 420	52633 5	41339	193	1018	5 18	207	1091	4 84	159 03	839 68	6 29	19714	1 04090	5072 5	0012370
4	204 310	41742 6	32784	152	802	6 58	162	855	6 17	126 12	665 91	7 93	24858	1 31248	4022 9	0019666
5	181 940	33102 2	25998	123	650	8 12	134	710	7 45	100 01	528 05	10 00	31346	1 65507	3190 2	0031273
6	162 020	26250 5	20617	104	550	9 60	112	595	8 87	79 32	418 81	12 61	39528	2 08706	2529 9	0049723
7	144 280	20816 7	16349	......	......	......	......	......	......	62 90	332 11	15 90	49845	2 63184	2006 2	0079078
8	128 490	16509 7	12966	66	352	15 00	74	387	13 65	49 88	263 37	20 05	62849	3 31843	1591 1	0125719
9	114 430	13094 2	10284	......	......	......	......	......	......	39 56	208 88	25 28	79242	4 18400	1262 0	0199853
10	101 890	10381 6	8153 2	48	250	21 11	52	271	19 50	31 37	165 63	31 38	99948	5 27726	1000 5	0317946
11	90 742	8231 11	6467 0	......	......	......	......	......	......	24 88	137 37	40 20	1 2692	6 65357	793 56	0505413
12	80 808	6529 94	5128 6	31	160	33 00	33	172	30 36	19 73	104 18	50 69	1 5890	8 39001	629 82	0803641
13	71 961	5178 39	4067 1	......	......	......	......	......	......	15 65	82 632	63 91	2 0047	10 5798	499 06	127788
14	64 084	4106 76	3225 4	23	118	44 74	24	125	42 24	12 41	65 525	80 38	2 5266	13 3405	395 79	203180
15	57 068	3256 76	2557 8	......	......	......	......	......	......	9 84	51 956	101 63	3 1860	16 8223	313 87	323079
16	50 820	2582 67	2028 6	14	76	69 47	15	80	66 00	7 81	41 237	128 14	4 0176	21 2130	248 90	513737

TABLE OF CARRYING CAPACITY OF WIRES.

UNDERWRITERS' RULES.

B & S. G.	TABLE A. Rubber Insulation. Amperes.	TABLE B. Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
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	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

TABLE OF DIMENSIONS OF PURE COPPER WIRE.*

No. B. & S.	Diam. Mils.	Area.		Weight and Length. Sp. Gr. 8.9.		
		Circular Mils.	Square Mils.	Lbs. per 1000 feet.	Lbs. per Mile.	Feet per Pound.
0000	460.000	211600.0	166190.2	640.73	3383.04	1.56
000	409.640	167805.0	131793.7	508.12	2682.85	1.97
00	364.800	133079.0	104520.0	402.97	2127.66	2.48
0	324.950	105592.5	82932.2	319.74	1688.20	3.13
1	289.300	83694.5	65733.5	253.43	1338.10	3.95
2	257.630	66373.2	52129.4	200.98	1061.17	4.98
3	229.420	52633.5	41338.3	159.38	841.50	6.28
4	204.310	41742.6	32784.5	126.40	667.38	7.91
5	181.940	33102 2	25998.4	100.23	529.23	9.98
6	162.020	26250.5	20617.1	79.49	419.69	12.58
7	144.280	20816.7	16349.4	63.03	332.82	15.86
8	128.490	16509.7	12966.7	49.99	263.96	20.00
9	114.430	13094.2	10284.2	39.65	209.35	25.22
10	101.890	10381.6	8153.67	31.44	165.98	31.81
11	90.742	8234.11	6467.06	24.93	137.65	40.11
12	80.808	6529.94	5128.60	19.77	104.40	50.58
13	71.961	5178.39	4067.07	15.68	82.792	63.78
14	64.084	4106.76	3225.44	12.44	65.658	80.42
15	57.068	3256.76	2557.85	9.86	52.069	101.40
16	50.820	2582.67	2028.43	7.82	41.292	127.87
17	45.257	2048.20	1608.65	6.20	32.746	161.24
18	40.303	1624.33	1275.75	4.92	25.970	203.31
19	35.890	1288.09	1011.66	3.90	20.594	256.39
20	31.961	1021.44	802.24	3.09	16.331	323.32
21	28.462	810.09	636.24	2.45	12.952	407.67
22	25.347	642.47	504.60	1.95	10.272	514.03
23	22.571	509.45	400.12	1.54	8.1450	648.25
24	20.100	404.01	317.31	1.22	6.4593	817.43
25	17.900	320.41	251.65	.97	5.1227	1030.71
26	15.940	254.08	199.56	.77	4.0623	1299.77
27	14.195	201.50	158.26	.61	3.2215	1638.97
28	12.641	159.80	125.50	.48	2.5548	2066.71
29	11.257	126.72	99.526	.38	2.0260	2606.13
30	10.025	100.50	78.933	.30	1.6068	3286.04
31	8.928	79.71	62.603	.24	1.2744	4143.18
32	7.950	63.20	49.639	.19	1.0105	5225.26
33	7.080	50.13	39.369	.15	.8015	6588.33
34	6.304	39.74	31.212	.12	.6354	8310.17
35	5.614	31.52	24.753	.10	.5039	10478.46
36	5.000	25.00	19.635	.08	.3997	13209.98
37	4.453	19.83	15.574	.06	.3170	16654.70
38	3.965	15.72	12.347	.05	.2513	21006.60
39	3.531	12.47	9.7923	.04	.1993	26487.84
40	3.144	9.88	7.7635	.03	.1580	33410.05

*1 mile pure copper wire 1-16 in. diam. = 13.59 ohms at 15.5° C. or 59.9° F.

1 circular mil is .7854 square mil.

CHAPTER III

Current Generation in Dynamos — Dynamos — **Brushes and** Commutators.

Current Generation in Dynamos. If we take a coil of wire, Fig. 15, and rapidly thrust a magnet into it, we shall observe a certain deflection of the galvanometer needle shown with it. This deflection continues only while the magnet is in motion. After

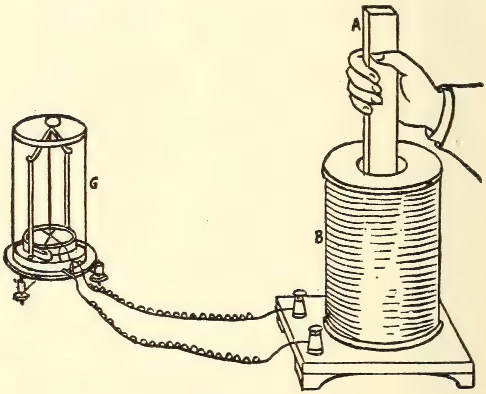


FIGURE 15.

we have inserted the magnet and it has come to rest the galvanometer needle will return to its normal position. When we withdraw the magnet the deflection of the needle will be in the opposite direction. If the magnet is inserted or withdrawn with a very quick motion, the deflection will be considerable. If the magnet is very slowly inserted or withdrawn the deflection will hardly be noticeable. The same phenomena will occur if instead of moving the magnet, we hold it stationary and move the coil, or if both of them be moved towards or from each other. The deflection of the compass needle indicates that a current of electricity is passing along the wire, and the experiments above described show exactly how currents of electricity are produced in dynamos.

An electromotive force is induced by rapidly cutting "lines of force," that is, by moving either a magnet over a wire or a wire over or near a magnet. The

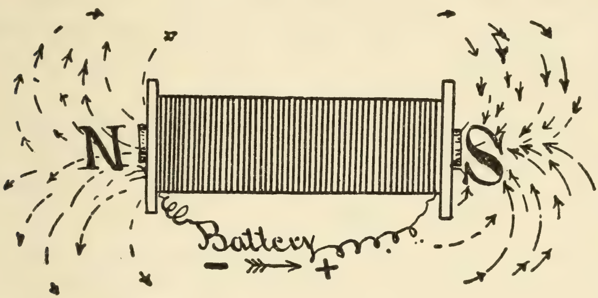


FIGURE 16.

current in turn is the result of this electromotive force acting in a closed circuit. A bar of iron becomes an electromagnet if we wind about it a few turns of wire and cause a current of electricity to flow along the wire, Fig. 16. The magnetism is conceived to consist of lines of force, which leave the bar at one end and enter it at the other, the direction of these lines depending upon the direction in which the current circulates about the bar of iron. The number of these lines of force depends upon the number of ampere turns in the iron bar and on the diameter, length and quality of the iron bar.

Ampere turns is a term used to indicate the magnetizing force; it is the number of turns of wire on a magnet multiplied by the current in amperes flowing through these turns of wire.

Haskins, in *Electricity Made Simple*, explains this thus: "If, for instance, we have a current of one ampere flowing through a single turn of wire around a bar of soft iron and we have developed enough magnetism to lift a keeper or other piece of iron, weighing one ounce, then with one-half the amount of current and two coils around the bar, we would obtain the same result, and with three turns of wire we would require but one-third the current to develop the same lifting power in the bar or magnet."

The law of magnetic flow is very much the same as the law of current flow. If the iron bar is of low magnetic resistance, the flow will be quite great; if of high resistance, the flow will be small.

Lines of force can also be shunted just as a current of electricity can; that is, they will follow the path of lowest resistance just as a stream of water or a current of electricity will.

Now let us consider the elementary sketch of a dynamo, Fig. 17. The wire *a* represents the armature and we have also the iron bar and the coil of wire wound on it and, for the present, we may consider the battery B as the source of the current which produces the magnetism or lines of force in the iron bar. The battery current magnetizes the iron bar (which in dynamos is known as the field magnet) and produces the lines of force indicated by arrows.

These lines of force leave the field magnet of our dynamo at the north pole marked N, and pass through the air-gap and armature into the south pole marked S.

As we begin to move the wire or armature, it cuts through these lines of force and begins to generate an electromotive force, which in turn will cause the current to flow if the circuit is closed through a lamp or other device.

This current reverses in direction as the wire *a* passes from the influence of the south pole into that of the north pole and the brushes B′ and B″, which transmit

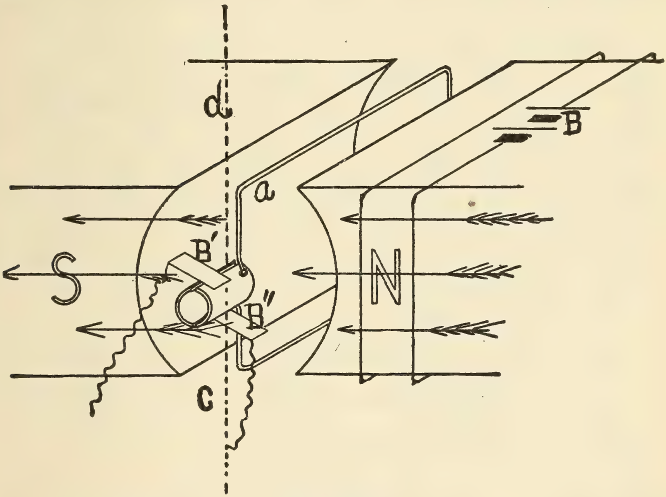


FIGURE 17.

the current to the outside wires, are so set that they change the connection of the wire *a* at the time that it passes from one pole to the other. By this means the current in the external circuit is kept constant in direction, although it alternates in the armature.

The faster we turn our wire or armature, the greater will be the electromotive force generated. Instead of using only one wire, as in Fig. 17, we may take many turns before bringing the end out, and in so doing obtain the well known drum armature, or, by a slightly different method of winding, the gramme ring armature, Fig. 18. Here we have many wires cutting the lines of force at once and our electromotive force with the same number of revolutions of the armature is correspondingly increased, and the more turns of wire we arrange to cut those lines of force per second the greater will be our E. M. F. Instead of providing

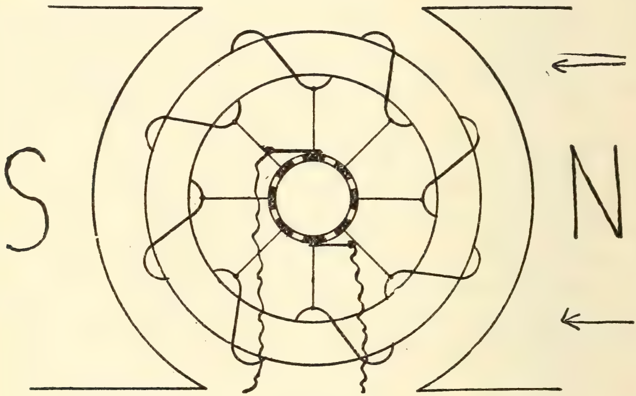


FIGURE 18.

more wire or increasing the speed of our armature we can increase the magnetism, or number of lines of force, by sending more current through the fields, that is increasing the "ampere turns."

If we wish to reverse the current flow we can do so by revolving the armature in the opposite direction, or by reversing the current through the fields.

Dynamos. Having so far considered the generation of currents in dynamos, we may now consider different types of dynamos and their uses. Fig. 19 shows a diagram of the wires and connections of a series dynamo. The principal use of this dynamo at present is in connection with series arc circuits. (See Fig. 7.) This dynamo is usually equipped with an automatic regulator (which will be explained later) to raise or lower the voltage as the number of lamps increases or

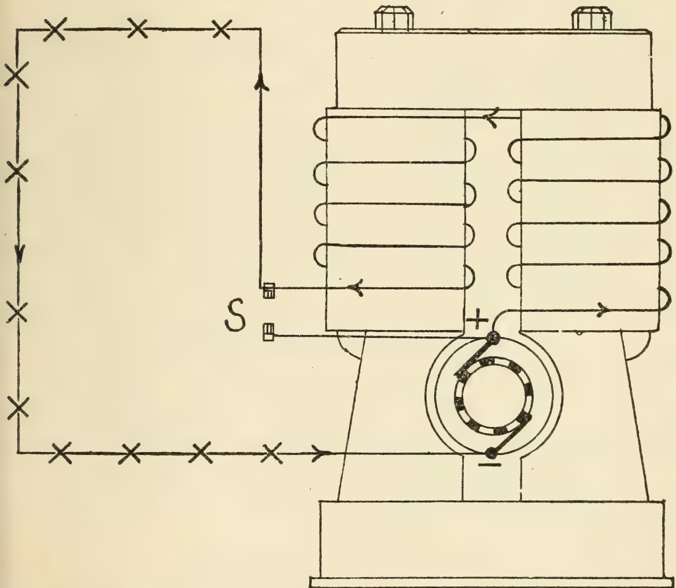


FIGURE 19.

decreases, the current remaining constant at about 10 amperes. By reference to the figure, we can trace the current as it flows from the + brush, in the direction of the arrows, around both field magnets and through the lamps, returning to the – brush on the dynamo. In our elementary sketch of a dynamo we used battery current to magnetize our fields; we need not consider that any more, for in practice all direct current dynamos produce their own magnetism by circulating some or all of their current through the field coils.

In the shunt wound dynamo, Fig. 20, the wire in the field winding is of such size and connected in such a manner as to have a resistance so high that only a

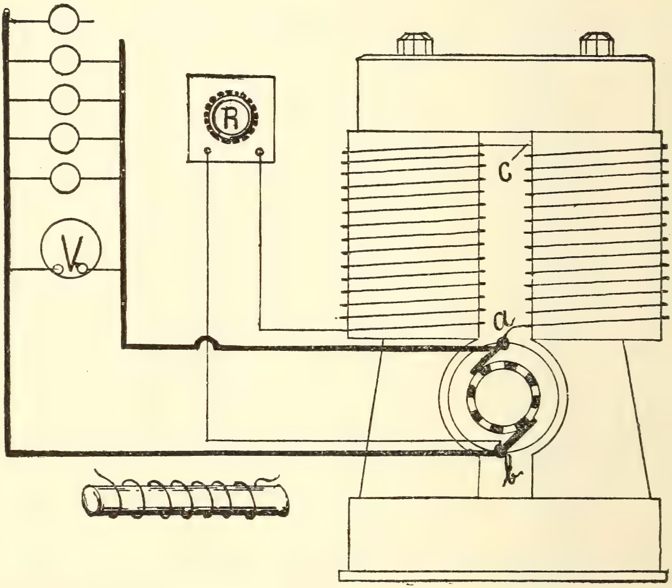


FIGURE 20.

portion of the main generated current of electricity passes around the field magnets. The quantity of current passing around these field magnets is also regulated by a resistance sometimes called a rheostat shown at R. The resistance to the flow of current through this box is adjusted by hand by the attendant and the flow of current through this rheostat and around the field magnet is what determines the electromotive force of the dynamo.

This type of dynamo is used for electric lighting and for operating motors. The electromotive force of such a dynamo remains nearly constant, but the current varies with the number of lights or motors used. If it were connected to too many lights it would deliver too much current and become overheated and perhaps burn out. The current leaves at the + brush, passes through whatever lamps happen to be switched on and returns to the – brush.

Fig. 21 shows a diagram of a compound wound dynamo. This is really a combination of the series and shunt dynamos. If the current in a series dynamo is not kept constant the magnetism in the fields will vary as the current varies, and consequently its voltage will be very unsteady. This makes such a dynamo unfit for use with variable currents.

The voltage of a shunt dynamo is quite constant with variable loads, but still it leaves much room for improvement; not because of any variation in the induced electromotive force, but because of the losses occurring in the armature and wires conveying current. The loss of voltage in the armature and line equals the current multiplied by the resistance; consequently, as the current increases more and more volts are lost and the pressure goes down. If we would have the pressure remain at its normal value, we must find some way to increase the field magnetism as the current delivered by the dynamo increases, and this is the purpose of the compound winding. The compound winding carries the total current of the dynamo around the fields, but only a few times, just often enough so that the increase in magnetism resulting from this current may make up for the loss in the armature or line. Dynamos may be compounded for any per cent. of loss desired.

The foregoing descriptions are those of direct current dynamos, and they are called direct or continuous

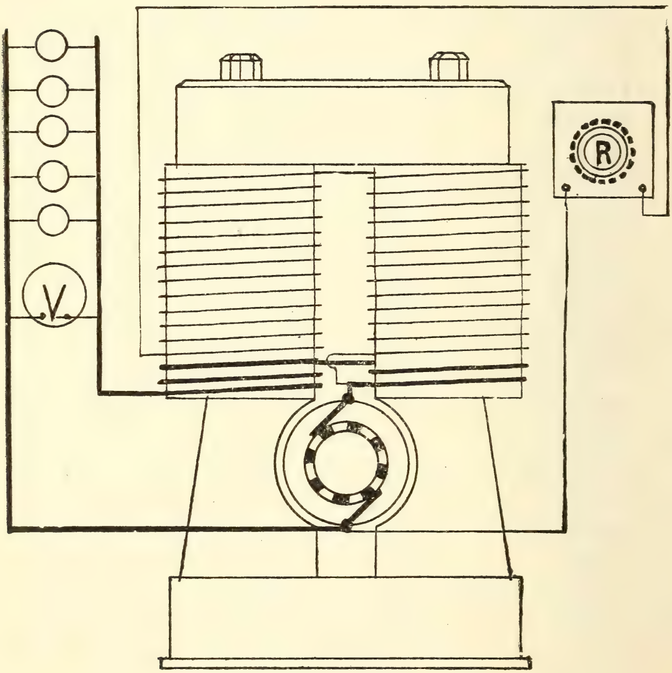


FIGURE 21.

current dynamos because the current flow continues in one direction out of the positive or + side of the dynamo, to the external circuit, and back again to the negative or – side of the dynamo. The current as it is generated in the coils of the armature which revolves between the field or pole pieces, is alternating; that is to say, if the armature wires were connected to collector rings the current in the outside wires would be reversed every time the position of the wire in the armature were changed from the influence of one pole piece to that of the other. If the coils constituting the armature are connected to a device called the commutator, they will be commutated or rectified.

Such a commutator is formed of alternate sections of conducting and non-conducting material, running parallel with the shaft with which it turns. It is

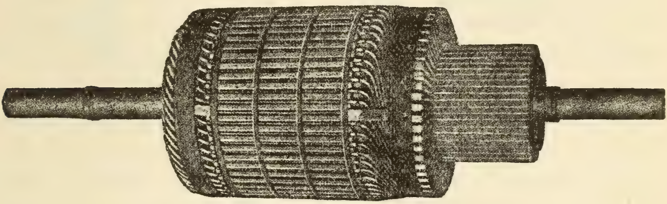


FIGURE 22.

placed on the shaft of the armature so that it rotates with it, as shown in Fig. 22. The brushes press upon its surface and collect the current from the bars. (See Fig. 31.) The function of the commutator is to change the connections of the armature coils from the + or positive to the negative or – side of the circuit at the time at which the coil connected to the bar under the brush passes from the influence of one pole piece into that of the other. This is the time at which the current in the coil reverses in direction, and is called the neutral point. If we consider, for the sake of simplicity, an armature having only one turn of wire on it, as Fig. 17, there will be a time while the coil is in the position indicated by dotted lines at *c* and *d* when no current is being generated. The brushes on any dynamo should always be set at this point, for this is the point of least sparking. In actual practice all commutators have quite a number of bars and it is impossible to avoid, in passing under the brushes, that at least two of them are in contact with a brush at the same time. If a brush did leave one bar before it touches another, the current would be entirely broken for that length of time and much sparking would result. The nature of all armature windings is such that while the brush is in contact with the commutator bars it short circuits that coil between them. This is the main reason why the brushes must be kept at a point at which the coil which is short circuited generates no current.

Although the electromotive force generated in one coil of a dynamo is very small, the resistance of the "short circuit" formed by the dynamo brush is also very small and therefore the current may be quite large. This current is the main cause of sparking in dynamos. The number of bars constituting a commutator depends upon the winding of the armature, and the number of coils grouped thereon. By increasing the number of coils and commutator sections the tendency to spark at the brushes is decreased, and the fluctuations of the current are also decreased. However, there are many reasons against making the number of bars on a commutator very great. Increasing the number of bars in a commutator increases the cost of manufacture, and in smaller dynamos if the number of bars be increased beyond a certain extent, each bar becomes so thin that a brush of the proper thickness to collect the current from the commutator would lap over too many bars of the commutator at one time. Each commutator bar should be of the size that will present sufficient metal for the carrying capacity of the current generated in the coil to which it is connected. Different builders of dynamos have different ideas as to the number of amperes that may be carried per square inch in a commutator bar, but where a commutator is made

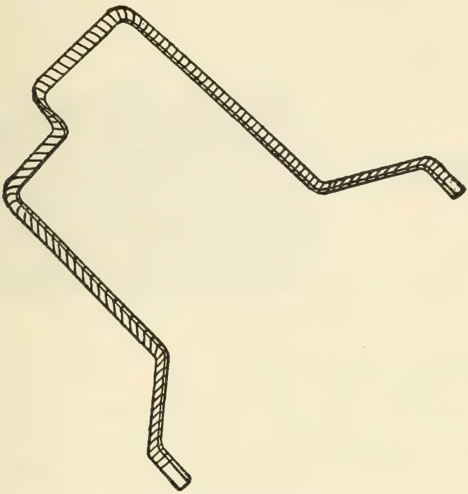


FIGURE 23.

of 95 per cent. copper it is usual to allow for each 100 amperes a commutator bar surface of 1½ sq. in.

The method of electrical connection between the commutator bar and the coil of the armature varies in different designs. Some builders solder the terminals of the coils to the commutator bars; others bolt the terminals of the coils to the bars; and some makers use hard drawn copper and "form" the armature coil in such a manner that both ends of the coil become commutator bars, making the coil continuous from one end of the commutator bar to the end of the diametrically opposite commutator bar.

In Fig. 23 we show a so-called "formed" armature coil, after it has been prepared by properly insulating it and bending it into shape ready to be applied to the laminated armature body.

In Fig. 24 is shown a "formed" coil armature with

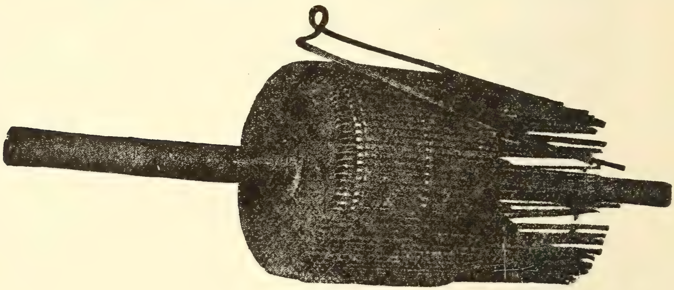


FIGURE 24.

the winding almost finished. The commutator is yet to be placed on the shaft and the coil terminals connected to the commutator bars.

In Fig. 25 we have an armature shaft with the laminated armature body keyed on to the shaft ready to be wound.

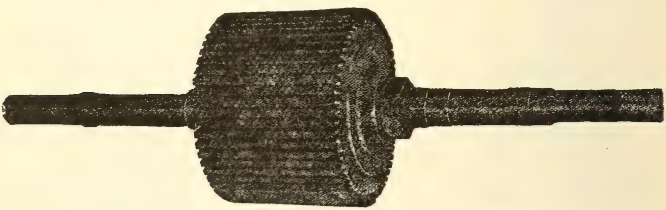


FIGURE 25.

The body on which the armature coils are to be wound is made up of sheet iron punchings and placed on the armature shaft in the same manner that you would put ordinary iron washers on a lead pencil. These punchings or discs are insulated from one another by having previously been painted with a coat of shellac; for there is the same tendency to produce current in the iron part of the armature, due to the cutting of the magnetic lines, as there is in the copper wire which is wound on its surface. If the iron core were solid, there would be a very large current circulating in the same direction as that which flows through the wires. Such a current would be entirely useless and would heat the armature; to prevent this the armature is built up of thin sheet iron discs.

Brushes and Commutators. Figs. 26 to 30 show different arrangements of modern brushes and brush-holders. These are used to take the current from the commutator and deliver it to the outside wires in the case of a dynamo, and for the opposite in the case of a motor.

There are many different designs and constructions of brushes and brush-holders, and these designs are brought about by the various ideas of different builders in their attempt to produce various advantageous results, but the electrical connections and underlying principles remain the same whether a copper or a carbon brush be used.

In any construction of brush holding device, if great care is not exercised in keeping it thoroughly clean, trouble is sure to be the result, and trouble of this nature increases so rapidly that unless the attendant immediately sets about to right it, a burned out armature is almost sure to be the consequence sooner or later. In alternating current dynamos, where brushes rest on collector rings instead of commutators, it is much easier to keep out of trouble, because the brushes in this case merely collect the current from the rings and do not commutate or rectify it.

The brushes and commutator of a dynamo or motor

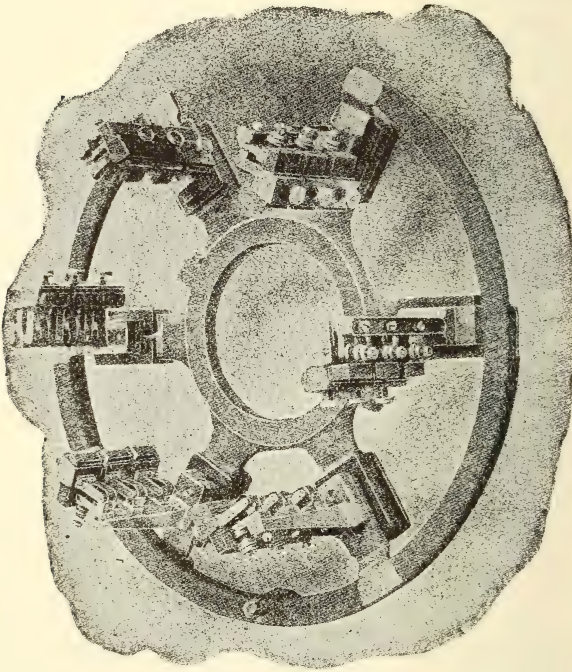


FIGURE 26.

are probably the most important parts with which the engineer has to deal. Great care should be taken that the brushes set squarely on the commutator and that the surface of the brushes and commutator are as smooth as possible. It is a good plan, and in some cases the brush-holders are so made, that the brushes set in a staggering position, that is to say, in a position so that all the brushes will not wear in the same place over the circumference of the commutator and

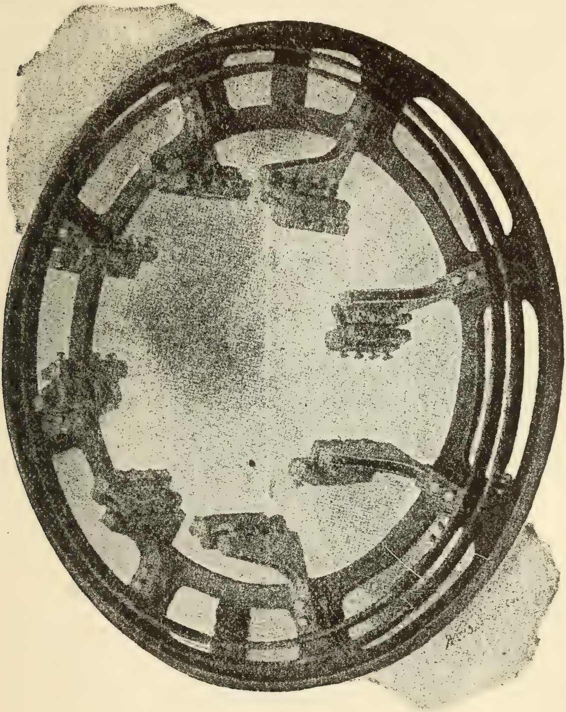


FIGURE 27.

cause uneven wear across the length of the commutator bars. In most machines the armature bearing is left so that there is more or less side motion, which, when the armature is running, causes a constant changing of the position of the brushes and commutator.

Whatever style of brush is used, the commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary unless the brushes cut, and then only at the point of cutting. A cloth (not cotton waste) slightly greased with vaseline and applied to the surface of the commutator while

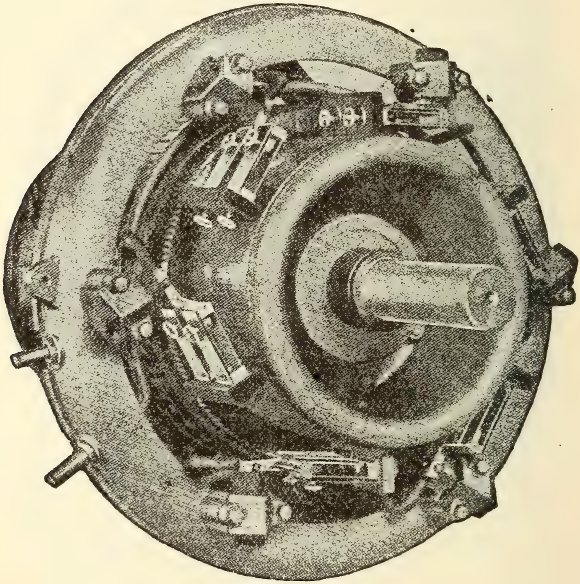


FIGURE 28.

running is best for the purpose of preventing the commutator from cutting. Should the commutator become rough, it should be smoothed with sandpaper, never using emery cloth, because emery cloth is conductor of electricity, and the particles of emery are liable to lodge themselves between the commutator bars in the mica and short circuit the two bars, thereby burning a small hole wherever such a particle of emery has lodged itself. The emery will also work into the brushes and copper bars and wear them down; it being almost impossible to remove all the emery.

In the end-on carbon brushes, Fig. 30, the contact surface of the brushes should be occasionally cleaned by taking a strip of sandpaper, with the smooth side of the paper to the commutator, and the sanded side toward the contact surface of the brush, and then by

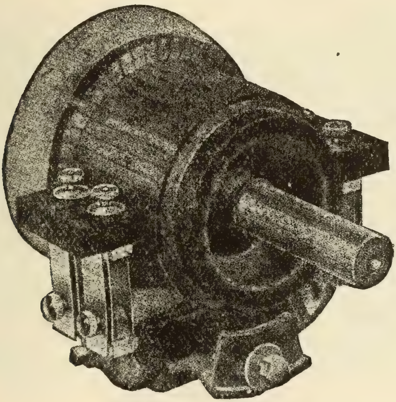


FIGURE 29.

leaving the tension of the brush down on the sandpaper, it is an easy matter to move the sandpaper to and fro and throughly clean off the glazed and dirty surface from the carbon, leaving it with a concave that will exactly fit the commutator.

The advantages of carbon brushes are many. Among the cardinal points are: The armature may run in either direction without it being necessary to alter the brushes; the carbon can be manufactured with a quantity of graphite in its construction, thereby lowering the mechanical friction of the brushes on the commutator; they do not cut a commutator so much by sparking; the commutator has a longer life, the wear being more evenly distributed.

Carbon brushes, due to their rather high resistance, will often heat up considerably, but, although this heat is objectionable, their resistance tends to cut down the sparking. The brushes are sometimes coated with copper to reduce their resistance. Often a carbon brush will be found which is very hard. As a rule such a brush should be thrown away, as it will heat abnormally and at the same time wear the commutator.

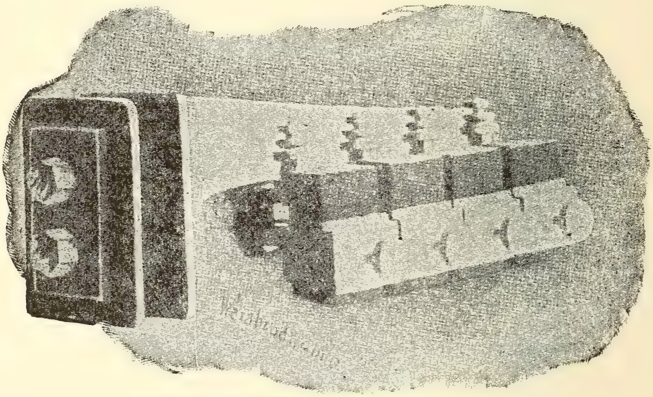


FIGURE 30.

In Fig. 31 we have one of the various so-called old styles of leaf brush-holders. The end-on brushes are more generally used in modern practice, because their contact surface area is not increased or decreased by wear. Consequently the brushes always remain in a diametrically opposite position. With the old style brush-holding device, where the brushes rest on the commutator at a tangent, great care should be exer-

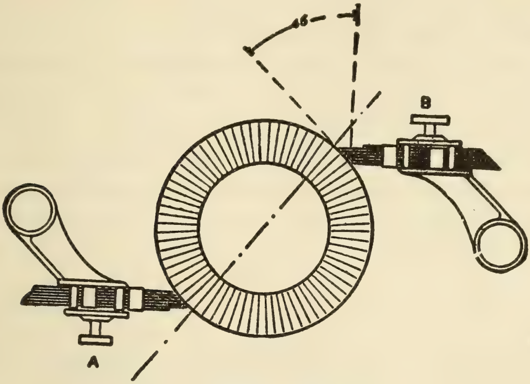


FIGURE 31.

cised not to allow the brushes to wear in a position sc that their points will be out of diametrical opposition.

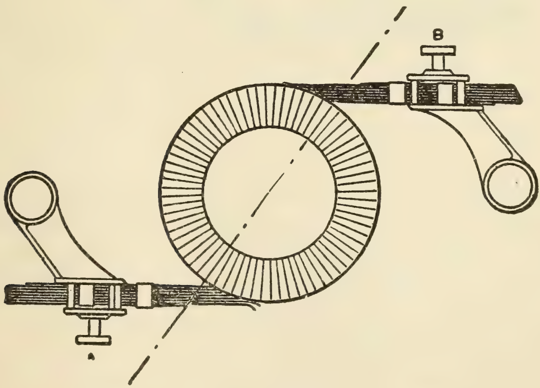


FIGURE 32.

In Fig. 31 we show the correct way that this tvpe of brush should be set.

In Figs. 32 and 33 we show the incorrect way.

By remembering that each one of the commutator bars is the end of a coil, and then just mentally tracing the current through the coils from one brush to the other, we can readily understand what the results are when the brushes are neglected and left in a relative position, as shown in these figures.

Sparking is the usual result of brushes allowed to wear to such an extent. Overloading of a dynamo or motor will also cause serious sparking, and no amount

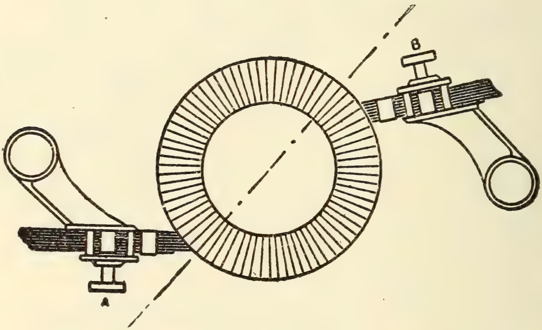


FIGURE 33.

of care can prevent damage to armature, commutator or brushes, if a machine is permitted to be overloaded

Sometimes the commutator will contain one or more bars which, as the commutator gets old and wears down, will wear away either too fast or too slow, due to the metal being harder or softer than the rest of the bars forming the commutator. This causes a roughness of the commutator and results in the flashing of the brushes and heating of both the commutator and brushes. About the only satisfactory method of remedying this evil is to take out the armature and have the commutator turned down in a lathe.

A short-circuited coil in the armature, or a broken armature connection, will also cause considerable sparking. Either of these conditions can be located by means of a Wheatsone bridge or by what is known as the fall of potential method. To make a test with this latter method, connect in series with the armature to be tested some resistance capable of carrying the necessary current, also an ammeter. Some apparatus for varying the current strength, such as a water rheo-

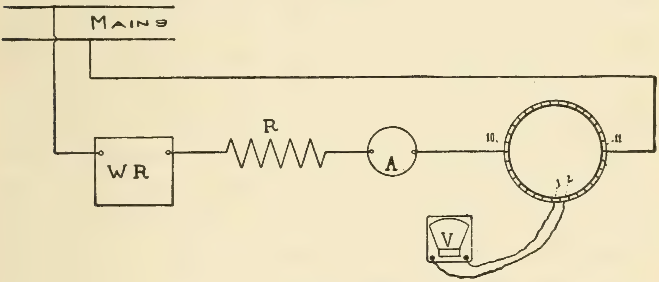


FIGURE 34.

stat or lamp rack, must be connected in the circuit, a diagram of which is shown in Fig. 34.

In the diagram, WR is the water rheostat or lamp rack, R the known resistance, A the ammeter and M the armature to be tested. By means of the water rheostat regulate the current passing over the apparatus until it is of such strength that a deflection can be obtained on a voltmeter when it is connected to two adjacent bars on the commutator. Suppose the armature coil between bar 1 and 2 on the commutator were broken. The voltmeter connected across these two bars would give the same reading as when connected across the two points 10 and 11. If the voltmeter were connected between any other two points on the commutator on the same side as the broken coil no deflection would be obtained, while connecting the voltmeter between any two adjacent bars on the other side of the commutator would give practically the same reading irrespective of which bars were used. The resistance of one or more sections of the armature winding could also be found by using Ohm's law, R = E/C, or the resistance would be equal to the voltage divided by the current as shown on the ammeter. It must be remembered that this latter will be true only when there is an open coil in one side of the armature, for in this case only will the whole current flow through the one side. If the coil between bars 1 and 2 were short circuited, the voltmeter would show practically no reading between these bars; while between any other bars some deflection would be obtained. An open circuit or short circuit will nearly always be found by examination, as the trouble usually happens very close to the commutator connections in the case of an open circuit and may very often be found between the commutator bars themselves, in the case of a short circuit. If the trouble is not at these places it will usually be in the windings, in which case the only remedy is to have it re-wound. Temporary repairs may be made in the case of an open circuit by short circuiting the commutator bars around the open circuit, but this method should only be used in emergency, as the sparking will in time destroy the commutator.

With many dynamos, especially of older types, it is necessary to shift the brushes with every change of load. The current produced by the armature makes a magnet out of it and the magnetism of the armature opposes that of the fields. In Fig. 35 the armature is working with a very light load and the lines of force of the field magnets are only slightly opposed by those

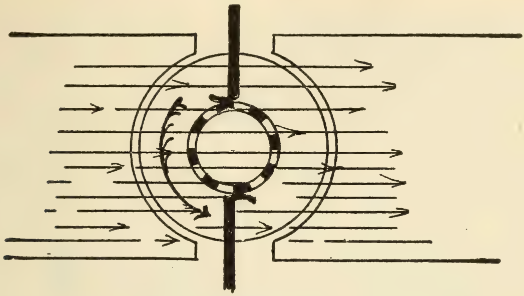


FIGURE 35.

of the armature. In Fig. 36 we assume a heavy load on the dynamo and consequently the magnetism of the armature opposes that of the fields. This changes the location of the neutral point (when the coils under the brush generate no current) and it becomes necessary to

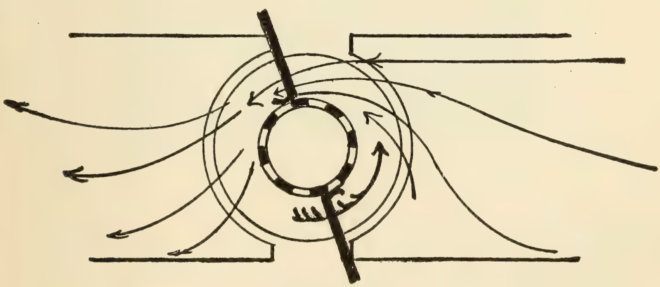


FIGURE 36.

shift the brushes accordingly, or great sparking would result. The amount of shifting necessary with changes of load varies in different dynamos. If the field is very strong compared to the armature, it will be but little. If the armature (as in some arc dynamos) is very strong compared to the field, it will be considerable.

In dynamos, with increasing load, the brushes should be shifted in the direction of rotation and in the opposite direction when the load decreases.

Never allow a dynamo or motor to stand in a damp place uncovered. Moisture is apt to soak into the windings and cause a short circuit or ground when started. Great care should also be used should it ever be found necessary to use water on a heated bearing. If the water is allowed to reach the armature or commutator, it is bound to cause trouble. Water should only be used in case of emergency, and then sparingly.

CHAPTER IV

OPERATION OF DYNAMOS

Constant Potential Dynamos. In order to thoroughly explain the operation of dynamos, let us assume that we have the task of starting a new shunt dynamo, one that has never generated any current. Our first step is to open the main switch and turn the rheostat or field

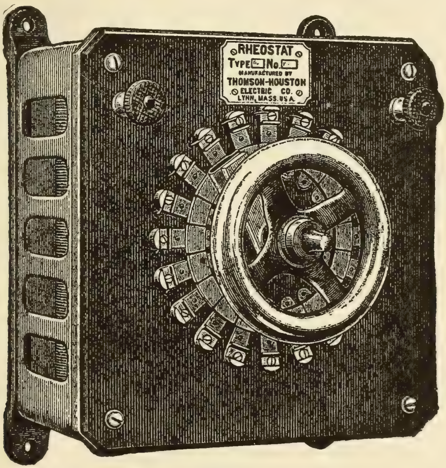


FIGURE 37.

resistance box so that all the resistance is in circuit. A rheostat consists of a number of resistances, Fig. 37, so arranged that they can be cut in or out of the circuit without opening the circuit. By reference to the figure it will be seen that the current enters at the handle and from there passes to the contact point upon which the handle happens to rest. If the handle is at 1 the current must pass through all the wire in the box; if it is at 2 it simply passes through the handle and out.

Rheostats for the shunt circuit of a dynamo should have sufficient resistance, so that when it is all inserted the voltage of the dynamo will slowly sink to zero. This method of stopping the action of a dynamo is

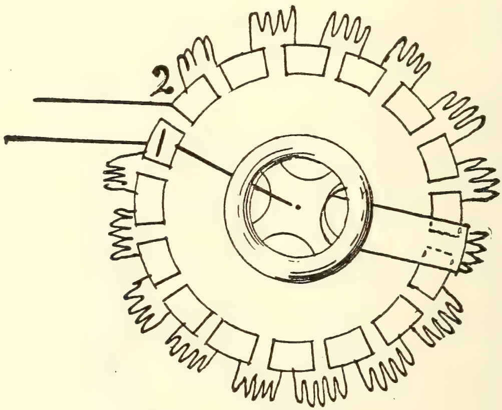


FIGURE 37.

perfectly safe and should be followed wherever possible.

We are now running our dynamo with all resistance in the shunt circuit. This is simply as an extra precaution because we know nothing about this particular dynamo. When it is known that the dynamo is in good order, the engineer or attendant usually cuts out all the resistance, and as the generator builds up or, in other words, generates current, he proceeds, by the aid of the resistance box, to cut down or diminish the flow of electricity around the field magnets of the dynamo, and thereby diminish the magnetic density of the field magnets and the electromotive force of the dynamo.

We must now gradually turn our rheostat so as to cut out resistance and watch the voltmeter, which is connected as shown at V in Fig. 20, and receives current whenever the dynamo is operating. Suppose that the voltmeter indicates nothing, and we find that the dynamo will not generate. On examination of all the connections we find everything correct, and we now discover that the dynamo field magnets do not contain what is termed "residual magnetism" sufficient to start the process of generating current.

Before an armature can generate current it must cut lines of force, that is, it must revolve in a magnetic field. If the dynamo has been generating current it is likely that the iron cores of the field magnets will retain sufficient magnetism to start the generation of current again. This magnetism which remains in the iron is known as residual magnetism. It will make itself manifest by attracting the needle of a compass, or if strong, a screw driver or a pair of pliers. If we find no magnetism in the iron core of the field magnets, we may take the ends of the shunt winding on the field magnets and pass current over them from a battery. This current will produce sufficient magnetism to cause the generator to build up; in other words, if we disconnect these batteries, and connect the wires back again from where we got them, we will find that we can generate current with the machine.

When the machine begins to generate, we watch the voltmeter and cut resistance in or out of the circuit according whether we need to lower or raise the voltage. If we have only one dynamo we may close the main switch before we begin generating or after we have attained full voltage.

Again referring to the pole pieces on the dynamo, it is possible that there is a sufficient quantity of residual magnetism in the pole pieces, and that the polarity of both field magnets, between which the armature is revolving, is the same. This would also cause the dynamo to fail in generating current. If sending battery current through the coils does not make one field a north pole and the other a south pole, one of the fields must be connected wrong, and we must make some changes in the connection.

Referring to Fig. 20, a and b are the terminals of the shunt winding on the fields. If the winding of the fields is correctly put on it will be as in the little sketch at lower corner; that is, if both field magnets were taken out of their places and put together, the winding should run as one continuous spool. But if the winding on one field is wrong, we need simply change its connection, as, for instance, transferring c to a and a to c.

In order that a dynamo may excite itself, it is necessary that the current produced by the residual magnetism shall flow in such a direction as to strengthen this residual magnetism. If the current produced by the residual magnetism flows through the field coils in the opposite direction this will tend to weaken the residual magnetism and consequently to reduce the current which flows.

For this reason if the first attempt to start a dynamo with battery current fails, the battery should be applied with the opposite poles so that the magnetism it produces in the fields will be in the opposite direction.

The magnetism, the fields, and all parts of the dynamo may be in perfect working order and yet a short circuit in any part of the wiring will prevent the dynamo from building up This short circuit will furnish a path of such low resistance that all current will flow through it and none can flow through the fields to induce magnetism. Often dynamos fail to generate because of broken wires in the field coils, poor contacts at brushes, or loose connections. Sometimes also part of the wiring may be grounded on the metal parts of the dynamo frame. A faulty position of the brushes may also be a cause for the machine not generating. In some machines the proper position for the brushes is opposite the space between the pole pieces, while in other machines their proper position is about opposite the middle of the pole piece. If the exact position is not known, a movement of the brushes will sometimes cause the generator to build up.

If there are several dynamos to be started great care must be taken to see that the second machine is operating at full voltage before the switch is closed connecting it to the switch board. The voltage should be exactly the same as that of the first machine and the rheostat worked to keep it so. If it is less, it is possible that the first machine will run the second as a motor; if it is more, the second machine may run the first as motor, the machine having the higher voltage will always supply the most current.

It is also necessary before throwing in the second machine (connecting it to the switch board) to see that its polarity is the same as that of the machine with which it is to run. By reference to Fig. 38 it will be seen that the + poles of both machines connect to the same bar, and if one of these machines is running and we wish to connect the other with it, we must first be sure that the wire of the second machine which leads to the top bus-bar is of the same polarity. That is, if the top bus-bar is positive, or sends out current, the wire of all dynamos connected to it must also be positive. The simplest way to find the positive pole of a dynamo is with a cup of water. Take two small wires and connect one to each of the main wires of the dynamo and then insert the bare ends of both wires into the water, small bubbles will soon be seen to rise in the water from one of the wires. That wire which gives off the bubbles is the negative wire. Take care that in making this test you do not get the ends of the small wires together or against the metal of the cup or you will form a short circuit. The polarity of both dynamos must be tested and wires of same polarity connected to the same bus-bar.

Where several machines are to be operated in parallel, compound dynamos are generally used, because it is troublesome to keep two shunt machines working in harmony.

The starting of a compound wound dynamo is the same as that of a plain shunt dynamo, but in connecting a compound wound dynamo to its circuit it is necessary to be sure that the shunt coils and series coils tend to drive the lines of force around the magnetic circuit in the same direction. If the series coil is connected up in the opposite direction to the shunt coil the dynamo will build up all right and will work satisfactorily on very light loads. When, however, the load becomes even, five or ten per cent. of full load, the voltage drops off very rapidly and it is impossible to get full voltage with even half the load on. This is because the ampere turns due to the series coils decrease the total ampere turns acting on the magnetic circuit instead of increasing them as the load comes on. This lowers the magnetic flux and of course lowers the resulting voltage. In such a case it will be necessary to reverse either the field or series coils.

Fig. 38 and the following description of compound dynamos and their connections is taken from *Wiring Diagrams and Descriptions*, by Horstmann and Tousley, published by Frederick J. Drake & Co., Chicago.

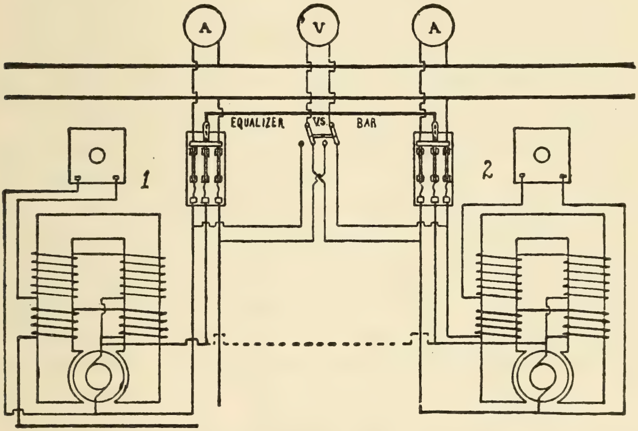


FIGURE 38.

Fig. 38 shows connections for two compound wound dynamos run in parallel. When two or more compound wound dynamos are to be run together, the series fields of all the machines are connected together in parallel by means of wire leads or bus-bars which connect together the brushes from which the series fields are taken. This is known as the equalizer, and is shown by the line running to the middle pole of the dynamo switch. By tracing out the series circuits it will be seen that the current from the upper brush of either dynamo has two paths to its bus-bar. One of these leads through its own fields, and the other, by means of the equalizer bar, through the fields of the other dynamo. So long as both machines are generating equally there is no difference of potential between the brushes of No. 1 and No. 2. Should, from any cause, the voltage of one machine be lowered, current from the other machine would begin to flow through its fields and thereby raise the voltage, at the same time reducing its own until both are again equal. The equalizer may never be called upon to carry much current, but to have the machines regulate closely it should be of very low resistance. It may also be run as shown by the dotted lines, but this will leave all the machines alive when any one is generating. The ammeters should be connected as shown. If they were on the other side they would come under the influence of the equalizing current and would indicate wrong, either too high or too low. The equalizer should be closed at the same time, or preferably a little before the mains are closed. In some cases the middle, or equalizer, blade of the dynamo switch is made longer than the outside to accomplish this. The series fields are often regulated by a shunt of variable resistance. To insure the best results compound machines should be run at just the proper speed, otherwise the proportions between the shunt and series coils are disturbed.

GENERAL RULES

1. Be sure that the speed of the dynamo is right.
2. Be sure that all the belts are sufficiently tight.
3. Be sure that all connections are firm and make good contact.
4. Keep every part of the machine and dynamo room scrupulously clean.

5. Keep all the insulations free from metal dust or gritty substances.

6. Do not allow the insulation of the circuit to become impaired in any way.

7. Keep all bearings of the machine well oiled.

8. Keep the brushes properly set and see to it that they do not cut or scratch the commutator.

9. If the brushes spark, locate the trouble and rectify it at once.

10. The durability of the commutator and brushes depends on the care exercised by the person in charge of the dynamos.

11. At intervals the dynamos must be disconnected from the circuit and thoroughly tested for leakage and grounds.

12. In stations running less than twenty-four hours per day, the circuit should be thoroughly tested and grounds removed (if any are found) before current is turned on.

13. Before throwing dynamos in circuit with others running in multiple, be sure the pressure is the same as that of the circuit; then close the switch.

14. Be sure each dynamo in circuit is so regulated as to have its full share of load, and keep it so by use of resistance box.

15. Keep belting in good order; when several machines are operating in parallel and a belt runs off from one, the others will run this machine as a motor.

16. In the same way if you shut down an engine driving a generator, the other generators will run the generator and the engine.

Constant Potential Switchboard. In Fig. 39 we show the usual type of switchboard employed to connect, or switch various dynamos and to feed various circuits from. These types, sizes and arrangements of switchboards vary and depend entirely on the type and size of the plant, the number of dynamos used and the number of circuits to be controlled. The switchboard in this cut has three dynamo panels and one load panel. At the left of the board and near the top is the voltmeter, while on the three left panels are the dynamo main switches and their respective amperemeters. On the lower part of these three machine panels will be noticed the protruding hand wheels of the field resistance boxes, which are hidden back of the board. The meter at the top of the right hand panel is the load amperemeter and registers the total number of amperes

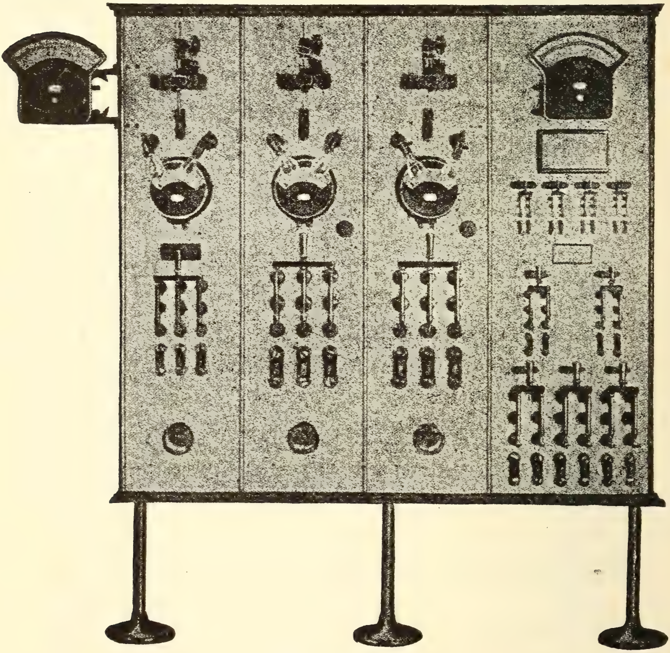


FIGURE 39.

that are being supplied to the circuits whose several switches are just below the meter.

Fig. 40 shows diagrammatically the reverse side of a similar switchboard. Below all of the switches there are installed fuses in each wire. The object of these fuses is to protect the wires and also the dynamos. These fuses consist of an alloy which melts at a comparatively low temperature. If, for instance, a short circuit occurs in any line, the current will suddenly become very great and will generate considerable heat. This heat will cause the fuse to melt and open the circuit. If the fuse did not melt the current would continue and overheat the wires, causing considerable

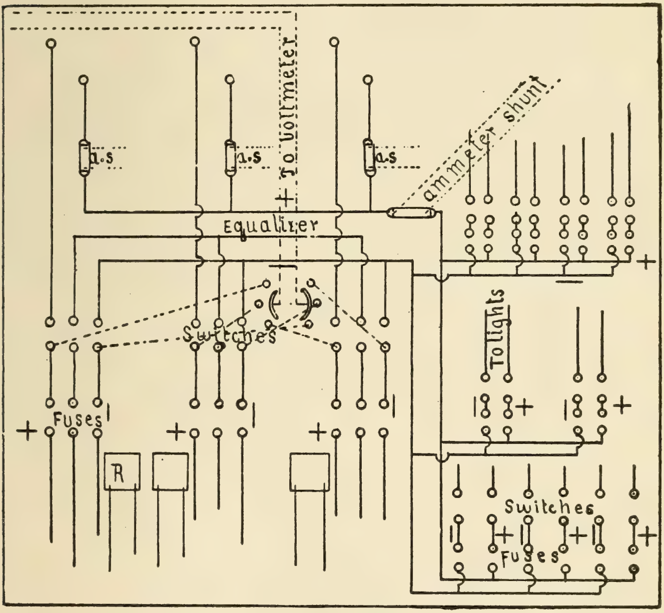


FIGURE 40.

damage and perhaps fires. The fuses should always be chosen of such a size that they will melt before the current rises enough to do any damage.

Operation of Constant Current Dynamos. Constant current dynamos differ from constant potential dynamos mainly in the higher voltage for which they are usually constructed. Such machines are always more or less dangerous to life, and great care must be taken not to touch any of the current-carrying parts with bare hands.

When such parts must be handled rubber gloves are very convenient and useful if kept dry. High voltage machines should always be surrounded by insulating platforms of dry wood, or rubber mats, so arranged that one must stand on them in order to touch any part of the machine. By reference to Fig. 19 it will be seen that the constant current dynamo is not equipped either with a voltmeter or a field rheostat; but an amperemeter should always be used. The troubles encountered with these dynamos are much the same as those of constant potential dynamos. Most of them are referred to in the following descriptions and instructions for different systems and to avoid repetition need not be mentioned here.

The type of dynamo generally used with constant currents is shown in Fig. 19 and is series wound; that is, the same current that passes through the lights also passes through the fields and excites them. The fields of this dynamo are connected with a short circuiting switch, S, which is generally used when the machine is to be shut down. When this switch is closed it forms a path of much lower resistance than do the fields of the dynamo and all current passing through it and the dynamo loses its magnetism and stops generating. A constant potential dynamo will not begin generating if there is a short circuit anywhere in the wiring connected with it, but with the constant current dynamo it is often necessary to provide a short circuit in order to start it. If there is very much resistance in the line or if it is entirely open the dynamo will fail to generate.

In order to start generation a small wire may be attached to one of the terminals of the dynamo and the other end brought in contact with the other terminal for a fraction of a second or the shortest possible instant. If the circuit happens to be arranged somewhat as shown in the figure, the plug may be inserted so that the dynamo is started through only one lamp. When this lamp is burning properly the plugs may be suddenly withdrawn and the current will now force itself through the other lamps. This process is known as "jumping in" and should be used only in an emergency, as much damage may be caused, especially if a dynamo is already running a large number of lamps and is then "jumped into" a bad circuit. This is also often done, but is just as dangerous as it would be to attempt to start a heavy steam engine by opening up the throttle valve with a quick jerk.

Constant current dynamos are always equipped with automatic regulators and before the dynamo is started special attention must be given the regulator to see that it is in proper working order.

Often it may be desirable and even necessary to run two dynamos in series, as, for instance, if a circuit has been extended beyond the capacity of one machine. In such a case the regulator of one machine is cut out and that machine set to operate at about its highest electromotive force, and the variations are taken care of by the other dynamo.

The Brush System. The brush arc dynamo is quite distinct from other constant current dynamos in general use. We shall therefore give the following description of it taken from literature furnished by the General Electric Company.

The brush arc generator is of the open coil type, the fundamental principle of which is illustrated in Fig. 41. Two pairs of coils, placed at right angles on an iron core, are rotated in a magnetic field. The horizontal coils represented in the diagram are producing their maximum electromotive force, while the pair of coils at right angles to them is generating practically no electromotive force. The brushes are placed on the segments of the four-part commutator, so as to collect only the current generated by the two horizontal

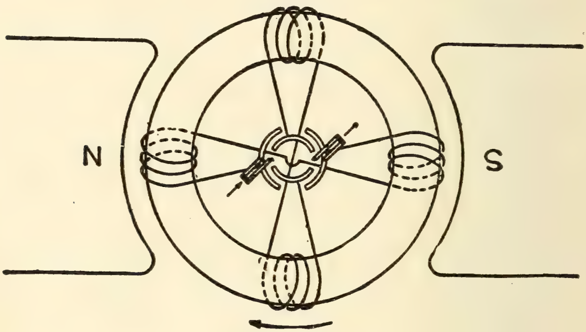


FIGURE 41.

coils. The other coils are open circuited or completely cut out of the circuit.

Such a machine will generate current, continuous in direction, but fluctuating considerably in amount. These fluctuations will be diminished by the addition of more coils to the armature.

Fig. 42 shows the connections of an eight-coil brush arc generator. Each bobbin is connected in series with the one diametrically opposite. The connection is not shown on the diagram. It will be noticed that of those coils connected to the outer ring on which the brushes A and A^1 bear, only 3, 3^1 are in circuit, 1, 1^1

being entirely cut out; while on the inside ring all coils 2, 2^1 and 4, 4^1 are in circuit, the two pairs being parallel; 4, 4^1 are coming into the field of best action; in other words, they are approaching that part of the field in which there is most rapid change of magnetic flux, while 2, 2^1 are approaching that part in which the flux is uniform. In 4, 4^1 there is an increasing electro-

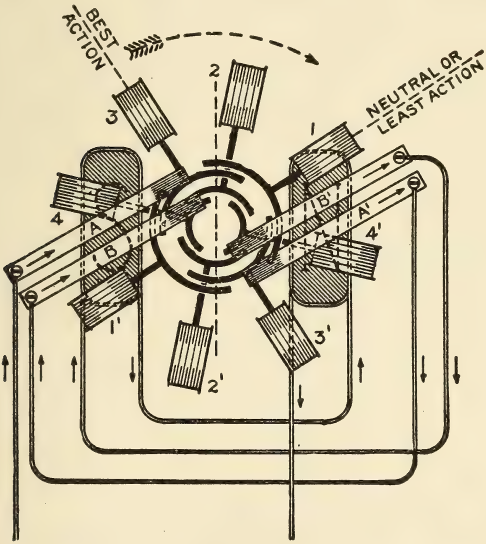


FIGURE 42.

motive force being generated, and the current is rising; while in 2, 2^1, the electromotive force is decreasing and the current falling. Unless 2, 2^1 were cut out of the circuit, a point would soon be reached where the electromotive force in 2, 2^1 would be zero, and consequently 4, 4^1 would be short circuited through 2, 2^1. Just before this occurs, however, 2, 2^1 have passed from under the brush and the small current still flowing draws out the spark one sees on the commutator of all open coil machines.

Setting the Brushes. A pressure brush should always be used over the under brush in the same holder, as it improves the running of the commutator and secures better contact on the segment. The combination is referred to as the "brush." The brushes should be set about 5⅛ in. from the front side of the brass brush-holder.

In setting the brushes, commence with the inner pair and set one brush about 5⅛ in. from the holder to tip of the brush, then rotate the rocker or armature until

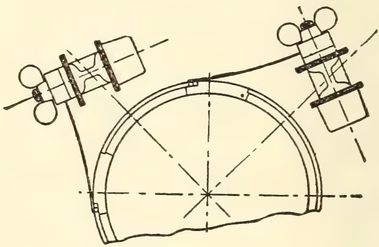


FIGURE 43.

the tip of the brush is exactly in line with the end of a copper segment, as shown in Fig. 43. The other brush should be set on the corresponding segment 90° removed (the same relative position on the next forward segment); but if the length of the brush from the holder is less than 5⅛ in., move both brushes forward until the length of the shorter brush from the holder is 5⅛ in. Now set the two extreme outer brushes in the same manner, clamping firmly in position, and by using a straight edge or steel rule, all the brushes can be set in exactly the same line and firmly secured. The spark on one of the six brushes may be a trifle longer than on the others. In this case, move the brush forward a trifle so as to make the sparks on the six brushes about the same length. Equality in the spark lengths is not essential, but it gives at a glance an indication of the running condition of the machine.

Brushes should not bear on the commutator less than ⅛ in. from the point of the brush, or, as illustrated in Fig. 44 (a), they will tend to drop into the commutator slots and pound the copper tip of the wood block, causing the fingers of the brushes to break off. If, on the other hand, the bearing is too far from the end, or the brushes are set too long, as in Fig. 44 (b), the

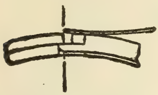


FIGURE 44A.

FIGURE 44B.

FIGURE 44C.

point of the brush will not be in contact with the segment, thereby prolonging the break, and allowing the spark to follow the tip with consequent burning of the segments and brushes.

Fig. 44 (c) shows correct seating with the tip of the brush nearly tangential and stiff on the segment as it leaves.

Care of Commutator. If the commutator needs lubrication, oil it very sparingly. Once or twice during a run is ample. If the oil has a tendency to blacken the commutator instead of making it bright, wipe the commutator with a dry cloth. Too much oil causes flashing.

The machine, of course, generates high potential, and the cloth, or whatever is used to oil the commutator, should therefore be placed on a stick so that the hand is not placed in any way between the brushes.

A rubber mat should be provided for the attendant to stand on when working around the commutator or brushes.

One hand only should be used, and great care exercised not to touch two brush clamps or brushes at the same time; never with switches closed.

As soon as current is shut off from the machine the commutator should be cleaned. A piece of very fine sandpaper held against the commutator under a strip of wood for about a minute before the machine is stopped, will scour the commutator sufficiently. The brushes need not be removed. An effort should be made to have the machine cleaned immediately after it is shut down. Five minutes at that time will give better results than half an hour when the machine is cold. Never use a file, emery cloth or crocus, on the commutator. New blocks will sometimes cause flashing, due to the presence of sap in the wood. The machine should be run for a few hours with a slightly longer spark, say ½ in., and the commutator then thoroughly cleaned with fine sandpaper.

All constant current arc machines require an automatic regulator to increase the voltage as more lamps are cut into the circuit and decrease it as lamps are cut out.

We will give only one of the several forms of regulators used with this system.

The form 1 regulator is placed on the frame of the machine beneath the commutator, and a constant motion is imparted to its main shaft through a small belt running around the armature shaft. (See Fig. 46.) By means of magnetic clutches and bevel gears, a pinion shaft is rotated, which moves the rack and the rocker arm and so shifts the brushes on the commutator to maintain a spark of about 3/8 in. on short cir-

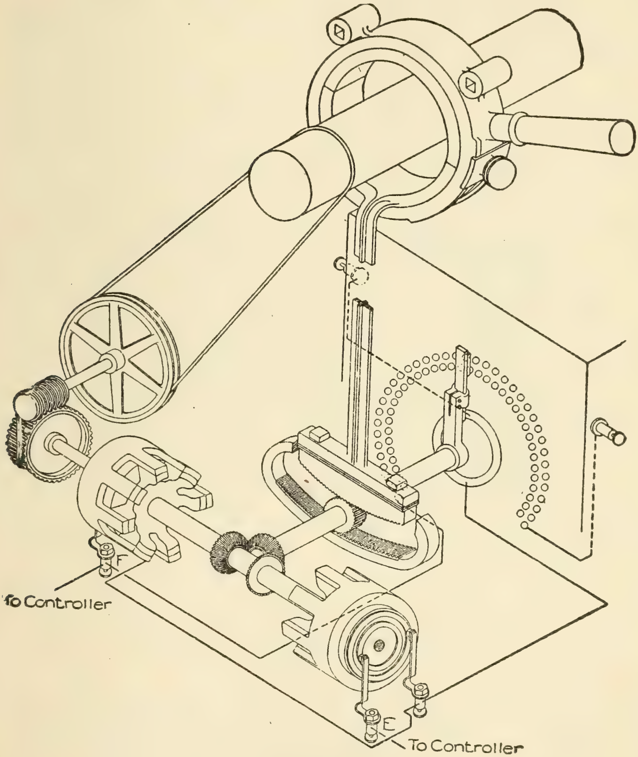


FIGURE 46.

cuit and 1/8 in. at full load; at the same time the rheostat arm is moved over the contacts to cut resistance in or out of the shunt around the field circuit.

The current for the magnetic clutches is regulated by the controller.

The controller consists principally of two magnets which are energized by the main current and act when the current is too high or too low by sending a small current to one of the clutches.

A careful examination of the controller (see Fig. 47), in connection with Fig. 46, will give a clear idea

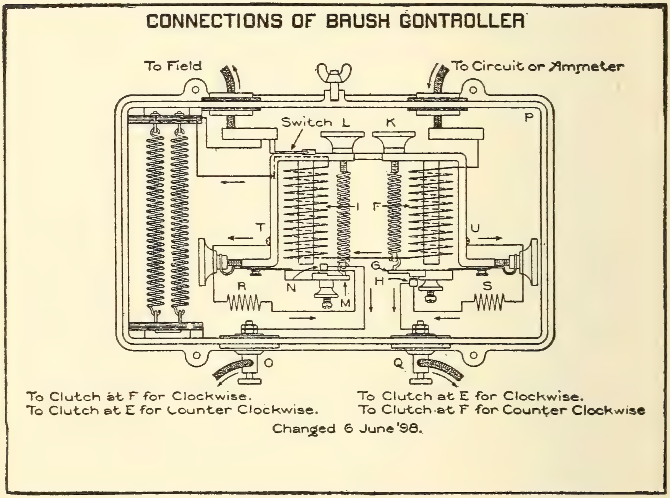


FIGURE 47.

of its regulating action. It is generally advantageous to make the yoke which carries the brushes on the machine and the arm moving the rheostat, rather tight. As the magnetic clutches act with considerable force, it is not necessary to adjust these moving parts so loosely that they will move without considerable pressure on the rocker handle. Less difficulty will then be experienced in adjusting the controller.

For shunt lamps, the controller may be adjusted to permit a variation of .4 ampere above or below normal; for differential lamps, the variation above and below normal should not exceed .2 ampere. The limits given in the following instructions are for differential lamps, and may be extended .2 ampere above or below for shunt lamps.

If the controller is out of adjustment and fails to keep the current normal, do not try to adjust the tensions of both armatures at the same time. For example, suppose the current is too high, either one of the two spools may be out of adjustment. The left-hand spool I may not take hold quickly enough, or the spool F may take hold too quickly. To make the adjustment, screw up the adjusting button K on the right hand spool, increasing the tension. This will have a tendency to let the current fall much lower before the armature comes in contact with H, to cause the current to increase. By simply tapping the armature G quickly with a pencil or piece of wood, forcing it down to its contact, and at the same time watching the ammeter, the current may be brought up to 6.8 amperes if 6.6 amperes is normal, or to 9.8 if 9.6 amperes is normal. With the current at 6.8 amperes, which is .2 ampere high, the adjusting button L should be turned to increase the tension on this spring until the armature M comes in contact with contact N, which will force current down through O. The clutch which pulls the brushes forward and rocks the rheostat back for less current will thus be energized. Repeat this adjustment two or three times, but do not touch the adjusting button K; adjust L until it is just right.

At the side of the armature M a little wedge is screwed in by means of an adjusting button, and increases or decreases the leverage on this armature. See that this wedge is fairly well in between the core or frame of the spool and the spring of the armature. The armature M may have to be taken out and the spring slightly bent. It is advisable to have the screw which passes through the adjuster button L about half way in, to allow an equal distance up and down for adjusting this lighter spring after the wedge shaped piece is in the right position to give the necessary tension on the spring which is fastened to the armature M.

In the right-hand corner P, a small bent piece of wire is placed for tightening up the screw which fastens the spring to the frame of the spool. As the contact made by the spring and the frame of the spool held together by a screw and button is a part of the magnetic circuit, it will be almost impossible to get this spring back to exactly the same tension after once removing it. Therefore, the adjusting buttons of the controller must be turned slightly in order to bring it back to its proper adjustment. This, however, is an after consideration, and care should be taken to have the screw which holds the spring and frame together always tight.

Having adjusted the spool I so that the current will not rise above 6.8 amperes (or 9.8 amperes), move the armature M up to contact N with a pencil or piece of wood, causing the current to be reduced to about 6.2 (or 9.2). After the current settles at this point, decrease the tension on the spring which is fastened to armature G, allowing this armature to fall down to contact H. Current will then flow through Q, which will rock the brushes back and also move the rheostat arm for more current. As the spool I has been adjusted for 6.8 (or

9.8) amperes, the current cannot rise above that amount no matter how the spool F is adjusted.

With very little practice in moving the armature of one spool with a pencil, the other can be adjusted much more readily than if an attempt is made to adjust the screws K and L at the same time.

The two small shunt coils, R and S, are connected around the two contacts simply to decrease the spark between the silver and platinum contacts. If they should become short circuited in any way, so that their resistances become diminished, sufficient current may pass through either of them to operate the regulator. If unable to locate the trouble disconnect these coils at points T and U, when a thorough examination can be made. M and G need not move more than just enough to open the contact; $\frac{1}{32}$ in. is ample.

In starting the machine, the lower switch, which short circuits the field, should be opened last.

The switch in the left-hand corner of the controller, figure 47 cuts out the two resistance wires which are used to force the current through wires O and Q to the clutches. Open this switch, which leaves the automatic device of the controller in circuit, so that it will move the brush rocker. Unclamp the brush rocker from the rheostat arm rocker. Move the brushes by hand to give the proper spark, allowing the rheostat arm, however, to be moved by the controller. After the switches are opened, the rheostat arm will go clear around to a full load position, and then, as the current rises, the controller takes hold and brings the arm back. In the meantime, rock the brushes forward or backward and keep the spark about the proper length, say ⅛ in., at full load to ⅜ in., on short circuit. Gradually the rheostat arm will settle, the spark will become constant, and the machine will give its proper current. Then clamp the rocker and rheostat arm together and let the machine regulate itself.

This method is much better than opening the switches on the machine and allowing the wall controller to take care of the machine from the start. By allowing the controller to start the machine, a trifle longer spark is obtained than by the other method,

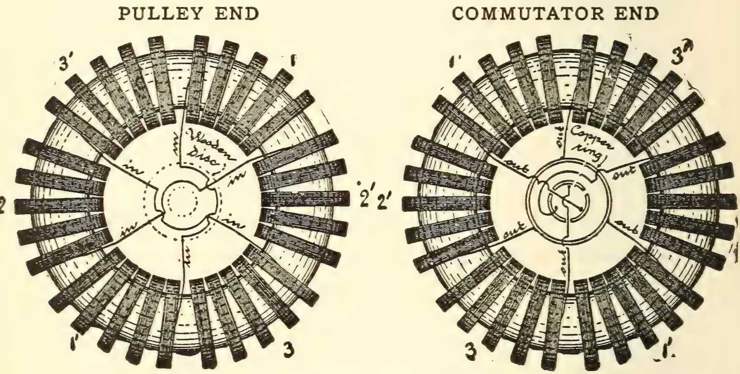


FIGURE 48.

unless the machine is run from the beginning on a very full load.

The machine will require a trifle longer spark on light load, or on bad circuits, than when running at full load. This fact should be borne in mind in wet weather, when trouble with grounds is experienced.

A reliable ammeter should always be connected in the circuit of an arc generator, so that the exact current may be read at a glance. It should be connected into the negative side of the line where the circuit leaves the regulator.

The Thomson-Houston System. The Thomson-Houston dynamo differs from other arc dynamos principally in the nature of its armature winding. This is shown in Fig. 48. One end of each of the three coils is connected to a copper ring common to all. The other end of each coil terminates at one of the three commutator segments. The management and operation of the machine will appear from the following instructions taken from pamphlets furnished by the General Electric Company.

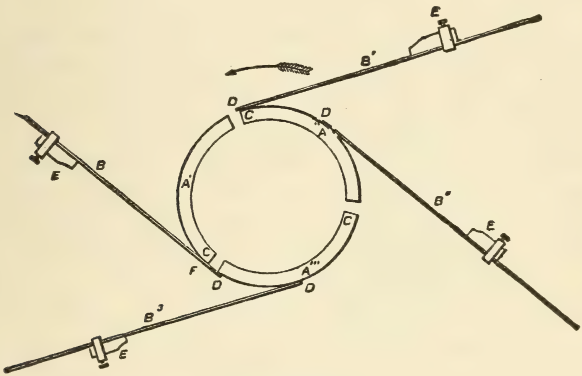


FIGURE 50.

Setting the Cut-out. After the brushes are in position the cut-out must be set. This is done by turning the commutator on the shaft in the direction of rotation (if the commutator is set in position the whole armature must be revolved) until any two segments are just touching the primary brush on that side, as segments A′ and A‴ touch brush B^4 in Fig. 50.

Under these conditions brush B^1 should be at the left-hand edge of upper segment. Then turn commutator until the same two segments are just touching brush B^2, when the end of brush B^3 should just come to the right-hand edge of the lower segment. If the secondary brush projects beyond the edge of the segment the regulator arm should be bent down; if it does not come to the edge of the segment, the arm should be bent up.

Care must be taken that the regulator armature is down on the stop when the cut-out is being set. These adjustments by bending regulator arm are always made in the factory before testing the machine, and should never be made on machines away from the factory, unless the regulator arm has been bent by accident. If it becomes necessary to make any adjustments they should be made by means of the sliding connection attached to the inner yoke.

Always try the cut-out on both primary brushes. If it does not come the same on both, turn one over. If the brush-holders are correctly set by the gauge, there should be no trouble in getting the cut-out set properly after one or two trials.

To set the commutator in the proper position on a right-hand machine, with a ring armature, find the leading wire of No. 1 coil. It is the custom in the factory to paint this lead red, also to paint a red mark on the center band between two groups of coils, namely, the last half of No. 1 coil and the first half of No. 3 coil. The first half of a coil is that group from which the lead comes. The last half is diametrically opposite the first half and the lead wire belonging to it is connected with the brass ring on the outside of the connection disk on the commutator end.

In Fig. 51 the first halves of the three coils are represented by 1, 2 and 3, and the last halves by 1′, 2′ and 3′.

A narrow piece of tin with sharply pointed ends is bent up over the sides of the middle band at the center of the red mark so that the points are opposite each other.

When the red mark and red lead have been found, turn the armature until the last half of No. 1 coil has wholly disappeared under the left field and until the left-hand edge of the first coil to the right of the red

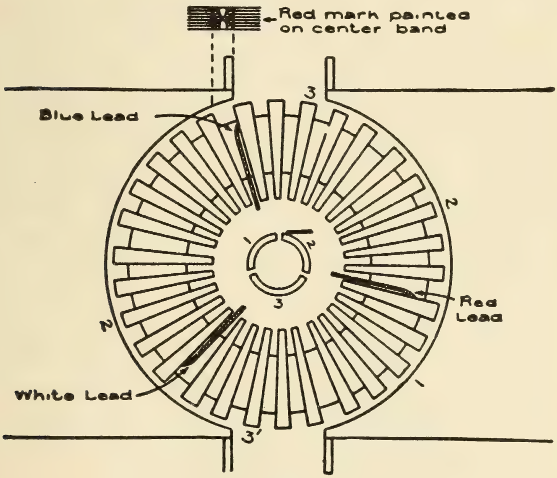


FIGURE 51.

mark (No. 3 in Fig. 51) is just in line with the edge of the left field. The red lead will then be in position shown in Fig 51, and the armature is in proper position to set the commutator.

In the case of the right-hand drum armature the leading wire of the first coil should be found. This lead may be recognized from the fact that it is more heavily insulated than the rest, and is found in the center of

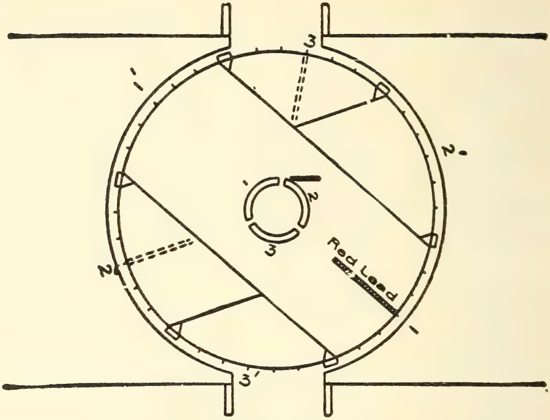


FIGURE 52.

the outer coil, on the commutator end. With this wire turned underneath, rotate the armature forward, or counter-clockwise, until the pegs on the right-hand

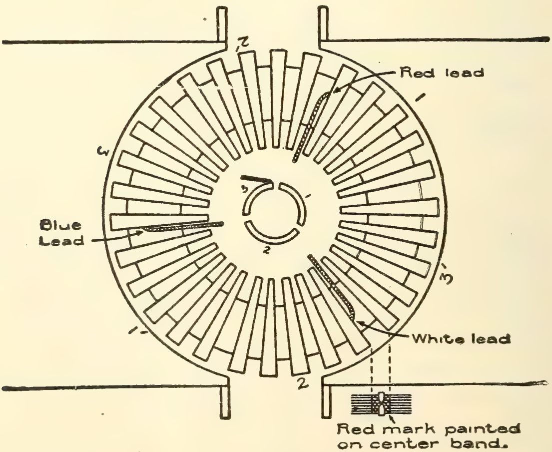


FIGURE 53.

side of this coil just disappear under the left field. (See Fig 52.)

The position of the red lead and the red mark on the band are the same on all armatures, but their positions in the fields of the machines called left-hand (clockwise rotation), should be as shown in Fig. 53 and 54 when setting the commutator.

When the armature of a right-hand machine is in position, the commutator is turned on the shaft until

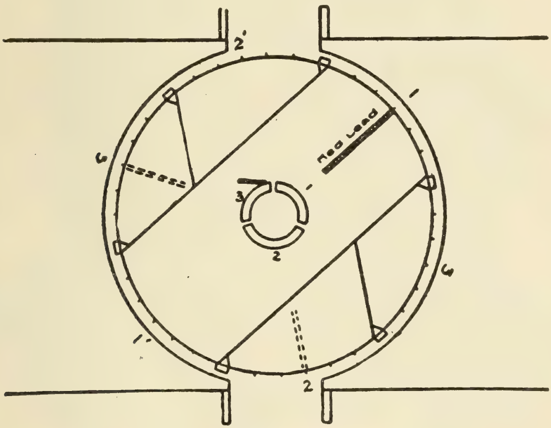


FIGURE 54.

segment No. 1 is in the same relative position as the last half of No. 1 coil; segment No. 2 should correspond with the last half of No. 2 coil, and segment No. 3 with the last half of No. 3 coil, as shown on Figs. 51 and 52.

For left-hand machines, see Figs. 53 and 54.

The distance from the tip of the brush, which is on top, to the left-hand edge of No. 2 segment on a right-hand machine, or to the right-hand edge of No. 3 segment in a left-hand machine is called the lead, and should be made to correspond with the following table.

TABLE OF LEADS

DRUM ARMATURES.				RING ARMATURES.			
C^{12}	$\frac{1}{4}$	inch	positive	K^{12}	$\frac{3}{16}$	inch	positive
C^{2}	$\frac{3}{8}$	"	"	K^{2}	$\frac{1}{8}$	"	"
E^{12}	$\frac{7}{16}$	"	"	M^{12}	$\frac{1}{4}$	"	negative
E^{2}	$\frac{1}{4}$	"	"	M^{2}	$\frac{1}{2}$	"	"
H^{12}	$\frac{1}{4}$	"	"	LD^{12}	$\frac{1}{4}$	"	positive
H^{2}	$\frac{1}{4}$	"	"	LD^{2}	$\frac{1}{8}$	"	"
				MD^{12}	$\frac{13}{32}$	"	"
				MD^{2}	$\frac{13}{32}$	"	"

Place the screws in the binding posts at the lower ends of the sliding connections, and put on the dash pot connections between the brushes, with the heads of the connecting screws outward. In every case the barrel part of the dash pot is connected to the top brush-holder, and plunger part to the bottom brush-holder.

See that the field and regulator wires are connected and that all connections are securely made.

When all connections have been made, make a careful examination of screws, joints and all moving parts. They must be free from stickiness and not bind in any position.

To determine when the machine is under full load, notice the position of the regulator armature, which should be within $\frac{1}{8}$ in. of the stop. At full load the normal length of the spark on the commutator should be about $\frac{3}{16}$ in. If it is less than this, shut down the machine and move the commutator forward or in the direction of rotation until the spark is of the desired length. If the spark is too long, move the commutator back the proper amount.

A general view of the complete dynamo is given in

Fig. 55, and will help explain the regulator used with this system.

The regulator is fastened to the frame of the machine by two short bolts. On the right-hand machine its position is on the left-hand side, as shown in Fig. 55. On the left-hand machine, *i.e.*, one which runs clockwise, its position is on the opposite side. Before fill-

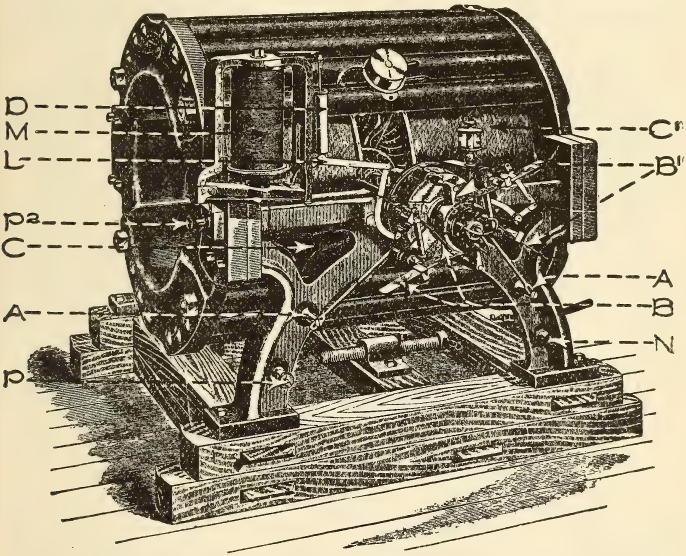


FIGURE 55.

ing the dash pot D with glycer.ne, see that the regulator lever and its connections, brush yokes, etc., are free in every joint, and that the lever L can move freely up and down. Then fill the dash pot D with concentrated glycerine. The long wire from the regulator magnet M is connected with the left-hand binding post P of the machine, and the short wire with the post P^2 on the side of the machine. The inside wire of the field magnet, or that leaving the iron flange, of the left-hand field should be connected into post P^2 also, as shown in Fig. 55. The electric circuit (see Fig. 56) should be complete from post P^1, on the controller magnet, through the lamps to the post N on the machine, through the right-hand field magnet C, to the brushes B^1B^1, through the commutator and armature to the brushes B B, through the left-hand field C,

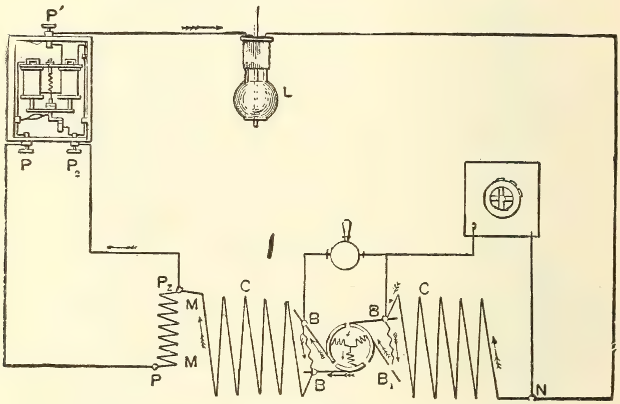


FIGURE 56.

to posts P^2 and P, thence to posts P^2 and P on the controller magnet, through the controller magnet to P^1. The current passes in the direction indicated by the arrows

When an arc machine is to be run frequently at a small fraction of its normal capacity, the use of a light load device is advisable to secure the best results in regulation.

The rheostat for this purpose (see Fig. 57) is connected in shunt with the right field of the generator.

Facing the rheostat with the right binding posts at the bottom, the contact on the right side or No. 1 gives open circuit and throws the rheostat out of use. Point No. 2 gives a resistance of 44 to 46 ohms and Point No. 3 gives a resistance of 20 to 22 ohms.

This rheostat with a 75-light machine allows the following variations: Point 1, 75 to 48 lights; Point 2, 48 to 25 lights; Point 3, 25 lights or less. For use with

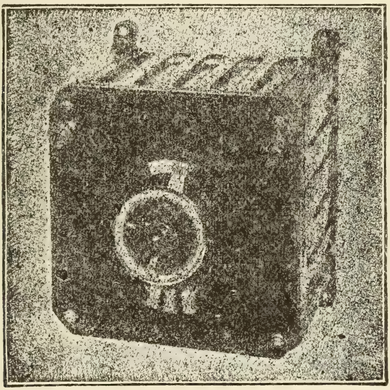


FIGURE 57.

other sizes of generators, the adjustment of the rheostat must be made to suit the conditions.

When the rheostat is in use, the sparks at the commutator will be somewhat larger than normal, but will not be detrimental.

The controller magnet (see Fig. 58) is to be fastened securely by screws to the wall or some rigid upright support, taking care to have it perfectly plumb. It is connected to the machine in the manner shown in Fig. 55, *i.e.*, the binding post P^2 on the controller magnet is connected to the binding post P^2 (see Fig. 55) on the end of the machine, and likewise the post P on the controller to the post P on the leg of the machine; the post P^1 forms the positive terminal from which the circuit is run to the lamps and back to N.

Great care should be taken to see that the wires P P

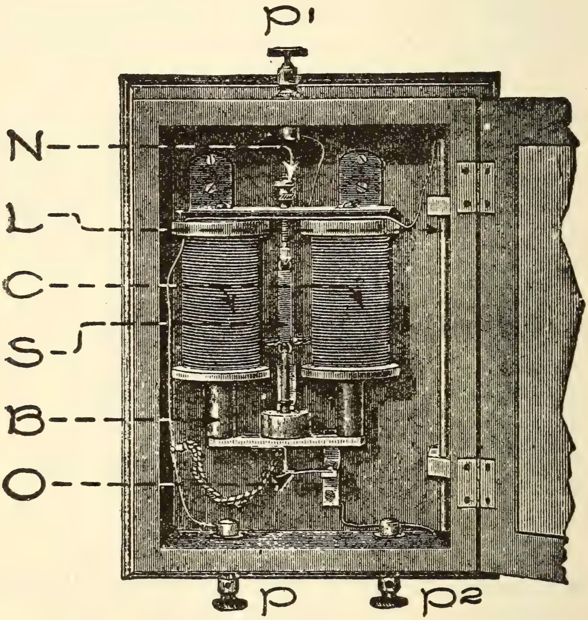


FIGURE 58.

and P^2 P^2 are fastened securely in place; for if connection between P and P should be impaired or broken, the regulator magnet M would be thrown out of action, thus throwing on the full power of the machine, and if the wire P^2 P^2 should become loosened, the full power of the magnet M would be thrown on, and the regulator lever L, rising in consequence, would greatly weaken or put out the lights.

The wires leading from the controller magnet to the machine should have an extra heavy insulation.

Care should be taken in putting up the controller magnet that the following directions are followed:

1. The cores B of the axial magnets C C must hang exactly in the center, and be free to move up and down.

2. The screws fastening the yoke or tie pieces to the two cores must not be loosened.

3. The contacts O must be firmly closed when the cores are not attracted by the coils C C, which is the case, of course, when no current is being generated by the machine, and when the cores are lifted, the contacts must open from $\frac{1}{64}$ in. to $\frac{1}{32}$ in.; a greater opening than $\frac{1}{32}$ in. has the effect of lengthening the time of action of the regulator magnet. This tends to render the current unsteady, and in case of a very weak dash pot or short circuit might cause flashing. Adjustment must be made if necessary by bending the lower contact up or down, taking care that it is kept parallel with the upper contact, so that when they are closed, contact will be made across its whole width. If this adjustment is not properly made there will be destructive sparking on a small portion of the contact surfaces.

4. All connections must be perfectly secure.

5. The check nuts N must be tight.

6. The carbons in the tubes L must be whole. These carbons form a permanent shunt of high resistance around the regulator magnet M, and if broken will cause destructive sparking at contacts O, burning them and seriously interfering with close regulation of the generator. In case a carbon should become broken,

temporary repairs may be made by splicing the broken pieces with a fine copper wire.

To keep the action of the controller perfect the contacts O should be occasionally cleaned by inserting a folded piece of fine emery cloth and drawing it back and forth.

The amount of current generated by each machine

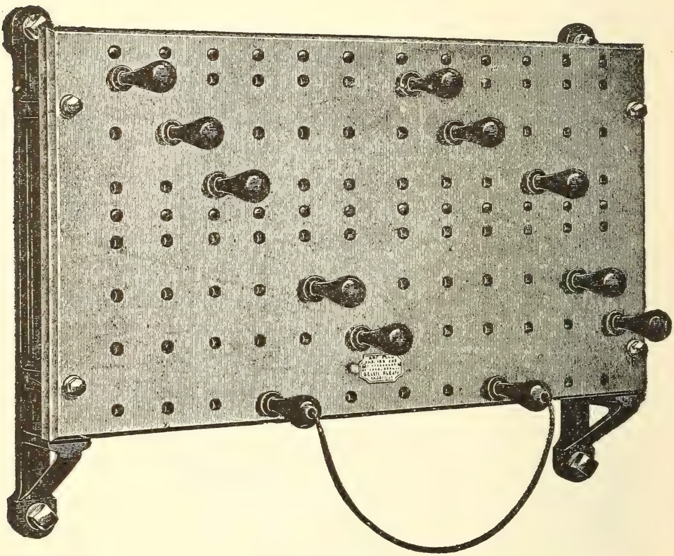


FIGURE 59.

depends upon the adjustment of the spring S. If the tension of this spring is increased the current will be diminished; if the tension is diminished, the current will be increased.

In starting these dynamos when the armature has reached its proper speed, the short circuiting switch on the frame should be opened. This method allows the generator to take up its load gradually, and is a very important point in the handling of the machine.

Arc Switchboards. Fig. 59 shows a general view of the Thomson-Houston plug switchboard. A rear view of the same board is given in Fig. 60.

In a standard panel the number of horizontal rows of holes equals one more than the number of generators. The vertical holes are always twice the number of generators. The positive leads of the generators are

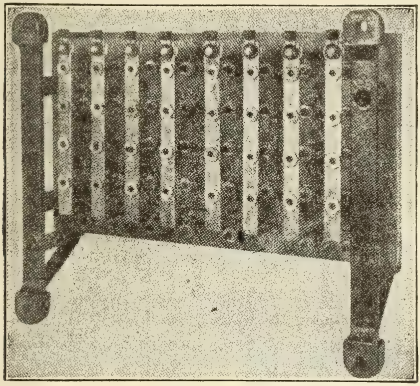


FIGURE 60.

attached to the binding posts on the left-hand ends of the horizontal conductors. The negative leads are connected to the corresponding binding posts at the right-hand end of the board.

The positive line-wires are connected to the vertical straps on the left, and the negative wires to the similar straps on the right of the center panel.

If a switchboard plug be inserted in any of the holes of the board, it puts the corresponding generator lead and the line wire in electrical connection, but as the positive line wires are back of the positive generator leads only, it is not possible to reverse the connection of the line and the generator accidentally, though any other combinations of lines and generators can be made readily and quickly.

The holes of the lower horizontal rows have bushings connected with the vertical straps only. Plugs connected in pairs by flexible cable and inserted in the holes put the corresponding vertical straps in connection as needed, and normally independent lines may be connected when one generator is required to supply several circuits.

Lines and generator leads may be transferred, while running, by the use of these cables, without shutting down machines or extinguishing lamps.

The standard boards are arranged for an equal number of generators and circuits, but special boards for any ratio of circuits to generators can be built.

As it is sometimes convenient, even in small plants, to interchange lines and generators without shutting down machines, a special transfer cable with plugs has been devised. This serves the same purpose as the regular transfer cable, but the plugs may be used in any of the holes of the switchboard, as they are insulated, except at the tip, and when inserted connect with the line strips only.

The transfer of circuits from one generator to another gives trouble to dynamo tenders who are not familiar with the operation of these plug switchboards. Fig. 61 illustrates the successive steps for transferring the lamps of two independent circuits from two generators to one without extinguishing the lamps on either circuit.

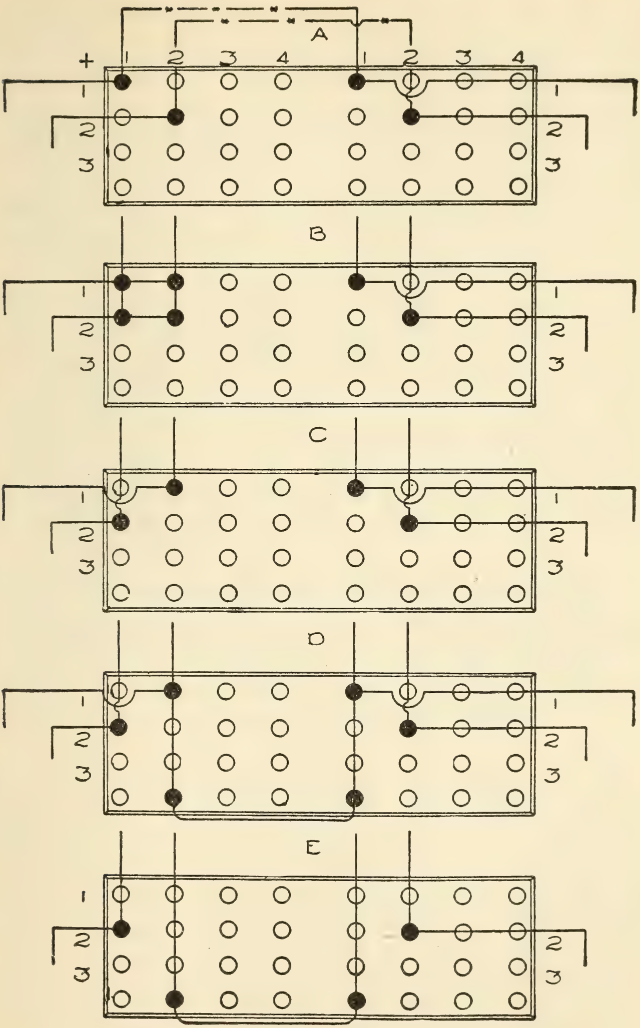


FIGURE 61.

This process is a very simple example of switchboard manipulation, but illustrates the method used for all combinations.

The location of plugs is shown by the black circles, which indicate that the corresponding bars of the horizontal and vertical rows are connected.

Circuit No. 1 and No. 2, running independently from generators No. 1 and No. 2 respectively, are to be transferred to run in series on generator No. 2.

In A, Fig. 61, are two circuits running independently; in B the positive sides of both generators and circuits are connected by the insertion of additional plugs.

At C both generators and circuits are in series.

Next insert plugs and cables as shown in D. Then withdraw plugs on row corresponding to generator No. 1, and the circuits No. 1 and No. 2 are in series on machine No. 2, and machine No. 1 is disconnected as at E.

Similar transfers can be made between any two circuits or machines, and by a continuation of the process additional circuits can be thrown in the same machine. The transfer of the two circuits to independent generators is accomplished by reversing the process illustrated.

Fig. 62 shows the wiring and connections of the Western Electric Co.'s series arc switchboard. At the top of the board are mounted six ammeters, one being connected in the circuit of each machine. On the lower part of the board are a number of holes, under which, on the back of the board, are mounted spring jacks to which the circuit and machine terminals are connected. For making connections between dynamos and circuits, flexible cables terminating at each end in a plug, are used; these are commonly called "jumpers." The board shown has a capacity of six machines and nine circuits, and with the connections as shown machine 1 is furnishing current to circuit 1, machine 2 is furnishing current to circuits 2 and 3, and machine 4 is furnishing current to circuits 4, 5 and 7. In connecting together arc dynamos and circuits the positive of the machine (or that terminal from which the current is flowing) is connected to the positive of the cir-

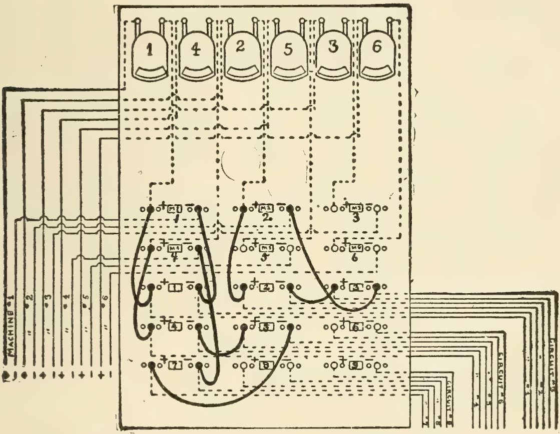


FIGURE 62.

cuit (the terminal into which the current is flowing). Likewise the negative of the machine is connected to the negative of the circuit. Where more than one circuit is to be operated from one dynamo, the — of the first circuit is connected to the + of the second. At each side of the name plate (at 3, for instance) there are three holes. The large hole is used for the permanent connection, while the smaller holes are used for transferring circuits, without shutting down the dynamo. Smaller cables and plugs are used for transferring. If it is desired to cut off circuit 5 from machine 4, a plug is inserted in one of the small holes at the right of 4, the other plug being inserted in one of the holes at the left of 7. Circuit 5 would now be short circuited, and the plug in the + of 5 can now be transferred to the permanent connection in the + of 7, and the cords running to 5 removed. If it is desired to cut in a circuit, say circuit 6 onto machine 2, insert a cord between the – of circuit 2 and the + of 6 and another between the – of 6 and the + of 3. Now pull the plug on the cord connecting – of 2 and the + of 3 and insert the permanent connections. In cutting in circuits, if they contain a great number of lights, a long arc may be drawn when the plug between 2 and 3 is pulled, and it is sometimes advisable to shut down the machine when making a change of this kind.

CHAPTER V

MOTORS.—ALTERNATING CURRENT MOTORS.

Motors. Any dynamo may be used as a motor and consequently we have as many types of motors as there are types of dynamos. The pull of a motor depends upon the repulsion and attraction between the lines of force, or magnetism of the wire and core of the armature and that of the fields. We have seen that in a dynamo, as we force a wire through a magnetic field, current is generated. The more current there is generated or flowing in such a wire, the greater will be the expenditure of power necessary to force such a wire through a magnetic field; in other words, the currents flowing in the wires of a dynamo armature, always tend to drive the armature in a direction opposite to that in which it is being driven.

If, then, instead of revolving a dynamo armature by mechanical means, we connect it to a source of electricity and allow a current to flow through it we must obtain motion, and the direction of this motion will depend upon the direction in which the current flows, so long as this current does not alter the magnetism of the fields.

We have already seen that the electric motor is built exactly like a dynamo; consequently, as its armature revolves it not only does useful work, such as turning whatever machinery it is belted to, but it also generates an electromotive force. For instance, if a motor, running at full speed and receiving current from a dynamo (Fig. 63), were suddenly disconnected by opening the main switch, it would at once begin acting as a generator and sending out current. This can be easily seen with any motor equipped with a starting box, such as shown; for the current from the motor will continue to energize the fields and the little magnet M so as to hold the arm of the starting box until the motor has nearly come to rest. If it were not for the current generated by the motor, this arm would fly back the instant the switch is opened.

The electromotive force set up by a motor always opposes that of the dynamo driving it; that is, the current which the motor tends to send out would flow in the opposite direction to that which is driving it.

This may be compared, and is somewhat similar, to the back pressure of the water which a pump is forcing into a tank. If the check valves were removed and the steam pressure shut off, the water would tend to force the pump backward.

This electromotive force is called the counter electromotive force of the motor. The counter electromotive force of the motor varies with the speed of the motor and also limits the speed of the motor, for it is obviously impossible that a motor should develop higher counter E. M. F. than the E. M. F. of the dynamo driving it.

This highest possible speed of a motor is, then, that speed at which its counter E. M. F. becomes equal to the E. M. F. of the dynamo supplying the current, and this is the speed which would be obtained were the motor doing no work and running without friction. This condition is impossible in practice, and the counter E. M. F. of the motor is always less than the E. M. F. of the dynamo. In order to speed up a motor we must arrange it so that it must run faster in order to develop an E. M. F. equal to that of the dynamo; we can do this by lessening the number of turns of wire on the armature, or by lessening the magnetism of the fields. In doing so, however, we also lessen the capacity of the motor for performing work.

The power that can be obtained from an electric motor depends upon two things: the current flowing in its armature coils and the strength of magnetism developed in the fields.

Assuming the fields as remaining constant, the power of the motor must then vary as the current flowing through it. Suppose we have a motor being driven by an E. M. F. of 110 volts and it is doing no work; it will be running at full speed and its counter E. M. F. will therefore also be very near 110 volts. If now a load be thrown on this motor, it must get more current in order to develop the necessary power to carry the load.

Throwing on the load will decrease the speed of this motor, and consequently its counter E. M. F. will fall, say to 100 volts. The E. M. F. of the dynamo being 110 and the counter E. M. F of the motor 100, there will be considerable current forced through the armature of the motor, so that it can now handle the load.

The current in the armature at all times will equal $\frac{E - E'}{R}$ where E is the electromotive force of the dynamo, E′ the counter electromotive force of motor, and R the resistance of the motor armature. In order that a motor should keep a nearly uniform speed, for varying loads, the resistance of its armature should be very low, for then a slight drop in counter E. M. F.

will allow considerable current to flow through the armature. The above applies particularly to the shunt motor shown in Fig. 63. In this diagram C is a double pole fuse block, S the main controlling switch, R the starting box, or rheostat, M the magnet, which holds the arm of the starting box in place when it is brought

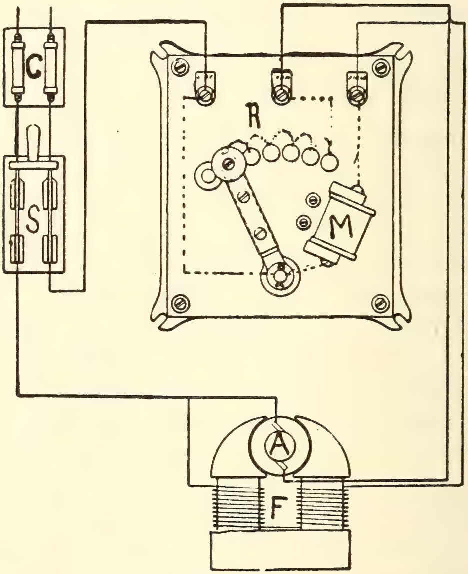


FIGURE 63.

over against it, F the fields, and A the armature of the motor.

The current enters, say at the right hand fuse, and passes to the starting box and along the fine wires shown in dotted lines through the fields of the motor and coil M to the other fuse. The fields of the motor and the little magnet M are now charged, but as yet there is no current passing through the armature and no motion. We now slowly move the arm on the starting box to the right; this admits a little current, limited by the resistance in the starting box, to the motor armature and it begins to revolve, and as we continue to move the arm to the right, the armature gains in speed because we admit more current to it by cutting out more and more resistance. When the armature attains full speed, the arm comes in contact with the little magnet M, and is held there by magnetism. The whole object of the starting box is to check the inrush of current, while the armature is developing its counter E. M. F. or back pressure.

When the armature has attained its normal speed, the starting box is no longer in use. If for any reason the current ceases to flow, the little magnet M loses its magnetism and releases the arm, which (actuated by a spring) flies back and opens the circuit so that, should the current suddenly come on again, the sudden inrush will not damage the armature.

In Fig. 64 are shown the connections of a series wound motor with an automatic release spool on the starting box of a sufficiently high resistance so it can be connected directly across the circuit. This becomes necessary since the field windings are in series with the armature.

The speed of a series motor may be decreased by connecting a resistance in series with the motor and may be increased in speed by cutting out some of the field windings. In electric railway work where two motors are used on one car, they are usually connected in series with each other in starting up and then in parallel with each other while running at full or nearly full speed. The series motor is well adapted to such work as electric railway work, or for cranes and so forth, because it will automatically regulate its speed to the load to be moved, exerting a powerful torque at a low speed while pulling a heavy load. Such a motor, however, requires constant attendance when the

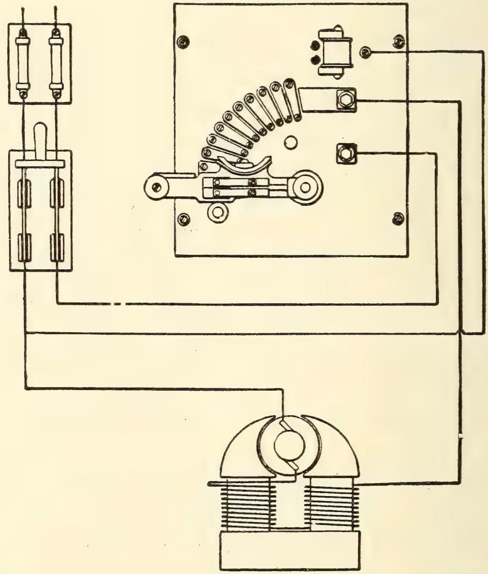


FIGURE 64.

load becomes light, as it will tend to "run away" unless its speed is checked.

In Fig. 65 we have a diagram of a compound wound motor connected with a type of starting box that cuts out the armature when current has been cut off the lines supplying the motor, as before explained. In addition to this there is another electro magnet which is traversed by the main current on its path to the armature. Should the motor be overloaded by some means, the current flowing to the armature would exceed the normal flow. The magnetism thus produced would overcome the tension of a spring on the armature of the so-called "overload magnet" and cause it to short circuit the magnet which holds the resistance lever and allow it to fly back and open the arma-

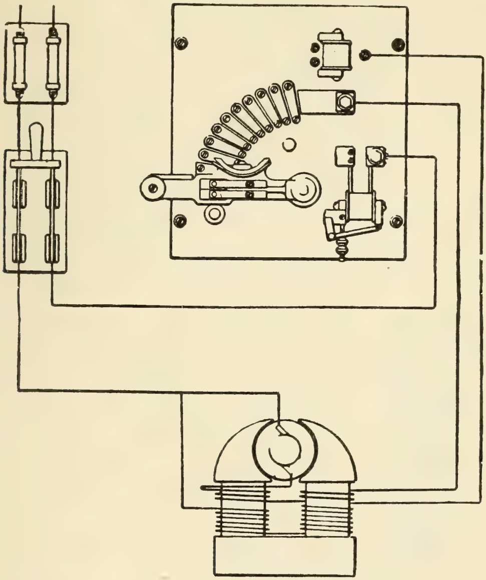


FIGURE 65.

ture circuit. By so doing the liability of burning out the armature due to overload is reduced to a minimum.

The compound motor may be made to run at a very constant speed, if the current in the series winding of the fields is arranged to act in opposition to that of the shunt winding. In such a case an increase in the load of a motor will weaken the fields and allow more current to flow through the armature without decreasing the speed of the armature, as would be necessary in a shunt motor. Such motors, however, are not very often used, since an overload would weaken the fields too much and cause trouble.

If the current in the series field acts in the same

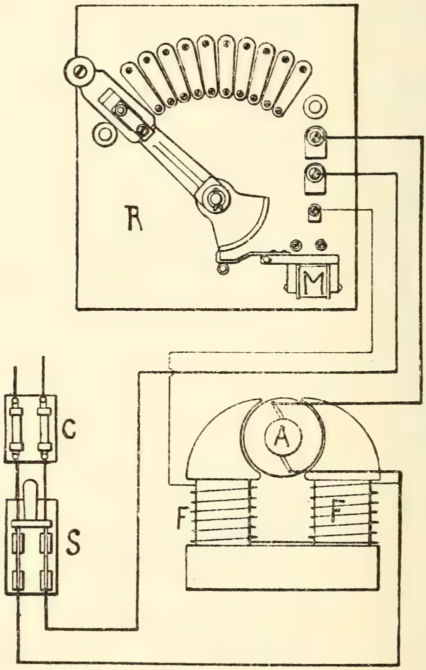


FIGURE 66.

direction as that of the shunt fields, the motor will slow up some when a heavy load comes on, but will take care of the load without much trouble. Fig. 66 shows a starting box arranged as a speed controller. It differs from other starting boxes only in so far that the resistance wire is much larger and that the little magnet will hold the arm at any place we desire, so that if we leave the arm at any intermediate point the motor will run at reduced speed. This sort of speed regulation can be used only where the load on the motor is quite constant. If the load varies, the speed will vary. Another and a better way of varying the speed of motors consists in cutting a variable resistance into the field circuit, as more resistance is cut into the circuit the fields become weaker and the motor speeds up. If possible, motors should be so designed that they can operate at their normal speed, and they will then cause little trouble.

Motors have much the same faults as dynamos, but they make themselves manifest in a different way. An open field circuit will prevent the motor from starting and will cause the melting of fuses or burning out of an armature. The direction of rotation can be altered by reversing the current through either the armature or the fields. If the current is reversed through both, the motor will continue to run in the same direction. A short circuit in the fields, if it cuts out only a part of the wiring, will cause the motor to run faster and very likely spark badly. If the brushes are not set exactly opposite each other, there will also be bad sparking. If they are not at the neutral point, the motor will spark badly; brushes should always be set at the point of least sparking. If it becomes necessary to open the field circuit, it should be done slowly, letting the arc gradually die out; a quick break of a circuit in connection with any dynamo or motor is not advisable, as it is very likely to break down the insulation of the machine.

The ordinary starting box for motors is wound with comparatively fine wire and will get very hot if left in circuit long. The movement of the arm from the first to the last point should not occupy more than thirty seconds, and if the armature does not begin to move at the first point the arm should be thrown back and the trouble located.

Alternating Current Motors. By a proper combination of two phase or three phase currents it is possible to produce a revolving magnetic pole. By placing inside of the apparatus which produces this revolving magnetic pole a suitable short circuited armature, this armature will be dragged around by the revolving pole in much the same way that a short circuited armature in a direct current machine would be dragged around if the fields were revolved. Such a machine is called an induction motor. The armature will revolve without any current entering it from the external circuit. This does away with commutators, collector rings, brushes, brush-holders, and in fact many of the parts which are so necessary in direct current machines. The rapidity of the alternations in the external circuit determines the speed of the motor.

Some alternating current motors are known as "synchronous" motors. What is meant by synchronous is, occuring at the same time, or in unison. As an example, suppose two clocks are ticking just alike so that the pendulums start and stop at the same time; we would hear but one tick. These two clocks would then be in synchronism. If an alternating current generator has 32 field coils and revolves at the rate of 60 R. P. M., then a synchronous motor with only 4 field coils would revolve at the rate of 480 R. P. M. This motor would operate in synchrony with the generator and yet would make 480 R. P. M. while the generator made 60 R. P. M.

CHAPTER VI

Fuses and Circuit Breakers. Fuses are metal wires or strips, generally made of an alloy of lead and antimony, the amount of each metal used being so proportioned that the wire will melt at a certain temperature. This metal is very similar to that used in the fusible plugs in boilers. These fuse strips or fuse wires are placed in the various circuits in such a manner that the current must first flow through the fuse before entering the lights, motors or other electrical apparatus. If a short circuit should occur, there would be an excessive amount of current flow through the fuse and the temperature of the metal would be raised to the point where it would melt and open the circuit. This would cut off the current and save the electrical apparatus from being damaged by the excessive current. Fuses are placed in the various circuits in accordance with the rules and regulations of the National Board of Fire Underwriters. These rules require a fuse to be placed in the circuit of every piece of electrical apparatus liable to be short circuited, and also at points where small wires are tapped onto larger ones, unless the main fuse in the larger wire is small enough to protect the smallest wire in the circuit. The ordinary commercial fuse wire is not intended to melt until the current has reached a strength of about twice the number of amperes marked on the fuse. A few good points to remember in regard to fuses are as follows: Unless the fuses are of the new enclosed type (fuses entirely encased in small tubes) or unless they are under the eye of a constant attendant, they should be enclosed in fireproof boxes. This should be done to minimize the chance of the red hot metal from a melted fuse dropping into some inflammable material. It is a very good plan to enclose all fuses. Fuses placed in a hot room will blow at a lower increase in current than those in a cool room. Always use copper tipped fuses, both for the purpose of getting a good contact at the binding screw and for the reason that the blowing point of a fuse wire depends on the length of the wire. Two pieces of fuse wire of the same diameter, but of different lengths, will not blow with the same current because the cooling effect of the terminals is greater with the shorter fuse.

In the larger size fuse strips see that the contacts between the fuse terminal and the binding post are free from dirt and that there is plenty of contact between them, otherwise the poor contact will heat up the terminal and the fuse strip and cause it to blow at a much lower current strength than that for which it is marked. Oil between the contacts will cause heating and the same result.

From the fact that when a fuse strip has blown the current will be off the circuits which are protected by the strip until the fuse has been replaced, and this takes some time, another device known as the circuit breaker has come into general use. The circuit breaker is simply a knife switch equipped with a spring which tends to open it, and is held in place by a small catch. The current passing through the switch also passes through the winding of a small solenoid on the inside of which is an iron core. When the current passing through the solenoid exceeds a certain amount, the iron core is drawn up into the solenoid, and in doing so strikes the catch holding the switch and releases it, thus opening the switch and cutting off the current. Circuit breakers are nearly always installed in the cir-

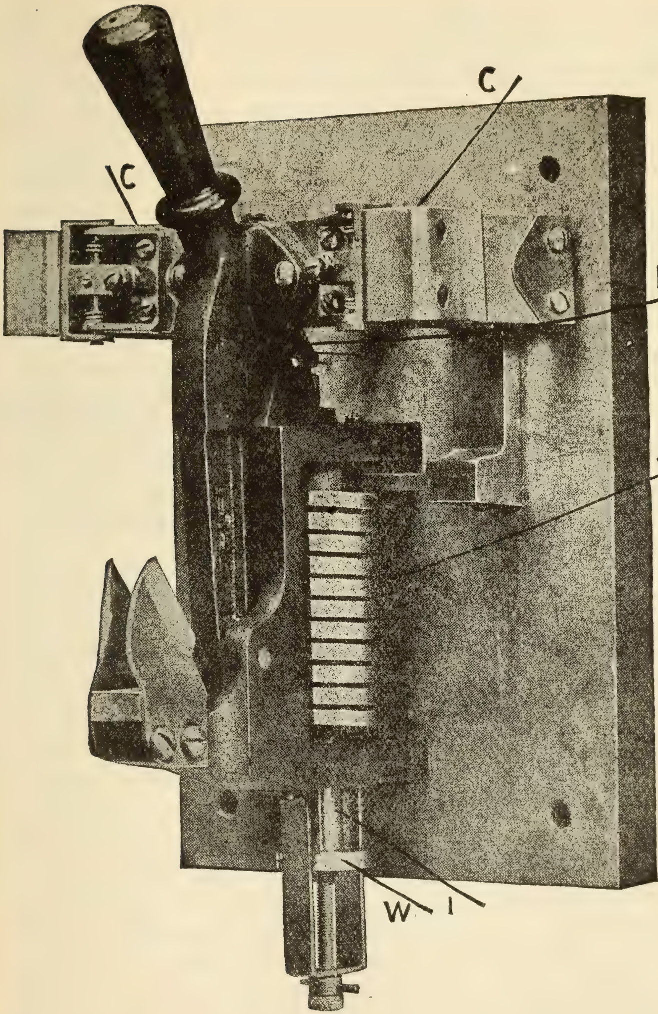


FIGURE 67.

cuits of generators, although fuses are also used. The fuse is rated higher than the circuit breaker, so that the circuit breaker will operate first and the fuse only operates when the circuit breaker fails to work. Circuit breakers are also used to a large extent in protecting large motors, and the small overload devices used on motor starting boxes are simply circuit breakers. Fig. 67 shows a view of an I-T-E circuit breaker. S is the solenoid and I the moveable iron core. This core is adjustable, by means of the washer W, so that it will operate at whatever current desired. L is the catch which holds the switch. Carbon contact pieces, C C, are so arranged that the current is broken on them, thus taking the arc off the blades. In Fig. 68 a diagram of a circuit breaker used for the protection of a motor is shown. In this case the circuit breaker is double pole; while the one shown in the preceding figure is single pole.

For small work, such as tap lines and small motors, the circuit breaker is too expensive to warrant its use, but for capacities of 50 amperes and over it is advisible to use the circuit breaker. Circuit breakers are also designed and used to prevent the liability of short circuits between generators connected in parallel, due to the reversal of polarity of one of the dynamos. In other words, should one of the dynamos become reversed in polarity while working in parallel with other machines, the polarity circuit breaker would open the machine-switch and cut it out. Circuit breakers of this description are also used in charging storage batteries. Sometimes circuit breakers are referred to as overload switches. The mechanical operation of these instruments can be readily understood when examined, as they are all of a very simple mechanical construction.

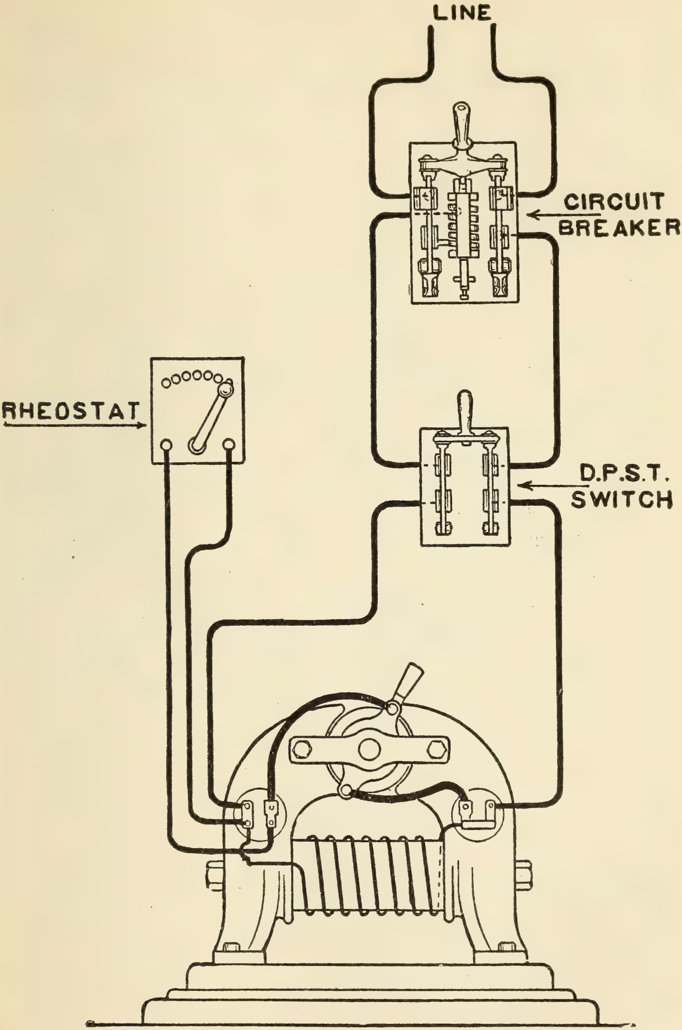


FIGURE 68.

CHAPTER VII

ALTERNATING CURRENT DYNAMOS

Alternating current dynamos are operated upon the same general principle of magnetic induction as that involved in continuous current dynamos. The mechanical construction, however, differs considerably in the two types of machines. The current produced in the two types is identical, but in the direct current machine this current is rectified by means of a commutator; that is, the current constantly flows out one wire and back in the other wire, never changing in direction in the external circuit. In the alternating current dynamo the current is sent to the line exactly as it is generated in the armature, flowing out one wire and back on the other and then reversing and flowing out on the wire on which it has just flowed in, and back on the wire on which it had formerly flowed out. An illustration which will more fully explain this action can be found by supposing the two ends of the cylinder of a piston pump were connected by means of a pipe and then, having done away with all the valve movements, the pumps were started. At the beginning of the stroke, water would be forced out one side of the cylinder around the pipe into the other side of the cylinder, and after the piston had reached the end of the stroke and started back, the water would then take a return course back to where it had started. In this case the pump could be likened to the dynamo and the pipe to the wires, and the current to the water flowing back and forth. The form and winding of alternating current dynamos varies considerably, but they generally follow the plan shown in Fig. 69. In the figure the pole pieces are alternately north (N) and south (S), while the armature is wound with the same number of poles, with the winding so arranged that the poles alternate. The fields are excited by direct current passing over the field coil windings. This

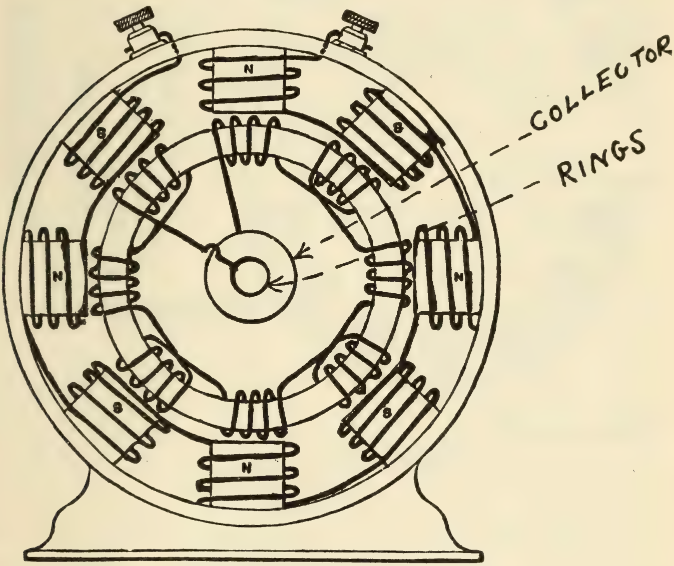


FIGURE 69.

direct current is usually obtained from another source aside from the current generated in the armature of the alternating current dynamo. A separate dynamo, called an exciter, is employed for supplying the current to the fields. There are some types of so called "composite wound alternating current dynamos" in which a part of the current from the alternator armature is rectified or commutated by means of a commutator mounted on the same shaft with the armature,

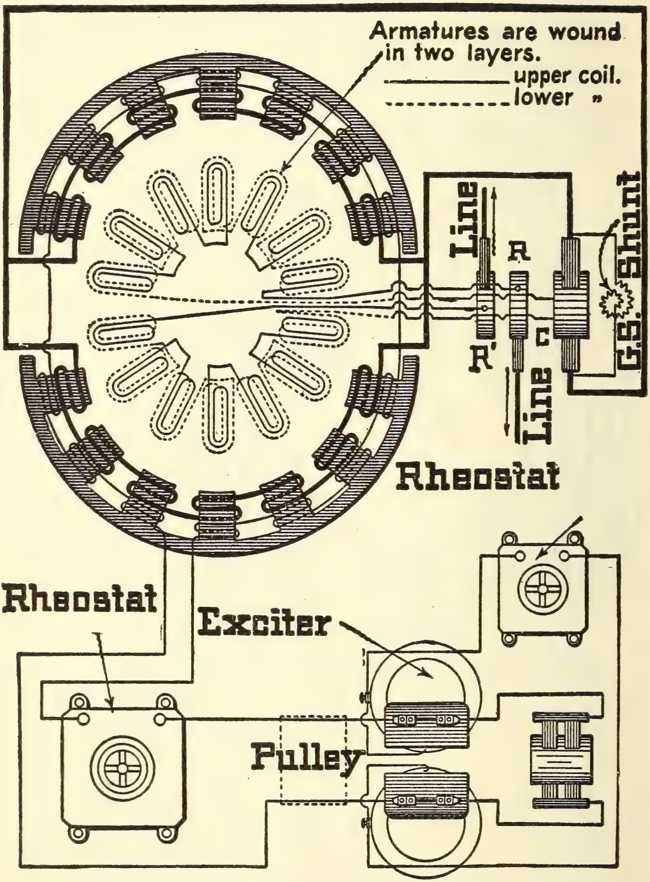


FIGURE 70.

and this commutated current passed around the field coils in a manner similar to the direct current compound wound dynamo. In Fig. 70 we have a diagram of connections of a composite wound machine made by the General Electric Company. It will be noticed that in connection with this dynamo we still employ a separate direct current exciting machine. The object of this composite winding is the same as with the compound wound direct current dynamo, namely, regulation under variable loads without the necessity of changing the strength of the field exciting current from the exciter dynamo. The winding of the alternate current armature consists of the same number of armature coils as there are pole pieces in the fields of the machine. The outer end of the first armature coil is left free to be connected to one of the collector rings, while the other end of the coil is connected to the inner end of the second coil; the outer end of the second coil is connected to the outer end of the third coil, and so on through the entire armature. In this class of winding you can readily see that while the coils connected from the underside or inner ends are under the influence of one polarity of field magnetism, the armature coils connected from the outer side are under an opposite magnetic influence. The purpose of forming the armature circuit in this manner may be fully understood when it is remembered that the magnetism from the north pole of a magnet will induce a flow of electricity in a coil of wire in a given direction, while the magnetism of the south pole will induce a flow of current in an opposite direction. Now, for the reasons just explained, the current in all of the coils of the armature will flow in the one direction, but as the armature is rotated sufficiently to move the coils from the influence of one pole to the influence of the opposite pole which is next to it, the action of all the magnetic poles of the field reverse all the inductions in the armature coils and cause the current to flow in an opposite direction. The number of reversals occurring during a revolution is determined by the number of poles that the armature coils pass during one revolution. One of these armature coils we will assume to be under a north magnetic influence and in its rotation it passes through a south magnetic influence, thence into a north magnetic influence again. The current has now alternated or reversed its direction of flow twice and has passed through what is called one cycle. If the current were making 120 alternations or passing through 60 cycles in one second, it would be known as making 60 cycles or alternating at the rate 7,200 alternations per minute. These are the general terms used in designating alternating currents.

By tracing out the circuits in Fig. 70, it will be seen that, assuming the current to be flowing into the collector ring R, it will pass through the upper half of the armature winding and out to the commutator C, where a part of it will be commutated (or changed into direct current), then flowing back around the lower half of the armature windings and out to the other collector ring R′. On the commutator C the upper line coming from the armature is connected to each alternate segment, while the lower line is connected to the remaining segments. The amount of current which is thus rectified and flows around the two halves of the field winding, which are connected in parallel, is regulated by means of the German silver shunt. The fields are also energized by the current generated in the small dynamo known as the exciter.

In Fig. 71 is shown an alternating current dynamo with its separate exciter The two collector rings are shown immediately at the right of the armature, while at the right of the collector rings is shown the commutator from which the current for the composite winding of the fields is taken. The current generated by the alternator is regulated in the same way as with direct current dynamos; that is, by varying the current sent around the field windings. This is accomplished by the use of a resistance box in series with the exciting

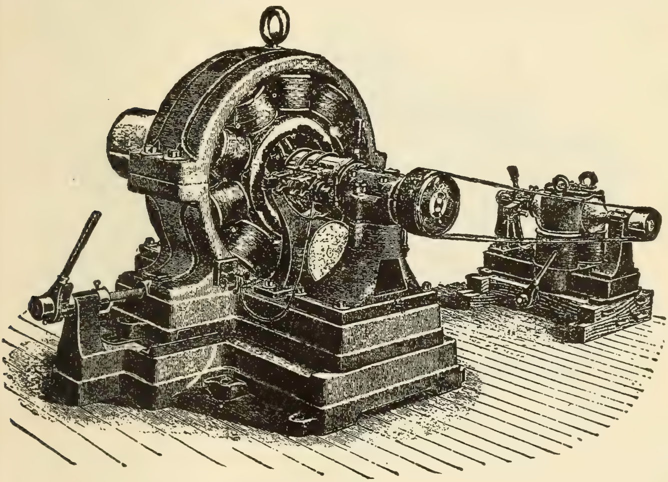


FIGURE 71.

current or by means of a resistance box connected in the fields of the exciting dynamo. This latter regulation is of course the more economical, as there would be considerable energy wasted were a resistance used in the main exciting circuit. Alternating currents are generally used where currents are to be transmitted long distances, as for instance, where power is derived from a water fall situated some distance from the point of use. Its adaptability for such work is apparent, because it can be generated at high voltages and transformed down to any voltage desired. It requires less copper to transmit it, due to the higher voltages employed. By the aid of transformers it can either be stepped up to a higher pressure or stepped down to as low a pressure or voltage as desired. Another great advantage is that, after it has been transmitted a considerable number of miles, by the aid

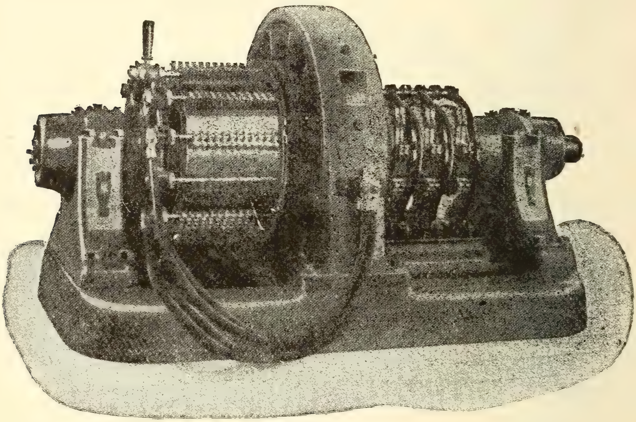


FIGURE 72.

of a rotary converter it can be converted into direct current.

Rotary transformers which transform the alternating current to a direct current are simply alternating current motors connected to direct current dynamos. Sometimes these machines are mounted on the same shaft; sometimes they are belted together, and in some cases the same windings are used for both machines; a commutator being mounted at one side of the armature from which direct current is taken while the alternating current is taken into the armature on a pair of collector rings on the opposite end of the shaft. In Fig. 72 is shown a view of a rotary transformer where the alternating current is taken in at the right, and direct current taken off at the commutator on the left.

By single phase we understand that the current flows out, gradually increasing in strength, then dying away and reversing in direction and again increasing and dying away. This action is shown by the curve in

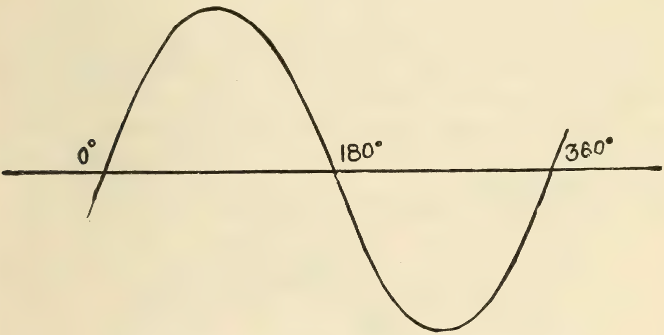


FIGURE 73.

Fig. 73. Although the single phase alternating current system is in advance of the direct current system for electrical power transmission, because permitting electrical power to be transmitted long distances at high potential, which can be readily increased or reduced by means of transformers, the single phase system is limited by the difficulty in obtaining a satisfactory self starting motor; therefore the use of the single phase current has been confined almost entirely to transmitting current for lighting. The development of the polyphase (two phase and three phase) alter-

nating systems possess all the advantages of the single phase system and at the same time permits the use of motors having not only most of the valuable features of the continuous current motors, but also some advan-

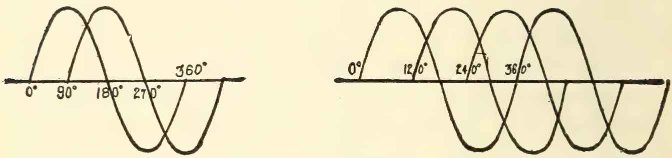


FIGURE 74.

tages over them. In the two phase system two currents displaced 90 degrees from each other and otherwise exactly similar to the single phase currents are used. In the three phase system three currents separated 120 degrees are used. These currents are shown in Fig. 74.

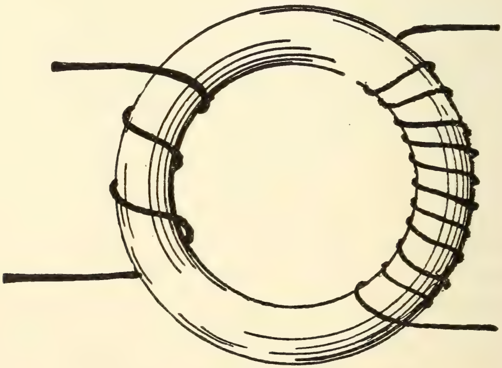


FIGURE 75.

In Fig. 75 is shown the principle upon which the transformer used in alternating current work are operated. Two separate coils of wire are wound on a ring of laminated iron. One of the coils contains a number of turns of fine wire, while the other contains only a few turns of large wire. When an alternating current is sent around the coils of fine wire, generally called the primary, a current will be induced in the coil of heavy wire, or secondary. The amount of current induced in the larger wire will be relatively greater in amperes and less in potential than that of the fine wire circuit. This ratio is almost entirely dependent upon the relative number of turns existing

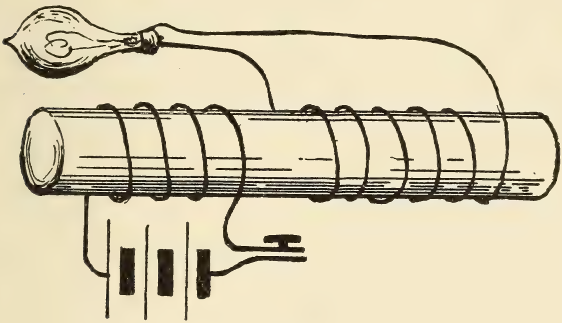


FIGURE 76.

between the large and the small wires. To illustrate, suppose we had a current of 10 amperes at a pressure of 1,000 volts in the primary, and there were ten times as many turns of wire in the primary coil as in the secondary, then we would get a current of 100 amperes at a pressure of 100 volts in the secondary coil. This same relation would hold true whatever the ratio between the number of turns on the two coils might be. In Fig. 76 is shown a core of iron having on one end a primary coil connected to a battery. On the other end of the core is another coil connected to the ends of which is an incandescent lamp. By making and breaking the battery circuit the lamp may be made to flash up, due to the great voltage induced in the secondary coil. This is a good thing to remember when working with a dynamo or motor. Do not quickly break the shunt field connection, as the increased voltage due to the current induced by the field magnet when the circuit is broken is liable to puncture the insulation and necessitate the re-winding of the field coil.

CHAPTER VIII

METERS

Volt and Ampere Meters. Two of the most important instruments used in electrical work are the voltmeter and amperemeter, the latter generally called ammeter. Classed with these instruments is a meter of an important nature called the wattmeter. We will first become acquainted with the voltmeter, which is an instrument, as its name implies, for measuring the voltage or potential or electromotive force between two wires. The general construction of this instrument is shown in Fig. 77.

In this diagram we show an instrument on the order of the Weston meter. This will serve as a good illustration that the operation of meters is very similar to the operation of motors. A permanent magnet, M, causes a magnetic flux across the air gap G, and situated in this gap is a bobbin, B, on which is wound a number of convolutions or turns of copper wire. The bobbin is made to revolve on jeweled bearings. The object of the jewel bearing is to have the instrument as much devoid of mechanical friction as possible. Two springs, S, one above and one below the bobbin, carry the current to the movable part of the meter. If the current is now caused to flow around the coil of wire, it will produce a torque or twist which will move the bobbin again the two hair springs, S. Like magnetic poles repel each other and unlike magnetic poles attract each other. The current flowing around the movable bobbin produces magnetism, and the quantity or strength of magnetism so produced is proportional to the amount of current which the pressure or voltage

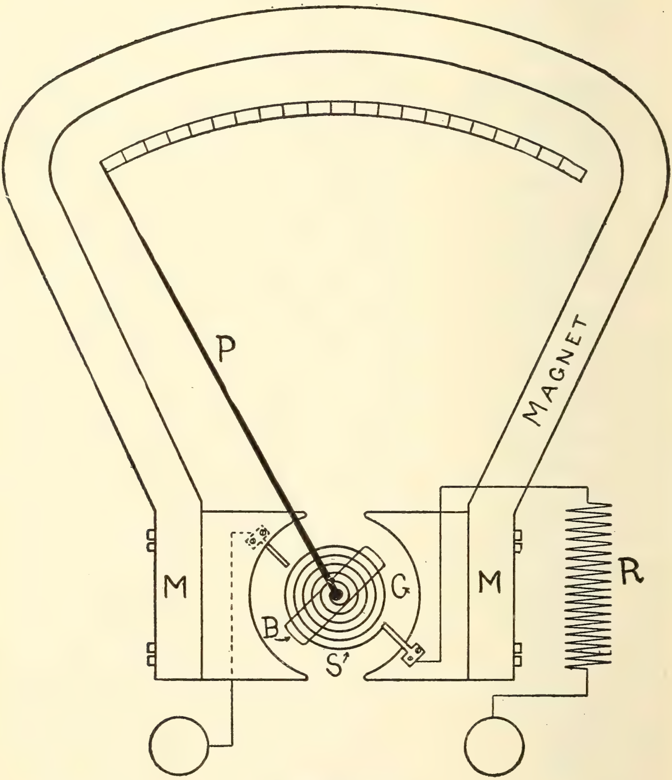


FIGURE 77.

will force through the winding of the movable bobbin so that the bobbin will continue to move until the torque exerted by the current equals the counter torque exerted by the spiral springs. A pointer, fastened to the shaft upon which the bobbin is mounted, passes over a graduated scale and indicates the pressure or volts. The capacity of this meter in volts will vary as the resistance of the wire connected in series with the bobbin varies. We will assume that we have a meter whose pointer reads from 0 to 125 volts. If we desired this same meter to read from 0 to 250 volts, we would put a resistance in the meter which would be twice as great as the one contained in the meter when reading from 0 to 125 volts. The permanent magnet of this meter is made of Tungsten steel, and this steel is artificially aged so that when the instrument leaves the factory the magnetizing power of the magnet will remain constant for a number of years. The current is brought into the instrument through the binding posts A and C, but before passing through the wire on the bobbin the current must pass over a path of very high resistance, R. This resistance is proportioned to the amount of pressure the meter is made to indicate, and in commercial construction instead of making bobbins of variable resistances, the bobbins are all made alike, and this dead resistance, R, is varied to comply with the pressure that it is to indicate with the instrument. In voltmeters used on a 500 to 600 volt circuit, this resistance will measure from 65,000 to 75,000 ohms. The current which flows through the winding on the bobbin at full voltage is very small, and when registering 110 volts amounts to about one seven-hundredth of an ampere. Since it is the number of ampere turns that produces the magnetic density in an electro magnet, it can be seen that even one seven-hundredth of an ampere, if passed around a bobbin a considerable number of times, will produce quite a strong magnetic flux and pull. Voltmeters are often referred to as being "dead beat." What is meant by dead beat is the tendency of the pointer to move from one position to another with very little or no swinging to and fro. In this type of voltmeter this dead beat effect is produced in the following manner: The core of the bobbin B being constructed of copper, when a current flows over the winding of the bobbin and causes it to revolve, eddy currents are produced in the copper (in much the same way that current is produced in the revolving armature of a dynamo), and these eddy currents tend to arrest the motion of the bobbin. In the best voltmeter construction the resistance wire used is made of a metal which will not vary much in resistance at different temperatures. It can readily be seen that, were a meter which was constructed and correctly calibrated at 70° F., surrounding temperature, mounted on switchboard in an engine-room with the temperature at 90° or 95°, the meter would not register absolutely correct, because the resistance of the wire would be considerably increased, due to the increase of the surrounding temperature. The effect of this would be a smaller flow of current at an equal voltage through the bobbin in the meter, and consequently a smaller amount of magnetism and a lower reading of the instrument.

We will assume that a copper cable of about the size of one's wrist is conducting a current of about three thousand amperes. Now, if a monkey wrench or hammer were to be lying within a few inches of this cable, before current was flowing, the monkey wrench or hammer would be attracted to the cable. The rapidity with which the monkey wrench would be attracted to the cable would be proportional to the weight of the iron in the wrench and the amount of the current flowing through the cable. This, I think, will explain an electrical phenomenon which will assist us to understand what are called the magnetic vane voltmeters and ammeters. This principle is shown in Fig. 78.

A certain amount of current passing over the path A, which consists of several turns of wire, will attract an iron form, B, mounted on the spindle with the

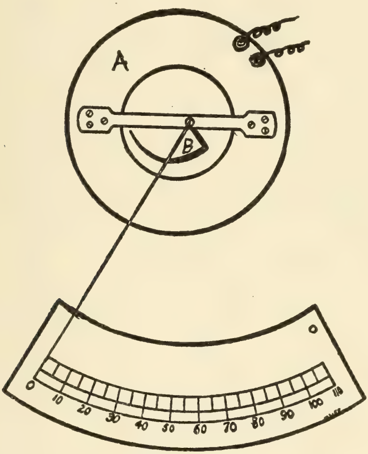


FIGURE 78.

pointer. The attraction will be proportional to the amount of current flowing over the copper conductor. The advantage of such an instrument is its simplicity, but the disadvantage is its inaccuracy. Its simplicity is apparent, and its inaccuracy is due to the residual magnetism that remains in the iron part B when the current through the conductor has been reduced. When the indicator is caused to move upward on the scale, the instrument will register practically correct, but as the flow of current over the conductor A diminishes or decreases, the residual magnetism remaining in the iron part B will have a tendency to cause it to lag back. Amperemeters are constructed on practically the same lines as explained in the construction of voltmeters, except that in ammeters the whole current to be measured passes through the coil A, this coil being made of comparatively few turns of large wire, while in voltmeters the resistance is very high. Ammeters are placed in series with one of the leads and voltmeters in shunt with the current to be measured. In some ammeters a resistance block, usually called a shunt, is employed, over which the main current is caused to flow, and the ammeter is connected to both ends of this resistance block. In this way only a very small portion of the total current is caused to flow through the ammeter. In this case a milli-voltmeter, with the scale graduated to amperes, is employed. By Ohm's law we know that the voltage is equal to the current times the resistance, E = CR. The resistance remaining constant, the voltage is proportional to the current, so that the amount of current sent through the milli-voltmeter or ammeter is exactly proportional to the current flowing through the shunt. Fig. 79 shows connections for ammeters which carry the entire current and those used with a shunt.

The object of such a construction is apparent. In the installation of the switchboard, where each ammeter registers several thousand amperes, it is not necessary to construct the large conductors in such a manner that the total current is caused to flow through the ammeter. For each 1,000 amperes passing over the shunt only about one-half an ampere will pass through the ammeter, and the little bobbin will then cause a deflection of the pointer in the meter and the pointer will register 1,000 amperes. Meters of this description are usually connected to their resistance blocks by a pair of No. 16 flexible lamp cords. When installing meters of this class, never cut off any of the

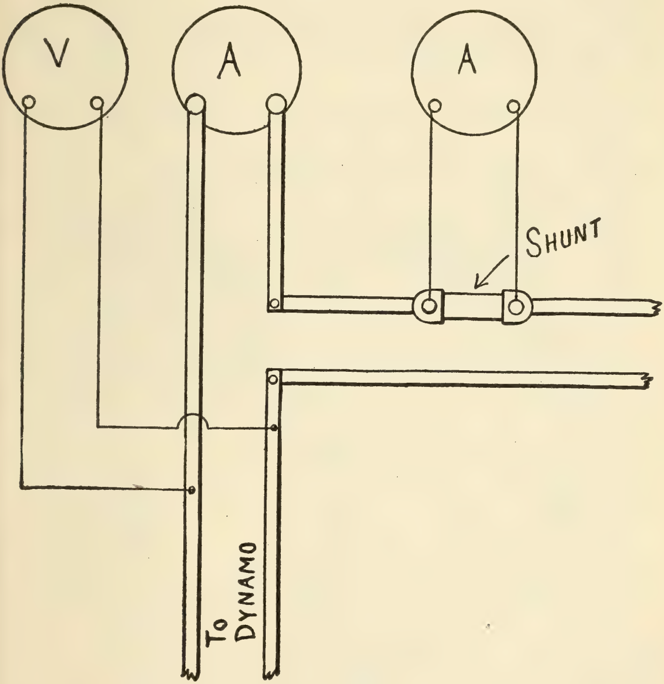


FIGURE 79.

flexible cord which is supplied with the ammeter, as the resistance of the cord becomes a part of the resistance in the meter. By cutting off some of this cord it can be readily seen that the meter will register more current than it should.

Another kind of meter is constructed on the solenoid principle, and is shown in Fig. 80. In this instrument the helix is a bare copper wire and is wound in an open coil form. It is curved in the shape of a segment of a circle, the center of which is at the pivot on which the needle is suspended. The pointer or needle is attached and projects downward to the scale. The helix is made of copper rod or is cast to the shape

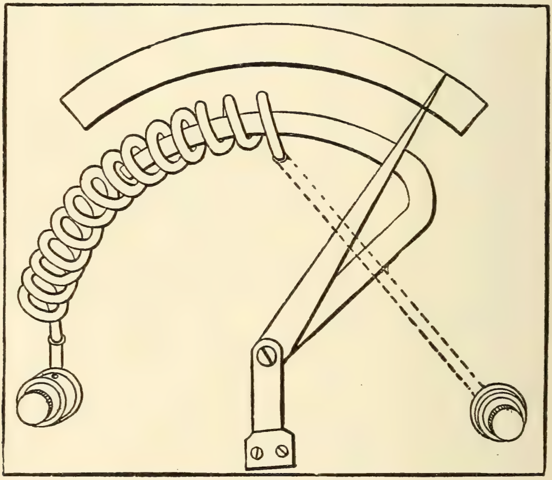


FIGURE 80.

required. Being of an open coil type, it is not necessary that it be insulated with insulating material because the air spaces between the turns becomes the insulation. Although not the best insulator by any means, there are few substances which possess better insulating qualities than air, although on account of its absorption of moisture, it becomes often a much poorer insulator than many other materials. In this type of instrument it will be seen that as the number of amperes flowing over the coil is increased it produces an increased electromagnetic pull on the iron section or core entering it. As this electro magnetic pull is

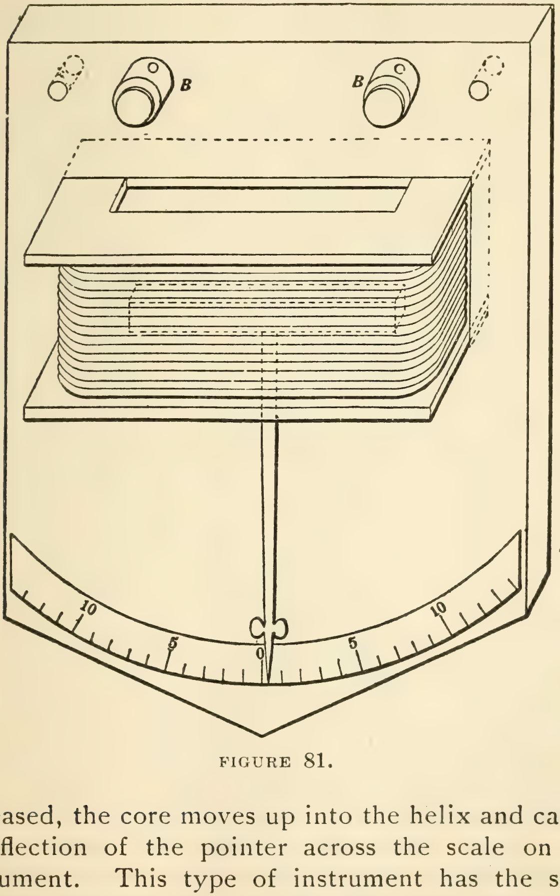


FIGURE 81.

increased, the core moves up into the helix and causes a deflection of the pointer across the scale on the instrument. This type of instrument has the same objection as that of the magnetic vane instrument, namely, residual magnetism of the iron, and hence error in the reading while the current flowing is being diminished.

Another style of simple ammeter or voltmeter is shown in Fig. 81. This instrument consists of a frame made of non-magnetic material, around which the wire is wound, the ends of the wires being connected to the binding posts. The armature of this instrument, as in all other similar instruments, is connected to the pointer, and may be constructed of several pieces of iron. The principle of its working is similar to that described above, in that the armature tends to set itself at right angles to the wire through which the current passes. This style of instrument is used where current is liable to flow in either direction.

A simple form of meter for measuring current is shown in Fig. 82. Here we have an amperemeter which consists of a strip of copper fastened to a block of wood or other insulating material, as shown at A. A piece of magnetized steel, B, to which a needle, C, is attached, swings on a pivot or shaft which is suspended at the bridge D. A scale is provided from which the number of amperes flowing can be obtained. The needle is rigidly attached to the magnetized steel B and moves with it. The action of this instrument is as follows: When a magnetized piece of steel is brought near to a conductor through which a current of electricity is passing, the magnetized steel tends to set itself at right angles to the direction of the current. The stronger the current becomes, or the more highly magnetized the piece of steel may be, the nearer to a position of right angles the armature will assume. It is not practical to use this construction of an instrument to cover a range of more than one-half of a right angle, for when the needle moves through an angle of about 50 degrees, it will require a much greater increase of current in proportion to the movement to obtain the deflection and the additional degree of the indicating needle. Such an instrument as the above may also be used to determine the direction of flow of

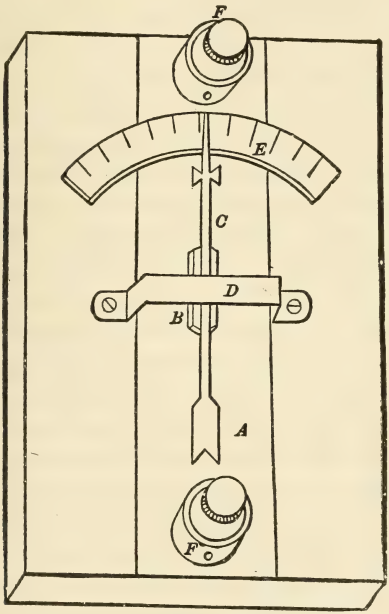


FIGURE 82.

current in a wire and is sometimes quite convenient on arc circuits which are liable to have their currents reversed either by wrong plugging of the board or the reversing of polarity in the dynamo.

Voltmeters and ammeters used with alternating currents must, of course, differ in some respects from those employed for continuous currents. Alternation of the current does not permit the utilizing of the magnetic effect of the current to the same extent or in exactly the same manner as continuous currents, but when the cores of magnets are built up of soft iron wires of small diameter, the resulting attraction between coil and core is similar, though not so strong as between a coil carrying direct current on a solid iron core.

Another type of ammeter and voltmeter used with alternating or direct current is known as the hot wire instrument. A rather long, thin platinum wire is placed in the circuit and so arranged that its elongation or expansion resulting from the heating effect of the current passing over it is made to operate a pointer mounted on a jeweled bearing. These instruments absorb but little current and are claimed to be permanently correct. This class of instrument may be used on either direct or alternating current, and when used on alternating current the frequency or alternations make no difference in the operation of the instrument. It is also unaffected by external magnetic fields, such as a neighboring dynamo or motor, and can be used close to a wire conducting current without being affected in its accuracy. When used as an ammeter it is connected in shunt with a resistance placed in the main circuit in the same manner as described for direct current ammeters, and in this way but a very small proportion of current is made to pass over the instrument. Separate resistances are also furnished with the instruments; so that by connecting these in series with the instrument they can be used over a very wide range.

Wattmeters. A few years ago, where current was sold by central stations to consumers, or in any other place where it was desirable to measure the power furnished in the form of electricity, there were several kinds of differently constructed meters used to measure the amount of current. Some of these meters were based on the chemical action of the current; the current in passing to the work depositing metal from one plate to another. The plates or terminals of the meters were weighed before being placed in the circuit and again weighed on being taken out, the amount of metal having been deposited determining the amount of current used, as explained in the fore part of the book. Of late, however, most of the recording wattmeters in use are operated on the principle of the Thomson wattmeter. As has been explained under the definition of units, the work done (watts) is equal to the current (amperes) multiplied by the electromotive force (volts), or $W = C \times E$. For a wattmeter to register correctly it must take a record of the volts and amperes.

The Thomson wattmeter is simply a small motor in which the armature is used as a voltmeter and the fields as an ammeter. The armature is wound with fine wire and is connected to a small commutator made up of metal bars. Two very thin metal brushes bear on this commutator and carry the current to and from the armature. The armature is connected across the mains in just the same way as a voltmeter would be connected. The fields are wound with a coarse wire and are connected in series with the main circuit, thus acting as an ammeter.. It can readily be seen that with the armature influenced only by the voltage, and the fields by the current passing through the mains, the two acting together will correctly measure the power supplied. As the voltage rises or lowers, the speed of the armature will be affected accordingly, and as the current through the fields varies the electromagnetic effect produced by the fields and in which the armature revolves will vary, thus also varying the speed. By reference to Fig. 83, the fields F F are connected in series with one of the mains and the armature A is

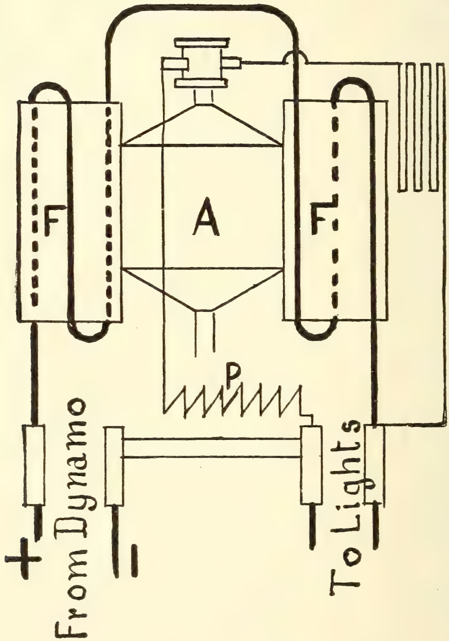


FIGURE 83.

connected across the mains. Fig. 84 is a simplified diagram. Attached to the shaft on which the armature rotates is a copper disc which revolves between the poles of a permanently magnetized steel magnet. Eddy currents are generated in this copper disc as the armature rotates, thereby acting as a brake against which the armature must work. Connected to the top of the shaft is a train work of wheels which move small pointers over the dials on the face of the instrument and record the amount of current which has passed through the meter. As no iron is used in either the armature or fields of the motor, the meter can be used on either alternating or direct current.

In Fig. 85 we show a two wire meter with the case removed.

In Fix. 86 a three wire meter is shown.

Directions for Reading Meter Dials. To correctly read the sum indicated on the dial of a recording meter, the

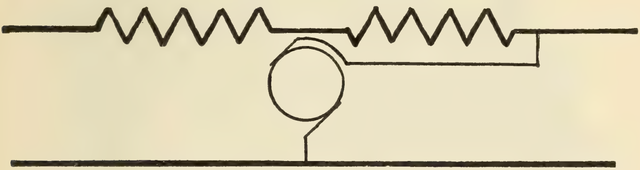


FIGURE 84.

directions given herewith should be thoroughly understood and carefully followed.

The figures (1,000, 10,000, etc.) under or over each dial refer to a complete revolution of the hand at that dial.

Therefore, each division on the dial to the extreme right indicates not one, two, three, or four thousands of units, but one, two, three, or four hundreds of units.

A complete revolution of the hand counts one thousand, and will have moved the hand on the second dial one division. Thus in reading Diagram No. 6, Fig. 87 the first dial (that on the extreme right) indicates 700, not 7,000.

A hand to be read as having completed a division, must be confirmed by the dial before it (to the right). It has not completed the division on which it may appear to rest, unless the hand before it has reached

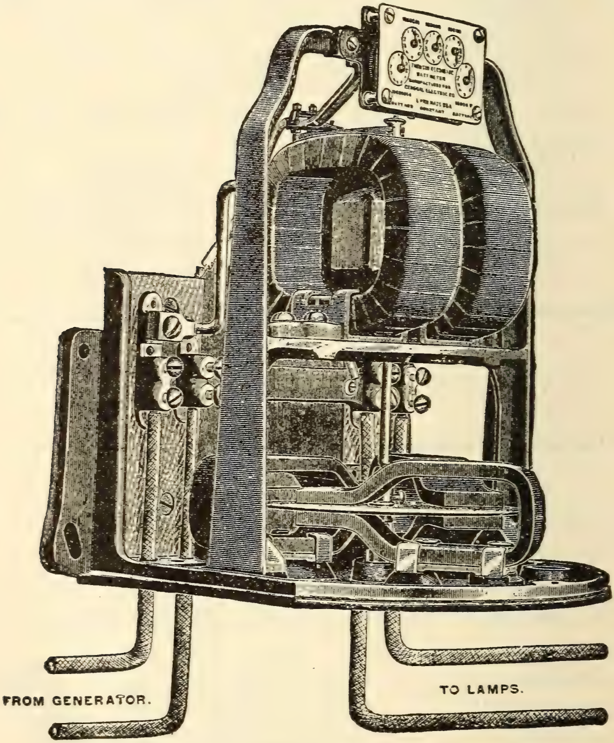


FIGURE 85.

or passed 0, or, in other words completed a revolution. For this reason it will be found easier and quicker to read a dial from right to left, as shown by reading Diagram No. 2, Fig. 87.

The first dial (the extreme right) indicates 900. The second hand apparently rests on 0, but since the first rests only on 9 and has not completed its revolution,

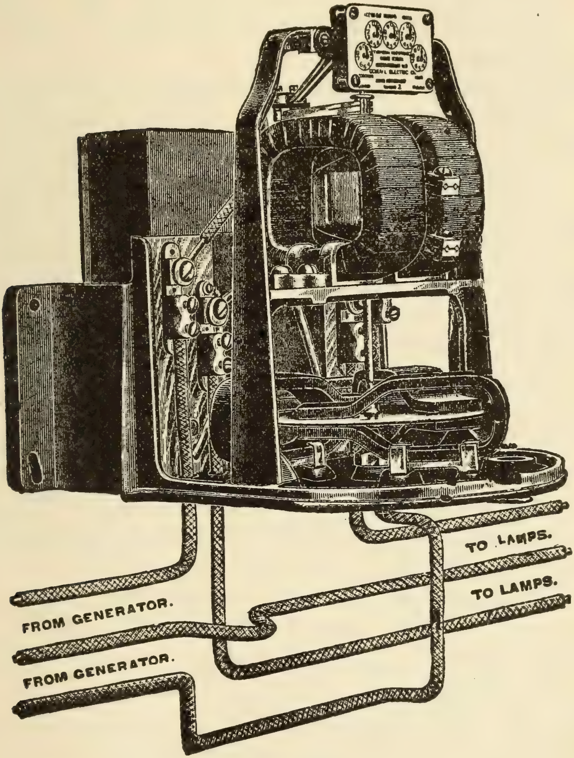


FIGURE 86.

the second dial also indicates 9. This 9, placed before the 900 already obtained, gives 9,900.

This is also true of dial 3. The second hand, at 9, has not quite completed its revolution, so the third has not completed its division, therefore another 9 is obtained, making 99,900. The same is true of dial 4, making 999,900.

The last dial (the extreme left) appears to rest on 1, but since the fourth is only 9, the last has not completed its division, and therefore reads 0. The total reading is 999,900.

The hands are sometimes slightly misplaced. In Diagram No. 8 the first diagram (the extreme right) reads 0, which gives 000. The hand of the second dial is misplaced. As the first registers 0, the second should rest exactly on a division; therefore it should have reached 8, making 8,000. The third hand is apparently on 3, but since the second hand is at 8, the third cannot have completed a division and must, therefore, indicate 2. The two remaining dials are correct, and make a total of 9,928,000.

In Diagram No. 9, the second dial hand is misplaced, for since the first indicates 1, the second should have just passed a division. As it is nearest to 8 it must have just passed that figure. The remaining three dials are approximately correct. The total indication is 9,918,100.

In Diagram No. 10, the second and fourth dial hands are slightly behind their correct position, but not enough to mislead in reading. The total indication is 9,928,300.

By carefully following these directions little difficulty will be found in reading the dial, even when the hands become misplaced.

Note whether there is a constant marked on the dial. If there is, multiply the dial reading by the constant. With constant ½, multiply by ½; that is, divide by 2.

The "constant" of a meter is the term applied when

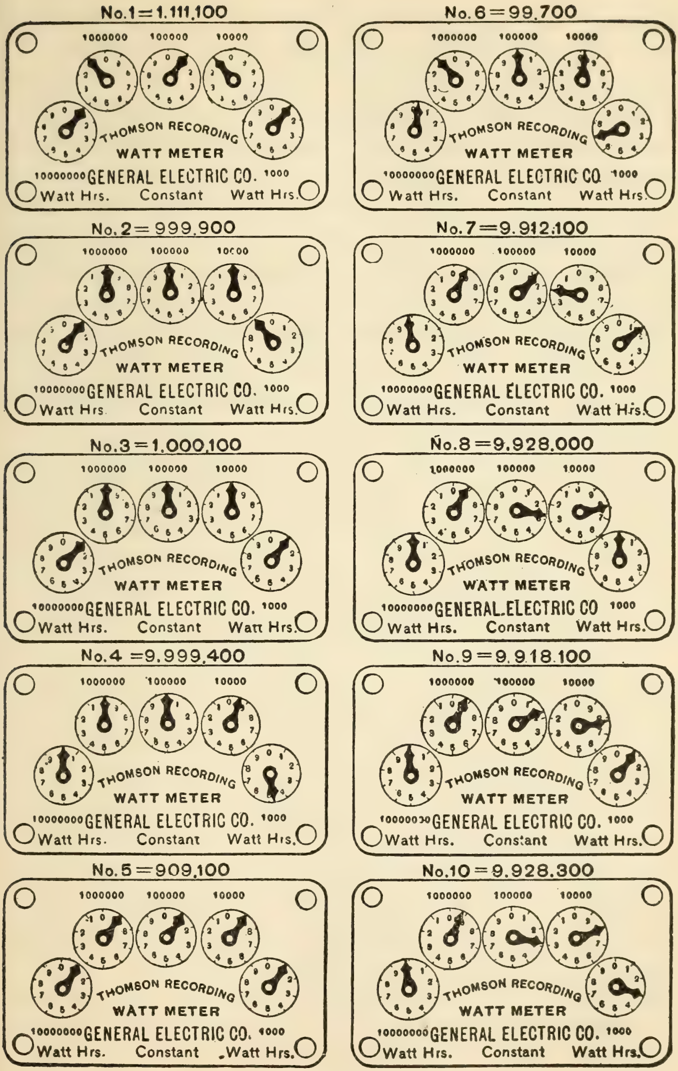

No. 1 = 1.111,100
No. 2 = 999.900
No. 3 = 1,000,100
No. 4 = 9.999,400
No. 5 = 909,100
No. 6 = 99.700
No. 7 = 9.912,100
No. 8 = 9,928,000
No. 9 = 9.918.100
No. 10 = 9.928.300
1000000 100000 10000
THOMSON RECORDING
WATT METER
10000000 GENERAL ELECTRIC CO. 1000
Watt Hrs. Constant Watt Hrs.

FIGURE 87.

the meter is constructed to run at a lower speed than what would be necessary to measure the true number of watts which has passed through it. For instance, if the constant is 2 and the meter has registered 5,000 watt-hours, then the meter having run only half as fast as it should, we multiply 5,000 by 2, which gives us 10,000 watts as the actual amount that has passed through the meter. This scheme becomes necessary in order to register a large amount of current with a meter small in bulk or size. For convenience the maker often takes a 220 voltmeter which would read the number of watts direct on the dial at 220 volts and sells it for a 110 voltmeter by marking a constant on the dial of the meter.

CHAPTER IX

Arc Lamps. The principle on which the arc lamp operates is shown in Fig. 89. Current is caused to flow from one carbon point to another through a space or gap between the carbons. The heat of the arc is sufficiently high to disintegrate the carbon and reduce it to a vapor, this vapor filling the space between the carbon points. The current passes over this space in a bow-shape path or arc, and it is from this fact that the lamp gets its name. The arc is constantly moving, and generally revolves around the carbon points. This can be easily seen by looking closely at a burning lamp through a smoked glass. After a lamp has been burning for some time on direct current the carbons assume the shape shown in Fig. 88, the upper or positive carbon assuming a cup shape, while the lower carbon generally burns to a point. This cup shape formation on the upper or positive carbon acts as a reflector to throw the light downward. The positive carbon burns away about twice as fast as the negative carbon and lamps must be trimmed accordingly. Sometimes the current feeding arc lamps (on direct current systems) becomes reversed, either through the dynamo reversing its polarity or through wrong plugging of the switchboard. The lamps will now burn "upside down," or, in other words, the bottom carbon will be the positive one. In such a case, if let go, the carbon holders or the lamp will be burned and the lamp will burn for only half the time for which it was intended, owing to the fact that the lower or negative carbon is only one-half as long as the upper or positive carbon. Such a condition can be determined by either of the following ways: See if the light is being thrown downwards. See which carbon is burning away the faster. Raise the carbons and notice the formation of the carbon tips. When the carbons are separated it will be noticed that the tip of one carbon is considerably hotter than the other and is heated a longer distance from the point; this is the positive carbon.

FIGURE 88.

The action of the arc lamp used on direct current constant current systems is shown in Fig. 89. Current passes through wire T and over the coarsely wound solenoid M, thence down to the carbon, across the arc or crater, into the negative carbon and out again on the wire T′. The regulating action is as follows: A coil M′, constructed of fine wire and of high resistance, is connected in shunt across the arc. The action of the current flowing through the solenoid M across the crater or arc produces a magnetic pull on the solenoid core A and causes a separation of the carbons. As these carbons burn away the resistance across the crater increases and a very small portion of the main current is caused to flow through the shunt coil M′. The magnetic pull of the shunt solenoid overcomes that of the series solenoid with the result that the solenoid core A is drawn into coil M′ and the upper carbon thus lowered, decreasing the gap at the arc. In this way a constant regulation is going on, tending to keep the two carbons at a uniform distance apart. The upper carbon rod is held by means of a clutch. When the carbons have burned away, so that the lowering of the solenoid does not lower them to the proper extent, the clutch is released and the carbon drops, thus feeding the lamp. Some lamps are manufactured wherein the lower carbon is positive. This causes the light emitted from the crater to be projected upwards. The arc lamp frame is supplied with a shade on which the light cast from the arc is reflected downward. The advantage of this system is to obtain a better diffusion and distribution of the light beneath the arc lamp. This lamp is not now generally used.

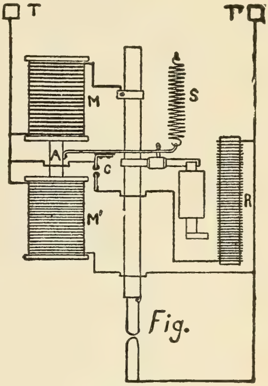


FIGURE 89.

Fig. 90 shows a diagram of connections for the improved Brush arc lamp. These lamps are used on constant current or series systems and their action is as follows:

The carbons should rest in contact when the lamp is cut out. When the switch is opened, part of the cur-

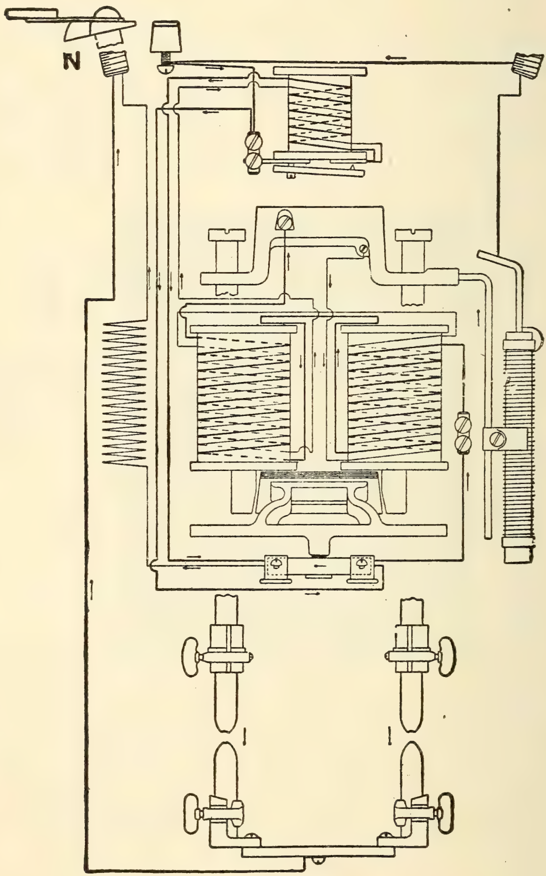


FIGURE 90.

rent from the positive terminal hook P goes through the adjuster to the yoke and thence through the carbon rod and carbons to the negative terminal hook N. The remainder of the current goes to the cutout block, but, as the cutout block is closed at first, the current crosses over through the cutout bar to the starting resistance, and so to the negative side of the lamp. A part of it, however, is shunted at the cutout block through the coarse wire of the magnets and so to the upper carbon rod and carbons and out. This shunted current energizes the magnet and so raises the armature which opens the cutout and at the same time establishes the arc by separating the carbons.

The fine wire winding is connected in the opposite direction from the coarse wire winding, and its attraction is therefore opposite. When the arc increases in length, its resistance increases, and consequently the current in the fine wire is increased. The attraction of the coarse wire winding is therefore partly overcome and the armature begins to fall. As it falls, the arc is shortened and the current in the fine wire decreases. The mechanism feeds the carbons and regulates the arc so gradually that a perfect, steady arc is maintained.

The fine wire of the magnets is connected in series with the winding of a small auxiliary cutout magnet at the top of the mechanism.

This magnet, which also has a supplementary coarse winding, does not raise its armature unless the voltage at the arc increases to 70 volts. The two windings connect at the inside terminal on the lower side of auxiliary cutout magnet, and the current from the fine wire of the main magnets passes through both windings and then to the cutout block and so to the starting resistance and out.

If the main current through the carbon is interrupted (as by breaking of the carbons) the whole current of the lamp passes through the fine wire circuit. Before this excessive current has time to overheat the fine wire circuit, it energizes the auxiliary cutout magnet, and closes a circuit directly across the lamp through the coarse wire on the auxiliary cutout to the main cutout block, and thence to the negative terminal.

The auxiliary cutout operates instantly, and prevents any danger to the magnets during the short period required for the main armature to drop and throw in the main cutout. When the main cutout operates, the armature of the auxiliary cutout falls, because there is not sufficient current in that circuit to energize the magnet.

The voltage at which the auxiliary cutout magnet operates depends on the position of its armature, which is regulated by the screw securing the armature in position. It should not be adjusted to operate at less than 70 volts.

One of the three methods of suspension may be used for Brush lamps. If chimney suspension, which is the most common, is adopted, the wire, cable or rope used to suspend the lamp must be carefully insulated from the chimney. For this purpose a porcelain insulator should be inserted between the support and the lamp, as shown in Fig. 91.

Hook suspension may be used to advantage in some places, but great care must be taken to insulate the supporting wires from any conductors, as the hooks form the terminals of the lamps.

The most convenient arrangement for indoor use is to suspend the lamp from a hanger board. The porcemain base of the hanger board prevents short circuits or grounds.

A protecting hood is not necessary for outdoor use, as the lamp chimney and its base are one casting and effectually exclude rain or snow water.

The lamps run on circuits of 6.6 amperes for 1,200 and 9.6 amperes for 2,000 nominal candlepower. In case it is necessary to run a lamp on a circuit differing from the standard, the lamp may be adjusted by moving the contact on the adjuster. About one ampere either above or below the normal may be compensated for by this means.

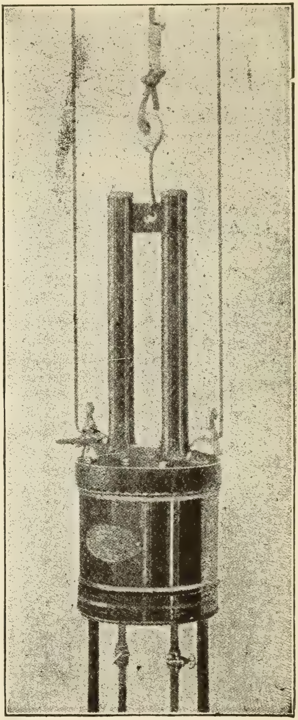


FIGURE 91.

Permanent adjustment for special circuits of variation greater than one ampere is made by filing the soft iron armature. The clutch should be so adjusted that the center of the armature is $\frac{13}{16}$ in. above the plate when the trip on the first rod is touching the bushing, and $\frac{11}{16}$ in. when the trip on the second rod is in a similar position. A small gauge is convenient for adjusting the clutch. The position of the trip of the clutch determines the feeding point of the lamp.

After thoroughly repairing and cleaning the lamp, it should be run a short time before installing. Lamps should not be tested in an exposed place, as a strong draft of air will cause unpleasant hissing which may be mistaken for some internal trouble.

Lamps should not hiss or flame if good carbons are used. A voltmeter should always be used when adjusting or testing.

The lamp terminals are marked P (positive) and N (negative) and should be connected into circuit accordingly.

The carbons should be solid and of uniform quality. For the best results, the upper carbon should be 12 in. × $\frac{7}{16}$ in., and the lower 7 in. × $\frac{7}{16}$ in. The stub of the upper carbon may then be used in the lower holder when retrimming.

At each trimming the rod should be carefully wiped with clean cotton waste. If any sticky or dirty spots appear, which cannot be readily removed with waste, use a piece of well-worn crocus cloth, always being careful to use a piece of clean waste before pushing the rod into the lamp. It should never be pushed up into the lamp in a dirty condition.

The carbon rod may be unscrewed and removed by a small screw driver or small strip of metal inserted in the slot cut in the rod cap. The cap will remain in the hole through the yoke when the rod is taken out.

In Fig. 92 an interior view of the Thomson-Houston arc lamp is shown. This lamp is also used on constant current systems.

The lamps should be hung from the hanger boards provided with each lamp, or from suitable supports of wire or chain.

As the hooks on the lamp form also its terminals, they should be insulated, where a hanger board is not used, from the chains or wires used to support the lamp.

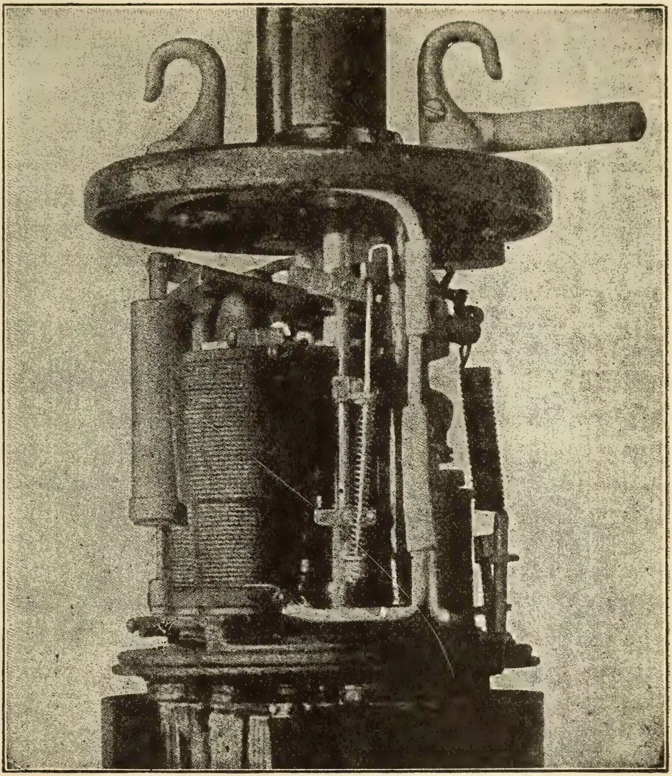


FIGURE 92.

When the lamps are hung where they are exposed to the weather, they should be covered with a metal hood, to prevent injury from rain and snow.

In such cases, care should be taken that the circuit wires do not form a contact on the metal hood and short circuit the lamp.

Before the lamps are hung up they should be carefully examined to see that the joints are free to move, and that all connections are perfect.

No lamp should be allowed to remain in circuit, with the covers removed and the mechanism exposed. Such practice is dangerous, and in violation of insurance rules.

The object of testing the lamps in the station is to find any defects, if such exist, and to test all the conditions of running before delivering them to customers. The lamps should not be hung up in their respective places in the external circuit, until everything is running with perfect satisfaction.

The tension of the clamp which holds the rod is adjusted by raising or lowering the arm at the top of the guide rod. (See Fig. 93.) If the tension is too great the rod and clutch will wear badly and the feeding will be uneven, causing unsteadiness in the lights. Too little tension will not allow the clutch to hold up the rod and any sudden jar to the lamp will cause the rod to fall and the light to go out.

The double carbon, or M lamp, should have the tension of the second carbon a trifle lighter than the first one.

When adjusting the tension, be sure to keep the guide rod perpendicular and in perfect line with the carbon rod; it should be free to move up and down without sticking.

The tension of the clutch in the D lamp should be the same as that of the K lamp. It is adjusted by tightening or loosening the small coil spring from the arm of the clutch to the bottom of the clamp stop.

To adjust the feeding point in the K lamp, press down the main armature as far as it will go, then push

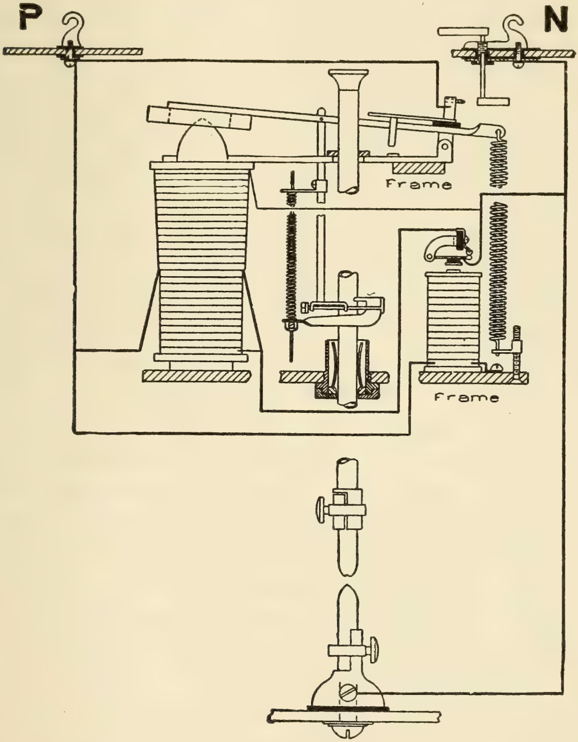


FIGURE 93.

up the rod about one-half its length, let go the armature and then press it down slowly and note the distance of the bottom side of the armature above the base of the curved part of the pole. When the rod just feeds, this distance should be ¼ in. If it is not, raise or lower the small stop which slides on the guide rod passing through the arm of the clutch, until the carbon rod will feed when the armature is ¼ in. from the rocker frame at base of pole.

To adjust the feeding point of the M lamp, adjust the first rod as in the K lamp. Then let the first rod down until the cap at the top rests on the transfer lever. The second rod should feed with the armature at a point $\frac{1}{16}$ in. higher than it was while feeding the first rod, that is, it should be $\frac{5}{16}$ in. from rocker frame at base of pole.

The feeding point of the D lamp is adjusted by sliding the clamp stop up or down, so that the rod will feed when the relative distances of the armature of the lifting magnet and the armature of the shunt magnet from rocker arm frame are in the ratio of 1 to 2. There should be a slight lateral play in the rocker, between the lugs of the rocker frame.

The armatures of all the magnets should be central with cores, and come down squarely and evenly. There should be a separation of $\frac{1}{32}$ in. between the silver contact points, when the armature of the starting magnet is down. This contact should be perfect when the armature is up. The arm for adjusting the tension should not touch the wire or frame of the lamp when at the highest point. There should be a space of $\frac{3}{32}$ in. or ⅛ in. between the body of the clutch and the arm of the clutch, to allow for wear on the bearing surfaces.

Always trim the lamp with carbons of proper length to cut out automatically, that is, have twice as much carbon projecting from the top as from the bottom holder. Always allow a space of ¼ in., when the lamp is trimmed, from the round head screw in the rod, near the carbon holder, to the edge of the upper bushing, so that there will be sufficient space to start the arc.

The arcs of the 1,200 candlepower lamps should be adjusted to 3-64 in., with full length of carbon. Arcs of 2,000 candlepower lamps should be adjusted from $\frac{1}{16}$ to $\frac{3}{32}$ in when good carbons are used.

The action of a lamp that feeds badly may often be confounded with a badly flaming carbon. The distinction can readily be made after a short observation. The arc of a lamp that feeds badly will gradually grow long until it flames, the clutch will let go suddenly, the upper carbon will fall until it touches the lower carbon, and then pick up. A bad carbon may burn nicely and feed evenly until a bad spot in the carbon is reached when the arc will suddenly become long and flame and smoke, due to impurities in the carbon. Instead of dropping, as in the former case, the upper carbon will feed to its correct position without touching the lower carbon.

In a series arc lamp the shunt coil is used to regulate the voltage over the arc. With constant potential arc lamps this shunt coil is not needed, owing to the fact that the voltage over the lamp is practically constant. Fig. 94 shows a diagram of an arc lamp for use on constant potential circuits. The upper carbon is supported by means of an iron yoke which forms a core to the two solenoids M M. Current entering binding post T passes through the windings of these two solenoids and

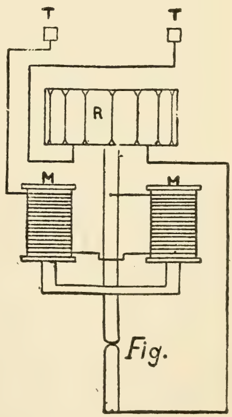


FIGURE 94.

then through the carbons and through the resistance coil R to the other terminal of the lamp. The action of the lamp is as follows: Current passing over the solenoids M M is regulated by the resistance across the arc. This current produces an electromagnetic pull on the iron core and floats, magnetically, the core and upper carbon. When the carbons burn away at the crater the distance from point to point of the carbons is increased and a corresponding increase in resistance to the flow of the current takes place. This reduces the flow of current around the solenoids and correspondingly reduces the electromagnetic pull on the core; the iron core and carbon fall a slight distance by gravity. In so doing the distance at the crater is decreased and the flow of current increased, thus increasing the flow of current around the solenoids and drawing up the core and carbons. In this way a very nice equilibrium between gravity and magnetic pull is maintained. It will be noticed that this lamp has no automatic cutout as has the constant current arc lamp. In a series arc lamp when the carbons are all consumed, the automatic cutout closes the circuit from the positive and negative binding posts of the individual arc lamp, thereby maintaining a path through the arc lamp over which the current can continue to flow to supply the remaining arc lamps in the series circuit.

The series arc, as its name would indicate, is the most simple of all lighting circuits. The lamps are arranged so that all the current from the positive pole of the dynamo goes through each, and from the last on the conductor leads back to the dynamo. The series system is more generally used where it is desired to illuminate a large district, as in street lighting. It is also used to some extent in store lighting, although the series arc is fast being replaced with the constant potential arc for this purpose.

In the low tension or constant potential arc lamp the use of a cutout mechanism is not necessary, because these lamps burn singly across the system of wiring, where a constant potential is maintained, and hence when the carbons are all consumed, current simply ceases to flow across them. In the open arc lamp the potential across the crater is usually from 45 to 50 volts, while in the inclosed arc lamp the potential across the crater is from 68 to 75 volts. This is due to the increased resistance through the crater, because of the peculiar nature of the gases emitted from the crater burning in a condition with practically no atmosphere. When such an arc lamp is connected across a 110 volt circuit, the lamp contains a resistance coil in the mechanism box over which the current must flow before producing the arc, R (Fig. 94). This resistance coil assists to reduce the pressure from 110 volts down to the pressure required by the arc or crater. If, for instance, the electromotive force across the wires supplying current to a low tension arc lamp is 110 volts and the pressure required to maintain the arc or crater is 70 volts, then the resistance coil chokes down the electromotive force from 110 to 70, or 40 volts. If the arc consumes 4 amperes of current then the loss is 4 (amperes) times 40 (volts), or 160 watts. This 160 watts is lost by heat radiating to the atmosphere from the wire of the resistance coil. The constant potential lamp is usually referred to as the low tension arc lamp. The high tension arc lamp generally burns with the arc in the open air, while the low tension lamp burns with the arc encased in a small glass bulb so arranged as to permit the upper carbon to slide into the bulb in a manner that will maintain, as near as possible, a condition whereby the arc burns in a gas containing no oxygen. The enclosed arc lamp has the advantage of burning a considerable number of hours without being recarboned or trimmed; but it also has the disadvantage that the bulb enclosing the arc turns black after burning for some time, caused by the gases emitted from the arc. This renders the bulb partially opaque, consequently imprisoning a considerable quantity of useful light. Enclosed arc lamps are also operated in series systems, and where they are so used the objection of loss due to the cutting down of the voltage (as in constant potential lamps) is overcome. Enclosed lamps are also operated on alternating current systems.

The operation of the alternating arc lamp and the mechanism in the lamp is very similar to that of the direct current arc lamp, but the magnets instead of being constructed of solid iron, are laminated in a similar manner as the system of lamination explained in the construction of armatures. These laminated cores and other parts forming the magnetic circuit in the arc lamp are necessary to avoid eddy currents. The crater has neither a cup shape on the upper carbon nor a point on the lower carbon, because current flows through the crater alternately positive and negative with each alternation. In the alternating arc lamp the upper and lower carbons burn away with almost equal rapidity, and the same quantity of light is projected upward as downward.

In Fig. 95 is shown an arc lamp with case removed. The two upper coils are the coarsely wound series coils, while the two lower coils are the finely wound shunt coils. This lamp is adapted for an enclosed arc bulb. The magnetically attracted cores are U shaped, and both cores are connected together mechanically by non-magnetic metal, such as brass or zinc, so that the magnetism set up in the shunt coils will not be affected by the magnetism set up by the series coils. This scheme is used in alternating current lamps, while in direct current lamps the cores are made of H shaped iron not laminated.

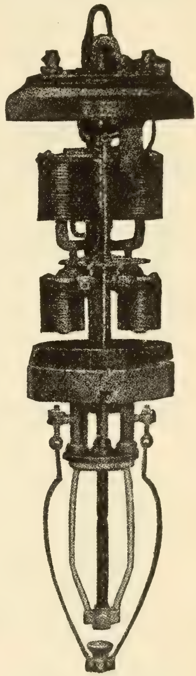


FIGURE 95

In Figs. 96 to 98 are shown three views of series enclosed alternating current arc lamps of the Western Electric Company.

Fig. 96. Side view of lamp, showing one series and one shunt spool, lever movement and adjusting weight. This weight is fastened upon a threaded rod, and the finest adjustment can be obtained by screwing the weight backward or forward. Threads can be clamped in position when the correct adjustment is obtained.

Fig. 97. Front view of lamp, showing shunt spools, supporting resist ance and cutout. Note that lever carries no current when in normal working position, but that insulated bridge forms connection across two contacts, completing cutout circuit when in position shown in cut.

Fig. 98. Rear view of lamp, showing series spool, short circuiting switch and manner of suspending dash pot. Note that the dash pot is inverted, allowing sucn

dirt as may accumulate therein to fall out rather than in the dash pot.

The three cuts show the manner of suspending the spools and their accessibility, it being possible to remove any spool by simply taking out the two screws

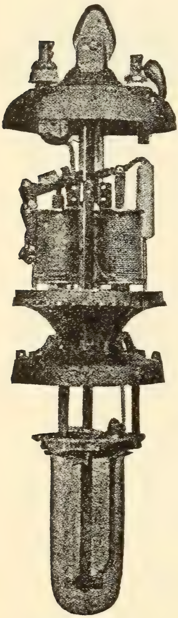


FIGURE 96.

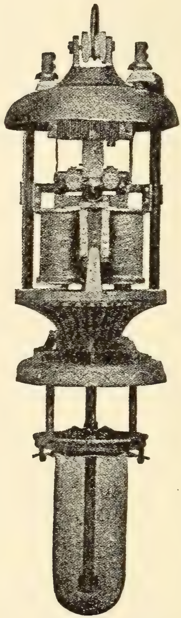


FIGURE 97.

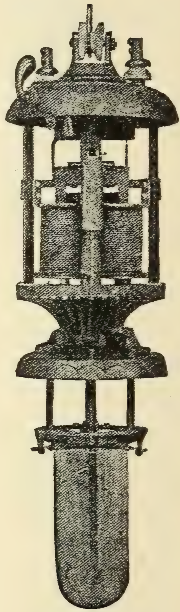


FIGURE 98.

which fasten it to the frame, and lifting it off the lower support.

The carbons used in arc lamps are extremely hard and dense. They are made from a mixture of powdered gas house coke, ground very fine, and a liquid like molasses, coal tar, or some similar hydro-carbon, forming a stiff, homogeneous paste. This is molded into rods or pencils of required size and length, or other shapes, being solidified under powerful hydrostatic pressure. The carbons are now allowed to dry, after which they are placed in crucibles or ovens, thoroughly covered with powdered carbon, either lamp-black or plumbago, and baked for several hours at a high temperature. After cooling, they are sometimes repeatedly treated to a soaking bath of some fluid hydro-carbon, alternated with baking, until the product is dense as possible, all pores and openings having been filled solid. Arc carbons are often plated with copper by electrolysis, to insure better conductivity.

It is said that one 2,000 candlepower arc lamp will light in open yards 20,000 sq. ft.; in railroad stations, 14,000 sq. ft.; in foundries and machine shops, 5 000 to 2,000 sq. ft. Where good, even illumination is desired, it is advisable to use a greater number of smaller lamps evenly distributed.

CHAPTER X

Incandescent Lamps. As nearly every one is familiar with the construction of the incandescent lamp no detailed description will be undertaken, suffice it to say that the incandescent lamp comprises a carbon filament enclosed in a glass bulb from which the air has, as far as possible, been withdrawn, the carbon filament being soldered to the ends of small platinum wires entering the glass shell. Incandescent lamps can be burned either in series or in multiple; the multiple system being the most used. Series incandescent lamps are used to a considerable extent in the smaller towns for street lighting and also for the small miniature lamps burned in series on a constant potential system and used for decorative purposes. They are also used in street car lighting.

When incandescent lamps are to be used in series, they should be carefully selected; there is quite a difference in the current consumed by different lamps, even of the same make, and when they are all limited to the same current quite a difference in candlepower may be noticeable. Some will be above their rated candlepower and others below.

The resistance of an incandescent lamp when cold is very high, varying in the ordinary 16 candlepower 110 volt lamp from 600 to 1,000 ohms. When the lamp becomes heated, as when current is passing through it, the resistance reduces considerably, being in the 16 candlepower 110 volt lamp about 220 ohms.

The current required by the various incandescent lamps varies considerably for lamps of the same voltage and candlepower, but a good average which can be used in figuring currents is ½ ampere for a 16 candlepower 110 volt lamp and ¼ ampere for the 220 volt 16 candlepower lamp. The amount of power, in watts, consumed by a lamp is equal to the voltage multiplied by the current, or $W = C \times E$. A 16 candlepower 110 volt lamp taking ½ ampere would consume $110 \times \frac{1}{2} = 55$ watts, while a 220 volt lamp taking ¼ ampere would consume $220 \times \frac{1}{4} = 55$ watts. It will thus be seen that while the current and voltage may vary, the amount of power consumed will be approximately the same for all 16 candlepower lamps. Lamps are rated at a certain number of watts per candle, the amount varying from 3 to 4 watts for 16 candlepower 110 volt lamps. The proper lamp to be used varies according to the conditions. While less power is consumed in a 3.1 watt lamp, the life of the lamp is comparatively shorter, so that the lamps will have to be renewed oftener. With a 4 watt lamp a greater amount of current is consumed, but the life of the lamp is longer. Another point of great importance in burning incandescent lamps is the voltage. The table below shows what effect variation in voltage has on the candlepower and efficiency.

An increase in voltage increases the candlepower. This increases the efficiency and shortens the life as follows:

A lamp burning at—

Normal voltage gives 100 per cent. C. P. and consumes 3.1 Watts per C. P.

1	per cent.	above	normal	gives	106	per cent.	C. P.	and	consumes	3.	Watts	per	C. P.
2	"	"	"	"	112	"	"	"	"	2.9	"	"	"
3	"	"	"	"	118	"	"	"	"	2.8	"	"	"
4	"	"	"	"	125	"	"	"	"	2.7	"	"	"
5	"	"	"	"	132	"	"	"	"	2.6	"	"	"
6	"	"	"	"	140	"	"	"	"	2 5	"	"	"

A lamp burning at normal voltage should give its full candlepower at its rated efficiency. A 3.1 watt lamp burning below its voltage loses its efficiency and candlepower as follows:

If burned—

1 per cent. below normal it gives	95 per cent. C. P. and consumes	3.2 Watts per C. P.
2 " " " " " "	90 " " " " "	3.35 " " "
3 " " " " " "	85 " " " " "	3.5 " " "
4 " " " " " "	80 " " " " "	3.6 " " "
5 " " " " " "	75 " " " " "	3.75 " " "
6 " " " " " "	70 " " " " "	4. " " "
10 " " " " " "	50 " " " " "	4.6 " " "

By referring to the table it will be seen that with the voltage raised 3 per cent. (on a 110 volt system to a little over 113 volts) the candlepower will increase 18 per cent., or in other words, a 16 candlepower lamp would be raised to nearly 19 candlepower. At the same time raising the voltage will decrease the life of the lamp. This is shown in the following table where, with an increase of 6 per cent. in the voltage, the life of the lamp is reduced 70 per cent. A lamp at normal voltage has 100 per cent. life.

The same lamp	1 per cent. above normal loses	18 per cent. life.
" " "	2 " " " " "	30 " " "
" " "	3 " " " " "	44 " " "
" " "	4 " " " " "	55 " " "
" " "	5 " " " " "	62 " " "
" " "	6 " " " " "	70 " " "

To obtain satisfactory results, the voltage should be kept constant at just the proper value.

Considerable heat is generated in an incandescent lamp, so that as a general rule it is a bad plan to use paper shades which come very close to the bulb. Where lamps are hung so that there is a liability of their coming in contact with surrounding inflammable material, such as in warehouses and store-rooms, it is a good plan to enclose the lamp in a wire guard.

The following table will prove a handy reference for estimating the number of lamps (8 to 50 C. P.) that can be run per horsepower or kilowatt. The table is figured for theoretical values, so that the actual horsepower or kilowatts delivered must be used, or else values less than those given must be used to allow for loss in the lines.

Candle-power.	Efficiency.	Total Watts.	Per Horsepower.	Per Kilowatt.
8	3.5	28	26.6	35.7
8	4	32	23.3	31.2
16	3	48	15.5	20.8
16	3.1	50	14.9	20
16	3.5	56	13.3	17.8
16	4	64	11.6	15.6
20	3	60	12.4	16.6
20	3.1	62	12	16.1
20	3.5	70	10.6	14.2
25	3	75	9.9	13.3
25	3.1	77.5	9.6	12.9
25	3.5	87.5	8.5	11.4
25	4	100	7.4	10
32	3	96	7	10.4
32	3.1	99.2	7.5	10
32	3.5	112	6.6	8.9
50	3	150	4.9	6.6
50	3.1	155	4.8	6.4
50	3.5	175	4.2	5.7

The first column gives the candlepower. The second column gives the number of watts consumed for each single candlepower obtained, and is called the efficiency of the lamp. Multiply the total candlepower by the efficiency and you get the total number of watts consumed by the lamp. The fourth column shows the number of lamps per 746 watts, and the last column the number of lamps per 1,000 watts.

The current and watts consumed by 110 volt lamps of the different candlepowers are approximately given below.

4 candlepower	..............0.18	amperes,	20 watts
8 "	..............0.29	"	32 "
16 "	..............0.5	"	55 "
32 "	..............1.0	"	110 "

The light given off by an incandescent lamp varies according to the position from which it is viewed. In some makes of lamps most of the light is given off directly downward, while in other lamps the maximum light is given off in a horizontal direction. The best lamp to use must be determined by the location of the lamp and the place where the light is required. By the use of suitable reflectors or shades the light can be thrown in any direction desired. A 16 candlepower lamp if placed seven feet above the floor will light up a floor space of 100 sq. ft., providing the walls are of a light color. If the walls are of a dull color, or if a bright illumination is desired more lamps should be used. Glass globes placed over the lamps reduce the light to a considerable extent, as is shown in the following table:

Clear glass	10	per cent.
Holophane	12	"
Opaline	20 to 40	"
Ground	25 to 30	"
Opal	25 to 60	"

CHAPTER XI

The Nernst Lamp. Very recently a new type of electric lamp has been introduced which has a few characteristics of the arc lamp and many of the characteristics of the incandescent lamp. It is a lamp that can be successfully operated only on alternating currents. That part of the lamp from which the light is emitted is called the glower. The glower performs about the same functions as does the filament in an incandescent lamp.

In Fig. 99 a diagram of a six glower lamp is shown. The six glowers are shown at 6. These glowers are in the shape of small rods and are composed of an oxide which, at the normal temperature, is of very high resistance, the resistance being so high that practically no current can flow through them. When these rods become heated, the resistance reduces considerably, so that they will conduct current. The heaters which are composed of a considerable length of fine platinum wire embedded in porcelain, are shown at 5. The action of the lamp is as follows: Current enters at 1, and being unable to flow over the glowers on account of their high resistance, passes to the cutout 4′, then through the platinum wire of the heaters back to the other side of the cutout 4. As the platinum wire in the heaters becomes heated, the glowers, which are placed directly below them, also heat up and in time their resistance becomes so reduced that current will pass through them. The current will now pass through the glowers to what is known as the ballast, 7. This ballast is composed of fine iron wire and its purpose is to steady the current through the glower. From the fact that iron wire increases in resistance with increase of current, this wire acts as a regulator, tending to cut

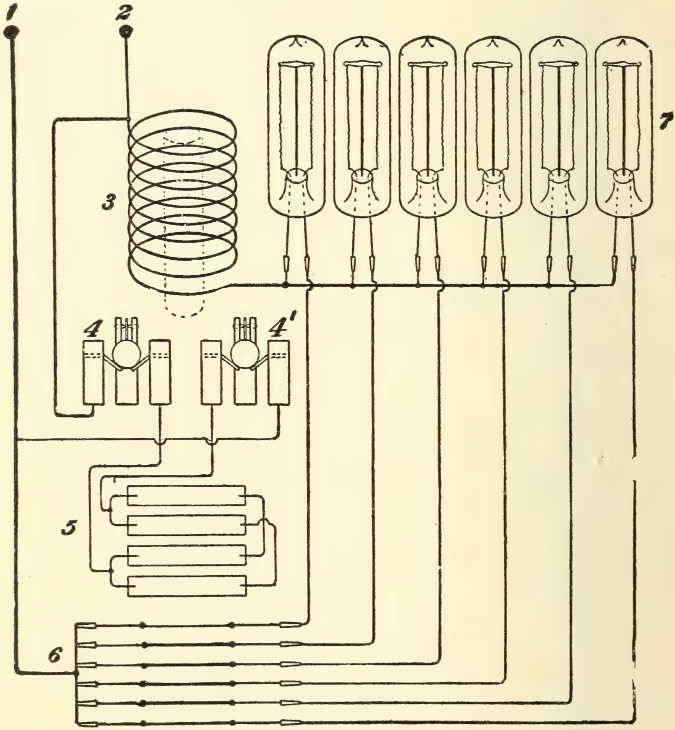


FIGURE 99.

down any fluctuations in the current strength. It will be noticed that there is a separate ballast for each glower. From the ballast the current flows around the coil of wire 3. Inside of this coil is an iron core which moves up and down, and connected to the lower end of this core are the cutouts 4,4′. As the glower becomes heated, more current is sent around this coil, until it becomes of such strength that the core is drawn in, thus opening the cutouts. All of the current will now flow through the glowers. The Nernst lamp does not operate successfully on direct current,

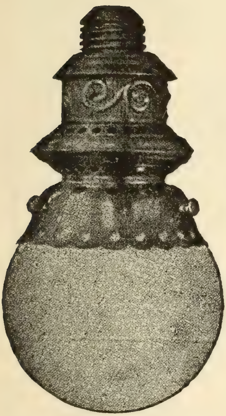


FIGURE 100.

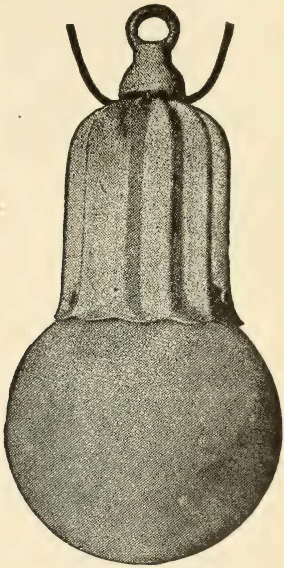


FIGURE 101.

due to the blackening of the glower caused by decomposition of the platinum contacts with which they are connected. These lamps are made in sizes of from 1 to 30 glowers, and they consume about 88 watts per glower. The light resembles very closely the light from a Welsbach gas burner, although the green tinge of the Welsbach is not present.

In Fig. 100 is shown the single glower lamp assembled, which can be inserted in an ordinary Edison socket.

In Fig. 101 the six glower lamp, with dome attached, is shown.

CHAPTER XII

Line Testing. In the operation of electric light and power circuits three principal causes of trouble are continually encountered. These are the open circuit, the short circuit, the ground, and also combinations of these, as there is nothing which prevents the existence of all three defects on any line at the same time. In order to study these properly, let us refer to Fig. 102, which shows an ordinary incandescent circuit equipped with the necessary cutout and a switch.

An open circuit may be caused by poor contact, or

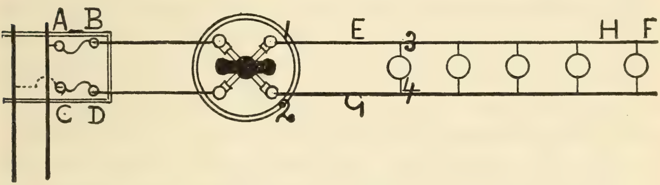


FIGURE 102.

failure to make any contact at all, of the fuse. If this is the cause, the light can be made to burn by connecting the fuse terminals A and B or C and D by means of short pieces of wire. Such wire must, however, be used only for an instant to make sure of the trouble, and proper fuses must then be provided. Another method of locating an open circuit in the fuse consists of moistening the finger tips and placing the tips of two fingers of the same hand on B and D. If the fuses are in order, a slight shock will be felt; this method is applicable only on low voltage systems and must never be used where the voltage exceeds 250.

If the fuses are found all right, the next place to look for the cause of an open circuit is at the switch. The contact points of switches are often so badly burned or covered with dirt and grease that they do not make proper connection and hence the lights will not burn.

The switch can be tested with the fingers just as we tested the cutout, and if the shock is felt the line is all right to this point. In testing the switch, be sure you test at the proper point (1 and 2) in the figure which shows a switch, the blades of which cross. Some switches make connection straight along without crossing. In testing with a wire, as shown above, be very careful not to connect the points 1 and 2 at the switch, or you will have a short circuit.

If the line is found alive at the far side (points 1 and 2) of the switch shown, and still the lights do not burn, it is quite likely that there is a broken wire between the switch and the lamps. This break in the wire is not always visible, as often the wire is entirely concealed, and even when the wire is in plain view, the break may extend only to the copper and leave the outer insulation apparently perfect.

If we are dealing with concealed wires that appear only where the lights are connected, we must first examine the connections at all such places and see whether they are in good order. If we find nothing wrong there we may proceed to locate our open circuit (which we shall assume to be at E) by the following method: In place of one of the fuses AB or CD, connect any incandescent lamp (if plug cutouts are used the lamp can be screwed in instead of the plug). Now connect a wire from 1 or 2 of the switch to 3 or 4 of the nearest lamp.

If we happen to connect our wire from 1 to 4 we shall make a short circuit and the lamp at the cutout will burn at full candlepower, but none of the other lamps will burn at all. Now disconnect the test wire from 4 and connect it at 3; if the broken wire is at E, as we have assumed, all the lights will now burn in series with the lamp in the cutout. If there are but few lights connected in the circuit, this lamp will burn at about half candlepower; if there are many lamps connected it will come nearly to full candlepower, and the lamps in the circuit will show nothing.

If instead of an open circuit the cause of our trouble is a short circuit, it will first make itself evident by a burned out fuse in the cutout at AB or CD.

A little experience will soon enable one to judge whether a burned out fuse is due to an overload or a short circuit; the damage to terminals and the evidence of burning will be much greater from a "short" than from a slight overload.

Often the current that "blows" the fuse will also burn out the wire which caused the "short," so that the line will seem perfectly clear when a new fuse is inserted.

If an inspection of the wires and apparatus does not reveal the location of the trouble, we may fuse up one side of the circuit and connect an incandescent lamp in place of the other fuse. If the "short" is still on, the lamp will burn at full candle power.

A short circuit may consist of anything of low electrical resistance that brings the wires of opposite polarity into electrical connection with each other. Thus, if the two points, F and G, although several hundred feet or even yards apart, were in connection with gas or water piping of low electrical resistance, all current would flow through the piping from F to G, and there would be none to flow through the lamps. Short circuits are also often caused by small wires inside of sockets or fixtures coming in improper contact. In one instance a short circuit which caused a search of several hours was finally located in the butt of an Edison base lamp, the center contact piece of which had been put on crooked in such a manner that when the lamp was screwed into its socket this center piece made connection with opposite poles within the socket.

If a careful examination does not reveal the "short" it will be necessary to cut the wires, say at H; if this clears the line so that all lamps nearer the cutout than H burn, the trouble must be beyond H; if not, the line must be cut again nearer the cutout until finally the exact location of the trouble is found.

Any connection of any part of an electrical circuit to *earth* is called a "ground," and wires so connected are said to be grounded. One ground on a system will not necessarily do much harm or interfere with the operation of the system. It will, however, greatly increase the probability of electric shocks to people coming in contact with any part of the wiring. Also, if there is a ground on one side of a system, the appearance of a second ground on the other side of the system will be equal to a short circuit, if both are of low resistance, and probably cause the burning out of fuses or wires.

If a ground is of high resistance, it may merely waste energy through leakage of current; or it may cause slow destruction of a wire or sometimes a gas or water pipe by electrolytic action. Aside from direct contact with metal parts of buildings, the most prolific cause of grounds is found in dampness.

Grounds may be located by means of the Wheatstone bridge, magneto or a common bell and battery. After removing the fuses from the grounded part of the system, connect one side of the apparatus to a good ground, such as a water pipe, and the other side to the system. Proceed in the same way as explained for short circuits; that is, cut the lines until the ground is located, or the line shows clear. Where the wiring is concealed and there are a number of switches controlling chandeliers, grounds can very often be located by switching off one fixture at a time, for when the grounded fixture is switched off the line will show clear.

To facilitate the discovery of grounds as soon as they come on, most switchboards are equipped with ground detectors of some kind.

The cheapest and easiest to install of these consists of two lamps in series, as shown in Fig. 103. So long

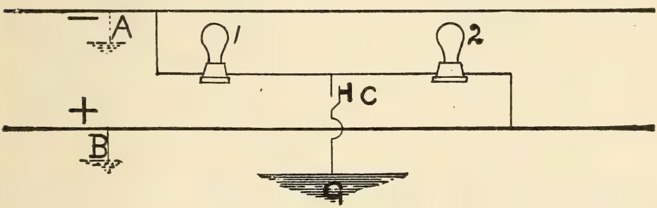


FIGURE 103.

as both sides of the system are clear of grounds, the lamps will both burn at equal candlepower (rather dim) no matter whether the buttom C be pressed or not. But should a ground come on the + wire, say at B, and the button C be then pressed, the lamp 2 will be deprived of current and lamp 1 will burn at full candlepower. In such a case the current passes from the + wire to the ground B, through the ground to C, button C and lamp 1 to the – wire. Should a ground come at A, lamp 1 would be cut out and 2 would

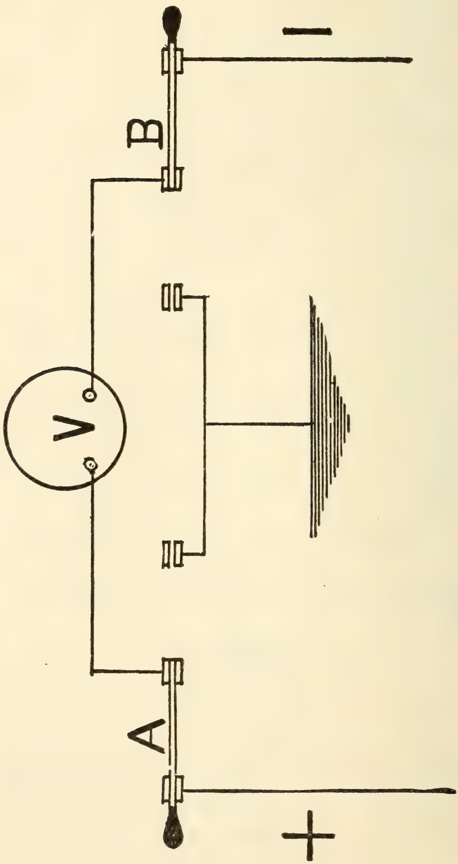


FIGURE 104.

burn at full candlepower. The great disadvantage of the lamp ground detector lies in the fact that it is not very sensitive; that is unless the ground is of quite low resistance the difference in the brilliancy of the lamps will hardly be noticeable.

A much more satisfactory arrangement is that shown in Fig. 104, where a voltmeter is connected for that purpose. With the two single pole switches A and B in the position shown, the voltmeter indicates the pressure of the dynamo; if B is thrown over, the current from the + wire passes through the voltmeter to the ground, and if there is a ground on the – wire it will indicate it. If B is thrown back and A over, a

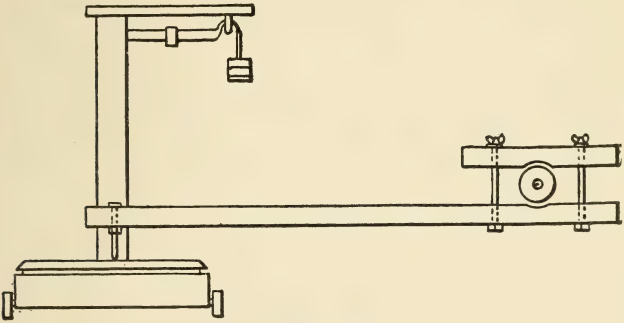


FIGURE 105.

ground on the + wire will be indicated. If the system is perfectly clear, the voltmeter will indicate nothing with either one of the switches thrown over. This test of lines and circuits should be quite frequently made.

Testing Efficiency of Dynamos and Motors. The simplest means of testing the efficiency of motors is shown in Fig. 105.

This is known as the Prony brake, and consists of a pair of clamps arranged for thumb screws and fastened to the pulley of the motor, and a set of scales.

We will assume that we are testing the efficiency of a motor. We will arrange the clamps over the pulley as shown in the figure and on the long end of the clamp we will arrange a bolt, from which we may impart the pressure obtained to the platform of a pair of scales. In the circuit supplying the motor with current we will connect an amperemeter and a voltmeter. We will now start the motor and press down on the clamps by means of the thumb screw, until the mechanical energy expended is sufficiently high to cause the desired consumption of current shown by the amperemeter at the pressure shown by the voltmeter. With a tachometer or speed indicator we will find the number of revolutions of the motor per minute. When this has been done, we will take the weights on the scales and balance the pressure brought down on the platform. Now stop the motor. The weight indicated by the scales is that weight which the motor would have revolved through a circle, the radius, or half the diameter of which is the distance from the center of the motor shaft to the center of the bolt pressing on the scale platform, Fig. 105. To find the horsepower exerted, multiply the distance between the bolt and the armature shaft by 2. This will be the diameter of the circle described. Multiply this by 3.1416. This will be the circumference of the circle described. Multiply this by the number of pounds indicated by the scales, multiply this by the number of revolutions per minute, and divide the answer by 33,000.

Suppose your amperemeter registered 50.9 amperes and your voltmeter registered 110 volts. This would be $50.9 \times 110 = 5{,}599$ watts consumed. Divided by 746 watts, the electrical horsepower would be 7½ horsepower consumed.

Suppose the dynamometer proved that you obtained six actual mechanical horsepower. Then 6 divided by 7½ would be 80 per cent. efficiency which the motor would have for changing electrical energy into mechanical energy.

To test the efficiency of a dynamo we must first find how much power is being delivered to it by the engine. This is done in the usual manner by means of the indicator, etc. Having obtained this, it is simply necessary to connect an ammeter and voltmeter and, taking simultaneous readings of both, find the power given out by the dynamo by multiplying together the volts and amperes.

As an example, suppose we have found that our engine is delivering 40 H. P. while we are obtaining from our dynamo 200 amperes at 110 volts pressure. 200 × 110 divided by 746 will give us the electrical energy we are receiving; in this case a trifle less than 29.5 H. P. To find the efficiency of the dynamo we divide the power received from the dynamo by that delivered to it by the engine, 29.5 divided by 40 equals .737, which is the efficiency of this dynamo. When testing dynamos it is usual to provide an artificial load which can be kept constant. Large metal plates, preferably copper, are connected to the positive and negative mains of the dynamo and immersed in a barrel of water. The quantity of current that will flow from one plate to the other can be regulated by dissolving more or less salt in the water and by immersing the plates more or less and also by bringing them closer together. The greater the surface of the plates immersed in the water and the nearer they are brought together, the greater will be the current. Be very careful and do not let the plates touch each other. Before accepting a new dynamo a test run of twenty-four hours at full load is usually made and the water rheostat need be used only to keep the load constant when lights are switched on or off.

Photometer. The amount of light given off by an incandescent lamp is measured in candlepower. To determine the candlepower of a lamp, an apparatus known as the photometer is used. Fig. 106 shows a diagram of what is known as the Bunsen photometer. S is a scale divided into inches, meters, or any suitable divisions, at one end of which is placed a standard lamp and at the other end the lamp to be measured.

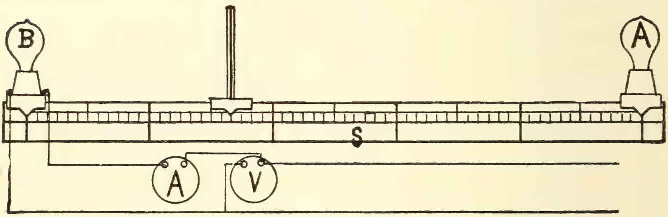


FIGURE 106.

A small screen, made of white paper having a grease spot in the center, is mounted on a stand so that it can be moved along the scale. To operate the instrument, move the screen to such a point that the grease spot becomes invisible from either side. The two candlepowers are now to each other as the squares of their distances from the screen. For instance, suppose the lamp A is a standard 16 candlepower lamp and at the point where the grease spot is invisible the distance from B to the screen is 20 in., and from A to the screen 40 in., then B is to A as 20 squared is to 40 squared, or as 400 is to 1,600 or one-fourth as great; therefore B is a 4 candlepower lamp. Care must be taken that the two lamps are burning at just the proper voltage, otherwise the comparison will not be accurate. Instruments of the kind just described are made in a variety of different patterns, but their principle remains the same. Candlepowers may also be compared by a method known as Rumford's. Take a pencil or other opaque rod and place it in front of a white piece of paper or light-colored wall. Now place

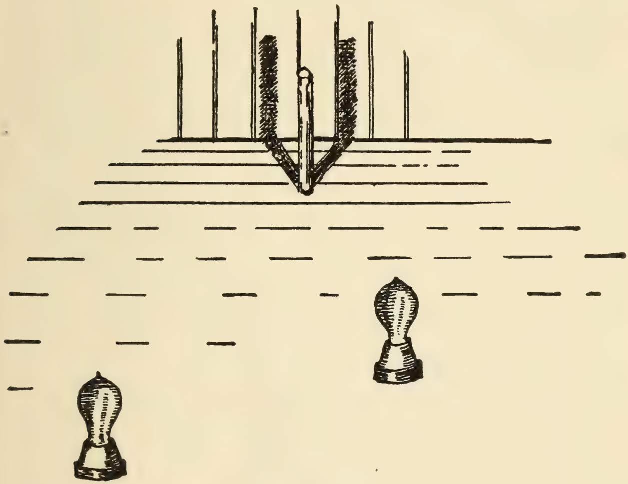


FIGURE 107.

in front of it, but separated so that there will be two separate shadows cast, the two lamps to be compared. By moving one of the lamps away from, or closer to, the screen, at some point the two shadows will become of the same density. Now measure the distances of the two lamps from the screen, and their candlepowers will be to each other as the squares of the distances; (Fig. 107).

If the current consumed by a lamp and the voltage maintained at its terminals are measured by an ammeter and voltmeter, as shown in Fig. 106, we need only find the watts (current times volts) and divide by the candlepower to find the efficiency of the lamp. If, for instance, the 4 candlepower lamp B is taking $\frac{1}{6}$ ampere at 110 volts, we have $18\frac{1}{3}$ watts expended on it; this divided by the candlepower 4 shows an efficiency of $4\frac{7}{12}$ watts per candle.

CHAPTER XIII

Storage Batteries. The storage battery is often referred to as an accumulator. An accumulator is an appliance for storing electricity. It depends upon the chemical changes undergone by certain substances when subjected to the action of an electric current. Strictly speaking, it is not correct to say that electricity is stored in an accumulator, although as far as external results is concerned such appears to be the case. What it really does is this: The current flowing into the accumulator produces a gradual chemical change or decomposition of the active elements of which the battery is constructed. This change continues to take place as long as the charging current is applied. This is known as electrolytic action. As soon as the current ceases, so also does the chemical decomposition of the elements cease, and if the terminals be then connected by a wire, a reversal of the chemical process commences. Particles gradually reform themselves into original chemical combinations, and by so doing produce a current of electricity which flows in opposite direction to that originally used for charging.

An early form of accumulator, though more of experimental than practical interest, was Grove's gas battery. This was composed of a series of cells, each cell comprising two tubes, closed at the upper ends, and dipping down into a glass jar containing acidulated water. Each tube had a platinum wire fused into the closed end, from which a strip of platinum foil extended downwards into the liquid. The outer ends of the platinum wires were provided with terminals, by means of which several of these cells were connected together. A charging current was then applied and resulted in the gradual decomposition of the water in the various glass jars. Hydrogen collected on one of the platinum plates in each of the cells and oxygen on the other. If after a short time the charging source was disconnected from the wires joined to the outer terminals of the cells and a galvanometer substituted, it was found that a current would then flow in the reverse direction until all the separated hydrogen and oxygen gases had recombined to form water again.

From a practical point of view the gas battery was deficient, inasmuch as it would only supply current for a very short time, and several workers set themselves the task of contriving an arrangement to obviate this defect. The most successful of these early workers was Plante, and he found in the course of his experiments that the best results were to be obtained by using lead plates or electrodes in a dilute solution of sulphuric acid. He made a cell by taking two long strips of sheet lead, placed one over the other with pieces of insulating material between, and coiling these up into spiral form. These plates were provided with separate terminals and were placed in a jar containing a solution of sulphuric acid. The action of the charging current was to decompose the water in the solution, the oxygen combining with the metal of the positive plate and thus forming peroxide of lead, whereas the hydrogen was simply deposited on the negative plate and there remained in gaseous form. On discontinuing the charging current, the hydrogen combined with the oxygen in the solution to form water again, while the peroxide of lead was deoxidized, the lead remaining on the surface of the plate as spongy lead, and the oxygen reëntered the solution to compensate for the oxygen which was extracted therefrom by the hydrogen in forming water. Plante found that this method of construction enabled him to get an electromotive force of from 2 to 2.5 volts, as against 1.47 volts given by Grove's gas battery.

Plante's experiments did not, however, terminate with this achievement, and he next introduced a method for considerably increasing the available metallic surface of the electrodes. This plan is known as "forming" the plates, and consists of repeating for a considerable time the following series of operations: (1) charge the accumulator, (2) discharge ditto, (3) recharge, but with the charging current entering in the reverse direction, (4) again discharge. This series of reversals in charging and discharging, if kept up for several days, has the effect of causing the lead plates to become very porous or spongy in character, and, therefore, by reason of the additional surface of contact between electrolyte and electrode thus provided, enables the cell to retain a much greater charge than it would otherwise.

It is not difficult to see that this work of forming is of a somewhat tedious and expensive character, and with the object of reducing this process to a minimum, another inventor, Faure, conceived the idea of using plates coated with a paste of lead-oxide, a plan which made it possible to use an accumulator with success after being charged only two or three times. When first introduced, some difficulty was found in making the lead-oxide paste adhere properly to the plates, and various means were devised to overcome this drawback. Scratching and indenting the lead plates was tried, but this was ultimately superseded by the plan of making perforated plates in the form of grids, the paste being pressed into the perforations. With various slight modifications, in the shape of perforations, this device has been found to answer exceedingly well, and is now very generally adopted.

When an accumulator is freshly charged, it would be found to have an electromotive force of about 2.25 to 2.5 volts, but after being used a short time this falls to about 2 volts, at which figure it remains until the cell is nearly exhausted. For many purposes, however, a higher voltage than this is required, and it then becomes necessary to have several cells joined in series, so as to give a total voltage equal to the number of cells multiplied by 2. Thus 20 cells of 2 volts each, if joined in series, would give an electromotive force of 40 volts; 50 cells would give 100 volts, and so on.

The quantity of current which a cell will accumulate or store depends upon the area of its plates; the larger the plates the greater the capacity of the cell, and the higher the permissible rate of discharge. As it is not always convenient to use very large plates where great capacity is required, the same result may be obtained by using a number of small plates to increase the available plate surface, but in such cases the plates must be connected in parallel. That is, the positive plates must all be connected to one terminal, and the negative plates all to the other terminal, thus forming practically two plates divided into a number of branches.

The capacity of an accumulator is usually measured in ampere hours. Thus an accumulator which will discharge a current of ten amperes for one hour, or of five amperes for two hours, or of one ampere for ten hours, is said to have a capacity of ten ampere hours. As a general rule, it may be estimated that an accumulator has a capacity of six ampere hours for each square foot of positive plate surface.

For charging storage batteries the shunt dynamo is generally used, and the voltage must be kept as nearly constant as possible. Fig. 108 shows a very simple installation where the battery is intended to be charged during the running time of the dynamo and to carry the lights during such time as the dynamo is not in

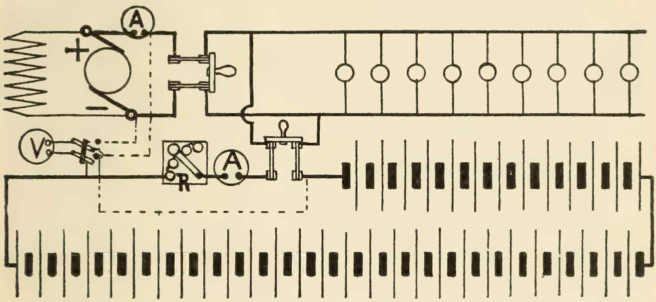


FIGURE 108.

action. The ammeter A, in the battery line, should be of a kind which indicates the direction of the current passing through it. The rheostat R is used to regulate the charging current and the voltmeter V is connected so that either the voltage of the dynamo or the battery may be taken. In addition to this voltmeter a low reading meter should also be provided to test single cells. An automatic circuit breaker is also often provided to open the circuit should the current through it flow in the wrong direction. Should, for any reason, the voltage of the dynamo fall below that of the battery while charging, the battery would begin to discharge through the dynamo. Where it is important that the voltage supplied by the battery shall be at the same voltage as that supplied by the dynamo, a "booster" is employed to help charge the battery. Such a booster increases the electromotive force at the terminals of the battery sufficient to allow it to be charged to the full pressure of the dynamo. In setting up and charging storage batteries, detailed instructions should be obtained from the makers and rigidly followed.

CHAPTER XIV

Electrolysis. Electrolysis is chemical decomposition effected by means of the flow of an electric current. By electrolytic action it is possible to deposit metals, such as gold, silver, nickel, etc., over the exterior surface of other metals. This process is ordinarily called nickel plating, gold plating, etc., and is carried on by means of tanks in which there are liquids holding in solution some of the various metallic salts. By placing over these tanks a bar or number of bars made of brass or copper, we may hang articles from these bars by means of wires, so that they are submerged in the solution. Now by using a dynamo whose output is low in pressure or electromotive force and high in quantity or amperes, and connecting the positive or outgoing terminal of this machine to a piece of metal, such as copper, nickel, gold, or silver, and submerging this metal in the liquid contained in the tank, the flow of current from this piece of gold or silver into the liquid or bath will carry with it, by electrolysis or electrolytic action, some of this gold or silver and deposit it on the articles suspended in the liquid, from the brass or copper bars to which the negative terminal of the plating dynamo is connected. The use of the bath containing metallic salts reduces the resistance from the metal to be deposited on the articles that are to be plated, which are the negative electrodes. This effects an equal deposit of metal over the entire surfaces being subjected to the electrolytic or plating action.

Where it is desired to cover such metals as steel or iron with silver or gold, it becomes necessary to subject the articles to be plated to what is called a striking bath. This striking bath consists of a system of electrolytic action as above described, where copper is first deposited over the surfaces of iron or steel. The more precious metals will distribute themselves over this copper surface more uniformly and in a finer grained manner than if the article had not been copper plated first. After the plated article has had sufficient metal deposited on its surface, it is put through a buffing and polishing process for its final finish.

Electrolysis has also been applied where it is desired to reclaim the precious metals from ores without smelting them. This method consists of immersing the ore in tanks filled with a solution. The ore receives current from the positive element of a dynamo through the liquid solution, and the metal in the ore is deposited on the negative plate in the vat, which is connected to the negative terminal of the dynamo. Thus by employing a process similar to electro plating it is possible to extract the metal from the ores in almost its pure state from the negative plate. The solution mentioned is water in which various kinds of metallic salts have been dissolved which bear a chemical relation to the metals to be extracted.

This short description will assist in explaining how electrolytic action takes place in water and gas pipes buried under the surface of the ground, when, for instance, electric railroads, operated in the vicinity are not properly constructed. In the construction of an electric street railroad or trolley line the generators are connected to the trolley wires usually at the positive terminals of the dynamos.

The current passes from the trolley line through the car to the rails and back to the negative pole of the dynamo. If the rails are not of sufficient carrying capacity, or if there is a pipe line of better carrying capacity near the rails, it is quite certain that some of the current will be carried by the pipes. Wherever the current leaves a pipe it carries some of the metal with it, and if there is much current a hole will soon be eaten into the pipe. As the pipes are mostly covered with rust, which is a partial insulator, the current will be most likely to enter and leave the pipe at some point which is comparatively bright and the electrolytic action will be concentrated at such points.

Heating by Electricity. The electric heater is simply a coil of wire through which enough current is caused to flow to produce quite an appreciable amount of heat. In the use of resistance coils for nearly all electrical purposes the function of the resistance coil is to cut down the flow of current required at some point, as for instance, where a resistance coil is used as a starting box on a motor. The flow of current across or through such a coil or coils, will produce heat, and shows one way in which electric power can be converted into heat. Another instance, if a contact is poorly made, the resistance to the flow of current offered by this contact produces heat and a consequent loss of watts. The voltaic arc in an arc lamp is another instance where resistance to the flow of current is interposed in the circuit and consequently produces heat.

The incandescent lamp is another instance where resistance is the cause of the production of heat, but, of course, in both the arc and incandescent light, the result desired is a maximum amount of light with a minimum amount of heat.

If we were to construct a coil of small wire, whose total resistance would be the same as that of another coil of large wire, it would be found that the coil of small wire would contain much less wire than the coil of large wire, both resistances being the same in ohms. Now if both these coils were connected across a circuit, we will say of 110 volts, the same amount of current would flow over both the coils, because their resistances are alike, but the smaller coil would get quite hot, while the larger coil would perhaps be just slightly warmed. The number or quantity of heat units gi en out by both coils are the same. The surface from which these heat units pass out into the atmosphere is much less in the smaller coil than in the large one, hence the smaller coil gets quite hot, sometimes even red hot. If we were to permit current to flow over this small coil and maintain its temperature at a low red heat, it would in time become oxidized by the chemical action of the oxygen in the air. To prevent this oxidization we may imbed this small coil in a porcelain cement, and after it has been properly imbedded in this cement we will put the entire coil and cement through a baking process, making the cement quite hard and sealing the wire coil from the influence of the oxygen in the atmosphere. Then we can take this coil so constructed and produce heat in a flat iron, or in a stove, in a curling iron, soldering iron, and in fact anywhere. The coil being so hermetically sealed it can also be used in chafing dishes, tea kettles, water urns, glue pots, etc. The principle of producing heat by electricity remains the same no matter where or how it is applied, the only difference necessary being in the form given to the heater coils.

Heating by electricity is quite an expensive and uneconomical proposition, and an idea can be obtained as to the quantity of current necessary to do electric heating, when we consider that in very cold weather it requires nearly as much power to operate the heaters in a street car system as it does to propel the cars.

CHAPTER XV

Lightning Arresters. Lightning arresters are needed on overhead, outdoor lines only. The simplest form of lightning arrester consists of two bare metal plates set very close together, but under no circumstances allowed to touch each other. (See Fig. 109.) One of these plates is connected to the overhead line and the other to the ground.

A sudden flow of current meets with an enormous opposition when it encounters the coils of a large electro magnet. Although the resistance of the air space between the two plates forming the lightning arrester may be several millions of ohms, it is far easier for the current to jump this air space in such a very short time as is taken up by a lightning discharge than it would be to force its way around the coils of the magnet. The reason for this is, that a current of electricity flowing through the coils of an electro magnet creates magnetism or lines of force. These lines of force cut through the coils on the magnet and in that way tend to produce a counter current, or counter electromotive force, which, for a very short time, is almost equal to the electromotive force creating it. Were the current flow to continue for any appreciable time this counter electromotive force would disappear entirely as soon as the magnetism reached its final strength.

In order, therefore, to facilitate as much as possible a lightning discharge towards the ground and away from the machinery and buildings, the wires leading from the arresters to the earth should be run in as straight a line as possible and be kept well separated from metal parts, especially iron of the building. Under no cir-

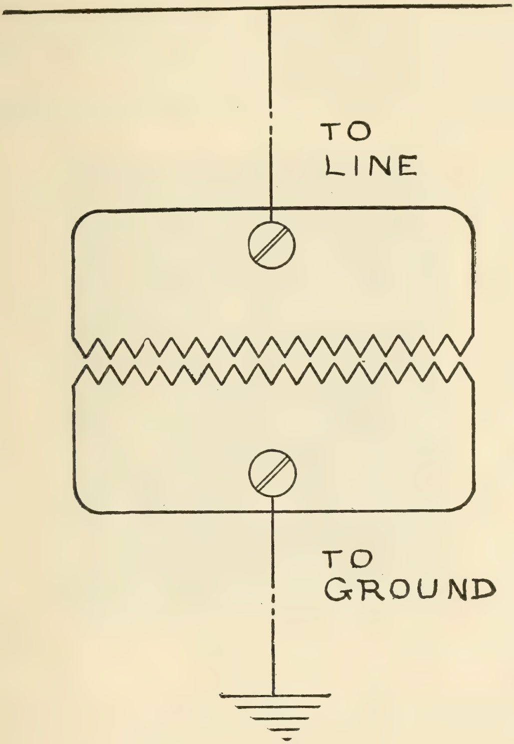


FIGURE 109.

cumstances should the ground wire be run in an iron pipe, nor should lead covered wires be used.

With the simple lightning arrester shown above there is great liability of the current from the dynamo following the arc caused by the lightning discharge to ground, and, as there must be two arresters, one on each side of the dynamo, this amounts almost to a short circuit and is very likely to put the dynamo out of service. Should such an arc continue for a few minutes, it may fuse the plates of the arrester. The arc can readily be extinguished by blowing it out or causing a strong blast of air to strike it.

To prevent trouble of this kind the Thomson light-

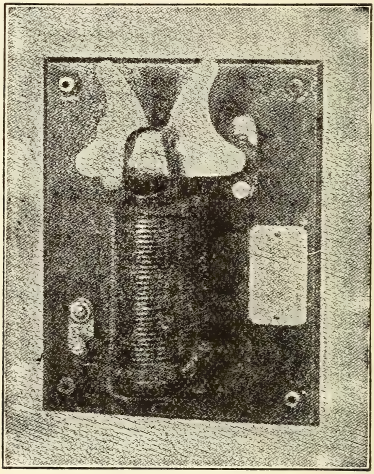


FIGURE 110.

ning arrester, shown in Fig. 110, was devised. This consists of the two diverging metal plates shown at the top of the figure, one of which is connected to the earth and the other to the line to be protected and an electro magnet, as shown. The current from the dynamo traverses the coils of the electro magnets. The action is as follows: When a lightning discharge through the arrester takes place, it forms an arc between the lower points of the plates above the magnets. These plates are very close together at the bottom. Now the electric arc is always strongly repulsed by a magnet, and hence the arc formed is forced upward where the plates diverge, and the space becomes too great for it to be maintained and it is then broken. The arc is virtually blown out by the magnetism.

EXAMINATION QUESTIONS AND ANSWERS

INTRODUCTION

The development of the science of steam engineering and the continually increasing demand for more power for manufacturing purposes and for transportation, both on land and sea, have in these modern times resulted in the creation of power plants, which are truly marvelous in their details when compared with the steam machinery of forty years ago. Even the last twenty years have witnessed tremendous developments along these lines, and we may imagine the effect it would have upon an engineer, who twenty years ago was counted as first class in his business, but who, having taken a Rip Van Winkle sleep of twenty years, is suddenly awakened and finds himself set down in the engine room of a first-class ocean steamer, or in the midst of one of our modern up-to-date power plants. The facts are, he would have hard work to recognize his surroundings. Even the steam gauges would indicate a pressure of 150 to 175 pounds more per square inch than did the old-time gauges. Therefore, in view of the remarkable improvements in steam machinery which have been made and are continually being made, it certainly behooves engineers to do their utmost to keep step with the march of progress. The author has endeavored, in the following pages, to place before his readers information in a catechetical form which will be found to cover all of the various details appertaining to the operation of modern steam plants, both stationary and marine.

C. F. S.

CHAPTER I

STEAM, HEAT, COMBUSTION, AND FUELS

Ques. 1.—What is steam?

Ans.—Steam is vapor of water.

Ques. 2.—At what temperature will water evaporate (boil) in the open air at sea level?

Ans.—212 degrees Fahrenheit.

Ques. 3.—If 1 cubic foot of water is evaporated at 212 degrees into steam at atmospheric pressure, how many cubic feet of steam will there be? In other words, what will the volume of the steam be?

Ans.—1,646 cubic feet.

Ques. 4.—Then what is the relative volume of steam at atmospheric pressure, and the water from which it was evaporated at 212 degrees?

Ans.—1,646 to 1.

Ques. 5.—What is the relative volume of steam at 200 pounds gauge pressure, and the water from which it was generated?

Ans.—132 to 1.

Ques. 6.—What is meant by the terms atmospheric pressure, gauge pressure, and absolute pressure, as applied to steam and other gases?

Ans.—The pressure in pounds exerted by the steam, or gas, on each square inch of the interior surface of the containing vessel, tending to rupture it.

Ques. 7.—What is vacuum?

Ans.—The absence of all pressure in the interior of a vessel.

Table 1, which follows, shows the physical properties of saturated steam from a perfect vacuum up to 1,000 pounds absolute pressure. It will be found convenient for reference.

TABLE 1

PROPERTIES OF SATURATED STEAM

Vacuum Inches of Mercury	Absolute Pressure Lbs. per Sq. Inch	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
29.74	.089	32.	0.	1091.7	1091.7	208,080	3333.3	.0003
29.67	.122	40.	8.	1094.1	1086.1	154,330	2472.2	.0004
29.56	.176	50.	18.	1097.2	1079.2	107,630	1724.1	.0006
29.40	.254	60.	28.01	1100.2	1072.2	76,370	1223.4	.0008
29.19	.359	70.	38.02	1103.3	1065.3	54,660	875.61	.0011
28.90	.502	80.	48.04	1106.3	1058.3	39,690	635.80	.0016
28.51	.692	90.	58.06	1109.4	1051.3	20,290	469.20	.0021
28.00	.943	100.	68.08	1112.4	1044.4	21,830	349.70	.0028
27.88	1.	102.1	70.09	1113.1	1043.0	20,623	334.23	.0030
25.85	2.	126.3	94.44	1120.5	1026.0	10,730	173.23	.0058
23.83	3.	141.6	109.9	1125.1	1015.3	7,325	118.00	.0085
21.78	4.	153.1	121.4	1128.6	1007.2	5,588	89.80	.0111
19.74	5.	162.3	130.7	1131.4	1000.7	4,530	72.50	.0137
17.70	6.	170.1	138.6	1133.8	995.2	3,816	61.10	.0163
15.67	7.	176.9	145.4	1135.9	990.5	3,302	53.00	.0189
13.63	8.	182.9	151.5	1137.7	986.2	2,912	46.60	.0214
11.60	9.	188.3	156.9	1139.4	982.4	2,607	41.82	.0239
9.56	10.	193.2	161.9	1140.9	979.0	2,361	37.80	.0264
7.52	11.	197.8	166.5	1142.3	975.8	2,159	34.61	.0289
5.49	12.	202.0	170.7	1143.5	972.8	1,990	31.90	.0314
3.45	13.	205.9	174.7	1144.7	970.0	1,846	29.60	.0338
1.41	14.	209.6	178.4	1145.9	967.4	1,721	27.50	.0363
0.00	14.7	212.0	180.9	1146.6	965.7	1,646	26.36	.0379

TABLE I—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
0.3	15	213.3	181.9	1146.9	965.0	1,614	25.90	.0387
1.3	16	216.3	185.3	1147.9	962.7	1,519	24.33	.0411
2.3	17	219.4	188.4	1148.9	960.5	1,434	23.00	.0435
3.3	18	222.4	191.4	1149.8	958.3	1,359	21.80	.0459
4.3	19	225.2	194.3	1150.6	956.3	1,292	20.70	.0483
5.3	20	227.9	197.0	1151.5	954.4	1,231	19.72	.0507
6.3	21	230.5	199.7	1152.2	952.6	1,176	18.84	.0531
7.3	22	233.0	202.2	1153.0	950.8	1,126	18.03	.0555
8.3	23	235.4	204.7	1153.7	949.1	1,080	17.30	.0578
9.3	24	237.8	207.0	1154.5	947.4	1,038	16.62	.0602
10.3	25	240.0	209.3	1155.1	945.8	998	16.00	.0625
11.3	26	242.2	211.5	1155.8	944.3	962	15.42	.0649
12.3	27	244.3	213.7	1156.4	942.8	929	14.90	.0672
13.3	28	246.3	215.7	1157.1	941.3	898	14.40	.0696
14.3	29	248.3	217.8	1157.7	939.9	869	13.91	.0719
15.3	30	250.2	219.7	1158.3	938.9	841	13.50	.0742
16.3	31	252.1	221.6	1158.8	937.2	816	13.07	.0765
17.3	32	254.0	223.5	1159.4	935.9	792	12.68	.0788
18.3	33	255.7	225.3	1159.9	934.6	769	12.32	.0812
19.3	34	257.5	227.1	1160.5	933.4	748	12.00	.0835
20.3	35	259.2	228.8	1161.0	932.2	728	11.66	.0858
21.3	36	260.8	230.5	1161.5	931.0	709	11.36	.0880
22.3	37	262.5	232.1	1162.0	929.8	691	11.07	.0903
23.3	38	264.0	233.8	1162.5	928.7	674	10.80	.0926
24.3	39	265.6	235.4	1162.9	927.6	658	10.53	.0949
25.3	40	267.1	236.9	1163.4	926.5	642	10.28	.0972
26.3	41	268.6	238.5	1163.9	925.4	627	10.05	.0995
27.3	42	270.1	240.0	1164.3	924.4	613	9.83	.1018
28.3	43	271.5	241.4	1164.7	923.3	600	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587	9.41	.1063
30.3	45	274.3	244.3	1165.6	921.3	575	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563	9.02	.1108
32.3	47	277.0	247.0	1166.4	919.4	552	8.84	.1131
33.3	48	278.3	248.4	1166.8	918.5	541	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	531	8.50	.1176
35.3	50	280.9	251.0	1167.6	916.6	520	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	511	8.19	.1221
37.3	52	283.3	253.5	1168.4	914.9	502	8.04	.1243

TABLE I—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F. In the Water h Heat-units	Total Heat above 32° F. In the Steam H Heat-units	Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
38.3	53	284.5	254.7	1168.7	914.0	492	7.90	.1266
39.3	54	285.7	256.0	1169.1	913.1	484	7.76	.1288
40.3	55	286.9	257.2	1169.4	912.3	476	7.63	.1311
41.3	56	288.1	258.3	1169.8	911.5	468	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460	7.38	.1355
43.3	58	290.3	260.7	1170.5	909.8	453	7.26	.1377
44.3	59	291.4	261.8	1170.8	909.0	446	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	439	7.03	.1422
46.3	61	293.6	264.0	1171.5	907.5	432	6.92	.1444
47.3	62	294.7	265.1	1171.8	906.7	425	6.82	.1466
48.3	63	295.7	266.2	1172.1	905.9	419	6.72	.1488
49.3	64	296.8	267.2	1172.4	905.2	413	6.62	.1511
50.3	65	297.8	268.3	1172.8	904.5	407	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	401	6.43	.1555
52.3	67	299.8	270.4	1173.4	903.0	395	6.34	.1577
53 3	68	300.8	271.4	1173.7	902.3	390	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384	6.17	.1621
55.3	70	302.7	273.4	1174.3	900.9	379	6.09	.1643
56.3	71	303.7	274.4	1174.6	900.2	374	6.01	.1665
57.3	72	304.6	275.3	1174.8	899.5	369	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	365	5.85	.1709
59.3	74	306.5	277.2	1175.4	898.2	360	5.78	.1731
60.3	75	307.4	278.2	1175.7	897.5	356	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351	5.63	.1775
62.3	77	309.2	280.0	1176.2	896.2	347	5.57	.1797
63.3	78	310.1	280.9	1176.5	895.6	343	5.50	.1819
64.3	79	310.9	281.8	1176.8	895.0	339	5.43	.1840
65.3	80	311.8	282.7	1177.0	894.3	334	5.37	.1862
66.3	81	312.7	283.6	1177.3	893.7	331	5.31	.1884
67.3	82	313.5	284.5	1177.6	893.1	327	5.25	.1906
68.3	83	314.4	285.3	1177.8	892.5	323	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	320	5.13	.1950
70.3	85	316.0	287.0	1178.3	891.3	316	5.07	.1971
71.3	86	316.8	287.9	1178.6	890.7	313	5.02	.1993
72.3	87	317.7	288.7	1178.8	890.1	309	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	306	4.91	.2036
74.3	89	319.3	290.4	1179.3	888.9	303	4.86	.2058
75.3	90	320.0	291.2	1179.6	888.4	299	4.81	.2080

TABLE I—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
76.3	91	320.8	292.0	1179.8	887.8	296	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293	4.71	.2123
78.3	93	322.4	293.6	1180.3	886.7	290	4.66	.2145
79.3	94	323.1	294.4	1180.5	886.1	287	4.62	.2166
80.3	95	323.9	295.1	1180.7	885.6	285	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	282	4.53	.2210
82.3	97	325.4	296.7	1181.2	884.5	279	4.48	.2231
83.3	98	326.1	297.4	1181.4	884.0	276	4.44	.2253
84.3	99	326.8	298.2	1181.6	883.4	274	4.40	.2274
85.3	100	327.6	298.9	1181.8	882.9	271	4.36	.2296
86.3	101	328.3	299.7	1182.1	882.4	268	4.32	.2317
87.3	102	329.0	300.4	1182.3	881.9	266	4.28	.2339
88.3	103	329.7	301.1	1182.5	881.4	264	4.24	.2360
89.3	104	330.4	301.9	1182.7	880.8	261	4.20	.2382
90.3	105	331.1	302.6	1182.9	880.3	259	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	257	4.12	.2425
92.3	107	332.5	304.0	1183.4	879.3	254	4.09	.2446
93.3	108	333.2	304.7	1183.6	878.8	252	4.05	.2467
94.3	109	333.9	305.4	1183.8	878.3	250	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	248	3.98	.2510
96.3	111	335.2	306.8	1184.2	877.4	246	3.95	.2531
97.3	112	335.9	307.5	1184.4	876.9	244	3.92	.2553
98.3	113	336.5	308.2	1184.6	876.4	242	3.88	.2574
99.3	114	337.2	308.8	1184.8	875.9	240	3.85	.2596
100.3	115	337.8	309.[illegible]	1185.0	875.5	238	3.82	.2617
101.3	116	338.5	310.2	1185.2	875.0	236	3.79	.2638
102.3	117	339.1	310.8	1185.4	874.5	234	3.76	.2660
103.3	118	339.7	311.5	1185.6	874.1	232	3.73	.2681
104.3	119	340.4	312.1	1185.8	873.6	230	3.70	.2703
105.3	120	341.0	312.8	1185.9	873.2	228	3.67	.2764
106.3	121	341.6	313.4	1186.1	872.7	227	3.64	.2745
107.3	122	342.2	314.1	1186.3	872.3	225	3.62	.2766
108.3	123	342.9	314.7	1186.5	871.8	223	3.59	.2788
109.3	124	343.5	315.3	1186.7	871.4	221	3.56	.2809
110.3	125	344.1	316.0	1186.9	870.9	220	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218	3.51	2851
112.3	127	345.3	317.2	1187.3	870.0	216	3.48	.2872
113.3	128	345.9	317.8	1187.4	869.6	215	3.46	.2894

TABLE 1—*Contiuued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
114.3	129	346.5	318.4	1187.6	869.2	213	3.43	.2915
115.3	130	347.1	319.1	1187.8	868.7	212	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210	3.38	.2957
117.3	132	348.2	320.3	1188.2	867.9	209	3.36	.2978
118.3	133	348.8	320.8	1188.3	867.5	207	3.33	.3000
119.3	134	349.4	321.5	1188.5	867.0	206	3.31	.3021
120.3	135	350.0	322.1	1188.7	866.6	204	3.29	.3042
121.3	136	350.5	322.6	1188.9	866.2	203	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201	3.24	.3084
123.3	138	351.8	323.8	1189.2	865.4	200	3.22	.3105
124.3	139	352.2	324.4	1189.4	865.0	199	3.20	.3126
125.3	140	352.8	325.0	1189.5	864.6	197	3.18	.3147
126.3	141	353.3	325.5	1189.7	864.2	196	3.16	.3169
127.3	142	353.9	326.1	1189.9	863.8	195	3.14	.3190
128.3	143	354.4	326.7	1190.0	863.4	193	3.11	.3211
129.3	144	355.0	327.2	1190.2	863.0	192	3.09	.3232
130.3	145	355.5	327.8	1190.4	862.6	191	3.07	.3253
131.3	146	356.0	328.4	1190.5	862.2	190	3.05	.3274
133.3	148	357.1	329.5	1190.9	861.4	187	3.02	.3316
135.3	150	358.2	330.6	1191.2	860.6	185	2.98	.3358
140.3	155	360.7	333.2	1192.0	858.7	179	2.89	.3463
145.3	160	363.3	335.9	1192.7	856.9	174	2.80	.3567
150.3	165	365.7	338.4	1193.5	855.1	169	2.72	.3671
155.3	170	368.2	340.9	1194.2	853.3	164	2.65	.3775
160.3	175	370.5	343.4	1194.9	851.6	160	2.58	.3879
165.3	180	372.8	345.8	1195.7	849.9	156	2.51	.3983
170.3	185	375.1	348.1	1196.3	848.2	152	2.45	.4087
175.3	190	377.3	350.4	1197.0	846.6	148	2.39	.4191
180.3	195	379.5	352.7	1197.7	845.0	144	2.33	.4296
185.3	200	381.6	354.9	1198.3	843.4	141	2.27	.4400
190.3	205	383.7	357.1	1199.0	841.9	138	2.22	.4503
195.3	210	385.7	359.2	1199.6	840.4	135	2.17	.4605
200.3	215	387.7	361.3	1200.2	838.9	132	2.12	.4707
205.3	220	389.7	362.2	1200.8	838.6	129	2.06	.4852
245.3	260	404.4	377.4	1205.3	827.9	110	1.76	.5686
285.3	300	417.4	390.9	1209.2	818.3	96	1.53	.6515
485.3	500	467.4	443.5	1224.5	781.0	59	.94	1.062
685.3	700	504.1	482.4	1235.7	753.3	42	.68	1.470
985.3	1000	546.8	528.3	1248.7	720.3	30	.48	2.082

Ques. 8.—How much pressure does the atmosphere exert upon the surface of the earth?

Ans.—14.7 pounds upon each square inch of the earth's surface.

Ques. 9.—What is understood by gauge pressure?

Ans.—Gauge pressure is the pressure over and above the 14.7 pounds atmospheric pressure.

Ques. 10.—What is absolute pressure?

Ans.—Absolute pressure is the total pressure above a perfect vacuum. It equals the sum of the gauge pressure and the atmospheric pressure.

Ques. 11.—How does pressure influence the boiling point of water?

Ans.—The higher the pressure, the higher must the temperature of the water be raised in order to cause it to boil.

Ques. 12.—In what way does pressure affect the volume of steam?

Ans.—The higher the pressure, the smaller will be the volume of the steam generated from a given weight of water.

Ques. 13.—In what light should steam be considered relative to work?

Ans.—As an agent through which heat performs the work.

Ques. 14.—What is the most important property of steam?

Ans.—Its expansive force.

Ques. 15.—What law governs this expansion?

Ans.—Boyle's law of expanding gases.

Ques. 16.—Define Boyle's law.

Ans.—The volume of all elastic gases is inversely proportional to their pressure.

Ques. 17.—What is heat?

Ans.—Heat is a form of energy which may be applied to or taken away from bodies.

Ques. 18.—Name the original source of heat, at least for this planet.

Ans.—The sun.

Ques. 19.—How was this heat made available for man's use?

Ans.—By being stored up in oil, wood, and the coal formations millions of years ago, by the rays of the sun.

Ques. 20.—What is the relation of heat to matter?

Ans.—All matter is charged with heat in a greater or less degree, depending upon the nature of the matter.

Ques. 21.—What is the specific heat of any substance?

Ans.—The ratio of the quantity of heat required to raise a given weight of that substance 1 degree in temperature, to the quantity of heat required to raise the same weight of water 1 degree in temperature, the water being at its maximum density, 39.1 degrees.

The following table gives the specific heat of different substances in which engineers are most generally interested:

TABLE NO. 2

Water at 39.1 degrees Fahrenheit	1.000
Ice at 32 degrees Fahrenheit	.504
Steam at 212 degrees Fahrenheit	.480
Mercury	.033
Cast iron	.130

TABLE NO. 2—*Continued*

Wrought iron	.113
Soft steel	.116
Copper	.095
Lead	.031
Coal	.240
Air	.238
Hydrogen	3.404
Oxygen	.218
Nitrogen	.244

Ques. 22.—What is sensible heat?

Ans.—Heat imparted to a body, and warming it. Sensible heat in any substance can be measured in degrees of a thermometer.

Ques. 23.—What is latent heat?

Ans.—Heat given to a body and not warming it; that is, the heat that is not shown by the thermometer.

Ques. 24.—Is the heat lost that thus becomes latent?

Ans.—It is not. On the contrary, it was required to produce the change in the body from the solid to liquid, or from the liquid to the gaseous state. For instance, in the transformation of ice into water, 180 degrees of heat becomes latent, and in changing the water into steam at atmospheric pressure 965.7 degrees of heat become latent.

Ques. 25.—What is the first law of thermo-dynamics?

Ans.—Heat and work are mutually convertible; that is, a certain amount of work will produce a certain amount of heat, and the heat thus produced will, by its disappearance, if rightly applied, produce a fixed amount of mechanical energy.

Ques. 26.—How is heat measured with relation to work?

Ans.—By the thermal unit.

Ques. 27.—What is a thermal unit?

Ans.—It is the quantity of heat required to raise the temperature of one pound of pure water one degree, or from 39 degrees, its temperature of greatest density, to 40 degrees.

Ques. 28.—What is the mechanical equivalent of heat?

Ans.—The mechanical equivalent of heat is the energy required to raise a weight of 778 pounds one foot high, or a weight of one pound 778 feet high; in other words, 778 foot pounds. This amount of energy is stored in one thermal unit, or heat unit.

Ques. 29.—In how many ways is heat transmitted?

Ans.—In two ways:—First by conduction; second, by radiation.

Ques. 30.—What is conduction of heat?

Ans.—Conduction is the transmission of heat from one body to another in direct contact with it.

Ques. 31.—Are all bodies equally good conductors of heat?

Ans.—No. The best conductors of heat are the metals, silver, copper, tin, steel, lead. The poorest conductors, or nonconductors, as they are termed, are hair, wool, straw, wood, liquids, and "dead" air, that is, air not in circulation.

Ques. 32.—What is radiation of heat?

Ans.—Radiation is the transmission of heat from one body to another through an intervening space between the bodies.

Ques. 33.—How is the heat in the furnace or fire-box of a boiler transmitted to the water in the boiler?

Ans.—By radiation and conduction through the heating surface of the boiler.

Ques. 34.—What is combustion?

Ans.—Combustion is the chemical union of the carbon and hydrogen of the fuel with the oxygen of the air.

Ques. 35.—What is one of the main factors in the proper combustion of fuels, especially coal?

Ans.—A proper supply of air.

Ques. 36.—What is the principal constituent of coal, oil, and most other fuels?

Ans.—Free or fixed carbon.

Ques. 37.—Are there other combustibles in fuels?

Ans.—Yes; hydrocarbons, a chemical combination of carbon and hydrogen in different ratios.

Ques. 38.—State the composition of air.

Ans.—By volume, 21 parts oxygen and 79 parts nitrogen; by weight, 23 parts oxygen and 77 parts nitrogen.

Ques. 39.—In what proportion do the atoms of carbon and hydrocarbons combine with the atoms of oxygen to form perfect combustion?

Ans.—One atom of carbon combines with two atoms of oxygen, expressed by the chemical symbol CO^2.

Ques. 40.—In the process of combustion, which combustible burns first?

Ans.—When fresh fuel is added to the fire, the hydrocarbons distill in the form of gas, and if the conditions of draught, admission of air, etc., are right, this gas will ignite and burn during its passage through the furnace and combustion chamber; otherwise it passes out of the stack in the form of smoke.

Ques. 41.—What are the common products of combustion?

Ans.—First, carbonic acid, resultant from the chemical union of one atom of carbon with two atoms of oxygen (symbol CO^2); second, water vapor, resultant from the chemical union of two portions of hydrogen, and one portion of oxygen (symbol H^2O); third, inert gases, like nitrogen, also unassociated oxygen, ash, and other products, due to the impurities contained in the coal, or other fuel.

Ques. 42.—In what form does the fixed carbon appear during the process of combustion?

Ans.—After the hydrocarbons have left it, the fixed carbon appears in the form of a glowing mass of coke, uniting with the oxygen to form carbonic acid, and all the heat stored in the carbon is liberated, provided the supply of air is correct; otherwise carbon monoxide (symbol CO) is formed, and only about one-third of the stored heat is liberated, the larger portion of the carbon passing off in the form of soot and smoke.

Ques. 43.—How many thermal units are contained in one pound of carbon?

Ans.—14,500 thermal units.

Ques. 44.—Theoretically, how much air is required for the complete combustion of one pound of coal?

Ans.—By weight, 12 pounds; by volume, 150 cubic feet.

Ques. 45.—Is this law carried out in practice?

Ans.—It is not; a much larger quantity of air (20 to 24 pounds per pound of coal) being supplied in order to insure that all the atoms of carbon may find oxygen.

Ques. 46.—In what two ways is the air supplied to boiler furnaces?

Ans.—First, by natural draught; second, by artificial or forced draught.

Ques. 47.—What causes natural draught?

Ans.—The air in the furnace and uptake becomes heated and consequently much lighter in weight than an equal column of outside air. The heated air is therefore continually rising and passing out of the funnel or smoke-stack, while the outside air rushes into the ash-pit and up through the grates to replace it.

Ques. 48.—How many systems of artificial or forced draught are there?

Ans.—There are two principal systems: First, that in which the air is forced directly into the ash-pits, through conduits leading directly from the fan, or other source of the blast; second, that in which the air is forced directly into the fire-room or stoke-hole, which is made air-tight for this purpose, and from thence the air finds its way into the furnaces on the same principle as when natural draught is employed.

Ques. 49.—Mention the two most important factors in the regulation of combustion.

Ans.—First, the draught; second, the kind and quality of the fuel.

Ques. 50.—What is meant by the expression "rate of combustion?"

Ans.—The rate of combustion means the number of pounds of fuel burned per square foot of grate surface per hour.

Ques. 51.—What are the usual rates of combustion with natural draught?

Ans.—For stationary boilers with shaking grates, from 12 to 18 pounds of coal per hour; for marine boilers, from 15 to 25 pounds.

Ques. 52.—What are the rates of combustion with artificial or forced draught?

Ans.—For stationary boilers, 25 to 35 pounds; for marine boilers, 20 to 50 pounds.

Ques. 53.—How should the air-supply be regulated in order to bring about complete combustion?

Ans.—Complete combustion can be secured only when the air is brought into direct contact, not only with the fuel, but also with the gases as they develop. If the air passing into the furnace above the fuel is first heated, much better results can be attained.

Ques. 54.—Why is it desirable to admit air (heated if possible) above the fire?

Ans.—In order to supply to the hydrocarbons the oxygen necessary to their complete combustion.

Ques. 55.—What will be the result if the supply of oxygen above the fire is not sufficient?

Ans.—A portion of the hydrocarbons will pass off unburned, and of other portions, only the hydrogen is burned, leaving the carbon to pass off as soot or smoke.

Ques. 56.—State another reason why the air should be admitted above the fire.

Ans.—If carbon monoxide (CO) has been formed in the combustion of the fixed carbon, the air above the fire would burn this into carbonic acid, thereby liberating a large additional amount of heat.

Ques. 57.—What is indicated by the formation of much smoke and soot?

Ans.—Incomplete combustion, as smoke and soot are simply unoxydized particles of carbon.

Ques. 58.—Is a high furnace temperature conducive to good combustion?

Ans.—It is; because the hydrocarbons unite with the oxygen much more quickly, and the fixed carbon also is much more completely united with oxygen in a high temperature.

Ques. 59.—Mention a very efficient agency for maintaining a high furnace temperature.

Ans.—Fire-brick arches and bafflers, for the gases to impinge against.

Ques. 60.—Assuming that good combustion is taking place in the boiler furnace, what will be the furnace temperature?

Ans.—From 2,500 to 3,000 degrees Fahrenheit.

Ques. 61.—What are the fuels most commonly used in boiler furnaces?

Ans.—Coal, wood, and oil.

Ques. 62.—What per cent of volatile matter is contained in most of the coals used in the marine service?

Ans.—About 20 per cent.

Ques. 63.—What are the advantages of fuel oil?

Ans.—Greater evaporative power for same weight and bulk, ease of manipulation, perfect control of the combustion to suit requirements of service, and cleanliness.

Ques. 64.—What are the principal objections to the use of oil as fuel for boilers?

Ans.—First, certain dangers involved in storing and using it; second, limited supply.

Ques. 65.—State the difference between the heating value of a pound of bituminous coal and a pound of wood.

Ans.—One pound of coal will evaporate from 8 to 9 pounds of water; one pound of wood will evaporate from 2½ to 3½ pounds of water.

Ques. 66.—What are the two principal kinds of coal used as fuel for boilers?

Ans.—First, anthracite or hard coal; second, bituminous or soft coal.

Ques. 67.—State the composition of hard coal.

Ans.—

*Carbon	per cent	91.05
Volatile matter	"	3.45
Moisture	"	1.34
Ash	"	4.16
		100.00

Ques. 68.—State the composition of the best soft coals.

Ans.—

†Fixed carbon	per cent	75.02
Volatile matter	"	20.34
Moisture	"	.61
Ash	"	3.47
Sulphur	"	.56
		100.00

*Thurston. †Kent.

Ques. 69.—Does this analysis apply to all bituminous coals?

Ans.—No; some of the poorer kinds run as low as 40 per cent in carbon, 32 per cent in hydrocarbons, and 12 per cent in ash.

Ques. 70.—How do these impurities affect the value of coal as a fuel?

Ans.—The mineral combination of sulphur and iron affects the keeping qualities of some coals. Ashes and mineral substances form clinkers on the grate bars by fusing together, thereby greatly impeding the passage of air through the fire.

TABLE NO. 3

ANALYSIS OF COAL FROM DIFFERENT STATES.

State	Kind of Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Pennsylvania	Youghiogheny	1.03	36.49	59.05	2.61	0.81
"	Connellsville	1.26	30.10	59.61	8.23	0.78
West Virginia	Quinimont	0.76	18.65	79.26	1.11	0.23
"	Fire Creek	0.61	22.34	75.02	1.47	0.56
E. Kentucky	Peach Orchard	4.60	35.70	53.28	6.42	1.08
"	Pike County	1.80	26.80	67.60	3.80	0.97
Alabama	Cahaba	1.66	33.28	63.04	2.02	0.53
"	Pratt Co.'s	1.47	32.29	59.50	6.73	1.22
Ohio	Hocking Valley	6.59	35.77	49.64	8.00	1.59
"	Muskingum "	3.47	37.83	53.30	5.35	2.24
Indiana	Block	8.50	31.00	57.50	3.00	
"	"	2.50	44.75	51.25	1.50	
W. Kentucky	Nolin River	4.70	33.24	54.94	11.70	2.54
"	Ohio County	3.70	30.70	45.00	3.16	1.24
Illinois	Big Muddy	6.40	30.60	54.60	8.30	1.50
"	Wilmington	15.50	32.80	39.90	11.80	
"	" screenings	14.00	28.00	34.20	23.80	
"	Duquoin	8.90	23.50	60.60	7.00	

Ques. 71.—How is coal measured?

Ans.—Usually by weight in pounds or tons. For storage purposes between 42 and 44 cubic feet per ton of 2,240 pounds are allowed.

Ques. 72.—What is the heating value in thermal units of one pound of bituminous coal?

Ans.—12,000 to 14,500 thermal units, depending upon the quality of the coal.

Ques. 73.—What is the average composition of wood?

Ans.—About 50 per cent of carbon, 40 per cent of oxygen, some hydrogen, and about 1 per cent of ash.

Ques. 74.—What is the average heating value of wood expressed in thermal units?

Ans.—From 6,000 to 8,000 thermal units per pound.

Ques. 75.—What woods are generally used for fuel?

Ans.—Hickory, oak, beech, pines, and firs.

Ques. 76.—What are the principal disadvantages in the use of wood as a fuel for steam boilers?

Ans.—First, a limited supply; second, great bulk in comparison to its heating value.

Ques. 77.—State the composition of fuel oil.

Ans.—Fuel oil contains about 86 per cent of carbon, 13 per cent of hydrogen, and 1 per cent of oxygen.

Ques. 78.—What is the heating value of fuel oil?

Ans.—20,000 to 22,000 thermal units per pound of oil.

Ques. 79.—What are the relative heating values of coal and wood?

Ans.—One pound of coal is equal to 2½ pounds of wood.

Ques. 80.—What is the best all-around fuel, with high heating value, and at reasonable cost?

Ans.—Coal. It is easily obtainable very nearly everywhere; it is safe to handle, and has small bulk in proportion to its heating value.

CHAPTER II

THE BOILER.

Ques. 81.—What are the leading types of boilers in use at the present day in the stationary and marine service?

Ans.—First, fire-tube boilers; second, water-tube boilers.

Ques. 82.—In what respect do they differ?

Ans.—Fire-tube boilers have the hot gases inside the tubes and the water surrounding them, while in water-tube boilers the water is inside the tubes and the hot gases and flame are on the outside.

Ques. 83.—Are boilers classified in any other way?

Ans.—Yes; low-pressure boilers, in which 55 to 60 pounds is the limit, and high-pressure boilers, carrying from 150 to 300 pounds pressure.

Ques. 84.—What are the most common forms of fire-tube boilers?

Ans.—First, the horizontal tubular boiler; second, the vertical tubular boiler; third, the Scotch boiler; fourth, the flue and return tube boiler; fifth, the Western river boiler.

Ques. 85.—Describe the horizontal tubular boiler.

Ans.—It consists of a cylindrical shell, having tubes of from 2 to 4 inches in diameter extending from head to head. There is usually a dome on top, and the boiler is set in brickwork, having the furnace underneath. The heated gases pass first under the boiler, and then return through the tubes to the breeching or uptake leading to the stack.

Ques. 86.—What are the leading features of the vertical tubular boiler?

Ans.—A cylindrical shell, having the fire-box or furnace in its lower end. The bottom ends of the tubes are expanded into the tube-sheet of the fire-box, and the top ends of the tubes are expanded into the top head of the boiler, and conduct the gases directly to the stack.

Ques. 87.—Are the tubes entirely submerged in this class of boilers?

Ans.—Not in all cases. Some forms of vertical boilers have a submerging chamber above the upper tube-sheet. This allows of a steam space above the top ends of the tubes, surrounding the smoke uptake, or smoke flue leading to the stack. The tubes are thus entirely submerged. In the flush-tube boiler the steam and water space is below the upper tube-sheet or head of the boiler, thus leaving the upper portion of the tubes surrounded only by steam.

Ques. 88.—Describe the Scotch boiler.

Ans.—The Scotch boiler may be made either single-ended or double-ended. The shell is cylindrical, with flat heads. The diameters range from 10 to 15 feet, and in some cases even 20 feet, with a length of from 7 to 11 feet. The Scotch boiler is horizontal, and is provided with two or more large corrugated furnace flues, placed near the bottom of the boiler, and extending from the front head to the combustion chamber in the rear.

Ques. 89—What is the diameter of these corrugated flues?

Ans.—From 3½ to 4½ feet, depen ng upon the size of the boiler.

Ques. 90.—How are these furnace flues secured in the boiler?

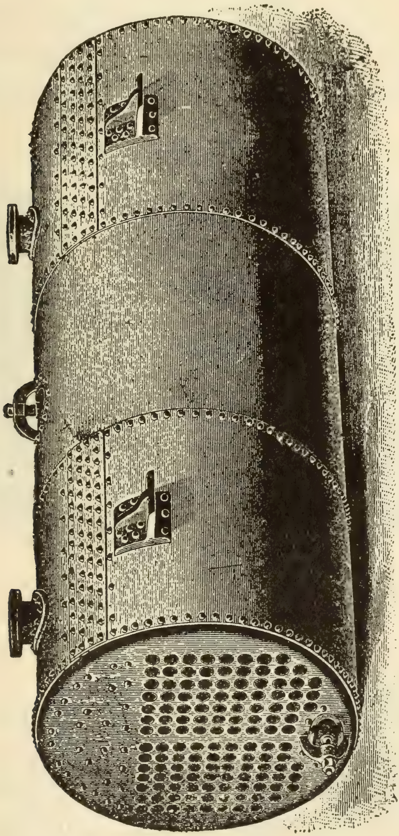


FIG. 1. HORIZONTAL RETURN TUBULAR BOILER.

Ans.—One end of the flue is riveted into the front head of the boiler, and the back end of the flue is riveted into the front sheet of the combustion chamber.

Ques. 91.—Describe the combustion chamber of the Scotch boiler.

Ans.—It is a chamber built of steel boiler plate, located at the rear end of the boiler, and entirely surrounded by water. A nest of tubes extends from the front sheet of the combustion chamber, above the corrugated furnace flue, to the front head of the shell.

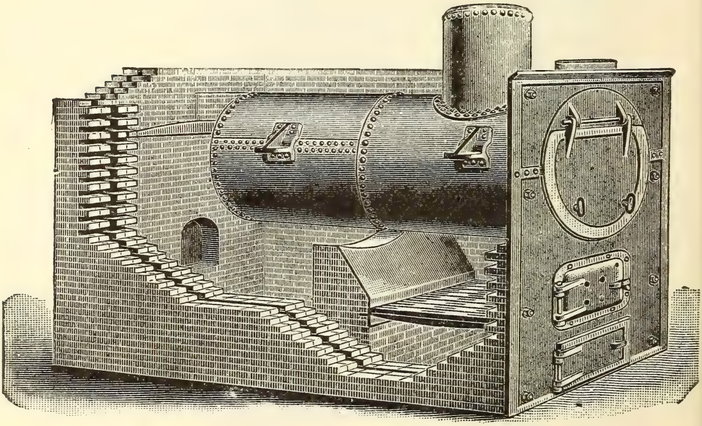


FIG. 2. STANDARD HORIZONTAL BOILER WITH FULL-ARCH FRONT SETTING.

Ques. 92.—Describe the course of the heated gases in the Scotch boiler.

Ans.—The furnaces proper, are placed within the corrugated flues, near the front end. The gases and smoke pass through the flues to the combustion chamber, and from thence return through the small tubes to the smokebox in front, and from there out through the stack.

Ques. 93.—How are the flat sides of the combustion chamber stayed?

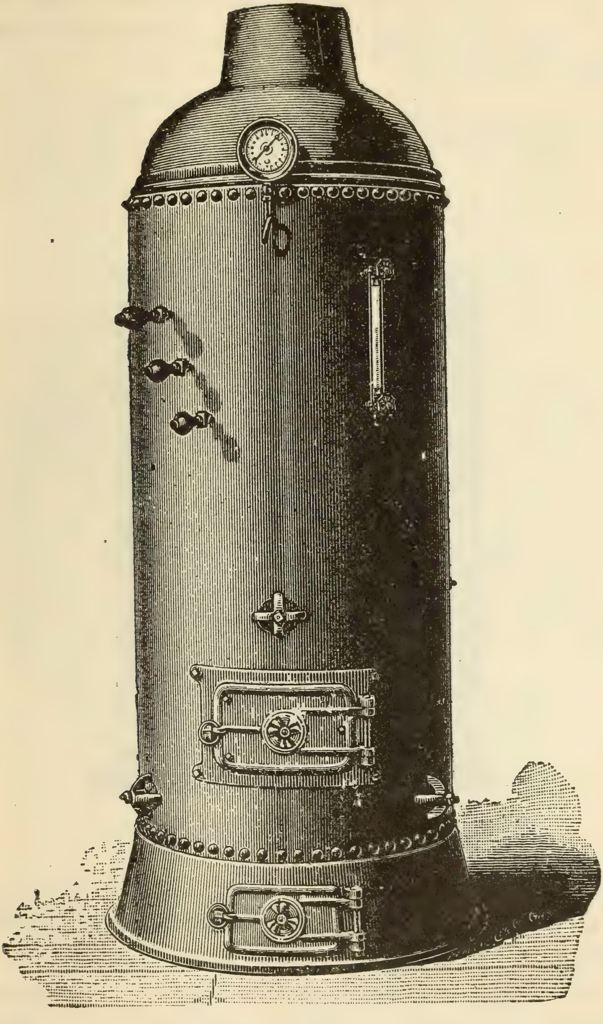


FIG. 3. VERTICAL TUBULAR BOILER, WITH FULL-LENGTH TUBES.

Ans.—By stay-bolts connecting with the shell and the back head. The small tubes serve as stays for the front sheet.

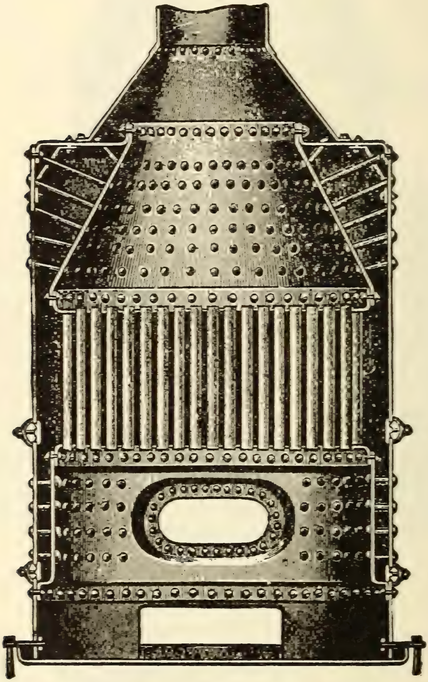


FIG. 4. VERTICAL MARINE BOILER, SHOWING DETAILS OF BRACING.

Ques. 94.—What is meant by double-ended Scotch boilers?

Ans.—Boilers having furnaces at each end. A double-ended Scotch boiler is in fact two single-ended boilers placed back to back.

Ques. 95.—What advantage has the Scotch boiler over other types?

Ans.—A very large amount of heating surface in proportion to its cubic contents.

Ques. 96.—What are the disadvantages connected with the use of the Scotch boiler?

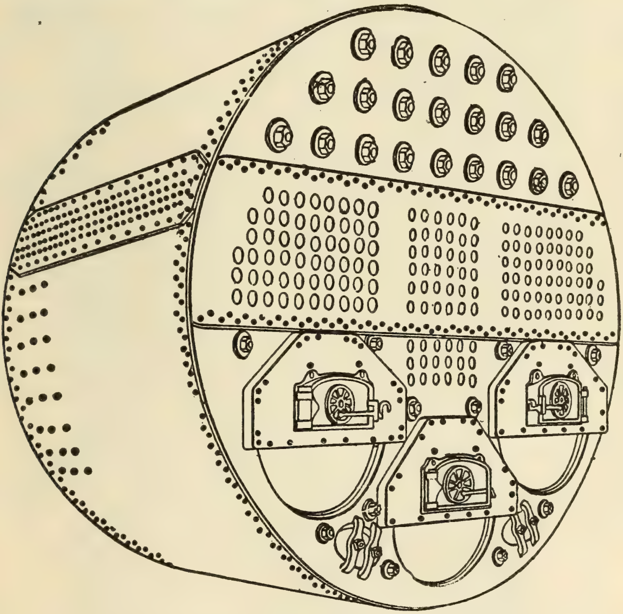


FIG. 5. SINGLE-ENDED SCOTCH MARINE BOILER.

Ans.—First, defective water circulation; second, liability to leaky tubes; third, unequal expansion of the parts, thereby setting up severe strains.

Ques. 97.—Is the Scotch boiler much used?

Ans.—It is in almost universal use in the large ocean-going merchant vessels.

Ques. 98.—What are the distinctive features of the flue and return-tube boiler?

Ans.—This form of boiler is cylindrical in shape in that part of the shell containing the large flues and small return tubes, but resembles a locomotive boiler in that portion containing the fire-box.

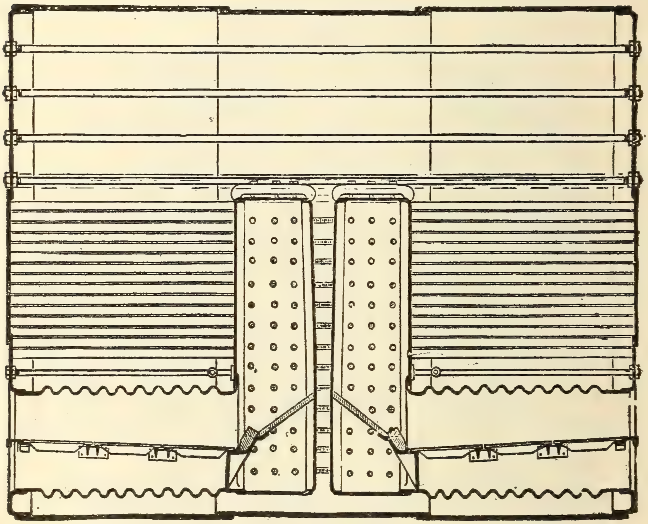


Fig. 6. Double-Ended Scotch Marine Boiler, Sectional View.

Ques. 99.—Describe the action of the heat in this boiler.

Ans.—The furnace or fire-box, resembling that of a locomotive, is located in the front end of the boiler. From thence large flues conduct the heated gases to the combustion chamber in the rear, similar to that of a Scotch boiler, and from there the gases return through the small tubes to the uptake.

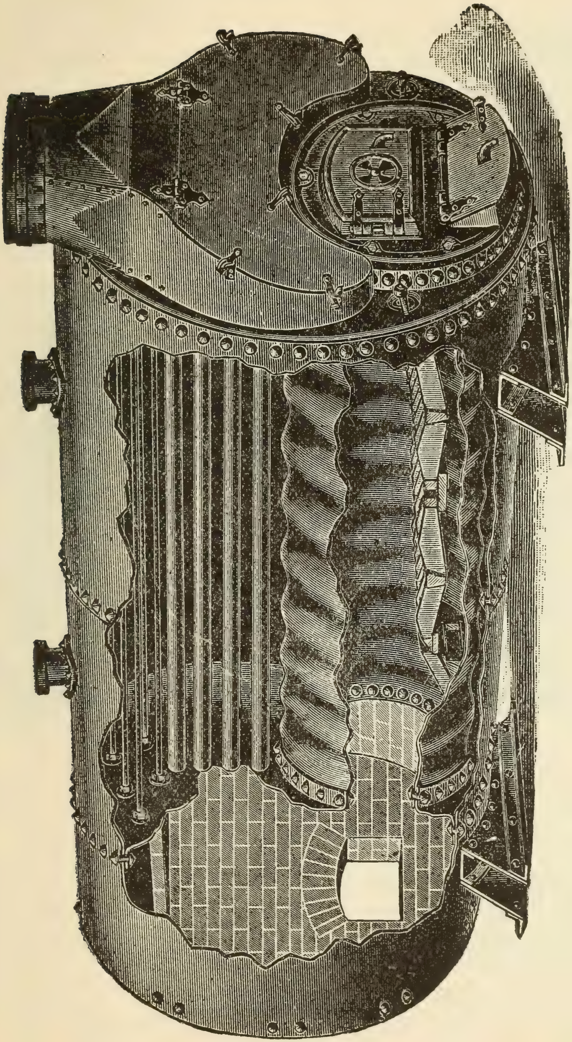


FIG. 7. RETURN FLUE, CORRUGATED FURNACE BOILER.

Ques. 100.—Describe the Western river boiler.

Ans.—This boiler is usually very long (25 to 30 feet) in proportion to its diameter. It consists of a cylindrical shell having two or more flues of large diameter (12 to 14 inches) extending its entire length. It is set in brick-work in the same manner as the horizontal tubular boiler is, the gases passing underneath the shell to the rear, and thence returning through the large flues to the uptake

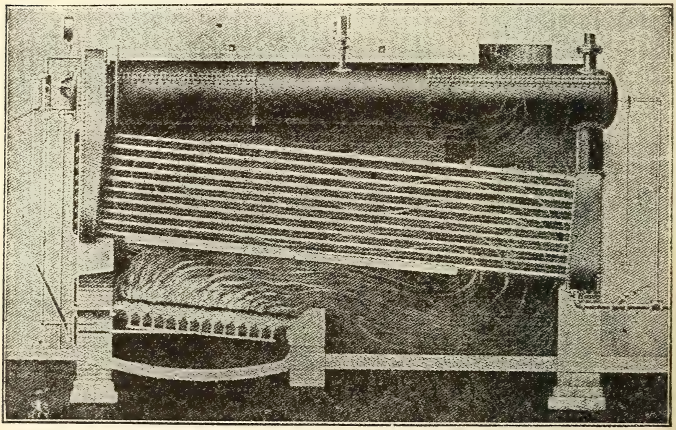


FIG. 8. THE BONUS-FREEMAN WATER-TUBE BOILER.

leading to the stack. It is a very simple boiler, and will withstand high pressures and hard usage.

Ques. 101.—Describe the locomotive boiler.

Ans.—The locomotive boiler consists essentially of a rectangular fire-box and a cylindrical shell. A large number of tubes of small diameter (2 inches) pass through the shell from the fire-box to the smoke-box, a continuation of the barrel at the front end.

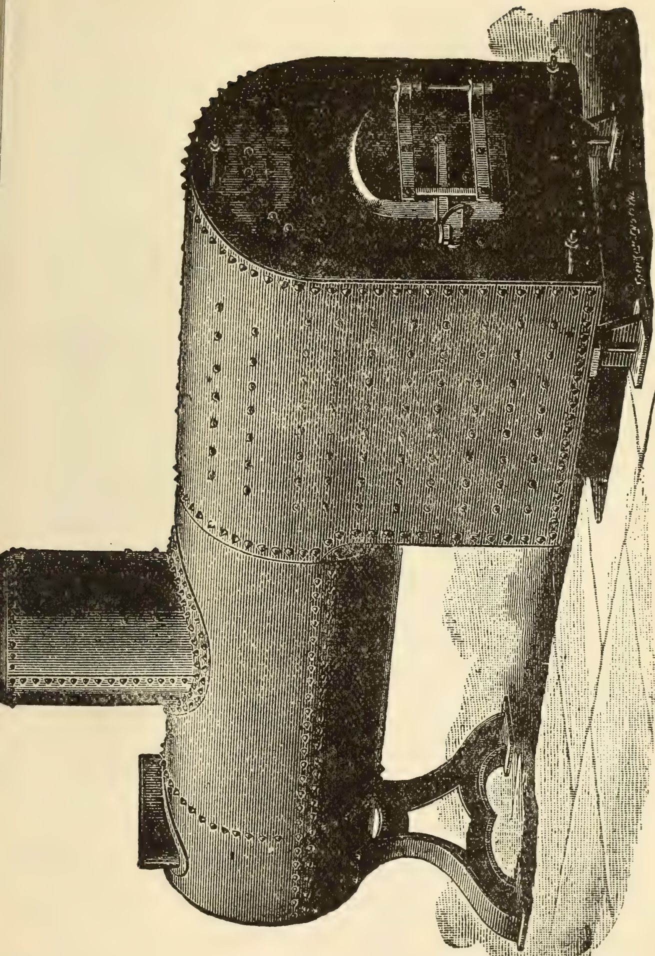


FIG. 9. PORTABLE OR LOCOMOTIVE FIRE-BOX BOILER, WITH WATER FRONT AND OPEN-BOTTOM FIRE-BOX.

Ques. 102.—How is the fire-box joined to the outer shell at the bottom?

Ans.—By a forged ring called the mud-ring, made of wrought iron or steel, through which long rivets pass, uniting the fire-box sheet and the outer sheet.

Ques. 103.—How are the flat sides of the fire-box stayed?

Ans.—By stay-blots screwed through the outer shell, into and through the fire sheet, and having both ends riveted down cold.

Ques. 104.—How is the flat crown-sheet of a locomotive boiler stayed?

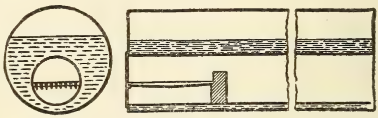


FIG. 10. CORNISH BOILER.

Ans.—By a system of crown-bars, made in the shape of double girders, the ends of which rest upon the side sheets of the fire-box. Crown-bolts pass up through the crown-sheet and crown-bars, and are secured by nuts resting upon saddles on top of the crown-bars. The heads of the bolts support the crown-sheet.

Ques. 105.—Is the locomotive boiler an economical boiler for stationary purposes?

Ans.—It is not.

Ques. 106.—Are there any other forms of cylindrical shell boilers besides those already referred to?

Ans.—Yes; the Cornish boiler, having a large central flue, in one end of which the furnace is located; the Lancashire boiler, a modification of the Cornish, containing two internal furnace flues, and the Continental boiler.

Ques. 107.—What is meant by Galloway tubes as applied to a boiler?

Ans.—Galloway tubes are conical-shaped water tubes which stand in an inclined position in the large flues of the Lancashire boiler back of the furnaces, and serve to circulate the water from the space below, to the space above the flues. They also act as bafflers to the gases in their passage through the flues, and thus provide increased heating surface.

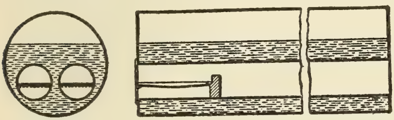


FIG. 11. THE LANCASHIRE BOILER.

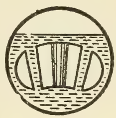


FIG. 12. THE GALLOWAY BOILER.

Ques. 108.—Describe the Continental boiler.

Ans.—The Continental boiler is a modification of the Scotch boiler, and is used to a large extent in the marine service. It is provided with a Morison corrugated furnace, and its efficiency as a steam generator has been established by a long series of practical tests.

Ques. 109.—What are the leading characteristics of the Bonson boiler?

Ans.—The Bonson boiler is a combination of the tubular and water-tube types. The water-tube member is in the form of a flat arch, and serves as a roof to the furnace. The cylindrical shell rests upon and is connected with front and rear steel saddles (water-chambers) and the water-tubes are connected with the lower portion of these saddles.

Ques. 110.—What route do the gases take in passing from the furnace of the Bonson boiler to the smoke-stack?

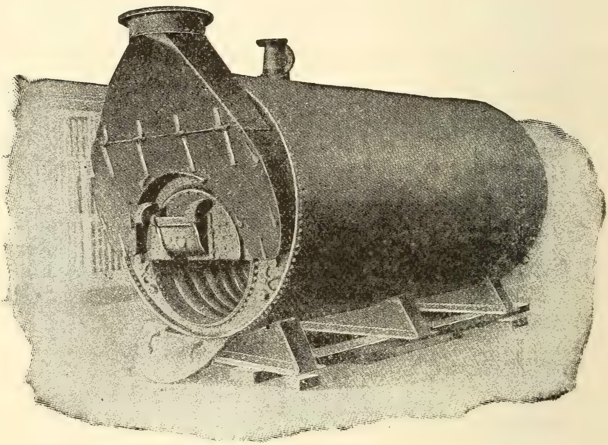


FIG. 13. CONTINENTAL BOILER, WITH MORISON CORRUGATED FURNACE, FOR MARINE OR STATIONARY SERVICE.

Ans.—They pass first under the water-tubes, which are lined with a special tile made of fire-clay, the sides of the furnace being also lined with fire-brick. The gases, after passing into the combustion chamber, at the rear, ascend and return through the fire-tubes in the shell, and from thence into the uptake at the front.

Ques. 111.—What are the leading characteristics of water-tube boilers?

Ans.—In water-tube boilers the larger part of the heating surface consists of tubes of moderate size (1 to 4 inches in diameter). There is always some form of separator, drum or reservoir into which the tubes lead. In this drum the steam is separated from the water. In some forms of water-tube boilers this shell or drum is of considerable size.

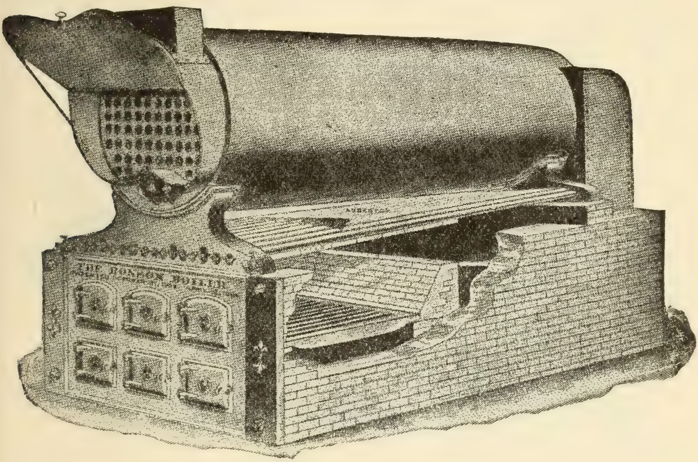


Fig. 14. The Bonson Boiler and Setting.

Ques. 112.—Is this drum exposed directly or indirectly to the heat?

Ans.—It is generally exposed indirectly, as the upper part is used for steam space.

Ques. 113.—What advantage is there in having a large size steam and water-drum?

Ans.—The advantage of having a good free water surface for the disengagement of the steam. The water occupies about one-third of the lower portion of the drum.

Ques. 114.—Are the upper ends of the tubes in all water-tube boilers entirely filled with water?

Ans.—Not in all cases. In some forms of water-tube boilers the upper ends of the tubes extend above the water level.

Ques. 115.—How are these different forms of water-tube boilers designated?

Ans.—First, as drowned tubes; second, as priming tubes.

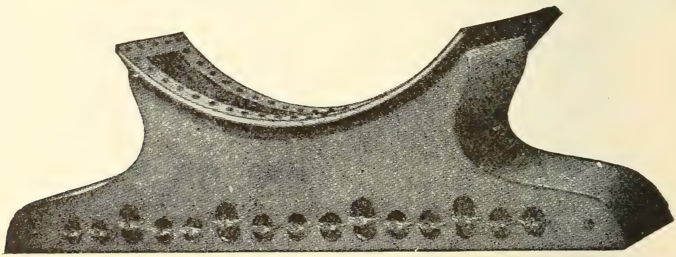


FIG. 15. STEEL SADDLE OF BONSON BOILER.

Ques. 116.—What are some of the advantages of water-tube boilers?

Ans.—They may be made light, powerful and able to withstand high pressures. They are quick steamers, that is, steam may be raised rapidly from cold water; also, the circulation of the water in them is good generally.

Ques. 117.—What are some of the disadvantages attending the use of water-tube boilers?

Ans.—They are difficult to inspect and clean. Also, owing to the large number of joints, leaks are liable to occur.

Ques. 118.—Describe briefly the Babcock & Wilcox water-tube boiler.

Ans.—There is a large horizontal cylindrical shell at the top for the purpose of supplying steam and water-space. The lower half of this shell contains water, and the upper half steam. The tubes are expanded into headers at each end. At the front end these headers are

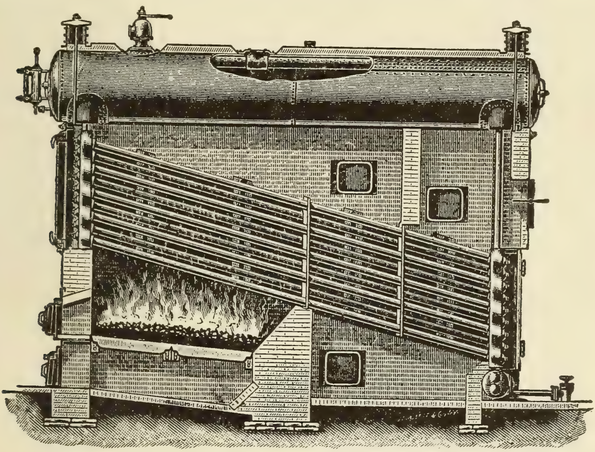


FIG. 16. BABCOCK AND WILCOX BOILER, FOR LAND SERVICE.

brought up near the shell, to which they are connected by a cross connection. The back end headers are connected to a mud-drum at the bottom, and to the shell at the top by slightly inclined tubes. The back headers being lower than the front headers, the tubes are thus inclined from front to back.

Ques. 119.—In what style are the tubes connected to the headers?

Ans.—They are staggered.

Ques. 120.—What is meant by staggered tubes?

Ans.—Staggered tubes are those which are not placed in vertical rows, that is, one directly above the other.

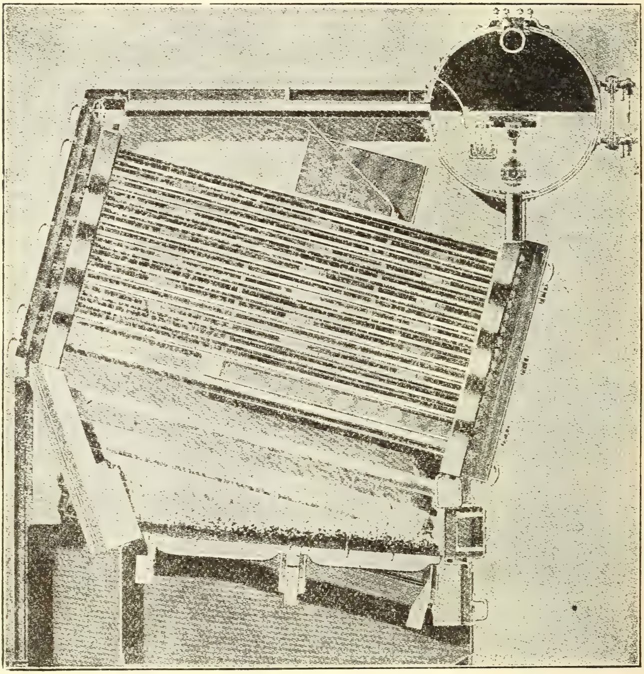


Fig. 17. Babcock and Wilcox "Alert" Type Marine Boiler. From B. & W. "Book Marine Steam," p. 154.

Ques. 121.—What are the facilities for cleaning these tubes?

Ans.—At each end of each tube there are hand-holes provided.

Ques. 122.—Describe the course of the gases for the Babcock & Wilcox boiler.

Ans.—A brick bridge wall at the back end of the furnace, together with special tiles placed among the tubes, compel the gases to first pass up among the tubes until they come in contact with the bottom of the shell for about two-thirds of its length from the front end. At this point a hanging bridge wall and special tiles deflect the gases downward in their course, and they again circulate among the tubes, passing underneath the tiles and up among the tubes again. The products of combustion thus pass over and around the tubes three times on their way to the uptake.

Ques. 123.—What portions of this boiler constitute the heating surface?

Ans.—The tubes, headers, and the lower half of the shell.

Ques. 124.—What course does the water take in its circulation in this boiler?

Ans.—Down from the shell at the rear to the water-tubes, thence forward and upward through the tubes. In its course through the tubes it becomes partially vaporized and of less density. It then passes up into the shell at the front, where the steam is disengaged.

Ques. 125.—Is the Babcock & Wilcox boiler much used in the marine service?

Ans.—Yes, it is used extensively in the British and United States navies, also in merchant steamers.

Ques. 126.—Is the form of this boiler the same for marine as for land service?

Ans.—It is not. The chief features in which it differs from the land boiler are, first, a very much larger grate area; second, the cylindrical shell is set transversely to the direction of the tubes; third, the fire-doors are located at what would be the rear of the land boiler; fourth, the tubes are much shorter, owing to the contracted space allowed on ocean steamers; fifth, the brickwork is surrounded outside by a metal casing.

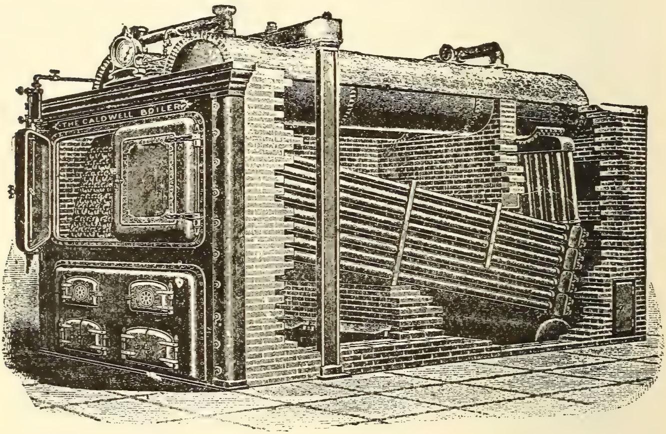


FIG. 18. THE CALDWELL BOILER.

Ques. 127.—Are there any other forms of water-tube boilers patterned after the Babcock & Wilcox boiler?

Ans.—There are several, prominent among which are the Caldwell and the Root boilers.

Ques. 128.—Describe the Caldwell boiler.

Ans.—It is similar in construction to the Babcock & Wilcox, except that the tubes, instead of being staggered vertically, are placed one directly above the other, with specially shaped fire-brick laid across alternate spaces between the tubes to deflect the gases.

Ques. 129. Describe the Root water-tube boiler.

Ans.—It consists of a nest of 4-inch tubes expanded into headers which are connected at front and back with a set of steam and water-drums about 15 inches in diameter. The tubes are inclined at an angle of about 20 degrees from the horizontal. At the rear end of each overhead water and steam-drum is a connection leading to the

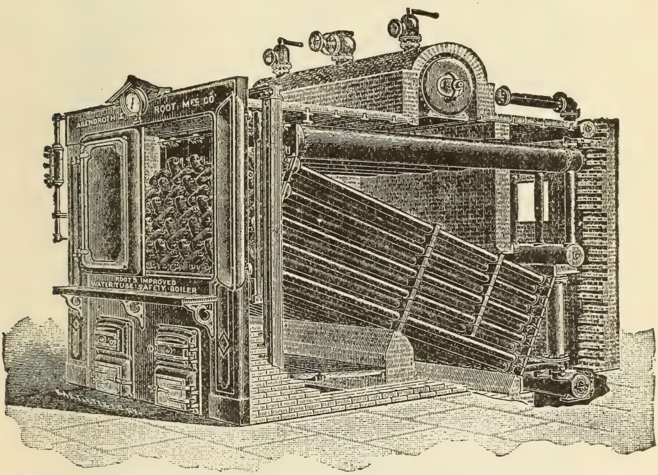


FIG. 19. THE ROOT WATER-TUBE BOILER.

steam-collecting header above, placed transversely to the direction of the other drums, and from this header two connecting pipes lead to a large steam-drum located at about the center of the boiler, and above all.

Ques. 130.—How does the water circulate in the Root boiler?

Ans.—It descends through vertical connecting pipes from the feed-drum at the rear to the mud-drum beneath.

From thence it passes into the back and lower ends of the tubes, and on up through the tubes, and into the overhead drums, into the upper halves of which the steam is disengaged.

Ques. 131.—Describe the Cahall water-tube boiler.

Ans.—The Cahall boiler is vertical, having a nest of

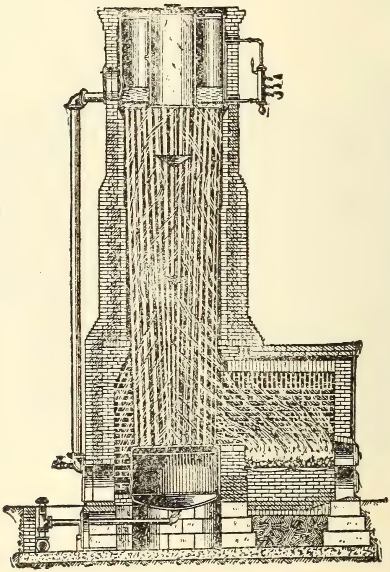


FIG. 20. THE CAHALL VERTICAL BOILER.

water-tubes standing nearly vertical. These tubes are connected with a shallow water-drum at the bottom, and a larger and deeper water and steam-drum at the top. The furnace is located alongside of the mud-drum, and the gases traverse among the tubes in a circuitous manner owing to bafflers placed among the tubes.

Ques. 132.—How do the gases escape to the stack in this boiler?

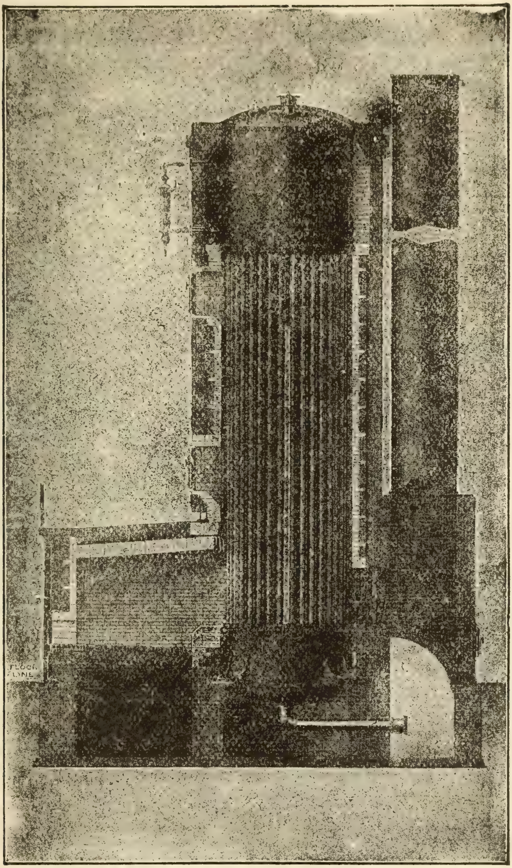


Fig. 21. Wickes Vertical Water-Tube Boiler.

Ans.—Extending through the center of the **annular drum** at the top is a flue through which the products of combustion find their way to the uptake.

Ques. 133.—Of what form is the Wickes boiler?

Ans.—The Wickes boiler consists of upper and lower vertical drums connected by vertical tubes. The furnace is external.

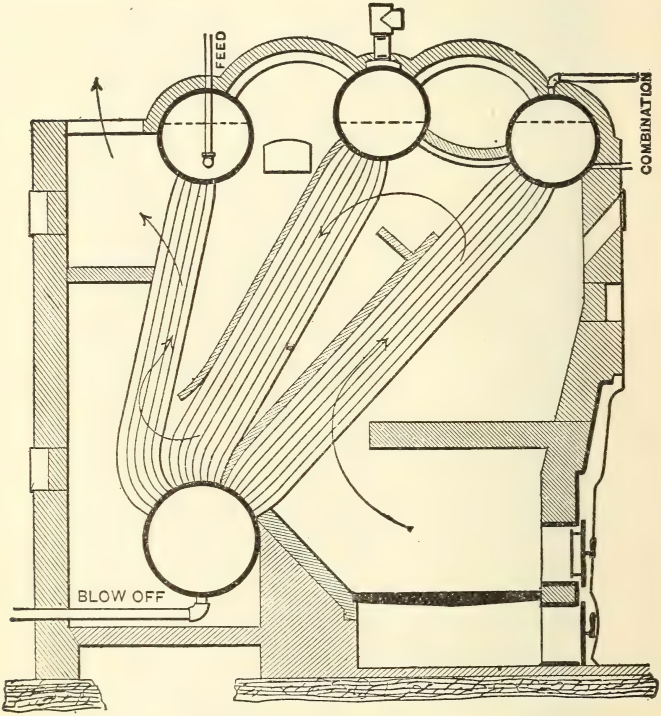


FIG. 22. THE STIRLING BOILER.

Ques. 134.—What course do the gases take in their passage to the stack, in the Wickes boiler?

Ans.—A thin partition wall of fire-brick is built between two adjoining middle rows of tubes. This wall causes the gases first to ascend to the top, and then downwards to the chimney flue at the bottom and opposite to the furnace.

Ques. 135.—Describe the Stirling boiler.

Ans.—In the Stirling water-tube boiler there are three horizontal steam and water-drums at the top, and

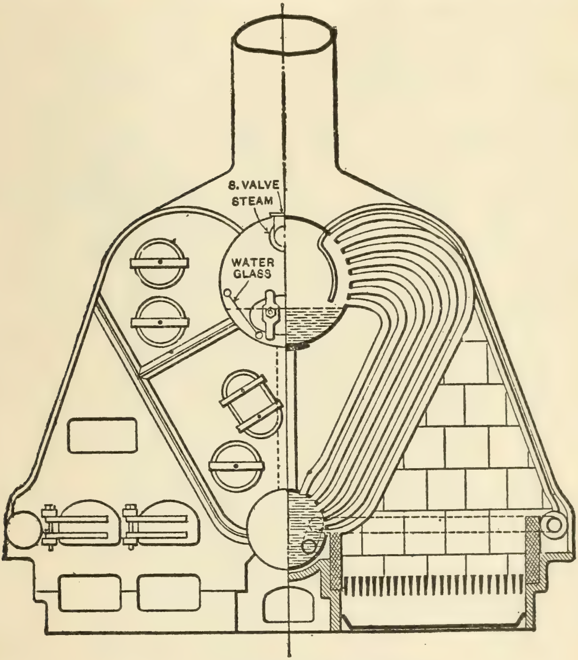


FIG. 23. THORNYCROFT BOILER.

one water-drum at the bottom. These drums are connected by three divisions of inclined and curved tubes.

Ques. 136.—How are the products of combustion led from the furnace to the uptake, in the Stirling boiler?

Ans.—Bafflers of fire-brick are placed back of the two first divisions of tubes. The first baffler causes the gases to ascend to the top of the first division of tubes; the second baffler deflects the gases downwards, around and among the tubes of the second division. The draught is then upwards again, surrounding the tubes composing the third division, thence to the stack.

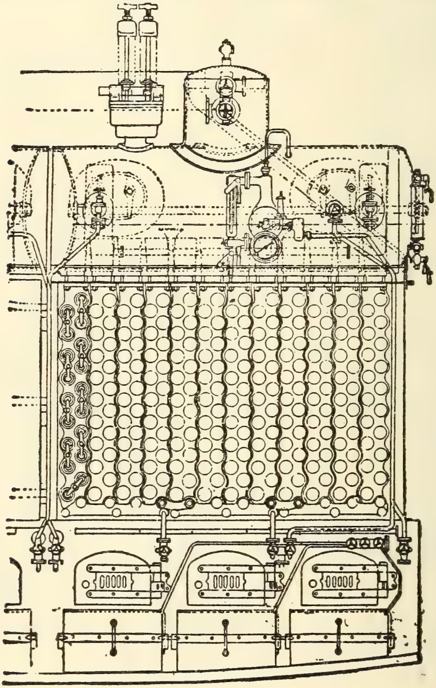


FIG. 24. THE NICLAUSSE BOILER.

Ques. 137.—Describe the Thornycroft boiler.

Ans.—The Thornycroft boiler is adapted for use on torpedo boats and high-speed yachts. A large horizontal steam-drum at the top is connected to a water-drum at the bottom by two groups of curved tubes of small diameter. The grates are located on each side of the water-drum. There are also two smaller drums at the bottom, one on each side, connected to the middle drum by small pipes.

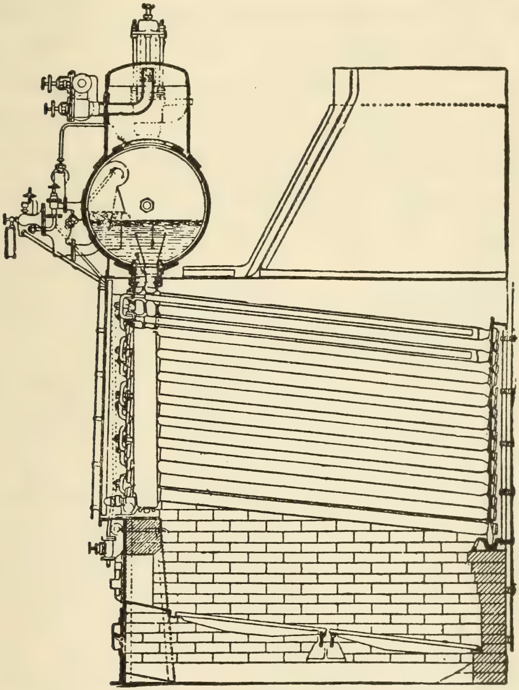


FIG. 25. THE NICLAUSSE BOILER—SIDE VIEW.

Ques. 138.—How does the water circulate in this boiler?

Ans.—Down from the top drum to the middle lower drum through special return water-tubes of large diameter, and from thence through the smaller tubes to the side drums. From there the water passes up through the curved tubes to the upper portion of the top drum, where the steam is disengaged.

Ques. 139.—Describe the Niclausse boiler.

Ans.—The Niclausse boiler is made up of a series of slightly inclined tubes. These tubes are double, that is, one inside the other, and they are connected to the front header in such a manner that the colder water flows down the inside tubes and returns to the front between the two tubes when heated by the action of the fire and hot gases on the larger outside tubes. Each vertical row of tubes is connected at the front end to a separate header, the headers being placed side by side, and all leading into a top drum or steam-collector.

Ques. 140.—How is the entering feed-water at the front kept separate from the hot ascending currents of water?

Ans.—By a diaphragm in the top drum that keeps the cooler water separate from the hot water and steam.

Ques. 141.—How are the tubes connected to the headers in the Niclausse boiler?

Ans.—By coned surfaces on the ends of the tubes bearing on similar coned surfaces in the headers, and kept in contact by outside dogs and nuts. These joints appear to cause no trouble by leakage.

Ques. 142.—Is the Niclausse boiler much used?

Ans.—It is used to some extent in the British navy, and also in several large United States war-ships.

Ques. 143.—Of what type is the Normand boiler?

Ans.—The Normand boiler is a marine water-tube boiler of the Thornycroft type. The two outer rows of tubes are formed into a wall of tubes, and in the vicinity of the furnace the tubes are arched upwards in order to form a combustion chamber. Back of the furnace the

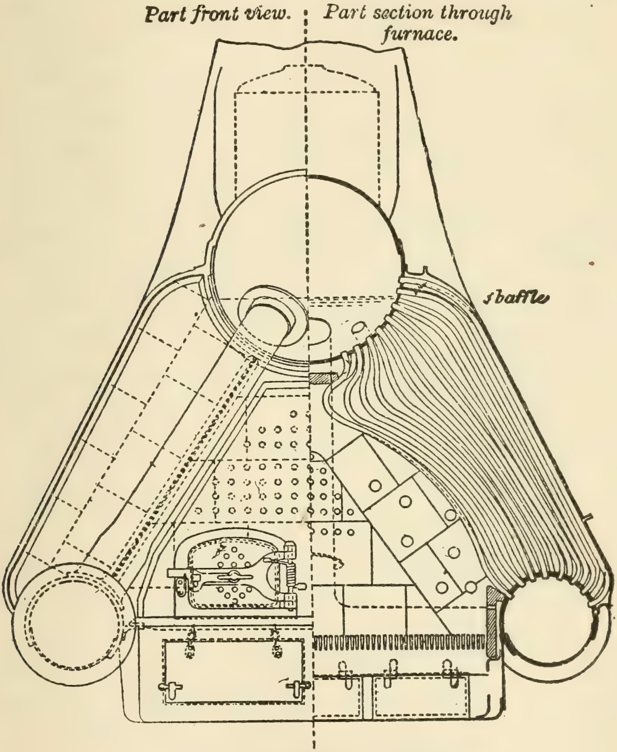


FIG. 26. THE NORMAND BOILER.

curvature is not so great, although all of the tubes are curved more or less, to permit of expansion when heated.

Ques. 144.—What course do the gases take in this boiler?

Ans.—The gases proceed from the fire among the tubes, and traverse the length of the boiler to the rear end, where they pass below a brick deflecting plate to the space surrounding those tubes that are less curved.

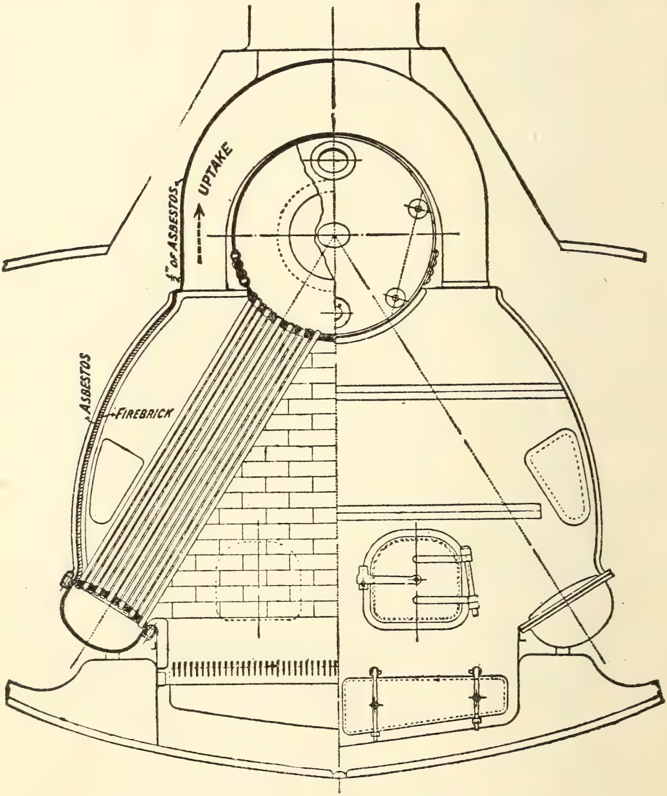


FIG. 27. THE YARROW BOILER.

Ques. 145.—What other peculiar feature characterizes the Normand boiler?

Ans.—Provision is made for the admission of air above the fire.

Ques. 146.—How is this accomplished?

Ans.—By means of a small air casing at the front and back, and a series of small holes one inch in diameter leading through the brickwork to the space above the fire.

Ques. 147.—For what kind of service is the Normand boiler mainly adapted?

Ans.—For torpedo-boat destroyers.

Ques. 148.—What is the distinguishing feature of the Yarrow boiler, among boilers having water-tubes of small diameter?

Ans.—The Yarrow boiler has straight tubes. It also has at the bottom on each side a small water-chamber or mud-drum with nearly flat tube-plates, into which the tubes are expanded. The tubes run in an inclined direction from these water-drums to the steam and water-drum at the top.

Ques. 149. In what manner does the water circulate in the Yarrow boiler?

Ans.—Those tubes which receive the most heat conduct the water from the lower drums to the upper drum, into which the steam is delivered. Other tubes which are cooler carry the water from the upper drum to the lower drums.

Ques. 150.—Describe the Mosher boiler.

Ans.—The Mosher boiler has two upper steam-drums and two lower and smaller water-drums, the water-drums being directly underneath the steam-drums. These drums are connected by curved generator pipes of small diameter, the pipes entering the steam-drums above the water-line.

Ques. 151.—How does the water find its way from the upper to the lower drums?

Ans.—By means of two external downtake pipes 4 inches in diameter. The boiler is cased in, the casing being lined with fire-brick.

Ques. 152.—For what class of service is the Mosher boiler mainly adapted?

Ans.—Torpedo boats and high-speed yachts.

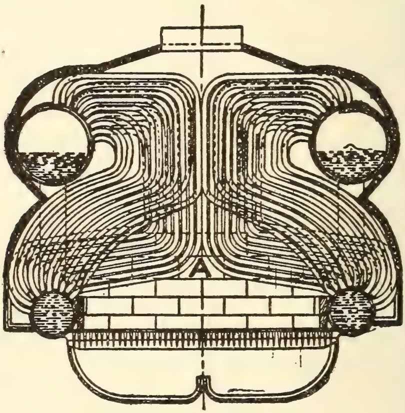


Fig. 28. The Mosher Boiler.

Ques. 153.—Describe the construction of the Almy boiler.

Ans.—It is made principally of short lengths of pipe screwed into return bends and into twin unions. At the bottom there is a larger pipe or header that surrounds the two sides and back of the grates, and there is a similar structure at the top, the two headers being connected by the smaller pipes.

Ques. 154.—How is the steam separated from the water in the Almy boiler?

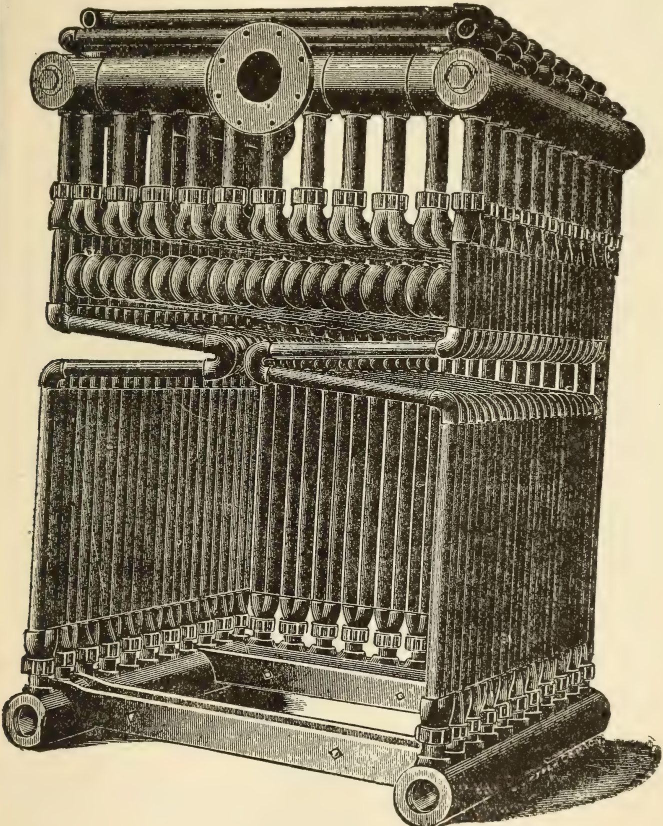


FIG. 29. THE ALMY BOILER.

Ans.—The steam and water are together discharged rom the upper header into a separator in front of the oiler, and from this separator the steam is drawn, while the separated water and the feed-water pass down through circulating pipes to the lower header.

Ques. 155.—What other peculiar feature attaches to this boiler?

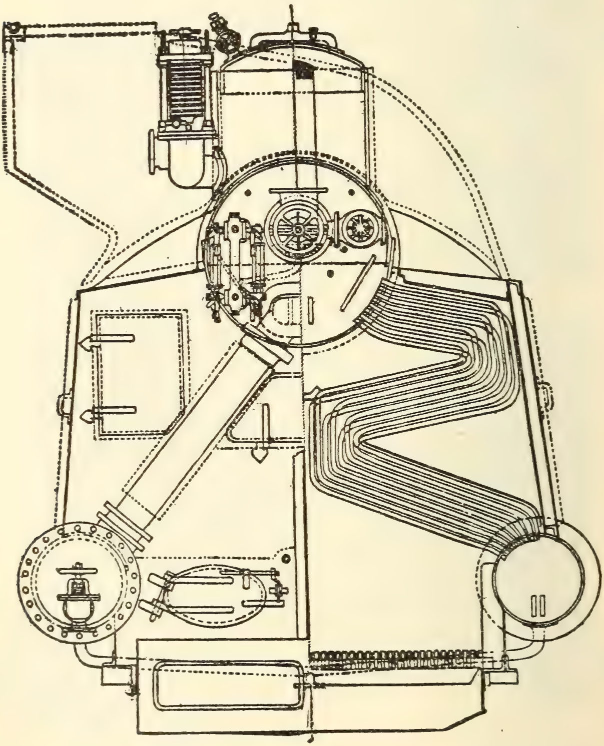


FIG. 30. THE DU TEMPLE BOILER.

Ans.—It is provided with a coil feed-water heater above the main boiler.

Ques. 156.—Describe in general terms the Du Temple boiler.

Ans.—It is of the same general character as the Thornycroft type, except that the generating tubes discharge into the steam-drum below the water-line.

Ques. 157.—How are these tubes connected to the drums?

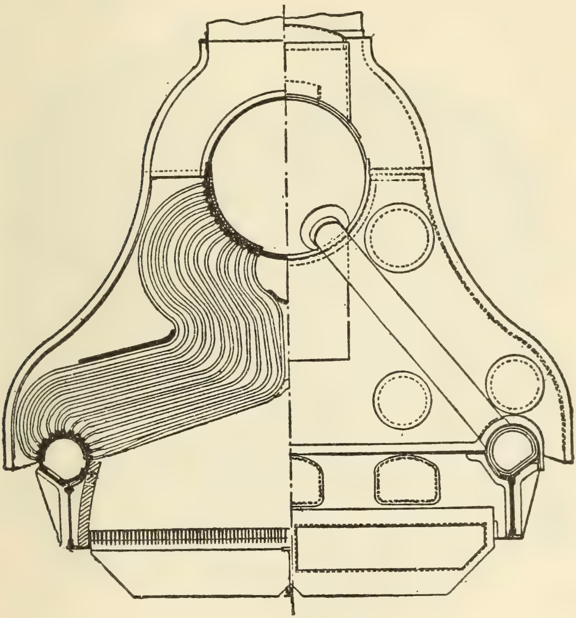


FIG. 31. REED'S BOILER.

Ans.—By cones and nuts.

Ques. 158.—Is the Du Temple boiler used to any great extent?

Ans.—Yes; it is used extensively in the French navy, especially on vessels of the torpedo-boat type

Ques. 159.—Describe Reed's boiler.

Ans.—This boiler resembles the Du Temple boiler. It has the usual top collector drum, and two lower drums with curved generating pipes connecting them.

Ques. 160.—How are the tubes attached to the drums?

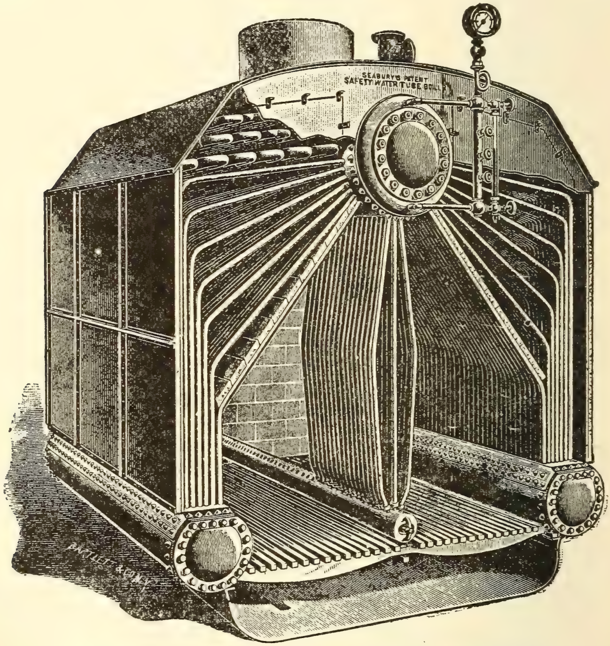


Fig. 32. The Seabury Boiler.

Ans.—By screwed connections at each end, with nuts inside the chambers.

Ques. 161.—How are the gases caused to traverse the heating surface in this boiler?

Ans.—By means of diaphragms fitted to the tubes.

Ques. 162.—What class of service is this boiler largely used in?

Ans.—British torpedo-boat destroyers, and also on third-class cruisers.

Ques. 163.—Describe the Seabury boiler.

Ans.—The Seabury boiler has three lower water-drums, the middle drum being smaller than the two outside drums. These drums are connected to one large steam and water-drum above by curved pipes of small diameter and the furnace is divided into two sections by the central nest of pipes. Above the boiler tubes and inside the casing there is a coil feed-water heater.

Ques. 164.—Describe the latest type of Belleville boiler?

Ans.—The Belleville boiler is a water-tube boiler, and is of extensive use on large ships. It is made up of two distinct series of straight tubes, larger in diameter than those of the curved type. These tubes are placed nearly horizontal, each alternate horizontal row being slightly inclined in the opposite direction to the row above it. The generator proper has a water-chamber below and a steam-drum or chamber on top, and the zigzagged tubes are connected to these respective chambers.

Ques. 165.—What kind of a furnace has this boiler?

Ans.—A rectangular brickwork furnace inclosed in a steel casing, and the generating tubes are placed directly over the grates, the bottom row of tubes being about two feet above the grates. Baffle plates are secured at intervals among the tubes for the purpose of causing the hot gases to traverse the whole of the heating surface.

Ques. 166.—How is circulation of the water secured in the Belleville boiler?

Ans.—By means of external return water-pipes, one on each side connecting the ends of the top drum with the lower water-chamber, the cooler water thus passing

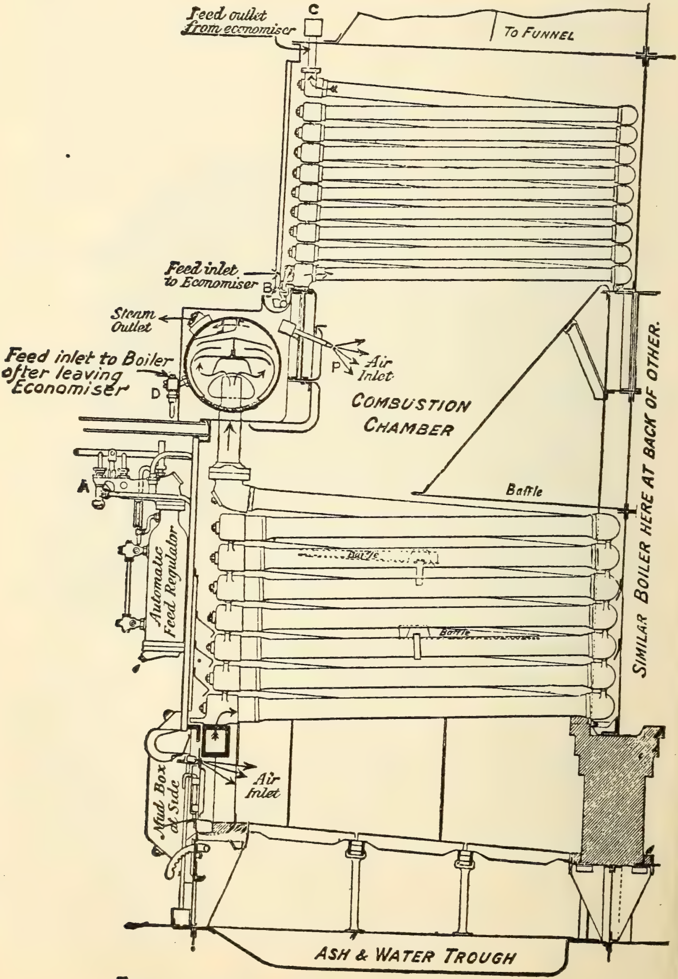


FIG. 33. BELLEVILLE BOILER WITH ECONOMISER.

down through these pipes into the lower drum, and from thence the heated water passes up through the generating tubes, discharging into the top drum, where the steam is disengaged.

Ques. 167.—What are the usual dimensions of the generating tubes?

Ans.—Four and one-half inches in diameter and seven feet six inches in length. The ends are connected by being screwed into malleable cast-iron boxes.

Ques. 168.—How is the economizer or feed-water heater attached to this boiler?

Ans.—It is placed directly above the generator, a space called the combustion chamber being left between the two series of tubes. The tubes of the economizer are smaller, being 2¾ inches in diameter. The general form of the economizer resembles that of the generator.

Ques. 169.—What is the course of the feed-water in this boiler?

Ans.—It enters the bottom of the economizer and is forced upwards to and fro through the zigzagged tubes to the top, and from thence it falls to the bottom of the hot water collector at the top, and then flows to the return pipes, through which it passes to the generator.

Ques. 170.—Mention another peculiar feature of this boiler.

Ans.—An automatic feed-regulating device worked by a float in a chamber acting upon the feed-valve.

Ques. 171.—Is the Belleville boiler an economical boiler?

Ans.—It is; an actual evaporation of from 9.3 pounds to 9.9 pounds of water per pound of coal having been obtained under test, with the feed-water at a temperature of 68 degrees.

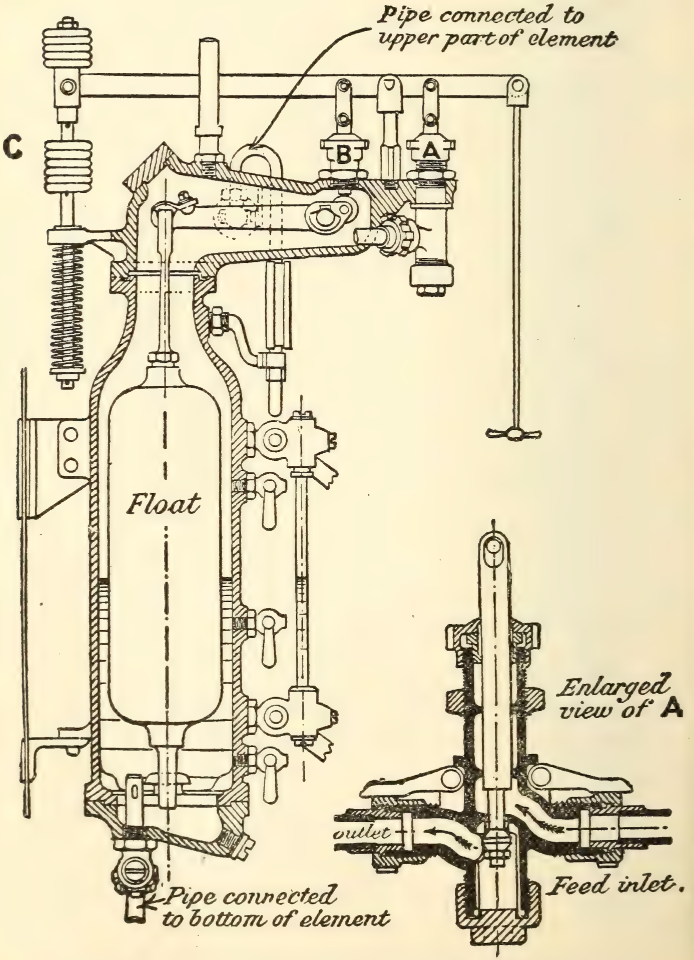


FIG. 34. AUTOMATIC FEED REGULATOR FOR BELLEVILLE BOILER.

CHAPTER III

BOILER CONSTRUCTION

Ques. 172.—What is the best material to use in the construction of the shell of the boiler?

Ans.—Open-hearth steel, having a tensile strength of from 55,000 pounds to 60,000 pounds per square inch.

Ques. 173.—What is meant by the expression tensile strength (T. S.)?

Ans.—The expression 60,000 pounds tensile strength means that it would require a pull of 60,000 pounds in

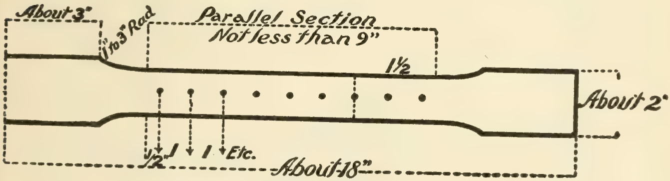


Fig. 35. Test Piece.

the direction of its length to break a bar of the material 1 inch square, or 2 inches wide by ½ inch thick, or 2.67 inches wide by ⅜ inch thick.

Ques. 174.—How are steel sheets for boiler construction tested?

Ans.—A small piece, called a test piece, is cut from each sheet and placed in a testing machine.

Ques. 175.—What is the working test for steel boiler sheets?

Ans.—A piece from each sheet is heated to a dark cherry red, plunged into water at 60° temperature, and bent double cold under the hammer, such piece to show no flaw or crack after doubling.

Ques. 176.—Of what material should the tubes of fire-tube boilers be made?

Ans.—A good quality of homogeneous iron.

Ques. 177.—What is the working test for boiler tubes?

Ans.—They should show no flaw when expanded into the flue-sheet and beaded.

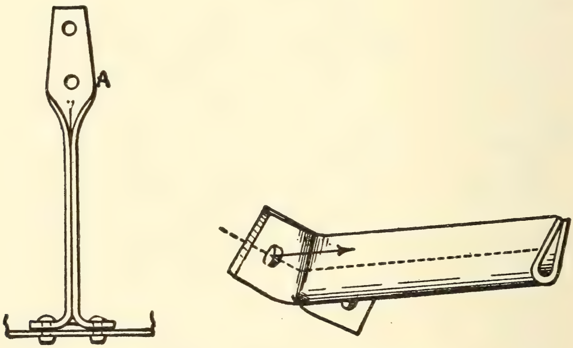


Fig. 36. Crow Foot Braces.

Ques. 178.—What should the specifications be regarding rivets?

Ans.—All rivet material should be of good charcoal iron, or mild steel, tough and soft. Test, a good rivet should bend double cold, without showing fracture.

Ques. 179.—Of what material are the tubes of water-tube boilers usually made?

Ans.—Of good charcoal iron or mild steel specially prepared for the purpose, and lap welded. or drawn.

Ques. 180.—What is the test for tubes from 3½ to 4 inches in diameter and No. 10 wire gauge?

Ans.—A piece 1½ inches in length is cut from one end of a tube, and this piece must stand hammering down cold vertically without showing a crack or split, when down solid.

Ques. 181.—Of what material should stay-bolts be made?

Ans.—Of iron or mild steel, especially manufactured for the purpose.

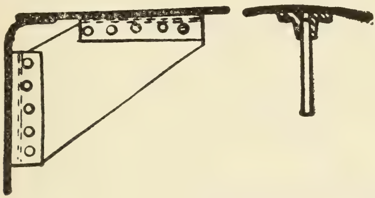


FIG. 37. GUSSET STAYS.

Ques. 182.—What should be the tensile strength of stay-bolt material?

Ans.—For iron, not less than 46,000 pounds; for steel, not less than 55,000 pounds.

Ques. 183.—What kind of material are braces and stays made of?

Ans.—The material for braces and stays should be of the same quality as the best stay-bolt stock.

Ques. 184.—What is the object sought in staying the flat surfaces of a boiler internally?

Ans.—The object is to strengthen those surfaces sufficiently to enable them to withstand the maximum internal working pressure to which they will be subjected.

Ques. 185.—Does the cylindrical portion of a boiler need bracing?

Ans.—It does not, for the reason that the internal pressure tends to keep it cylindrical.

Ques. 186.—What is the maximum direct pull per square inch of section that may be allowed on braces and stay-rods?

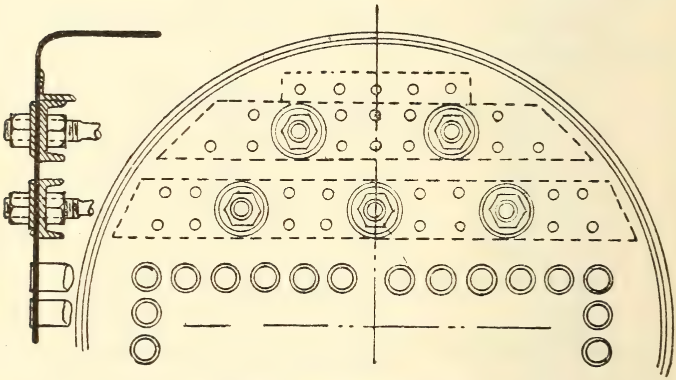


FIG. 38. THROUGH STAY RODS.

Ans.—For iron, 6,500 pounds; for steel, 8,000 pounds; and this point should be kept in view when spacing the braces.

Ques. 187.—What is meant by spacing braces?

Ans.—The distance from center to center that the stays are from each other at the point of their connection to the stayed surface.

Ques. 188.—Give an example.

Ans.—The stays in a certain boiler are spaced 8 inches apart, center to center, therefore each stay supports

8 x 8=64 square inches. Assuming the working pressure to be 100 pounds per square inch, the sectional area of each stay should be 1 square inch.

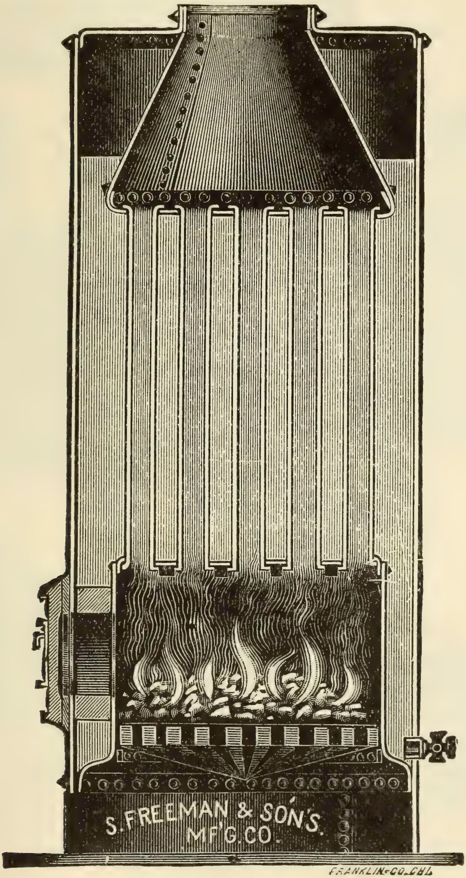


Fig. 39. Vertical Tubular Boiler, with Submerged Tubes.

Ques 189. —Suppose the working pressure is 250 pounds per square inch and the stays are spaced 6 inches center to center, what should be the sectional area of each stay?

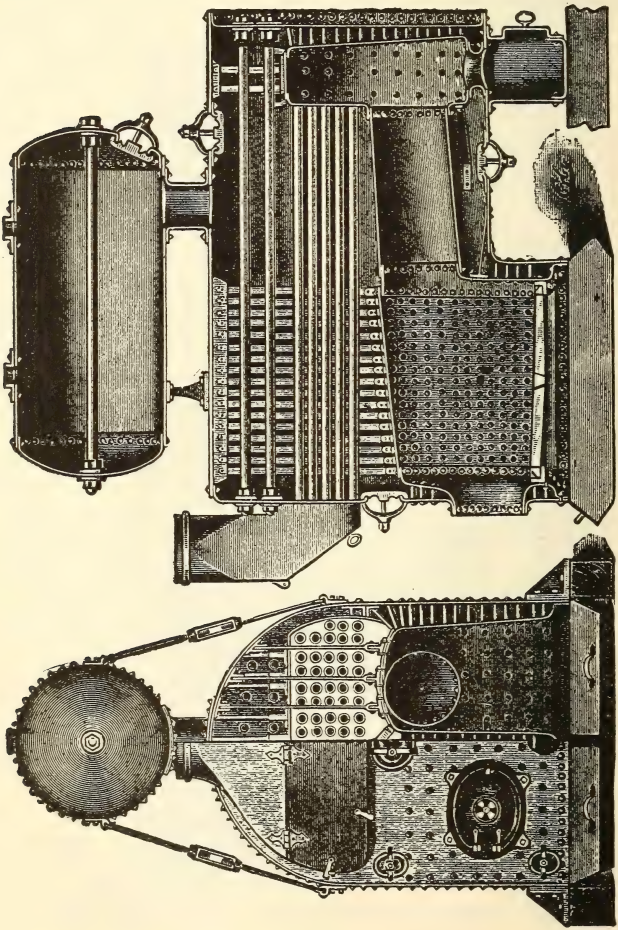


Fig. 40. Double Furnace Return Flue Marine Boiler.

Ans.—The pressure to be sustained by each stay would be 6x6=9000 pounds. Assume the stays to be of steel and unwelded, and allowing a direct pull of 7,200 pounds per square inch, the sectional area of each stay should be $\frac{9000}{7200}=1.25$ square inches; or, if the stays are 1.5 inches smallest diameter, and a direct pull of 8.000 pounds per square inch of section is allowed, they may be spaced 7 inches, center to center.

Ques. 190.—Of what forms are boiler stays usually made?

Ans.—For low-pressure boilers, crow-foot stays; for high-pressure boilers, through stay-rods and gusset-stays.

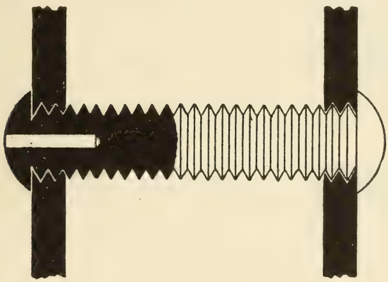


FIG. 41. COMMON STAY-BOLT.

Ques. 191.—Where are stay-bolts used?

Ans.—In fire-box boilers, and all boilers of the locomotive type, to tie the fire-box to the external shell.

Ques. 192.—How are stay-bolts applied?

Ans.—A continuous thread is cut on the stay-bolt rod, the same thread being also tapped in the holes in the external plate, and the inside sheet. The steel stay-bolt is then screwed through the plates and allowed to project far enough at each end to permit of its being riveted down cold.

Ques. 193.—What is the principal cause of the breaking of stay-bolts?

Ans.—The unequal expansion of the sheets into which they are screwed.

Ques. 194.—Why are stay-bolts sometimes drilled partly through their length?

Ans.—In order that, if the bolt breaks, the steam or water may blow out through the small hole and give warning of the break.

Ques. 195.—Describe the Tate flexible stay-bolt.

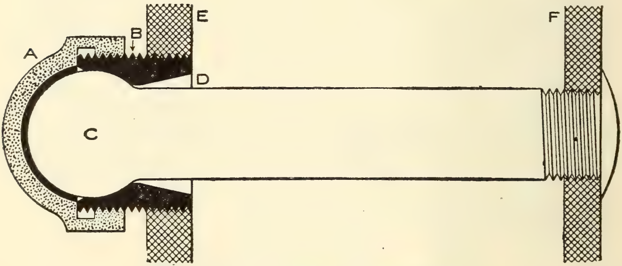


FIG. 42. TATE FLEXIBLE STAY BOLT.

Ans.—The outer head is ball shaped, and is inclosed within a socket formed by a sleeve that screws into the outer sheet and a cap that screws onto the sleeve. The other end of the bolt is screwed into and through the fire-sheet a sufficient distance to allow of riveting.

Ques. 196.—What is meant by the efficiency of a riveted joint?

Ans.—It is the per cent. of strength of the solid plate that is retained in the joint.

Ques. 197.—What is the efficiency of a properly proportioned double riveted butt-joint?

Ans.—From 71 to 75 per cent.

Ques. 198.—What is the efficiency of a properly proportioned triple riveted butt-joint with inside and outside welts or butt-straps?

Ans.—From 85 to 88 per cent.

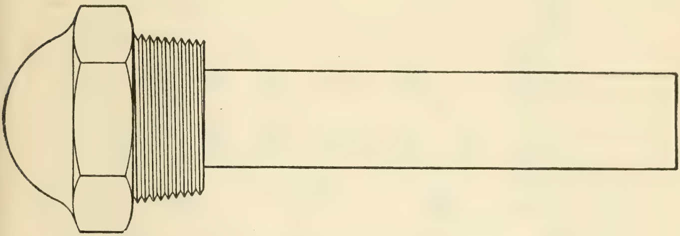


FIG. 43. TATE FLEXIBLE STAY-BOLT, UNTHREADED.

Ques. 199.—Where is the weakest portion of the triple riveted butt-joint?

Ans.—At the outer row of rivets.

TABLE 4

TABLE OF DIAMETERS OF RIVETS*

Thickness of Plate	Diameter of Rivet	Thickness of Plate	Diameter of Rivet
1/4 inch	1/2 inch	9/16 inch	7/8 inch
5/16 "	9/16 "	5/8 "	15/16 "
3/8 "	11/16 "	3/4 "	1 1/16 "
7/16 "	3/4 "	7/8 "	1 1/8 "
1/2 "	13/16 "	1 "	1 1/4 "

*Machine design—W. C. Unwin.

Ques. 200.—What percentage of efficiency may be retained in a properly designed quadruple riveted butt-joint having both inside and outside butt-straps?

Ans.—94 per cent.

Ques. 201.—Where is the weakest portion of such a joint?

Ans.—At the outer row of rivets.

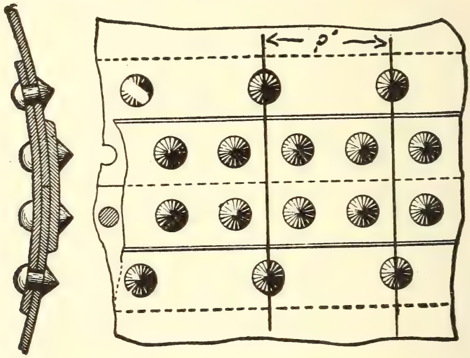


Fig. 44. Double Riveted Butt-Joint.

Ques. 202.—How may boiler heads be constructed which will not require to be stayed?

Ans.—By being dished, or "bumped up."

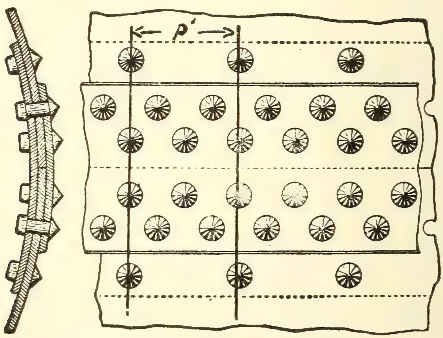


Fig. 45. Triple Riveted Butt-Joint.

Ques. 203.—What is the depth of dish, as adopted by steel-plate manufacturers?

Ans.—One eighth of the diameter of the head, when flanged.

Ques. 204.—What should be the thickness of the head as compared to the thickness of the shell?

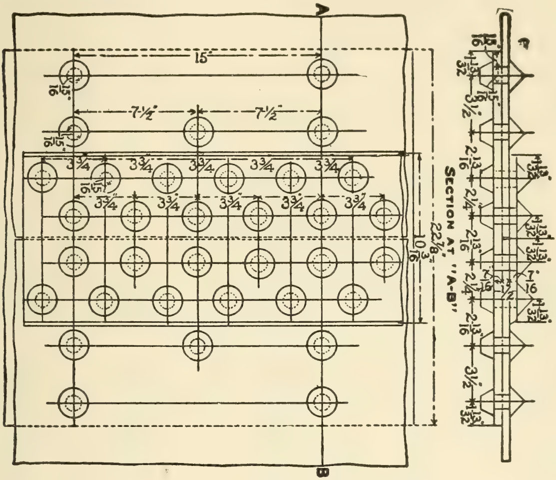


FIG. 46. QUADRUPLE RIVETED BUTT-JOINT.

Lloyd's rules, condensed, are as follows:

LLOYD'S RULES—THICKNESS OF PLATE AND DIAMETER OF RIVETS

Thickness of Plate	Diameter of Rivets	Thickness of Plate	Diameter of Rivets
⅜ inch	⅝ inch	¾ inch	⅞ inch
7/16 "	⅝ "	13/16 "	⅞ "
½ "	¾ "	⅞ "	1 "
9/16 "	¾ "	15/16 "	1 "
⅝ "	¾ "	1 "	1 "
11/16 "	⅞ "		

Ans.—The heads should be as thick, or slightly thicker, than the shell plate.

Ques. 205.—What method other than riveting may be, and sometimes is employed in the formation of boiler seams?

Ans.—Boiler seams may be welded if the material from which the plates are rolled is of the best, and great care and skill are exercised.

Ques. 206.—Mention two of the advantages possessed by welded seams over riveted seams?

TABLE 5

PROPORTIONS OF TRIPLE-RIVETED BUTT JOINTS WITH INSIDE AND OUTSIDE WELT

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Pitch of Outer Rows Inches	Efficiency Per Cent
3/8	13/16	3.25	6.5	84
7/16	13/16	3.25	6.5	85
1/2	13/16	3.25	6.5	83
9/16	7/8	3.50	7.0	84
5/8	1	3.50	7.0	86
3/4	1 1/16	3.50	7.0	85
7/8	1 1/8	3.75	7.5	86
1	1 1/4	3.87	7.7	84

Ans.—First, a good welded joint approaches more nearly to the full strength of the material than can possibly be attained by rivets, no matter how correctly designed the riveted joint may be; second, the welded joint, having a smooth surface inside the boiler, is much less liable to collect scale and sediment than is the riveted joint.

Ques. 207.—Why should the longitudinal or side seams of a boiler be stronger than the girth or round-about seams?

Ans.—Because the force tending to rupture the boiler along the line of the longitudinal seams is proportional to the diameter divided by two, while the stress tending to pull it apart endwise is only one-half that, or proportional to the diameter divided by four.

Ques. 208.—What is the formula for ascertaining the bursting pressure of a boiler?

Ans.—$\frac{TS \times T \times E}{R} = B$, in which

TS = Tensile strength
T = Thickness of sheet
E = Efficiency of joint
R = Radius (one-half the diameter)
B = Bursting pressure

Ques. 209.—How is the safe working pressure of a boiler ascertained?

Ans.—First calculate the bursting pressure, then divide this by the factor of safety, which usually is five, although in some instances a safety factor of eight is used.

Ques. 210.—In addition to the regular bracing and staying, how are the heads of return tubular and Scotch marine boilers greatly reënforced?

Ans.—By the tubes, which are expanded into the heads and beaded down on the ends.

Ques. 211.—Are the tubes always expanded into the tube-sheets?

Ans.—They are in fire-tube boilers. In some forms of water-tube boilers the tubes are screwed into the headers or chambers.

Ques. 212.—What type of furnace is largely used in internally fired boilers?

Ans.—The Morison corrugated furnace.

Ques. 213.—Mention three advantages gained by the use of corrugated furnaces.

Ans.—First, the corrugations (if properly made) add great rigidity and strength to resist the crushing strain to which the furnaces are subjected; second, there is more heating surface in a corrugated than in a smooth surface; third, the alternate expansion and contraction of the

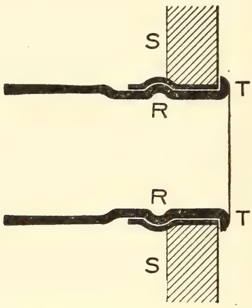


FIG. 47. SECTION OF TUBE EXPANDED INTO SHEET.

corrugated surface tends to loosen any scale that may form on the surface inside the boiler.

Ques. 214.—In regard to riveted seams, which is the better method, to drill or to punch the rivet-holes?

Ans.—The rivet-holes should be drilled. In good boiler work this method is now always followed.

Ques. 215.—What other important point should be kept in view in joining the plates of a boiler?

Ans.—To get the joint tight without caulking, or at least with as small an amount of caulking as possible.

Ques. 216.—Mention some of the injurious effects of excessive caulking.

Ans.—First, it is one of the most fruitful causes of grooving along the edges of the seams; second, it tends to raise the edge of the plate that is caulked, thereby causing looseness at the joint.

Ques. 217.—What other very important point should be secured in the construction of the boiler?

Ans.—The rivet-holes in the plates should come *fair* before the rivet is put in.

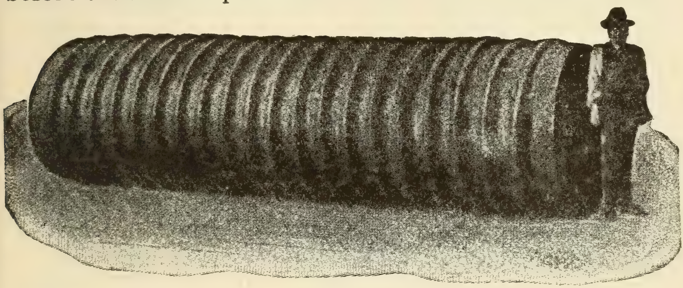


FIG. 48. MORISON CORRUGATED FURNACE.

Ques. 218.—If the rivet-holes do not come *fair* what should be done with them?

Ans.—They should be made exactly true by the use of a rimer.

Ques. 219.—What should not be done with the rivet-holes in case they do not come *fair?*

Ans.—They should not be drifted. A drift-pin is often the primary cause of starting a crack in a sheet.

Ques. 220.—What can be said generally concerning the construction of a boiler, especially one intended for high pressures?

Ans.—Only the best material should be used, and great care and skill should be exercised in all the detail of assembling it.

By reference to Chapter I, Part 2, of Swingle's "Twentieth Century Hand Book for Engineers and Electricians," the student will be enabled to obtain much more detailed information concerning boiler construction, the strength of riveted joints, bracing and staying, strength of material, etc., as all of these important features are dwelt upon at length and fully discussed.

CHAPTER IV

BOILER SETTINGS AND APPURTENANCES.

Ques. 221.—What kind of a setting is required for internally fired boilers?

Ans.—First, a good solid foundation; second, the boiler should be covered with non-conducting, non-combustible material of some sort, to prevent radiation of heat, and the whole should be encased in a sheet-metal jacket.

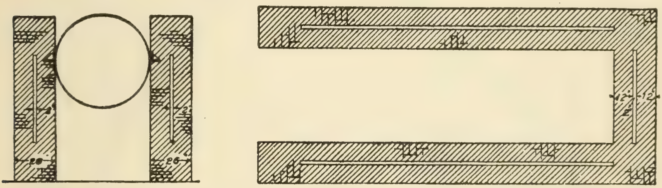


FIG. 49. PLAN AND ELEVATION OF BOILER SETTING, SHOWING AIR SPACES.

Ques. 222.—What kind of a setting is required for horizontal tubular and water-tube boilers?

Ans.—Brick walls with an inner lining of fire brick. When the boiler is supported by lugs resting upon the walls, a heavy iron plate should be imbedded in the brickwork, for each lug to rest upon. The walls should also be tied together, both endwise and transversly, by iron rods not less than 1¼ inch in diameter, extending clear through in both directions, the bottom rods to be laid in place as the walls are being built. These rods are to have a thread and nut on each end, and are secured to heavy cast or wrought iron bars called buck stays, placed vertically against the outside of the walls.

Ques. 223.—How may boiler walls be greatly protected from the injurious action of the heat?

Ans.—By leaving an air-space of 2 inches between the fire-brick lining and the outer wall, beginning at the level of the grate bars and extending as high as the center of the boiler. Above this height the walls should be solid.

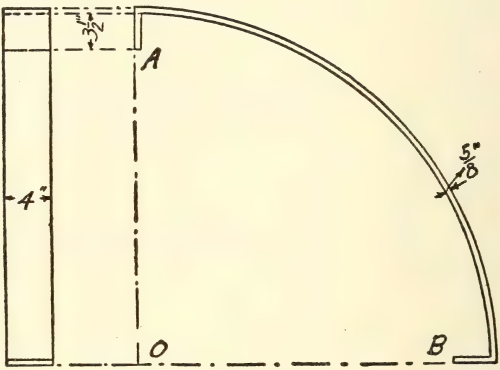


FIG. 50. CLAMP FOR BACK ARCH.

Ques. 224.—What is the duty of bridge-walls and bafflers?

Ans.—To present a hot surface for the unconsumed gases to impinge against, and also to divert the gases towards the heating surface of the boiler.

Ques. 225.—How may a good and durable back arch for a horizontal tubular boiler be constructed?

Ans.—Take flat bars of iron ⅝ inch thick by 4 inches in width, cut them to the proper length, bend them to the shape of an arch, and turn 4 inches of each end back at right angles. The clamp thus formed is to be filled with a course of side arch fire-brick, and will form a complete and self-sustaining arch 9 inches wide and with sufficient spring to cover the distance between the back wall and the back head of the boiler above the tubes. Enough of these arches should be made so that when laid side by side they will cover the distance from one side wall to the other, across the rear end of the boiler.

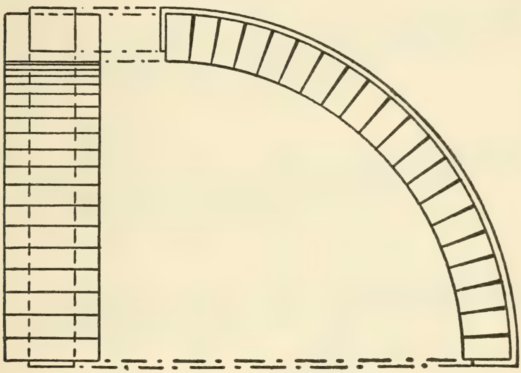


FIG. 51. BACK ARCH COMPLETE.

Ques. 226.—What advantages do this form of back arch possess over the ordinary flat cover?

Ans.—First, it can come and go with the expansion and contraction of the boiler; second, it always maintains a practically air-tight cover at this important point; third, in case of needed repairs to the back end of the boiler the sections may be easily removed, one at a time, and when the repairs are completed they may be reset with very small expense.

Ques. 227.—Give an easy rule for ascertaining the dimensions of the grates.

Ans.—For a horizontal tubular, the length of the grates should equal the diameter of the boiler. The width depends upon the construction of the furnace. If the fire-brick lining is built perpendicular, the width of grate will also equal the diameter of the boiler, but if

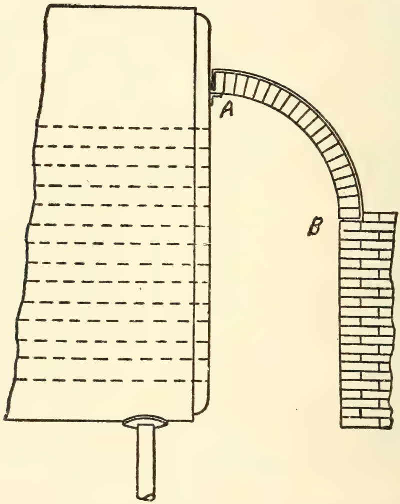


Fig. 52. Back Arch in Place.

the lining is given a batter of 3 inches, starting at the level of the grates, then the width of grate will be 6 inches less.

Ques. 228.—What is the ordinary ratio of grate surface to heating surface for land boilers, with natural draught?

Ans.—One square foot of grate surface to every 36 square feet of heating surface.

Ques. 229.—What ratio of grate surface to heating surface is usually chosen with forced draught?

Ans.—One square foot of grate surface to 40 square feet of heating surface, and in some instances the ratio is as high as 1 to 50.

Ques. 230.—How many different styles of grate-bars are in general use?

Ans.—Four; first, the common stationary grate, consisting of a plain cast-iron bar tapered in cross

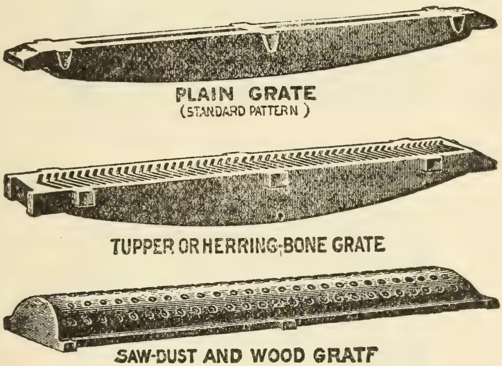


FIG. 53. GRATE BARS.

section and having small projections cast on the sides to keep the bars apart a sufficient distance; second, herring-bone grates, consisting of channel-shaped cast-iron bars having V-shaped openings on top to allow the air to pass through to the fire; third, shaking or rocking grates, fourth, dumping grates.

Ques. 231.—What percentage of the total grate area is usually allowed for the admission of air through the grates?

Ans.—From 30 to 50 per cent, depending upon the kind of coal used.

Ques. 232.—What is the heating surface of a boiler?

Ans.—All the surfaces that are in contact with and covered by water on one side and surrounded by flame or hot gases on the other side. The areas of these surfaces are estimated in square feet and added together.

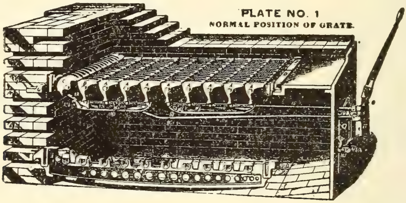


FIG. 54. M'CLAVE'S GRATES.

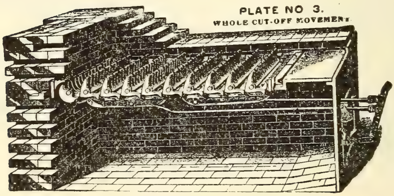


FIG. 55. M'CLAVE'S GRATES.

Ques. 233.—Is it possible to estimate the horse-power of a boiler from its heating surface?

Ans.—It is in a general way, but not accurately.

Ques. 234.—How many square feet of heating surface are usually allowed per horse-power?

Ans.—From 10 to 16 square feet, depending entirely upon the type of boiler.

Ques. 235.—Give some examples.

Ans.—For water-tube boilers 10 to 12 square feet of heating surface; for horizontal fire-tube, 12, for vertical fire-tube, 12 to 15, and for locomotive boilers, 12 to 16 square feet of heating surface per horse-power.

Ques. 236.—Why this difference?

Ans.—Because the heating surface is more effective in some types of boilers than it is in others.

Ques. 237.—What is the rule for calculating the heating surface of a horizontal tubular boiler?

Ans.—Taking the dimensions in inches, multiply two-thirds of the circumference of the shell by its length. Multiply the inside circumference of one of the tubes by its length, and this product by the number of tubes. Add these two products together, and to this sum add two-thirds of the combined areas of both tube-sheets and from this latter sum subtract twice the combined sectional areas of all the tubes. The result will be the heating surface in square inches, which, divided by 144, will give the number of square feet of heating surface.

Ques. 238.—What is the rule for finding the heating surface of vertical fire-box boilers?

Ans.—Multiply the circumference of the fire-box by its height above the grate. Find the heating surface of the tubes by the process given in the former rule and add these two products together, and to this add the area of the lower tube sheet. From this sum deduct the sectional area of all the tubes. The dimensions having been taken in inches, the result should be divided by 144 to ascertain the number of square feet of heating surface.

Ques. 239.—Why is the inside circumference of the tubes taken?

Ans.—Because in fire-tube boilers this is the portion that is directly exposed to the heat.

Ques. 240.—Why are the combined sectional areas of the tubes subtracted from the area of that portion of the tube-sheets that is exposed to the heat.

Ans.—Because the effective heating surface of a tube-sheet is the surface remaining after the areas of the openings through the tubes is deducted.

Ques. 241.—What is implied in the expression "a 3-inch boiler tube?"

Ans.—It means a tube 3 inches in external diameter.

Ques. 242.—Such being the case, which diameter should be considered in calculating the heating surface of fire-tubes?

Ans.—Only the inside diameter, which equals the outside diameter minus twice the thickness of the tube.

Ques. 243.—In calculating the heating surface of the tubes of water-tube boilers which diameter should be taken?

Ans.—The outside diameter, for the reason that the outside circumference is exposed to the heat.

Ques. 244.—How is the heating surface of a water-tube boiler ascertained?

Ans.—Much depends upon the style of boiler. A general rule and one that will apply in all cases, is to multiply the outside circumference of one of the tubes by its length, and this product by the number of tubes that are of a similar length and diameter. If there are various sections of tubes of varying lengths, the heating surface of each section must be ascertained separately and the whole added together. To this sum must be added the combined areas of those portions of the headers that are directly exposed to the heat, having first deducted the sectional area of the tubes. All of those portions of the steam and water-drums that are directly exposed to the heat should be estimated as heating surface also.

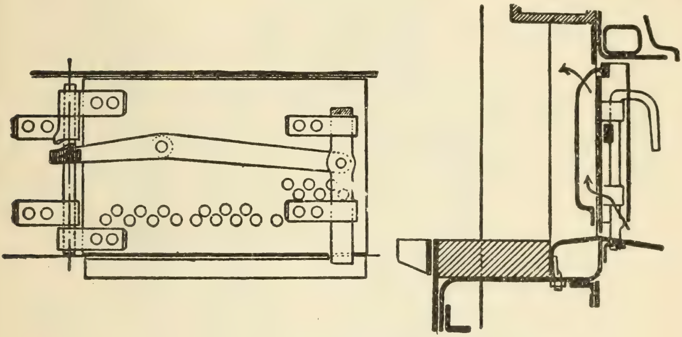


FIG. 56 DOOR OF A BELLEVILLE BOILER.

The door proper has an outer and inner plate, the former being a screen plate with edges open for the admission of air. The door is perforated with holes at the lower part, through which the air is drawn, and the inner plate, which is of cast iron, is closed at the bottom, and has holes for the discharge of air at the top. When the fires are alight, there is a continuous current of air flowing into the furnace through these plates.

Ques. 245.—What is the rule for ascertaining the heating surface of a Scotch boiler?

Ans.—The grates being set in the large main flues, only one-half of each flue area is available as heating surface. The following rule applies: To one-half the combined area of the main flue add the area of one head between the grate and water-line, minus the total cross-section of the tubes, plus one-half the cross-section of main flues, plus the combined inside area of the tubes, plus the inside area of the combustion chamber.

Ques. 246.—Give the rule for finding the heating surface of a corrugated flue.

Ans.—Multiply the average inside diameter in feet by the length of the flue in feet, and this product by the

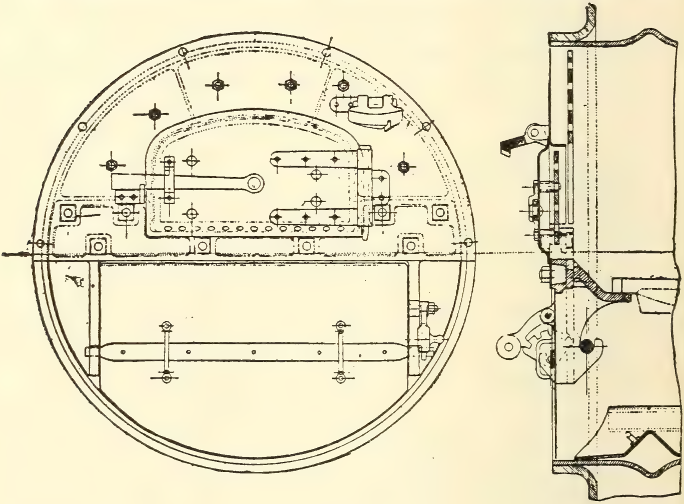


FIG. 57.

Shows another variety, the air being admitted through holes at the bottom of the wrought-steel door proper, a perforated inner cast-iron plate being fitted to shield the door. The wrought-steel furnace frame which carries the door also has an inner shield plate of cast-iron perforated with holes.

constant 4.93. The result is square feet of heating surface.

Ques. 247.—What is the duty of a safety valve?

Ans.—To automatically relieve the boiler of all pressure above a certain prescribed working pressure by allowing the surplus steam to escape into the atmosphere.

Ques. 248.—If a boiler had no safety valve, or if the safety valve should refuse to work, and all other exit from the boiler be closed, and heat continuously applied, what would be the result?

Ans.—An explosion must of necessity occur.

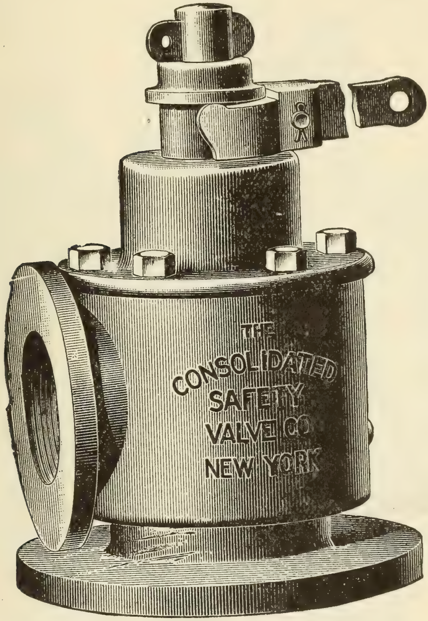


FIG. 58. POP VALVE.

Ques. 249.—How many types of safety valves are in use?

Ans.—Two; the lever safety valve, and the spring-pop safety valve.

Ques. 250.—Which is the best adapted to all kinds of service?

Ans.—The spring-loaded pop safety valve is, for the reason that any inclination of the boiler, such as that caused by the vessel's pitching and rolling in a heavy sea, does not interfere with the working of a spring-pop valve,

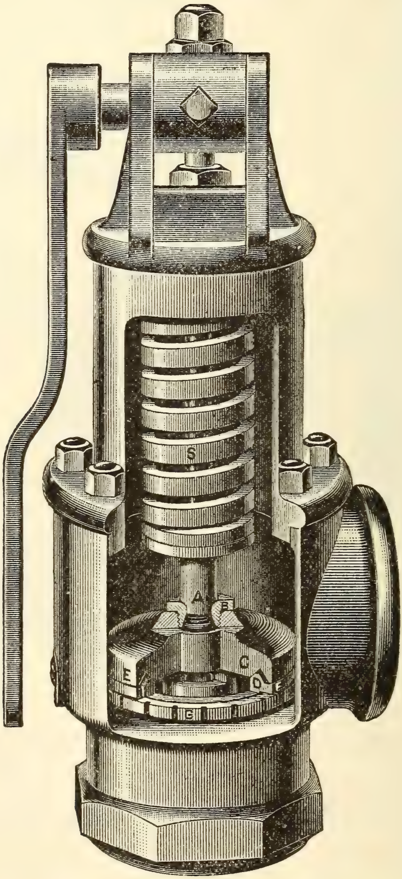


FIG. 59. INSIDE VIEW OF A POP SAFETY VALVE.

while on the other hand the leverage of a weighted lever valve decreases with any inclination of the boiler that would momentarily put the lever in an inclined position.

Ques. 251.—What is the United States marine rule for determining the area of lever safety valves for boilers?

Ans.—"Lever safety valves to be attached to marine boilers shall have an area of not less than 1 square inch to

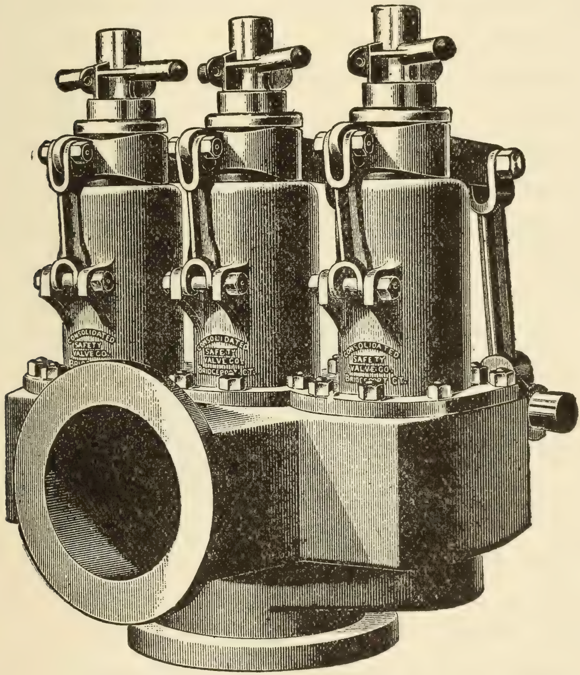


FIG. 60. TRIPLEX POP SAFETY VALVE.

every 2 square feet of grate surface in the boiler, and the seats of all such safety valves shall have an angle of inclination of 45 degrees to the center line of their axis."

Ques. 252.—What is the rule regarding spring pop safety valves?

Ans.—Three square feet of grate surface are allowed to each square inch of safety-valve area.

Ques. 253.—What other and more reliable method is there of calculating safety-valve area?

Ans.—The method by which the area of the valve is based upon the quantity of steam that the boiler is capable of generating.

Ques. 254.—Why is this method more reliable?

Ans.—For the reason that the rate of combustion varies greatly under different conditions, as, for instance, when forced draught is employed, a much higher rate of combustion is attained than is possible with natural draught.

Ques. 255.—Do the standard rules given in answers 251 and 252 hold good for safety-valve areas for all pressures?

Ans.—No; because the rate of efflux for steam increases as the pressure increases. Therefore, for the higher pressures the total safety-valve area may be reduced.

Ques. 256.—What should be the lift of a safety valve in order to allow the proper area of escape?

Ans.—One-fourth of the diameter of valve.

Ques. 257.—What is the rule for ascertaining the pressure at which a lever safety valve will lift when the weight and its distance from the fulcrum are known, as also the effective weight of the valve, stem, and lever?

Ans.—Multiply the weight by its distance from the fulcrum. Multiply the weight of the valve and lever by the distance of the stem from the fulcrum, and add to the former product. Divide the sum of the two products by the product of the area of the valve multiplied by its distance from the fulcrum. The result will be the pressure in pounds at which the valve will lift.

Ques. 258.—What is the rule for finding the distance that the weight should be placed from the fulcrum for a required pressure?

Ans.—Multiply the area of the valve by the pressure

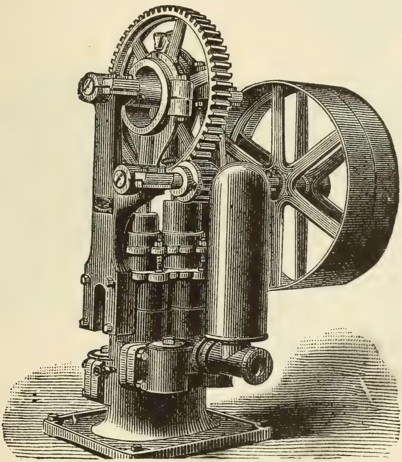


FIG. 61. DAVIS BELT DRIVEN FEED PUMP.

at which it is desired to have it lift, and from this product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of the stem from the fulcrum, and divide by the weight. The quotient will be the required distance.

Ques. 259.—What is the rule for ascertaining the weight required when all of the other factors are known?

Ans.—Multiply the area of the valve by the pressure, and from the product deduct the effective weight of the valve and lever. Multiply the remainder by the distance of the stem from the fulcrum and divide by the distance of the ball or weight from the fulcrum. The quotient will be the required weight in pounds.

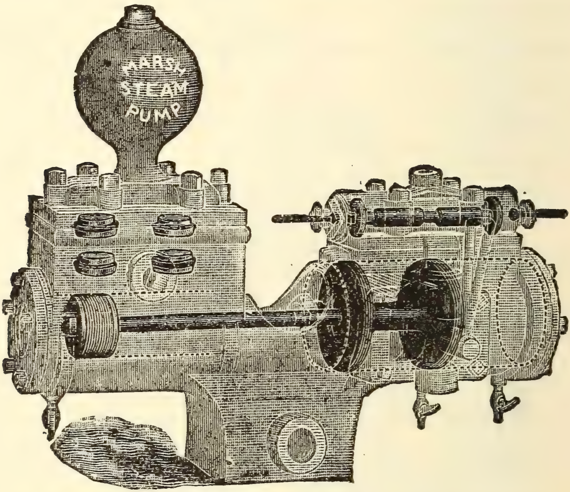


Fig. 62. Phantom View of Marsh Independent Steam Pump.

Ques. 260.—What can be said in general regarding the safety valve?

Ans.—It is one of the most useful and important adjuncts of a steam boiler, and if neglected, serious results are apt to follow.

Ques. 261.—Mention the two standard methods of supplying the feed-water to boilers under pressure?

Ans.—First, by the feed-pump; second, by the injector.

Ques. 262.—What advantage has the feed-pump over the injector?

Ans.—The advantage of being able to draw its supply of water from a heater, in which the exhaust steam is utilized for heating the feed-water before it enters the boiler. Great economy in fuel is thereby effected.

Ques. 263.—What is a duplex pump?

Ans.—A duplex pump consists of two steam-cylinders and two water-cylinders, each having the necessary pistons and valves. The steam-valves of one side are

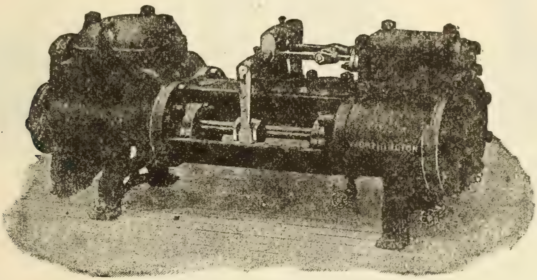


FIG. 63. WORTHINGTON DUPLEX BOILER FEED PUMP.

operated by the other side, and vice versa. Both water cylinders discharge into the same main. A common suction main serves both water-cylinders also.

Ques. 264.—If one side of a duplex pump becomes disabled from any cause, how may the other side be operated for the time being?

Ans.—Loosen the nuts or tappets on the valve-stem of the broken side and place them far enough apart so that the steam-valve will be moved through only a small portion of its stroke, thereby admitting only steam enough to move the empty steam-piston and rod, and thus work the steam-valve of the remaining side. The packing on the piston-rod of the broken side should be screwed up tightly, so as to create as much friction as possible, there being no resistance in the water end. In this manner the pump may be operated for several days or weeks, and thus prevent a shut-down.

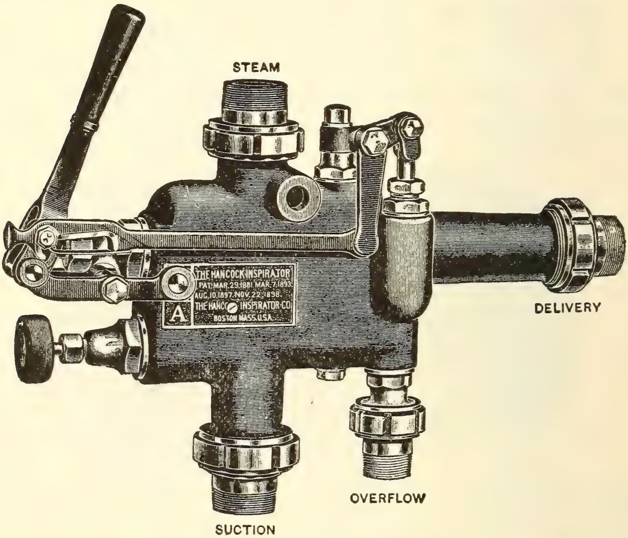


FIG. 64. THE HANCOCK INSPIRATOR.

Ques. 265.—How is the velocity of flow, or piston-speed per minute of a pump ascertained?

Ans.—Multiply the number of strokes per minute by the length of stroke in feet, or fractions thereof. This will give the piston-speed in feet per minute.

Ques. 266.—How is the velocity of flow in the discharge-pipe ascertained?

Ans.—Divide the square of the diameter of the water-cylinder in inches by the square of the diameter of the discharge-pipe in inches, and multiply the quotient thus

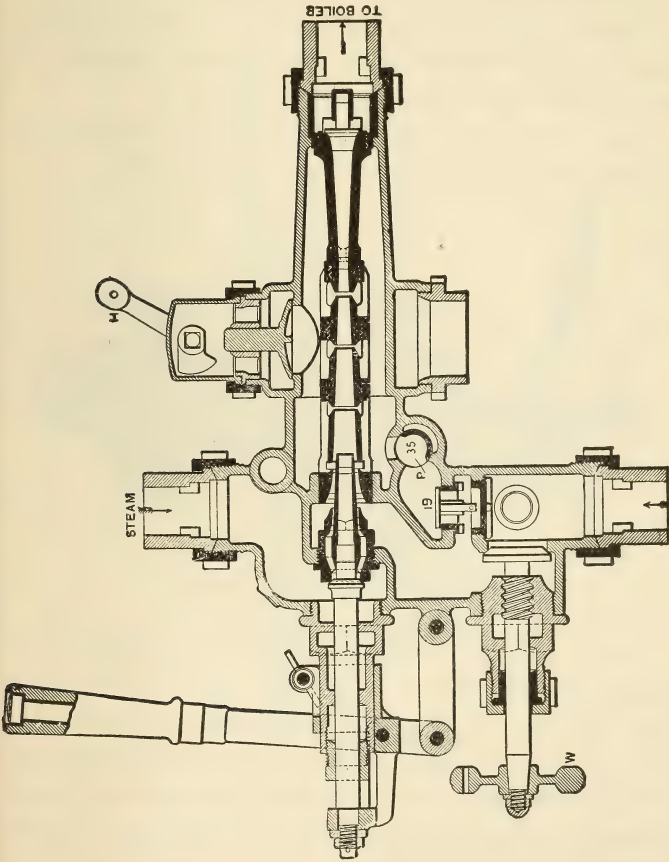


FIG. 65 THE SIMPLEX INJECTOR.

obtained by the piston-speed in feet per minute of the pump.

Ques. 267.—When the velocity in feet per minute is known, how may the number of cubic feet discharged per minute be ascertained?

Ans.—Multiply the area of the pipe in square inches by the velocity in feet per minute, and divide by the constant 144. The result will be the number of cubic feet of water or other fluid discharged per minute.

Ques. 268.—How may the required size and capacity of feed-pump for a certain boiler be ascertained?

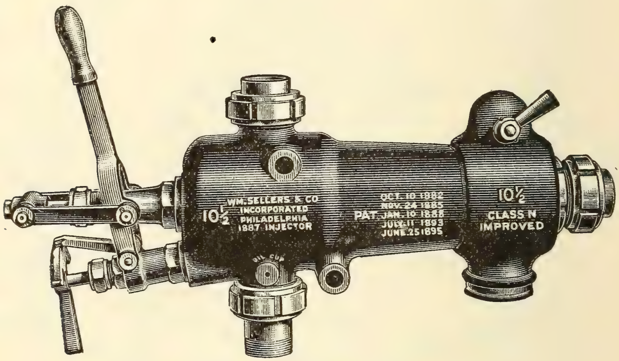


Fig. 66. The Self-Acting Injector.

Ans.—Multiply the number of square feet of grate surface by the number of pounds of coal it is desired to burn per hour per square foot of grate. This will give the total coal consumed per hour, which, multiplied by the number of pounds water evaporated per pound of coal will result in the total number of pounds water required per hour.

Ques. 269.—How may the required size of the feed-pump be ascertained from the number of square feet of heating surface?

Ans.—Allow a pump capacity of 1 cubic foot of water per hour for each 15 square feet of heating surface.

Ques. 270.—How can an injector lift and force water

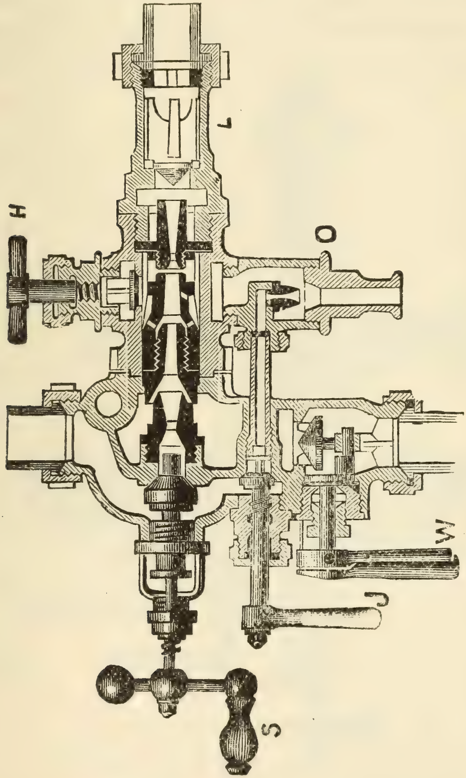


FIG. 67. THE "MONITOR" INJECTOR, INTERIOR VIEW.

into the boiler against the same or even higher pressure than the pressure of the steam supplied to the injector?

Ans.—An injector works because the steam imparts sufficient velocity to the water to overcome the pressure in the boiler.

Ques. 271.—What is the velocity of a jet of steam under 180 pounds pressure issuing from a nozzle?

Ans.—About 3,600 feet per second.

Ques. 272.—What is the velocity of a jet of water under a pressure of 180 pounds issuing from a nozzle?

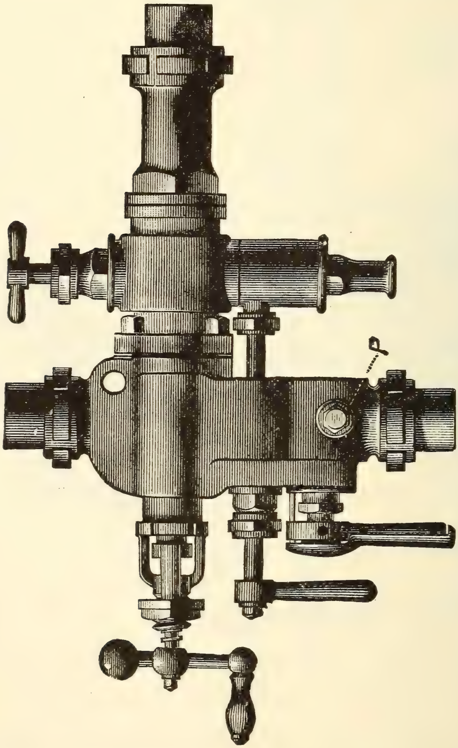


FIG. 68. THE "MONITOR" INJECTOR, EXTERIOR VIEW.

Ans.—Only 164 feet per second.

Ques. 273.—Why does the steam have so much greater velocity than the water, when the pressure in both instances is the same?

Ans.—Because of the latent heat that is stored in the steam.

Ques. 274.—What is the purpose of the combining tube in an injector?

Ans.—To bring the jet of steam and the jet of water into close contact in order that the steam may be con-

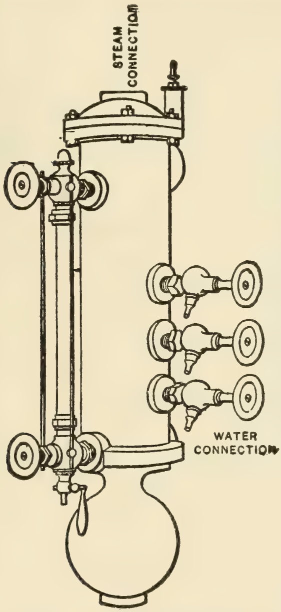


Fig. 69. Water Column.

densed and the size of the jet reduced sufficiently to allow it to enter the delivery tube, which is of smaller diameter than the combining tube.

Ques. 275.—What is the velocity of the combined jet of water and condensed steam as it leaves the combining tube and enters the delivery tube, assuming the steam-pressure in the boiler to be 180 pounds per square inch?

Ans.—198 feet per second.

Ques. 276.—What velocity is actually needed to cause the jet to enter the water-space of the boiler carrying 180 pounds pressure?

Ans.—Only 164 feet per second. The excess of 34 feet per second imparted to the velocity of the jet serves to overcome the friction of the feed-pipe and the resistance of the main check-valve.

Ques. 277.—In general terms, then, to what is the action of the injector due?

Ans.—The action of the injector is due to the high velocity with which a jet of steam strikes the water entering the combining tube, imparting to it its momentum and forming with it during condensation a continuous jet of smaller diameter, having sufficient velocity to overcome the pressure in the boiler.

Ques. 278.—What is the object in fitting a boiler with a check-valve in the feed-pipe?

Ans.—A check-valve is for the purpose of preventing the water in the boiler from backing up into the feed main and feed-pump.

Ques. 279.—Where should the check-valve be located?

Ans.—In the feed-pipe, as near to the boiler as possible.

Ques. 280.—For what purpose are gauge-cocks and water-gauge glasses?

Ans.—They are for the purpose of indicating the height of the water in the boiler while it is under pressure.

Ques. 281.—Describe the construction and operation of a glass water-gauge?

Ans.—A water-gauge, otherwise known as a water column or combination, is a cast-iron or brass cylinder connected to the steam-space of the boiler at the top, and to the water-space near the bottom. The normal position of the safe water-level is near the middle of the water-

FIG. 70. LOW WATER ALARM.

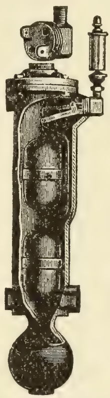


FIG. 71. COMBINED HIGH AND LOW WATER ALARM.

column, into one side of which are screwed brass fittings for the glass tube or water-glass, which is a strong tube of special manufacture. Each end of this tube passes through a stuffing box in the brass fittings. The joint is made steam tight by a rubber ring that fits around the tube and is compressed by a follower screwed onto it. The fittings that connect the water-column with the boiler are, or at least should be, equipped with automatically closing ball valves which will act in case the gauge-glass breaks.

Ques. 282.—Where are the gauge-cocks or test-cocks usually connected?

Ans.—They are usually connected to the water-column cylinder in such a position that the lowest one is at the desired water-level, one a few inches above that, and the third near the highest point of the heating service. These test-cocks should be opened several times a day in order to keep them clear for use in case the gauge-glass breaks.

Ques. 283.—What is liable to happen to the water-column?

Ans.—Unless the water and sediment are frequently blown out of it through the valve at the bottom provided for this purpose, the tubes and connections will become clogged, thus preventing a free circulation of the water, and the true water-level in the boiler will not be indicated as it should be.

Ques. 284.—What is a fusible plug?

Ans.—A fusible plug is a 1-inch brass pipe threaded plug, having its center drilled out to a diameter of not less than ½ inch, and the hole filled with Banca tin or other fusible metal.

Ques. 285.—Where should a fusible plug be attached to a boiler?

Ans.—A fusible plug should always be attached to that portion of the boiler that is first liable to become overheated on account of the water-level becoming too low.

Ques. 286.—Mention some proper locations for fusible plugs in various types of boilers?

Ans.—The back head of a horizontal tubular boiler, about 3 inches above the top row of tubes, the crown-sheet of a horizontal fire-box boiler; the lower tube-sheet of a vertical boiler, or sometimes in one of the tubes a few inches above the tube-sheet; in the lower side of the upper drum of a water-tube boiler. The fusible metal which fills the center of the plug is of conical form in order to prevent its being blown out by the pressure behind it. On the other hand, the melting point of this fusible metal is such that when the water falls below it, and the steam under pressure in the boiler comes in contact with it, the metal is melted and runs out, thus allowing the steam to escape through the hole and give the alarm. If the melted plug is located in the crown-sheet of a fire-box boiler, the escaping steam and water will quench the fire and thus lessen the danger of burning the sheet.

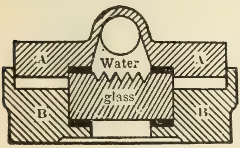


FIG. 72.

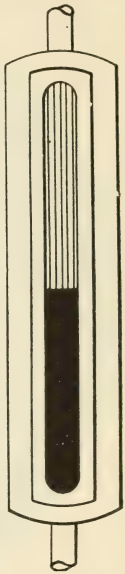


FIG. 72a.

Klinger's Water Gauge Mounting.—The usual round thin gauge glasses give trouble with high-pressure steam, owing to frequent fractures, while the water level is often indistinct. Klinger's glass, designed to obviate these defects, gives promise of success. It consists of a thick fl t glass, with smooth front and serrated back, shown in section Fig. 72. A and B, the front and back of the mounting, are bolted together with the glass and packing, shown by thick lines, between them. The serrations, when clean, cause the water to appear black, as in Fig. 72a.

Ques. 287.—For what purpose is a steam-gauge attached to a boiler?

Ans.—For the purpose of indicating the number of pounds pressure per square inch in the boiler.

Ques. 288.—What type of steam-gauge is in most general use?

Ans.—The Bourdon spring tube gauge.

Ques. 289.—Describe the construction of this gauge, and the principle upon which it operates?

Ans.—The Bourdon gauge consists of a thin, curved,

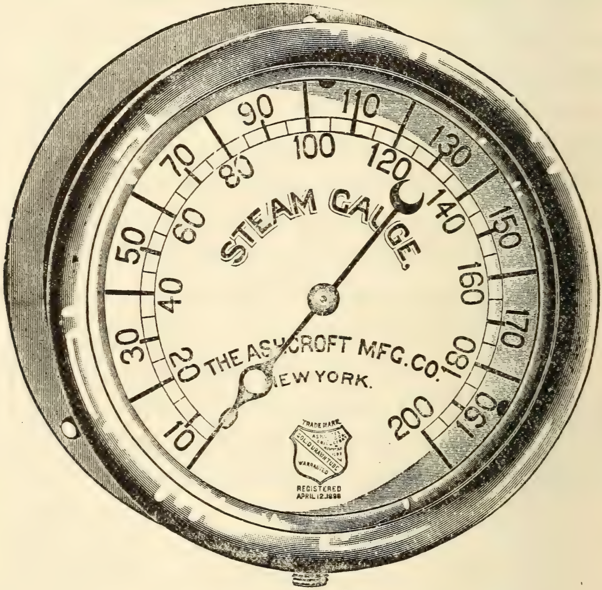


FIG. 73. AUXILIARY SPRING PRESSURE GAUGE.

flattened metallic tube closed at both ends and connected to the steam-space of the boiler by a small pipe bent at some portion of its length into a curve or circle that becomes filled with water of condensation, and thus prevents the live steam from coming directly in contact with the tube or spring, while at the same time the full pressure of steam in the boiler acts upon the tube, tending to straighten it. The end or ends of the spring tube being free to move, and connected by a suitable geared rack and pinion with the pointer of the gauge, causes it

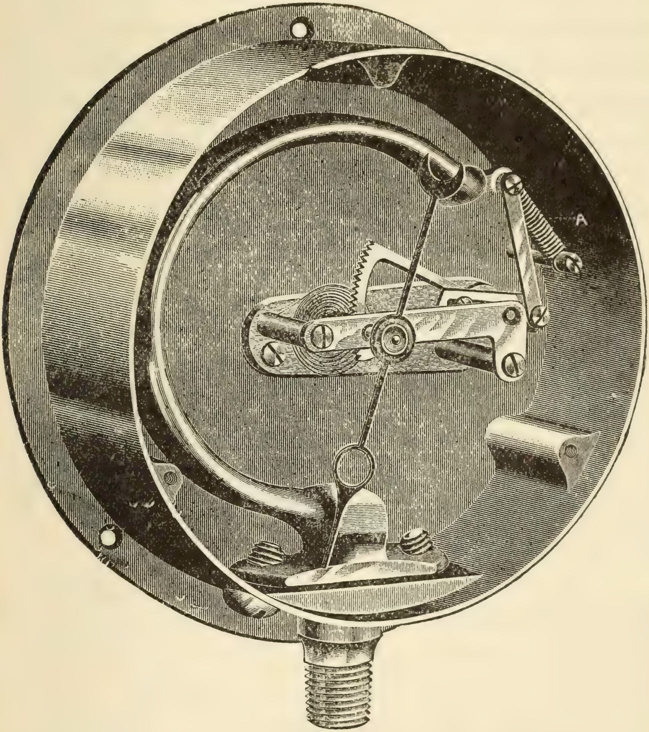


FIG. 74. AUXILIARY SPRING PRESSURE GAUGE, SECTIONAL VIEW.

to move across the face of the dial, thus indicating the pressure of the steam in pounds per square inch on the inner surface of the boiler. When there is no pressure in the boiler the pointer should stand at 0.

Ques. 290.—How should steam-gauges be cared for?

Ans.—They should be tested frequently by comparing them with a gauge that has been tested against a column of mercury.

Ques. 291.—How should the steam-space of the boiler be connected to the main steam-pipe or header?

Ans.—There should be a steam stop-valve placed in the connection between the boiler and the header. The valve

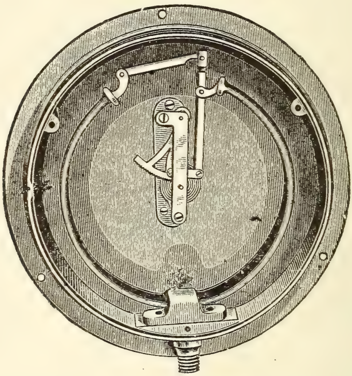


Fig. 75. Sectional View American Pressure Gauge.

used for this purpose is usually an angle-valve, and should be constructed so as to close automatically, especially in a battery of two or more boilers.

Ques. 292.—Why should this valve be self-closing in case the pressure in the header is higher than the pressure in the boiler?

Ans.—In order that in case of an accident to one of a battery of boilers the steam may be prevented from passing out of the header and into the disabled boiler.

Ques. 293.—Describe the construction and operation of an automatic steam stop-valve.

Ans.—The valve is opened and closed by means of a screw-stem passing out through the stuffing box, and fitted with a hand-wheel outside. In large-size valves this screw-thread is carried in a strong yoke outside the casing. The pressure from the boiler is on the under side of the valve-disk, thus tending to open it. The stem or spindle is independent of the valve, and is hollow to allow a smaller size sliding spindle connected to the valve to pass into it. This spindle serves to guide and hold the valve steady, while at the same time the valve is free to close automatically any time that the pressure in the main exceeds the pressure in the boiler.

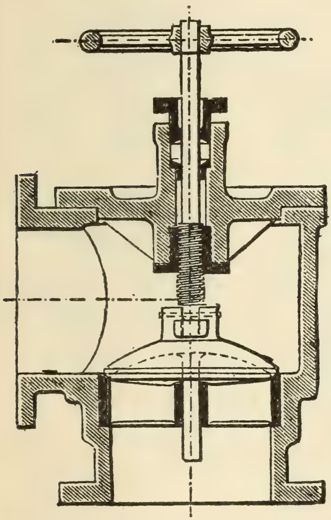


FIG. 76. SECTION OF AN ANGLE STOP-VALVE.

Ques. 294.—How is the steam admitted to the whistle or the steam siren?

Ans.—Through a special stop-valve, usually of the self-closing type, being worked by a spring on the valve.

Ques. 295.—Describe the action of the steam whistle.

Ans.—The steam whistle produces its sound by the vibrations of a thin stationary metallic cylinder, under the impact of the steam.

Ques. 296.—How does the steam siren produce its sound?

Ans.—By means of the rotations of a small slotted wheel which in turning opens and closes narrow slots in the casing.

Ques. 297.—How may the passage of water from the boiler into the steam-pipe be prevented to a large extent?

Ans.—By means of an internal pipe-extension called a dry pipe, that collects the steam from all parts of the steam-space through narrow slots on its upper side. The shape of these slots has a straining action on the steam.

Ques. 298.—What is the object in equipping a boiler with a surface blow-off?

Ans.—In order that it may catch and pass off impurities, such as grease, oil, and scum, floating on the surface of the water.

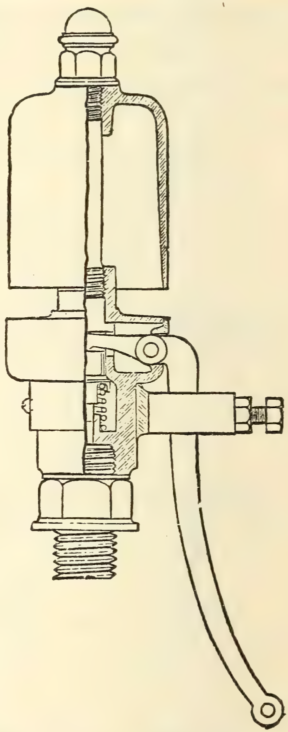


Fig. 77. Steam Fog-Whistle.

Ques. 299.—Describe the construction and operation of the surface blow-off.

Ans.—It is connected to the boiler near the water-level, and carries an internal pipe-extension that ends in a flat pan, directly below the water-line. It should be opened quite frequently, especially when muddy water is being fed to the boiler. This will allow the accumulated scum to pass out.

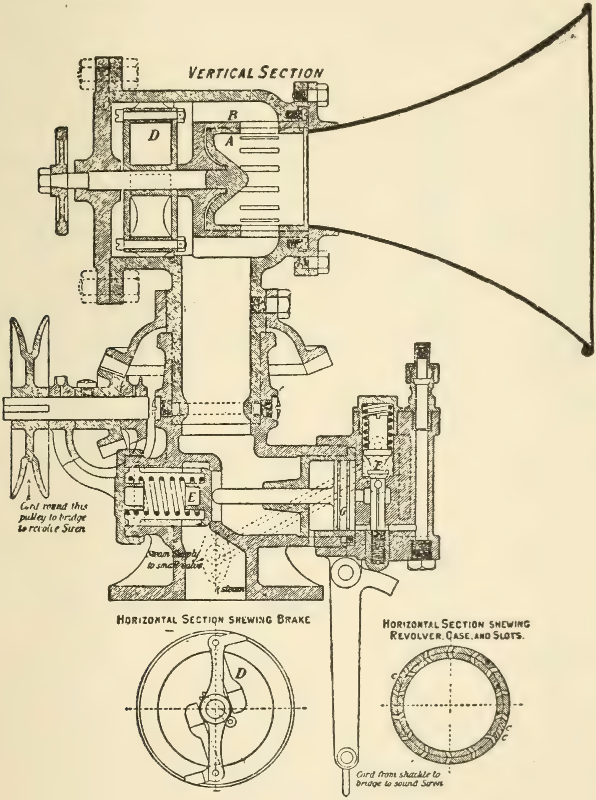


FIG. 78. SECTION OF A STEAM SIREN.

Ques. 300.—Where and how should the bottom blow-off be connected?

Ans.—The bottom blow-off should be connected to the lowest section of the boiler, and should be fitted with a straight-way valve, or a cock, in order that there may be no obstruction to the free passage of the mud and other sediment when the boiler is being cleaned.

Ques. 301.—For what purpose is the hydrometer-cock, and where is it located?

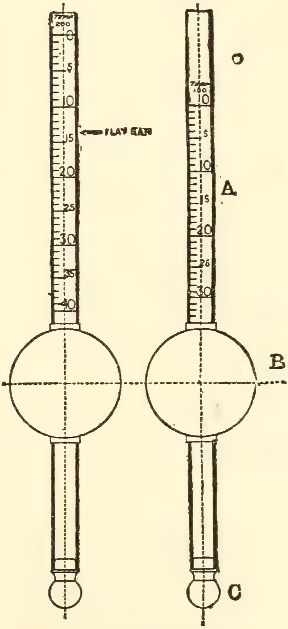


Fig. 79. Hydrometer.

Ans.—In the marine service the water used in the boilers is more or less impregnated with solid matter, and it becomes necessary to test the density of the water in the boilers at certain intervals. The hydrometer-cock is for the purpose of drawing off a quantity of water from the boiler for testing, and is fitted to the water-space of the boiler.

Ques. 302.—Describe the construction and use of the hydrometer.

Ans.—It is an instrument having a long, slender stem, made of either glass or metal. There are two bulbs in the stem. The smaller one is loaded and the larger one is hollow and filled with air, which gives the instrument buoyancy, and keeps it in a vertical position. The stem is graduated in degrees, each degree representing the presence of one-tenth the solid matter in sea-water.

Ques. 303.—What proportion of sea-water is solid matter?

Ans.—One thirty-second part.

Ques. 304.—Upon what principle are the readings taken from the hydrometer based?

Ans.—Upon the principle that when any body floats freely, the weight of the liquid displaced is equal to the weight of the body floating, so that the higher the density of the liquid the less depth will the body sink in it. If the instrument sinks only to the zero mark on the scale, the water is fresh: if it sinks to 10 degrees, it indicates the presence of one-thirty-second part of solid matter, and if it sinks to 40 degrees, it indicates a density caused by the presence of four times as much solid matter as there is in sea-water.

Ques. 305.—How is the water in the boiler tested with the hydrometer?

Ans.—A quantity of water is drawn off through the hydrometer-cock, fitted for this purpose into a long pot, into which the instrument is inserted.

Ques. 306.—How are boiler hydrometers graduated, with reference to temperature?

Ans.—They are usually graduated to suit a temperature of 200 degrees Fahrenheit, as that is about the temperature of the water a few seconds after being drawn off for testing.

Ques. 307.—How are the expansion and contraction of steam-pipes provided for?

Ans.—In the smaller sized pipes a bend can be put in the length of pipe that will answer the purpose, but in the large pipes an expansion joint, having a stuffing box for the pipe to slide in and out of the adjacent pipe is fitted.

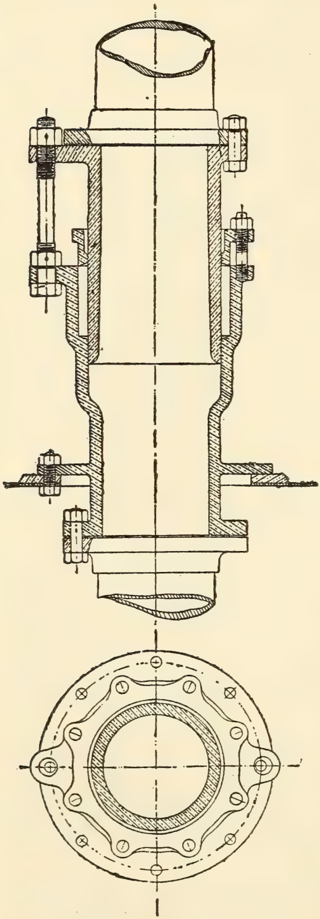


Fig. 80. Expansion Joint.

Ques. 308.—Why is it necessary to place a separator in the line of pipe leading from the boiler to the engine?

Ans.—The object of a separator is to provide an additional safeguard against priming, by preventing any water in the steam-pipe from entering the cylinder.

Ques. 309. — Describe the ordinary separator.

Ans.—It is a metal cylinder larger in diameter than the steam-pipe, and connected to the pipe near the engine, by flange connections in such a manner that the larger portion of the separator hangs in a vertical position below the pipe. It is divided from the top nearly to the bottom by a diaphragm, and the steam enters on one side, near to the top, and impinges against the diaphragm, passes underneath it, and out on the other side near the top.

Any water that reaches the separator is mostly left at the bottom, only the steam passing on to the engine cylinder. A valve is provided at the bottom of the separator for drawing off the water. The height of the water in the separator is shown by a glass gauge.

Ques. 310.—Describe the automatic steam separator.

Ans.—In addition to the usual diaphragm, it is fitted with an automatic blow-out apparatus, having a float that is raised as the water accumulates, and which by a system of levers opens a valve of large area for drainage. The automatic separation also has a hand blow-off valve.

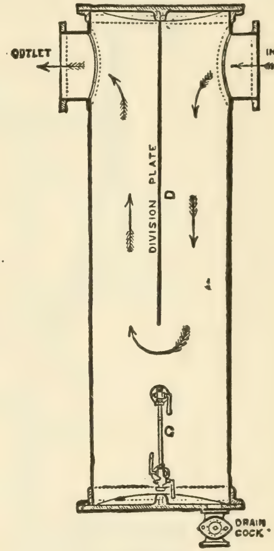


FIG. 81. SEPARATOR.

Ques. 311.—What is an asbestos-packed cock, and where is it used?

Ans.—An asbestos-packed cock has its top and bottom glands packed with asbestos, while the shell also has longitudinal grooves found in it which are packed with asbestos. These cocks are very suitable to use on boilers and steam piping where high pressures are carried, and at locations where cocks are more convenient than valves would be.

Ques. 312.—What are funnel dampers, and for what purpose are they attached?

Ans.—They are hinged dampers fitted in the uptakes leading from the boilers to the funnel, in order that each

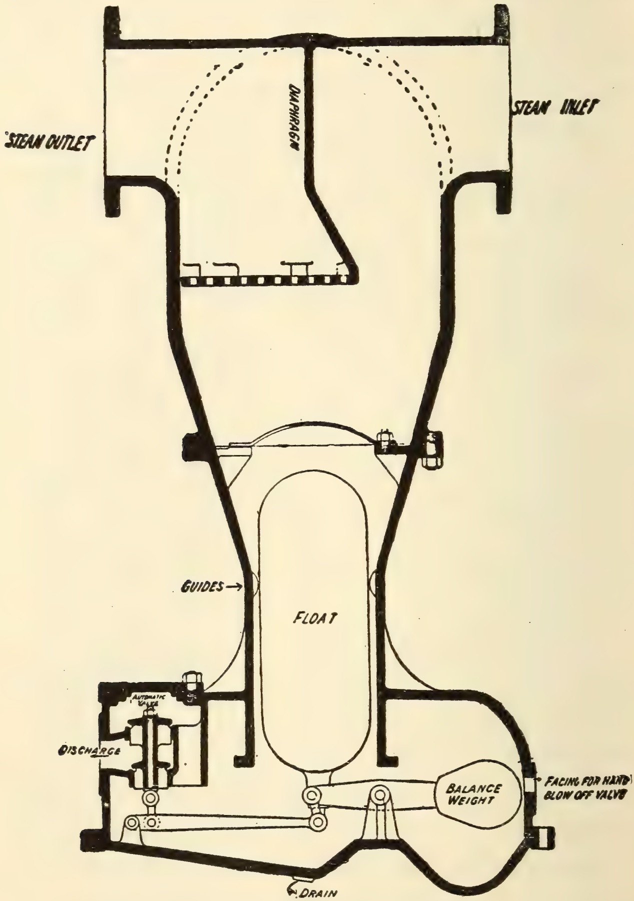


FIG. 82. AUTOMATIC SEPARATOR.

boiler may be shut off from the draught when not in use, and they are also for use when the fires are being cleaned.

These dampers should be fitted so that there are no means of closing them permanently, but that if released they will at once assume the open position.

Ques. 313.—What are funnel stays?

Ans.—Wire ropes carried from the top of the funnel to the ship's sides, and fitted with adjusting screws for the purpose of regulating the strains.

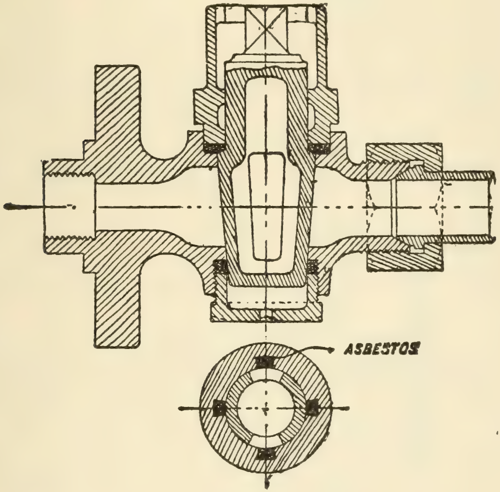


Fig. 83. Asbestos-Packed Cock.

Ques. 314.—What precautions should be taken with these stays before raising steam in the boilers?

Ans.—The adjusting screws should be slackened in order to allow for the expansion in the length of the funnel as it becomes heated.

Ques. 315.—What is the usual height of the funnels of modern vessels?

Ans.—Ninety to 100 feet, measured from the furnaces.

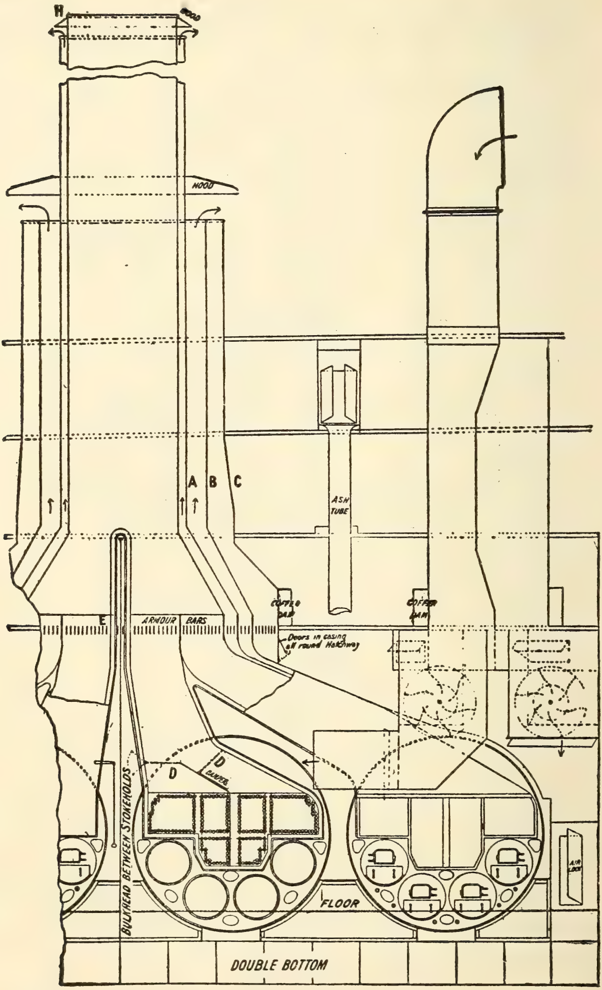


FIG. 84. SECTION OF ARMORED CRUISER, SHOWING STOKE-HOLD AND FUNNELS.

Ques. 316.—For what purpose is the funnel cover?

Ans.—It is fitted over the top of the funnel for use

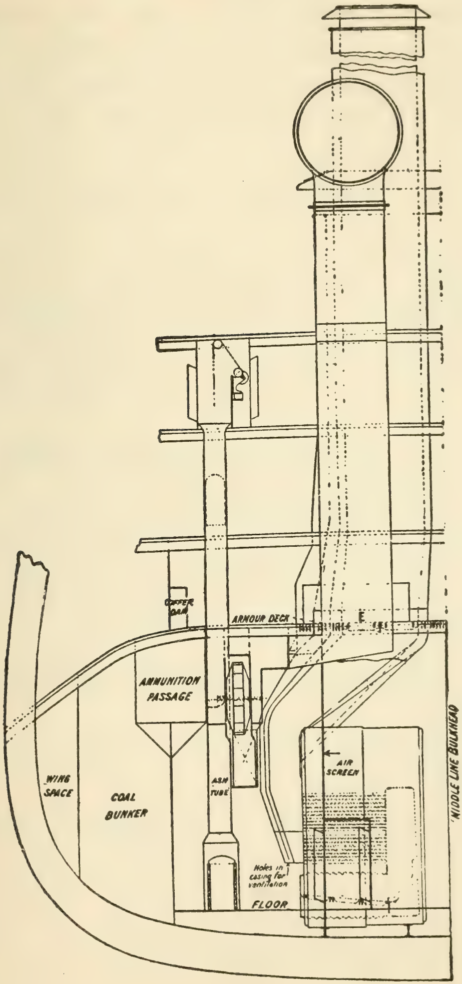


FIG. 85. SECTION OF ARMORED CRUISER, SHOWING AIR SCREEN AND COAL BUNKER.

when the ship is in harbor, or if any of the funnels are not in use, in order to prevent rain-water from entering and corroding the uptakes. These covers are kept a little above the top of the funnel, in order to allow sufficient space for the escape of smoke from small fires used for airing and warming the boilers while they are lying idle.

Ques. 317.—How is the stoke-hold of a steamer ventilated?

Ans.—When natural draught only is used, screens are required to keep the downward current of cool air separate from the upward current of warm or vitiated air, otherwise the circulation will not be as good as it should be.

Ques. 318.—When forced draught is employed for the furnaces, how is the air supplied?

Ans.—One of the oldest and at the same time most expensive methods is to admit a jet of high-pressure steam directly from the boilers to the base of the funnel. This is known as the steam blast. Another plan of using the steam blast is to admit small jets of steam into the furnace, over the fire.

Ques. 319.—What other principal plans for creating forced draught are employed?

Ans.—First, admitting jets of compressed air into the base of the funnel, in a manner similar to the steam-jet; second, fitting a centrifugal fan in the uptake; third, blowing the air into closed ash-pits; fourth, closing the stoke-hold and keeping it filled with slightly compressed air.

Ques. 320.—Of the plans just mentioned, which one is probably the most efficient?

Ans.—Closed stoke-holds, although the third plan, viz., blowing the air into closed ash-pits, is an efficient method, but a certain degree of danger attaches to it, on account of the pressure in the furnaces being greater

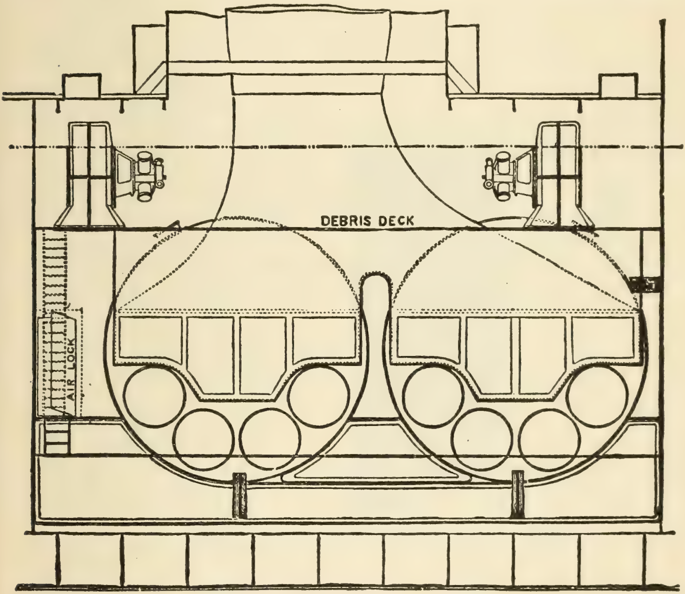


FIG. 86. CROSS SECTION OF STOKE-HOLD, SHOWING AIR LOCK.

than that in the stoke-hold, and unless proper precautions are taken before opening the furnace doors for the purpose of replenishing the fires, the flames may be blown into the stoke-hold and serious results follow.

Ques. 321.—Is this latter system of closed ash-pits much in vogue?

Ans.—It is used to a large extent in the United States navy, also many ships of the mercantile marine service. The British and other navies also use it to some extent.

Ques. 322.—How may this system of creating a forced draught be made safe, so as to guard against the flame being blown into the stoke-hold?

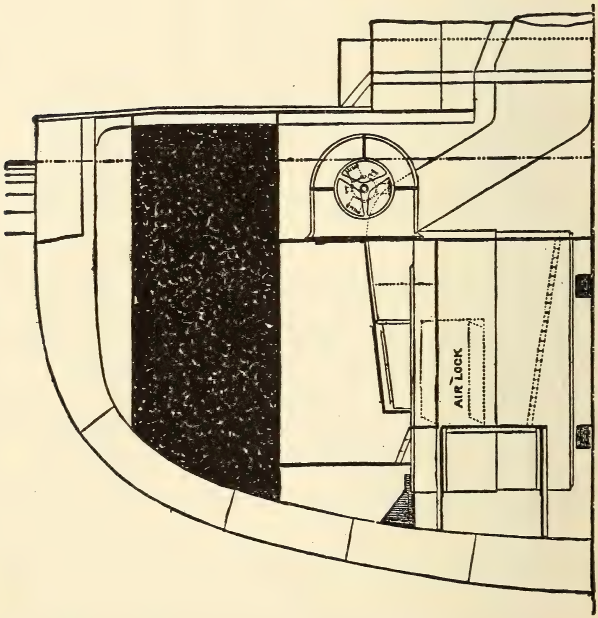


FIG. 87. ELEVATION OF STOKE-HOLD, SHOWING AIR LOCK.

Ans.—By fitting a device that automatically closes the air-supply to the ash-pit when the furnace door is opened for firing.

Ques. 323.—What is the object of providing air-locks in the hold of a vessel?

Ans.—In order to provide for passage to and from the stoke-holds, when under pressure.

Ques. 324.—Describe the construction and operation of an air-lock?

Ans.—An air-lock consists of a small air-tight chamber fitted with two hinged doors opening against the air

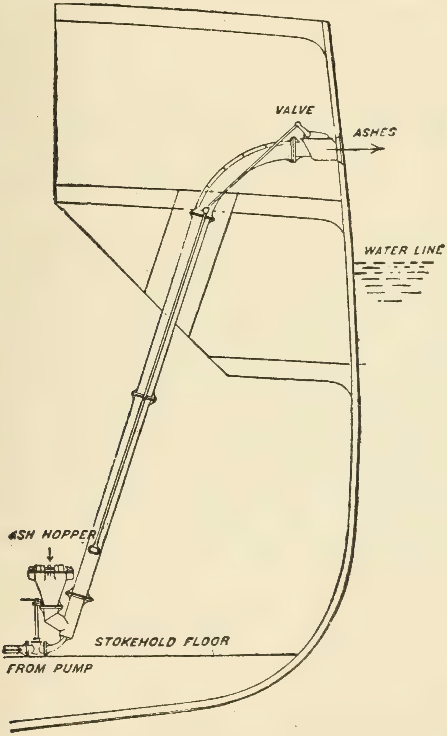


FIG. 88. SEE'S ASH EJECTOR.

In this apparatus, which is fitted in many large passenger steamers in which the raising of ashes on deck is objectionable, the ashes are placed in a trough leading to a pipe, a jet of water at a pressure of about 200 pounds per square inch from one of the pumps is then admitted, and scours the ashes along the pipe into the sea. A small valve is fitted to permit the entry of air into the pipe during the discharge. The apparatus is simple and efficient.

pressure. In passing through only one door is open at a time which makes it possible to enter or leave the stoke-hold without allowing much air to escape and thus reduce the air-pressure in the stoke-hold.

Ques. 325.—At what places aboard a ship are air-locks necessary?

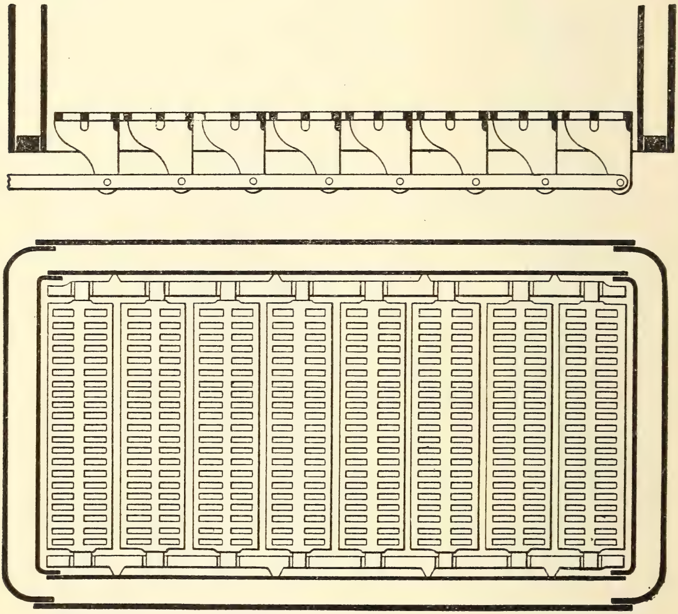


FIG. 89. SHAKING GRATES.

Ans.—At all places where communication is had between the compartments under pressure and any other part of the ship.

Ques. 326.—What are the advantages in general possessed by closed stoke-holds over other systems?

Ans.—First, a reduction in the space and weight required by the boilers, since, by the addition of fans and screens, which are light and inexpensive, and supply the necessary air under pressure to the furnaces, the boilers may be made to develop from 20 to 25 per cent more power, than they would with natural draught; second, by the employment of blowing fans, a continuous supply of fresh air in the stoke-hold is assured and the health and comfort of the men working there is much better provided for than it would be with natural draught.

Ques. 327.—How are the ashes raised from the stoke-hold to the deck, to be thrown overboard?

Ans.—By means of the ash-tube and engine; the ash-tube leading from stoke-hold to deck, and the engine raising the ashes in an ash-bucket, that passes through the tube. Another method is by means of the ash-ejector, which is simply an inclined tube running from the stoke-hold to above the water-line, and overboard. At the lower end of this tube is a hopper, into which the ashes are shoveled, and at the bottom of this hopper they are picked up by a jet of water of high velocity, and forced through the inclined tube overboard.

CHAPTER V

BOILER OPERATION

Ques. 328.—What should be the first care of an engineer, or water-tender, when he goes on watch?

Ans.—He should ascertain the exact height of the water in his boilers by opening the valve in each of the drain-pipes of the water-columns, allowing it to blow out freely for a few seconds, then closing it tight, and allowing the water to settle back in the glass.

Ques. 329.—What is one of the important duties of the firemen coming off watch?

Ans.—They should have the fires clean, the ash-pits all cleaned out, a good supply of coal on the floor, and everything in good condition for the oncoming force.

Ques. 330.—What implements are needed for successfully and quickly cleaning a fire?

Ans.—A slice-bar, a fire-hook, a heavy iron or steel hoe, and a lighter hoe for cleaning the ash-pit.

Ques. 331.—How may these tools be made, so that they will be light and easy to handle and at the same time strong and durable?

Ans.—After the working ends have been fashioned to the desired shape, let each be welded to a bar of 1-inch or 1⅛-inch round iron 10 or 12 inches in length. Then take pieces of 1-inch or 1¼-inch iron pipe, cut to the length desired for the handles, and weld the shanks of the tools to one end of the pipe handles and to the other end weld a ring handle or a short cross-bar to facilitate handling the tools.

Ques. 332.—When a fire shows signs of being foul and choked, what should be done at once?

Ans.—Prepare to clean it by allowing one side to burn as low as possible, putting fresh coal on the other side alone.

Ques. 333.—Describe the process of cleaning a fire.

Ans.—When the first side has burned as low as it can, without danger of letting the steam-pressure drop too low, take the slice-bar and shove it in along the side of the furnace, on top of the clinker, and back to near the bridge-wall, then, using the door-jamb as a fulcrum, give it a quick, strong sweep across the fire, and the greater portion of the live coals will be pushed over to the other side. What remains of the coal not yet consumed can be pulled out upon the floor with the light hoe and shoveled to one side, to be thrown back into the furnace after the clinker is removed. Having thus disposed of the live coal, take the slice-bar and shove it in on top of the grates, under the clinker, loosening and breaking it up, after which take the heavy hoe and pull it all out upon the floor, where the intense heat contained in the clinker should be quenched by a helper, with a pail of water, or water discharged from a small rubber hose.

Ques. 334.—Having gotten one side of the fire cleaned, what is the next move?

Ans.—Close the door for that side, and with the slice bar in the other side, push all the live coal over to the side just cleaned, where it should be leveled off, and fresh coal added. After this has become ignited treat the other side in the same manner.

Ques. 335.—Can a definite code of rules for hand firing, be laid down, that will suit all conditions?

Ans.—No; owing to the fact that there are so many different varieties of coal, some of which need very little stirring or slicing, while others, that have a tendency to coke and form a crust on top of the fire, need to be sliced quite often.

Ques. 336.—Mention a few general maxims that are applicable to all boiler-rooms.

Ans.—First, keep a clean fire; second, see that every square inch of grate surface is covered with a good live fire; third, keep as level a fire as possible; fourth, when cleaning the fire, be sure to clear all the clinkers and dead ashes away from the back end of the grates at the bridge-wall.

Ques. 337.—Why should the face of the bridge-wall, especially, be kept clean and free from ashes and clinker?

Ans.—For the reason that this is one of the best points in the furnace for securing good combustion, provided that the bridge-wall is kept clean from the grates up, and by keeping the back ends of the grates clean, the air is allowed a free passage through them and is permitted to come directly in contact with the hot fire-brick, and thus one of the greatest aids to good combustion is utilized.

Ques. 338.—In firing bituminous coal, what is a good plan to pursue in regard to the fire-doors, with some kinds of boilers?

Ans.—They should be left slightly open for a few seconds, immediately after throwing in a fresh fire.

Ques. 339.—Give the reason for doing this.

Ans.—Bituminous coal contains a large percentage of volatile (light or gaseous) matter, which flashes into flame the instant it comes in contact with the live fire in the furnace, and if a sufficient supply of oxygen is not present just at this particular time, the combustion will be imperfect, and the result will be the formation of carbon monoxide, or carbonic oxide gas, and the loss of about two-thirds of the heat units contained in the coal.

Ques. 340.—How may this great loss of heat be guarded against, in a great measure?

Ans.—By admitting a sufficient volume of air, either through the fire-doors, directly after putting in a fresh fire, or what is still better, providing air-ducts through the bridge-wall, or side walls, which will bring the air in above the fire.

Ques. 341.—What quantity of air is required for the complete combustion of 1 pound of coal?

Ans.—By weight, 12 pounds; by volume, about 150 cubic feet.

Ques. 342.—Is there any advantage gained by heating this air before admitting it to the furnace?

Ans.—There is a great advantage, provided the heat used for this purpose would otherwise be wasted. Great economy in fuel, and much better combustion, result from supplying heated air to the furnaces.

Ques. 343.—Describe the Howden draught system, as used in the marine service.

Ans.—There is a nest of tubes in the uptake that is enveloped by the hot gases on their way to the stack. The air is caused to pass through these tubes by a

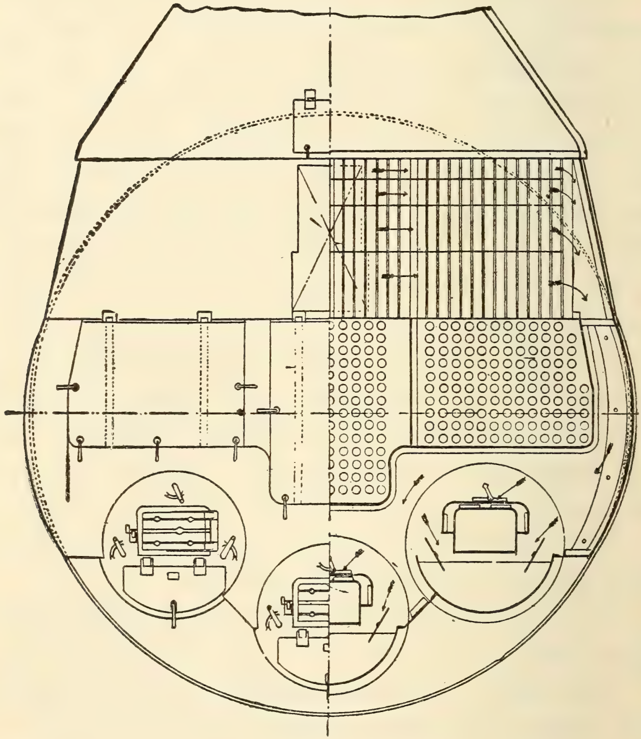


FIG. 90. ARRANGEMENT OF THE HOWDEN DRAUGHT SYSTEM.

blower-fan, and as a consequence is heated to a high degree before passing into the ash-pit. Some of this hot air is also directed into the furnace above the fire, thus securing a good combustion of the fuel.

Ques. 344.—What precautions should be taken regarding cleanliness of the tubes?

Ans.—The tubes of all boilers should be kept clean and free from soot, and especially does this apply to fire-

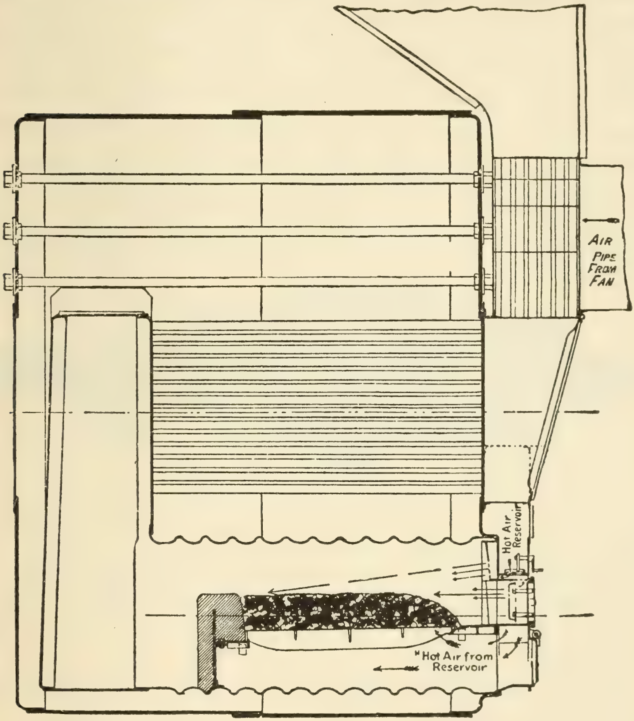


Fig. 91. Air Heater of the Howden Draught System.

tube boilers, for the reason that, when these tubes become clogged with soot, the efficiency of the draught is destroyed and the steaming capacity of the boiler is greatly reduced, because soot not only stops the draught but it is also a non-conductor of heat.

Ques. 345.—What methods are ordinarily employed for cleaning the soot and dust from tubes?

Ans.—First, the steam jet, if properly made and connected by steam hose so as to get dry steam of high pressure, will do very effective work; second, a scraper having steel blades expanded by springs so as to fit the inside of the tubes snugly, should be pushed through each tube once or twice during each twenty-four hours of service. This will cut the soot loose from the inside surface of the tubes, and greatly facilitate blowing it out with the steam jet. For the tubes of water-tube boilers

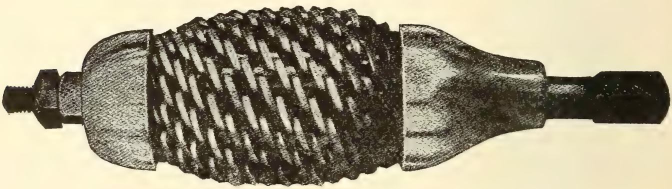


FIG. 92. SCRAPER FOR CLEANING FIRE TUBES.

the steam jet may be employed to advantage in cleaning the outside surfaces, and a rotary scraper driven by a small steam turbine is used for cleaning the scale formation from the inside.

Ques. 346.—How often should a boiler be washed out and cleaned inside?

Ans.—If the feed-water is impregnated to a considerable extent with scale-forming matter, the boiler should be washed out every two weeks, and if the water is very bad, the time should be shortened to one week.

Ques. 347.—How should a boiler be prepared for washing out?

Ans.—The fire should be allowed to burn as low as possible, and then be all pulled out of the furnace, the fire-doors left slightly ajar, and the dampers left wide open in order that the boiler may gradually cool.

Ques. 348.—Should a boiler be blown out, that is, emptied of water, while there is any steam-pressure in it?

Ans.—It should not.

Ques. 349.—Why not?

Ans.—For the reason that the sudden change of temperature from hot to cold has an injurious effect on the seams and braces. It is as bad a practice to cool a boiler down too suddenly as it is to fire it up too quickly.

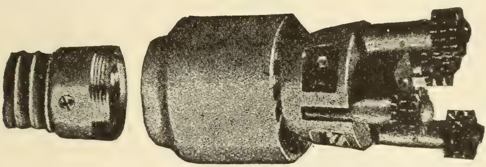


Fig. 93. Turbine Cleaner for Water Tubes.

Ques. 350.—What effect does the too sudden contraction or expansion of the boiler-plates have upon the riveted seams?

Ans.—Leaks are created, and very often small cracks radiating from the rivet-holes are started, and these becoming larger with each change of temperature, will finally destroy the strength of the seam and serious results will follow.

Ques. 351.—Suppose that all of the fire has been pulled from the furnace and that the boiler has stood until the steam-gauge indicates 20 pounds pressure, would it then be safe to blow all of the water out of the boiler?

Ans.—It would not, for the reason that the temperature of steam at 20 pounds pressure is 260 degrees Fahrenheit, and it may be assumed that the temperature of the metal of the boiler is at or near this temperature also. Assuming the temperature of the atmosphere in the boiler-room to be 60 degrees Fahrenheit there will be a range of 260 degrees — 60 degrees = 200 degrees Fahrenheit temperature for the boiler to pass through within a short time, which will certainly have a bad effect, and besides this, the boiler shell will be so hot that the loose mud and sediment left after the water has run out is liable to become baked upon the bottom sheets, making it much harder to remove.

Ques. 352.—Under what conditions is it best to empty a boiler of water preparatory to washing it out?

Ans.—After the boiler has become comparatively cool and there is no pressure indicated by the steam-gauge, the blow-off cock may be opened and the water allowed to run out. The gauge-cocks and drip-valve to the water-column should be left open to allow the air to enter and displace the water, otherwise there will be a partial vacuum formed in the boiler, and the water will not run out freely.

Ques. 353.—Mention some of the important duties of the boiler-washer.

Ans.—After the water has all run out and the boiler has cooled sufficiently to permit it, he should go inside (provided there is a man-hole) and after having thoroughly cleaned the inside of the boiler, he should closely examine all of the braces and stays, and if any are found loose or broken, they should be repaired at once, before the boiler is put in service again. The soundness of braces, rivets, etc., can be ascertained by tapping them with a light hammer.

Ques. 354.—What should be done with the tubes of fire-tube boilers when they become coated with scale on their outside surfaces?

Ans.—The boiler should be taken out of service, laid up temporarily, and the tubes taken out, cleaned, and those that are not corroded or pitted too badly may be made almost as good as new by cutting off 8 or 10 inches of the ends and welding pieces of new tubing on, to bring the tubes back to their original length, after which they may be put back in the boiler and be good for a long term of service. While the tubes are out of the boiler for repairs the boiler-washer will have a good opportunity to get inside and clean and inspect every portion of the inside.

Ques. 355.—What precautions should be taken when connecting a recently fired-up boiler with the steam main or header?

Ans.—First, the steam in the boiler to be connected should be raised to the same pressure as that in the main, then the dampers should be closed and the steam stop-valve should be opened slightly, just enough to permit a small jet of steam to pass through, which can be heard by placing the ear near the body of the valve. This jet of steam may be passing from the main into the newly connected boiler, or vice versa. Whichever way it is

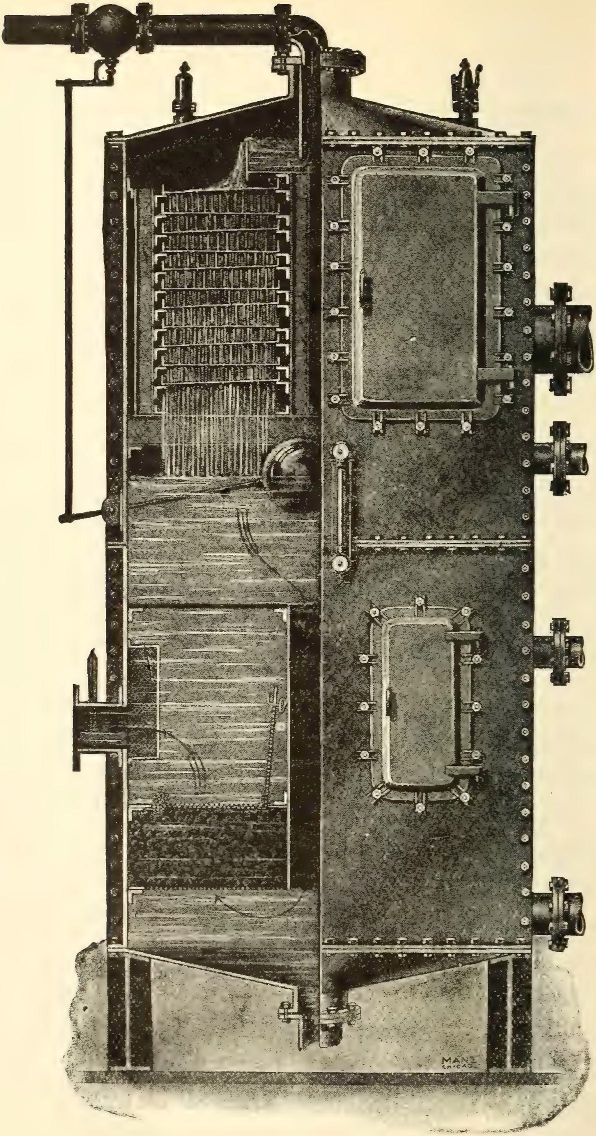


FIG. 94. SQUARE OPEN HEATER.

going, the valve ought not to be opened any farther until the flow of steam stops. This will indicate that the pressure has been equalized between the boiler and the main, and it will then be found that the valve will move much easier, and it may be gradually opened until it is wide open.

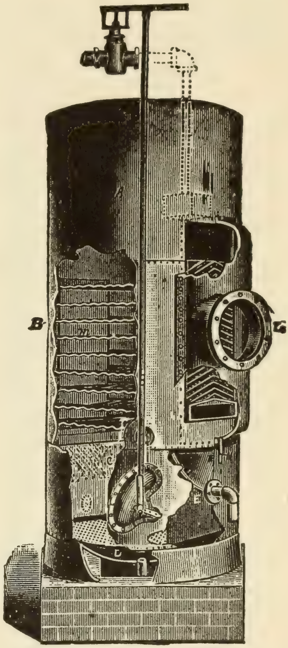


FIG. 95. INTERIOR VIEW OF OPEN HEATER.

Ques. 356.—Should cold feed-water ever be pumped into a boiler that is under steam?

Ans.—It should not, if it is possible to prevent it.

Ques. 357.—How may the feed-water be heated economically?

Ans.—By passing it through a feed-heater in which the heating agent employed is the exhaust steam from the engines.

Ques. 358.—How should the feed-water be supplied to a boiler while the boiler is being fired?

Ans.—It should be supplied just as fast as it is evaporated. The firing can then be even and regular.

Ques. 359.—If the supply of feed-water should suddenly be cut off owing to breakage of the pump or some other cause, and no other source of supply was available, what should be done?

Ans.—The dampers should be closed immediately, and all of the draught stopped. The fires should be deadened by shoveling wet or damp ashes in on top of them, or if ashes can not readily be procured, bank the fires over with green coal broken into fine bits. This, with the draught all shut off, will keep the fires dead, and if repairs to the feed-supply can not be made within a short time, the fires should be pulled, that is, if they have become deadened sufficiently.

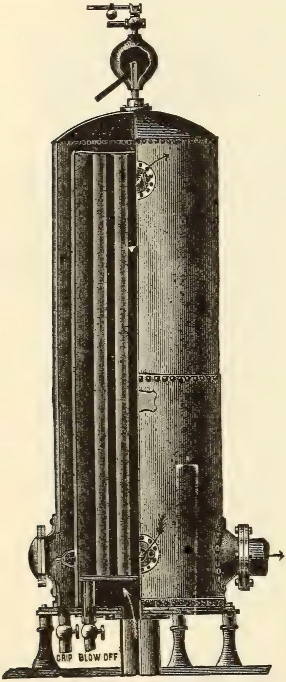


FIG. 96. BARAGWANATH STEAM JACKET FEED WATER HEATER.

Ques. 360.—Should the fires be pulled while they are burning lively?

Ans.—No; because the stirring will only serve to increase the heat, and the danger will be aggravated.

Ques. 361.—What is the primary object of making evaporation tests of boilers?

Ans.—To ascertain how many pounds of water per pound of coal the boiler is evaporating.

Ques. 362.—What other important details relating to the operation of the boilers may be ascertained through a well-conducted evaporation test?

Ans.—First, the efficiency of the boiler and furnace as an apparatus for the consumption of fuel and the evaporation of water; second, the relative value of different varieties of coal, and other fuels, as heat-producers; third, whether the boilers, as they are operated under ordinary everyday conditions, are being operated as economically as they should be; fourth, in case the boilers, owing to an increased demand for steam, fail to supply a sufficient quantity, whether or not additional boilers are needed, or whether the trouble could be overcome by a change of conditions in the operation of the boilers.

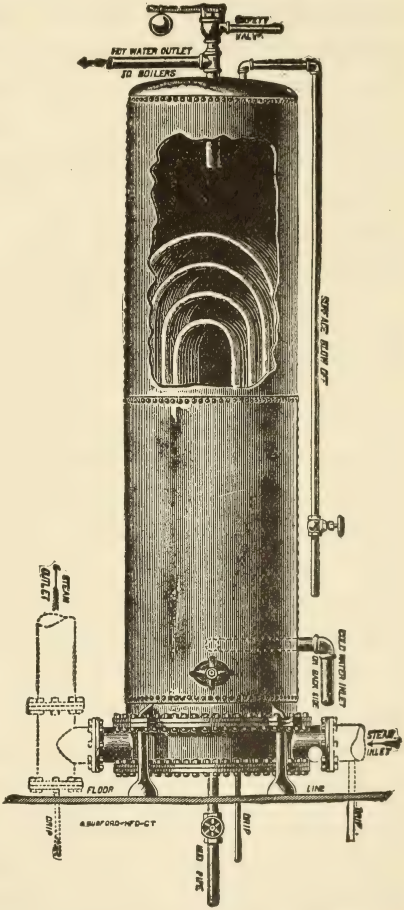


FIG 97. CLOSED FEED WATER HEATER.

Ques. 363.—What are the principal data to be noted down during the progress of an evaporation test?

Ans.—First, time—the number of hours that the test is conducted; second, the kind of coal burned; third, weight of coal consumed; fourth, weight of water evaporated during the test; fifth, weight of dry ash returned; sixth, moisture in the coal, per cent. seventh, dry coal corrected for moisture; eighth, weight of combustible; ninth, moisture in the steam, per cent; tenth, water corrected for moisture in the steam; eleventh, average temperature of the feed-water; twelfth, average temperature of the escaping gases; thirteenth, square feet of grate surface; fourteenth, square feet of heating surface; fifteenth, ratio of grate surface to heating surface.

Ques. 364.—How may the weight of the coal consumed during the test be ascertained?

Ans.—By having a small platform scales fitted with a wooden platform large enough to accommodate a wheelbarrow, or, in lieu of a barrow, a box large enough to contain two or three hundred pounds of coal. Each wheel-barrow load, or boxful of coal that goes to the boiler under test can then be weighed and the figures be placed upon a tally-sheet and added together at the close of the test, thus giving the total weight of coal consumed during the test. If, at the close of the test, there is any of the weighed coal left on the floor, it should be weighed back and deducted from the total weight.

Ques. 365.—How may the weight of water evaporated during the test be ascertained?

Ans.—By having a hot-water meter fitted in the branch feed-pipe leading to the boiler under test, or if this is not to be had, a substitute equally as accurate can be made by placing two small water-tanks, each having a capacity of 8 or 10 cubic feet, in the vicinity of the feed-pump.

These tanks can be made of light tank-iron, and each should be fitted with a nipple and valve, near the bottom, for connection with the suction side of the feed-pump. The tops of the tanks may be left open. A pipe leading from the main water-supply, with a branch to each tank, is also needed for filling them. If an open feed-water heater is used, and it is possible to place the tanks low enough to allow a portion of the hot water from the

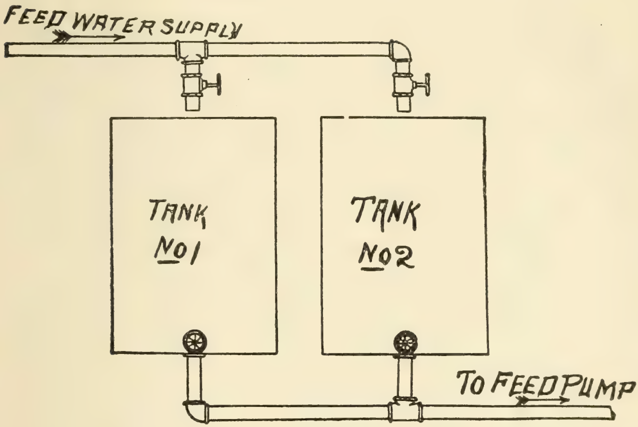


FIG. 98.

heater to be led into them by gravity, it will be desirable to do so. If this can not be done, some other provision should be made for at least partially warming the water before it goes to the boiler. The exact capacity of each one of these two tanks, either in cubic feet or in pounds of water, should be ascertained, and then all of the feed-water that is supplied to the boiler during the test is to be first passed through the tanks, which should be numbered one and two respectively, in order to prevent confusion in keeping a record of the number of tankfuls of water used during the test. Two tanks should be provided, in order that while the feed-pump is drawing the water from one, the other one may be filled. The feed-pump that is used to supply the boiler under test should have no connection whatever with the main feed-supply. By keeping tab of the number of tankfuls of water used during the test, and

TABLE 6

WEIGHT OF WATER AT VARIOUS TEMPERATURES

Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot
32° F.	62.42 lbs.	132° F.	61.52 lbs.	230° F.	59.37 lbs.
42°	62.42	142°	61.34	240°	59.10
52°	62.40	152°	61.14	250°	58.85
62°	62.36	162°	60.94	260°	58.52
72°	62.30	172°	60.73	270°	58.21
82°	62.21	182°	60.50	300°	57.26
92°	62.11	192°	60.27	330°	56.24
102°	62.00	202°	60.02	360°	55.16
112°	61.86	212°	59.76	390°	54.03
122°	61.70	220°	59.64	420°	52.86

multiplying this by the capacity of each tank, the total weight of water evaporated is ascertained.

Ques. 366.—How is the weight of dry ash ascertained?

Ans.—No water should be allowed to come in contact with the ashes during the test, or if it is absolutely necessary to use water, it should be used as sparingly as possible, and as the ashes are pulled from the furnace or ash-pit, they should be thrown to one side, and allowed to become dry, after which the weight can be ascertained by means of the scales that was used for weighing the coal.

Ques. 367.—How is the amount of moisture in the coal ascertained?

Ans.—This can generally be obtained from the reports of the geologist of the state in which the coal was mined.

Ques. 368.—How is the weight of dry coal corrected for moisture ascertained?

Ans.—Deduct the percentage of moisture in the coal from the total weight of coal consumed.

Ques. 369.—How is the weight of combustible ascertained?

Ans.—Deduct the weight of dry ash returned from the weight of dry coal corrected for moisture.

Ques. 370.—How is the percentage of moisture in the steam determined?

Ans.—By means of an instrument called a calorimeter, or if such an instrument is not at hand, the condition of the steam as regards its dryness may be approximately estimated by observing its appearance as it issues from a pet-cock, or other small opening into the atmosphere. Dry, or nearly dry steam, containing about 1 per cent of moisture, will be transparent close to the orifice through which it issues, and if it is of a grayish white color it may be estimated to contain not over 2 per cent of moisture.

Ques. 371.—How is water corrected for moisture in the steam arrived at?

Ans.—Deduct the percentage of moisture in the steam from the total weight of water evaporated during the test.

Ques. 372.—How is the average temperature of the feed-water obtained?

Ans.—By means of a hot-water thermometer connected to the feed-pipe near to the check-valve, but between it and the feed-pump. If the thermometer is not attached to the feed-pipe, the temperature of the water in each tank should be taken and noted down, during the time that the feed-pump is drawing from it. From these notations, made at regular intervals during the progress of the test, the average temperature of the feed-water is easily calculated.

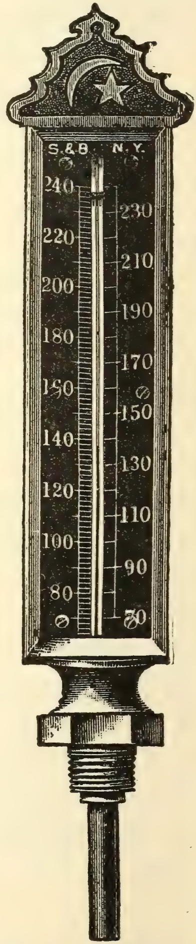


Fig. 99. Hot Water Thermometer.

Ques. 373.—How is the average temperature of the escaping gases determined?

Ans.—By readings taken at regular intervals from a thermometer connected in the uptake.

Ques. 374.—What should be done with the boiler and furnace before beginning an evaporative test?

Ans.—The boiler should be thoroughly cleaned, both inside and outside, and especially the heating surface, by scraping and blowing the soot out of the tubes, if it be a return-tubular boiler, and blowing the soot and ashes from between the tubes if it is a water-tube boiler. All dust, soot, and ashes should be removed from the outside of the shell, and also from the combustion chamber and smoke connections. The grate-bars and sides of the furnace should be cleared of all clinker, and all air-leaks made as tight as possible.

Ques. 375.—What should be done with the water-connections?

Ans.—The boiler and all of its water-connections should be perfectly free from leaks, especially the blow-off valve or cock. If any doubt exists as to the latter, it should be plugged, or a blind flange put on it.

Ques. 376.—Why is it required that especial care be exercised regarding the water-connections?

Ans.—For the reason that the test is made for the purpose of ascertaining the exact quantity of water that the boiler will evaporate with a given weight and kind of coal, and if any of the water fed to the boiler during the test is allowed to leak away, or if any water, other than that which has been measured by passing it through the tanks, is allowed to get into the boiler during the test, the results will be misleading and unreliable.

Ques. 377.—Before starting the test, what other details regarding the boiler should be attended to carefully?

Ans.—The boiler should be thoroughly heated, by having been run for several hours at the ordinary rate. The fire should then be cleaned and put in good condition to receive the fresh coal that has been weighed for the test.

Ques. 378.—What should be done regarding the water-level?

Ans.—At the time of beginning the test, the water-level in the boiler should be at or near the height ordinarily carried, and its position should be marked by tying a cord around one of the guard-rods of the gauge-glass, and, to prevent any possibility of error, the height of the water in the glass should be measured in inches, and a memorandum made of it.

Ques. 379.—What data regarding the steam-pressure should be recorded?

Ans.—The steam-pressure as indicated by the gauge should be noted at the time of starting the test, and also at regular intervals during the progress of the test, in order that the average pressure may be obtained.

Ques. 380.—When should the test begin?

Ans.—When all of the conditions just described have been complied with and the first lot of weighed coal has been fed to the furnace and the feed-pump is receiving water from one of the measuring tanks, the time should be noted and recorded as the starting time.

Ques. 381.—What length of time should an evaporation-test be conducted?

Ans.—Ten hours, if it is possible to continue it that long.

Ques. 382.—What conditions regarding the steam-pressure, condition of the fire and the water-level should prevail at the close of the test?

Ans.—They should be as nearly as possible the same at the close as they were at the beginning. The water-level should be the same and the quantity and the condition of the fire, also the steam pressure.

Ques. 383.—How may this be accomplished?

Ans.—Only by very careful work toward the close of the test.

Ques. 384.—If any of the weighed coal is left on the floor at the close of the test, what should be done with it?

Ans.—It should be weighed back and its weight deducted from the total weight.

Ques. 385.—If a portion of water is left in the last tank tallied, what disposition should be made of it?

Ans.—It should be measured and deducted from the total.

Ques. 386.—In making a test of the efficiency of the boiler, what is one of the most essential conditions to be taken into consideration?

Ans.—The boiler should be operated at its fullest capacity, from the beginning to the end of the test, and arrangements should be made to dispose of the steam as fast as it is generated.

Ques. 387.—How may this be done?

Ans.—If the boiler is in a battery and connected to a common header, the other boilers can be fired lighter during the test; but if there is but the one boiler in use, a waste-steam pipe should be temporarily connected, through which the surplus steam, if there is any, can be discharged into the open air, through a valve regulated as required.

Ques. 388.—If the boiler under test is fed by an injector instead of a pump during the test, from whence should the steam-supply for the injector be taken?

Ans.—The steam for the injector should be taken directly from the boiler under test, through a well-protected pipe. The steam for the pump, if one is used, should also be taken from the same source.

Ques. 389.—How should the temperature of the feed-water be taken when an injector is used?

Ans.—It should be taken from the measuring tanks, or at least from the suction side of the injector.

Ques. 390.—Why?

Ans.—Because the water in passing through the injector receives a large quantity of heat imparted to it by live steam directly from the boiler, and the temperature of the water after it leaves the injector would not be a true factor for use in calculating the results of the test.

Ques. 391.—For obtaining reliable and economical results in an evaporation-test, what conditions are essential regarding the draught?

Ans.—There should be a good, strong draught, which can be regulated by a damper, as desired. There should also be a draught-gauge connected to the uptake, for the purpose of measuring the draught.

Ques. 392.—Why is it necessary to measure the draught?

Ans.—The principal reason for measuring the draught is that in making comparative tests of the heating value of different varieties of coal, the conditions should be the same as near as possible in all of the tests made, and especially should this be the case with the draught. Therefore, by using a draught-gauge and measuring the draught during each test, there will be no uncertainty regarding this very important element.

Ques. 393.—Describe the construction and operation of a draught-gauge.

Ans.—The usual form of draught-gauge is a glass tube bent in the shape of the letter U. One leg is connected to the uptake by a small rubber hose, while the other leg is open to the atmosphere.

A scale marked in tenths of an inch is fitted between the two legs of the gauge. The glass tube is partly filled with water, which will, when there is no draught, stand at the same height in both legs, provided the instrument stands perpendicular, which is its normal position. When connected to the uptake, the suction caused by the draught will cause the water in the leg to which the hose is attached to rise, while the level of the water in the leg that is open to the atmosphere will be equally depressed, and the extent of the variation in fractions of an inch is the measure of the draught. Thus the draught is referred to as being .5 .7 or .75 inch.

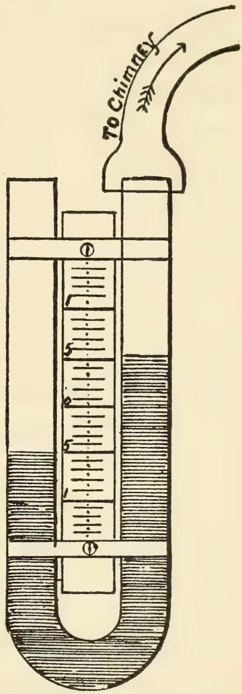


FIG. 100. DRAUGHT GAUGE.

Ques. 394.—What is the least draught that should be used, in order to obtain good results?

Ans.—The draught should not be less than .5 inch. Better results may be obtained with a draught of .7 inch.

Ques. 395.—If the test is made for the purpose of determining the efficiency of the boiler and setting as a whole, including grate, draught, etc., and also for comparing the heating qualities of different kinds of coal, what must the result be based upon?

Ans.—Upon the number of pounds of water evaporated per pound of coal burned.

Ques. 396.—What is implied in the expression "per pound of coal burned" as used in this connection?

Ans.—It includes not only the purely combustible matter in the coal, but the non-combustible also, such as ash, moisture, etc. Some varieties of Western coal contain as high as 12 to 14 per cent of moisture, and the ability of the furnace to extract heat from the mass is to be tested, as well as the ability of the boiler to absorb and transmit that heat to the water.

Ques. 397.—If the test is to determine the efficiency of the boiler itself as an absorber and transmitter of heat, what must be the factor for working out the result?

Ans.—The weight of the combustible alone must be considered.

Ques. 398.—When making a series of tests for the purpose of comparing the economical value of different kinds of coal, what conditions should prevail?

Ans.—The conditions should be as nearly uniform as possible; that is, let the tests all be made under ordinary working conditions, and with the same boiler or boilers, and if possible with the same fireman.

Ques. 399.—What is meant by the term "equivalent evaporation," as applied to the results of an evaporation-test?

Ans.—The term "equivalent evaporation," or the evaporation from and at 212 degrees, assumes that the

feed-water enters the boiler at a temperature of 212 degrees and is evaporated into steam at 212 degrees temperature, and at atmospheric pressure, as, for instance, if the top man-hole plate were left out, or some other large opening in the steam-space of the boiler allowed the steam to escape into the atmosphere as fast as it was generated.

Ques. 400.—Why is it necessary to introduce this feature into calculations of the results of evaporation-tests?

Ans.—Owing to the variation in the average temperature of the feed-water used in different tests, and also the variation in the average steam-pressure, it is absolutely necessary that the results of all tests be brought by computation to the common basis of 212 degrees in order to obtain a fair and just comparison.

Ques. 401.—Describe the method of calculation by which this is done.

Ans.—Suppose an evaporation-test to have been made, and that the average steam-pressure by the gauge was 85 pounds, which equals 100 pounds absolute pressure, and that the average temperature of the feed-water was 141 degrees. By reference to Table 1, Chapter 1, it will be found that in a pound (weight) of steam at 100 pounds absolute pressure there are 1,181.1 heat units or thermal units, and in a pound of water at 141 degrees temperature there are 109.9 heat units. It therefore required 1,181.1 — 109.9 = 1,071.9 heat units to convert 1 pound of feed-water at 141 degrees temperature into steam at 85 pounds gauge, or 100 pounds absolute pressure. Now to convert a pound of water at 212 degrees temperature into steam at atmospheric pressure and 212 degrees temperature, requires (according to Table 1) 965.7 heat units, and the 1,071.9 heat units would evaporate 1,071.9 ÷ 965.7 = 1.11 pounds of water from and at 212 degrees. The 1.11 is the factor of evaporation for 85 pounds gauge pressure, and 141 degrees temperature of feed-water.

Ques. 402.—What use is made of this factor of evaporation in the calculation?

Ans.—One of the results of the test was "weight of water corrected for moisture in the steam," and by multiplying this result by the factor of evaporation, the "equivalent evaporation" is ascertained.

Ques. 403.—Upon what is the factor of evaporation based, in any test?

Ans.—Upon the steam-pressure and the temperature of the feed-water.

Ques. 404.—Give the formula for finding this factor for any test.

Ans.—The formula is: Factor $=\frac{H—h}{965.7}$, in which H = total heat in the steam, h = total heat in the feed-water, and 965.7 = the number of heat units in a pound of steam at atmospheric pressure and 212 degrees temperature. Table 7 gives the factor of evaporation, already calculated, for various pressures and temperatures.

Ques. 405.—If it is desired to ascertain the cost of coal for generating the steam used for operating an engine that uses 30 pounds of steam per horse-power per hour, what is the method of calculation?

Ans.—If the engine uses 30 pounds of steam per horse-power per hour, and it has been found by the test that 1 pound of the coal used would evaporate 9 pounds of water into steam of the pressure at which it is supplied to the engine, the actual consumption of fuel by the engine

TABLE 7

FACTORS OF EVAPORATION

Feed Water Temperature	Gauge Press. 50 lbs.	Gauge Press. 60 lbs.	Gauge Press. 70 lbs.	Gauge Press. 80 lbs.	Gauge Press. 90 lbs.	Gauge Press. 100 lbs.	Gauge Press. 110 lbs.	Gauge Press. 120 lbs.	Gauge Press. 140 lbs.
212°	1.027	1.030	1.032	1.035	1.037	1.039	1.041	1.043	1.047
200°	1.039	1.042	1 045	1.047	1.050	1.052	1.054	1.056	1.059
191°	1.049	1.052	1.054	1.057	1.059	1.061	1.063	1.065	1.069
182°	1.058	1.061	1.064	1.066	1.069	1.071	1.073	1.075	1.078
173°	1.067	1.070	1.073	1.076	1.078	1.080	1.082	1.084	1.087
164°	1.077	1.080	1.083	1.085	1.087	1.090	1.091	1.093	1.097
152°	1.089	1.092	1.095	1.098	1.100	1.102	1.104	1.106	1.109
143°	1.099	1.102	1.105	1.107	1.109	1.111	1.113	1.115	1.119
134°	1.108	1.111	1.114	1.116	1.119	1.121	1.123	1.125	1.128
125°	1.118	1.121	1.123	1.126	1.128	1.130	1.132	1.134	1.137
113°	1.130	1.133	1.136	1.138	1.140	1.143	1.145	1.146	1.150
104°	1.138	1.142	1.145	1.148	1.150	1.152	1.154	1.156	1.159
95°	1.149	1.152	1.154	1.157	1.159	1.161	1.163	1.165	1.169
86°	1.158	1.161	1.164	1.166	1.169	1.171	1.173	1.174	1.178
77°	1.167	1.170	1.173	1.176	1.178	1.180	1.182	1.184	1.187
65°	1.180	1.183	1.186	1.188	1.190	1.192	1.194	1.196	1.200
56°	1.189	1.192	1.195	1.197	1.200	1.202	1.204	1.206	1.209
47°	1.199	1.201	1.204	1.207	1.209	1.211	1.213	1.215	1.218
38°	1.208	1.211	1.214	1.216	1.218	1.220	1.222	1.224	1.228

would be as follows: $30 \div 9 = 3.33$ pounds of coal per horse-power per hour, which, multiplied by the total horse-power developed by the engine, will give the total weight of coal consumed in one hour's run.

Ques. 406.—What is the meaning of the expression "boiler horse-power?"

Ans.—The latest decision of the American Society of Mechanical Engineers regarding the horse-power of a boiler is "that the unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation." That is, 34½ pounds of water evaporated per hour from a feed temperature of 212 degrees into steam of the same temperature.

This standard is equivalent to 33,317 heat units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed temperature of 100 degrees Fahrenheit into steam of 70 pounds gauge-pressure.

Ques. 407.—According to this rule, what would be the horse-power of a boiler in which during a 10-hour test, the evaporation from and at 212 degrees was found by calculation to have been 86,250 pounds of water?

Ans.—The horse-power developed would be $86,250 \div 10 \div 34.5 = 250$ horse-power.

Ques. 408.—In what way can the maximum economy in the consumption of coal be obtained?

Ans.—There is only one way, and that is by keeping a continuous supply of coal on the fires and admitting a regular and sufficient quantity of air for its combustion.

Ques. 409.—Can these conditions be reached by hand firing?

Ans.—They can not, no matter how careful and skilful the firemen may be.

Ques. 410.—Mention two of the principal disadvantages attending hand firing.

Ans.—First, durin the time of firing the furnace door is wide open, thus admitting a large volume of cold air; second, immediately after throwing in a fresh supply of coal, there is a sudden generation of gas, a large percentage of which escapes without being entirely consumed, and much heat is thus wasted.

Ques. 411.—What are the principles governing the operation of mechanical or automatic stokers?

Ans.—First, a continuous supply of coal and air; second, thorough regulation of the supply of fuel and air, according to the demand upon the boilers for steam; third, the intermittent opening and closing of the furnace doors is entirely prevented.

Ques. 412.—What are some of the disadvantages attending the use of mechanical stokers?

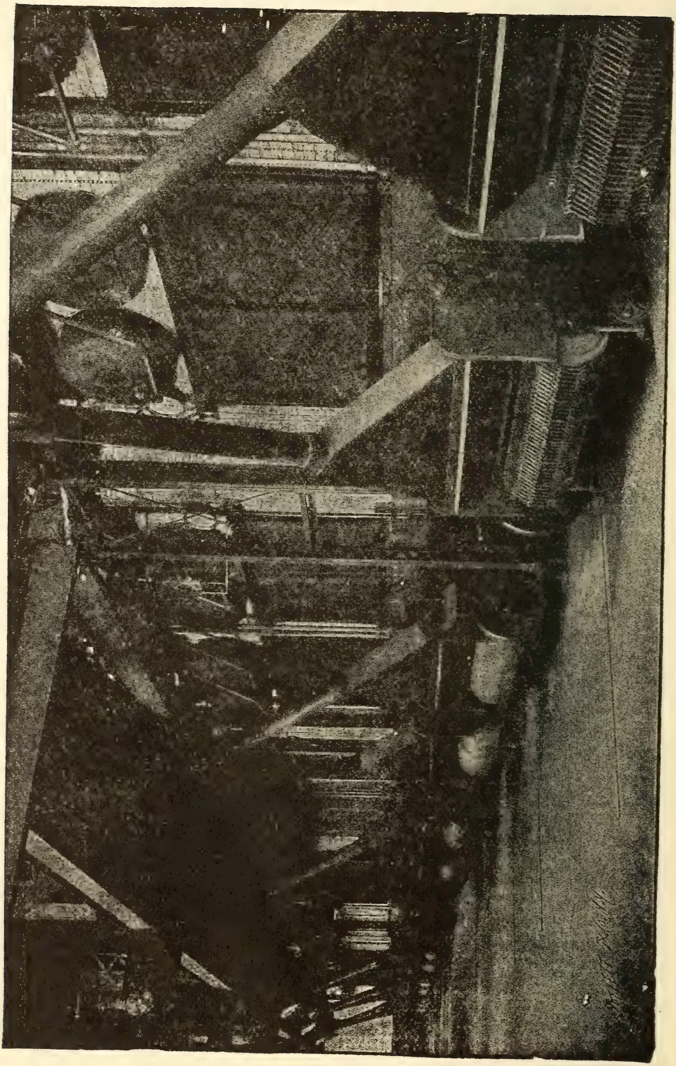
Ans.—First, the great cost of installing them; second, in case of a sudden demand upon the boilers for more steam, the mechanical stoker can not respond as promptly as in hand firing; third, the extra cost for power to operate them.

Ques. 413.—How many different classes of mechanical stokers are in use?

Ans.—Four general classes.

Ques. 414.—Describe the construction and operation of stokers belonging to Class 1.

Ans.—The grate consists of an endless chain of short bars, that travels in a horizontal direction from the front to the back of the furnace, over sprocket wheels operated either by a small auxiliary engine or by power derived from an overhead line of shafting in front of the boilers. The motion of the endless chain of grates is of course very



slow, but it is continuous and regular, receiving the supply of coal at the front and depositing the ashes at the back end, where they drop into the ash-pit.

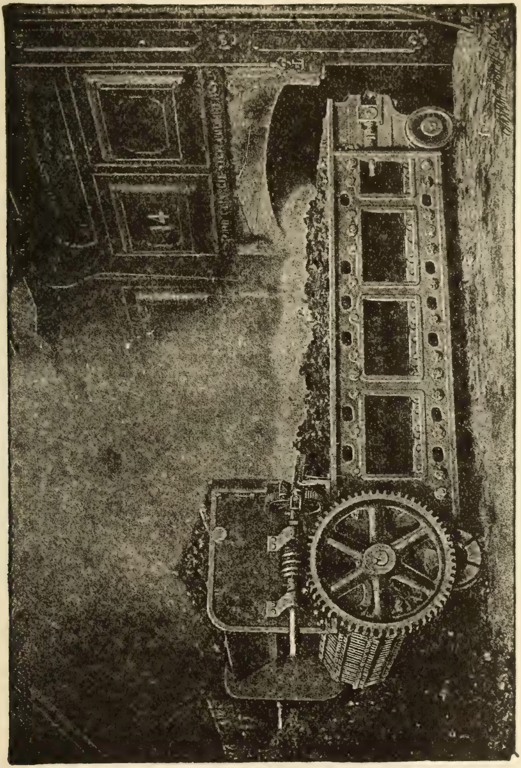


Fig. 102. Mansfield Chain Grate Stoker, Showing How It Can Be Withdrawn from Under Boiler.

Ques. 415.—What type of stokers is included in Class 2?

Ans.—Stokers having grate-bars somewhat after the ordinary hand-fired type, but having a continuous motion up and down, or forward and back. Although this motion is slight, it serves to keep the fuel stirred and loosened, thus preventing the fire from becoming sluggish.

Ques. 416.—What position do the grate-bars in Class 2 occupy?

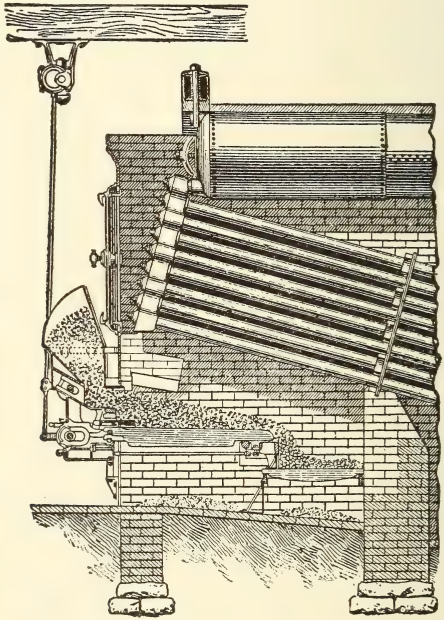


FIG. 103. VICARS MECHANICAL STOKER.

Ans.—Either horizontal, or slightly inclined, and their constant motion tends to gradually advance the coal from the front to the back end of the furnace.

Ques. 417.—What kinds of stokers are included in Class 3?

Ans.—Stokers in which the grates are steeply inclined.

The coal is fed onto the upper ends of the gates, which, having a slow motion, gradually force the coal forward as fast as required. In some stokers of this class, as, for instance, the Murphy, the grates incline from the sides towards the middle of the furnace, but in the majority of cases the inclination is from the front towards the back.

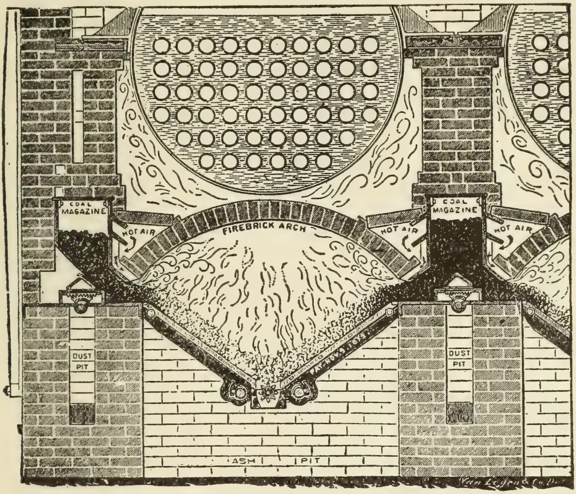


FIG. 104. THE MURPHY AUTOMATIC FURNACE.

Ques. 418.—What is the leading feature governing the operation of stokers belonging to Class 4 ?

Ans.—The coal is supplied from underneath the grates, and is pushed up through an opening left for the purpose midway of the length of the furnace. The gases, on being distilled, come in contact immediately with the hot bed of coke on top, and the result is good combustion.

Ques. 419.—What are stokers belonging to Class 4 called?

Ans.—Under-feed stokers.

Ques. 420.—What methods are employed for forcing the coal up into the furnace with under-feed stokers?

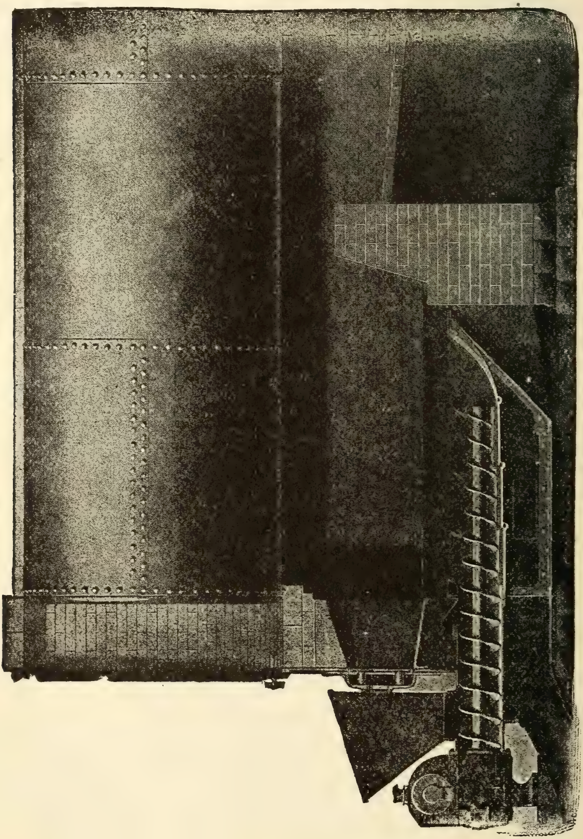


Fig. 105. Typical Setting of American Stoker Under a Return Tubular Boiler.

Ans.—Steam is the active agent, either by means of a steam-ram, or a long, slowly revolving screw, driven by a small engine.

Ques. 421.—How is the air supplied when an under-feed stoker is used?

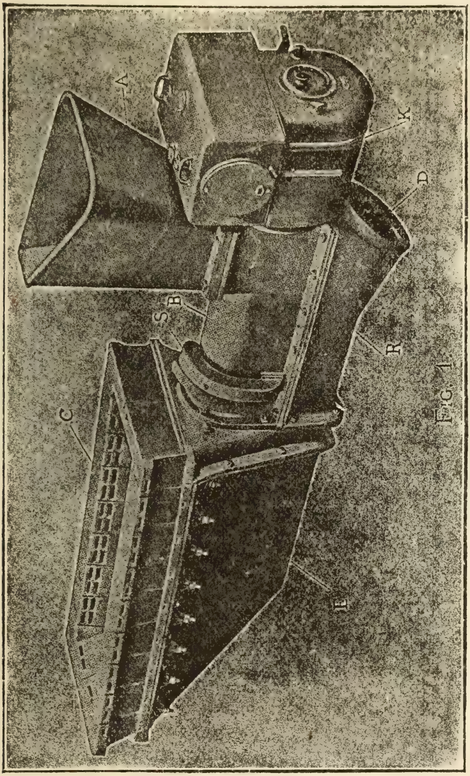


FIG. 106. STANDARD 8 AND 9 INCH AMERICAN STOKERS.

A. Coal hopper.
B. Conveyor pipe.
C. Tuyeres for introducing air to the fuel.
D. Opening to wind-box for air connections.
E. Wind-box for supplying air to tuyeres.
K. Automatic steam-motor for driving conveyor.
R. Air-pipe to wind-box.
S. Gas-ducts for returning volatile products from entering coal to furnace.

Ans.—Forced draught is employed, and the air is blown into the furnace through tuyeres.

Ques. 422.—How is the coal supplied to mechanical stokers, other than the under-feed type?

Ans.—In two ways; either by being shoveled by hand into hoppers in front of and above the grates, or, as is the case in most of the large plants using them, it is elevated by machinery and deposited in chutes, through which it is fed to each boiler by gravity. The coal used in mechanical stokers is in the form of screenings or nut coal.

Ques. 423.—Have mechanical stokers for feeding coal been applied in the marine service to any great extent?

Ans.—They have not, up to the present time.

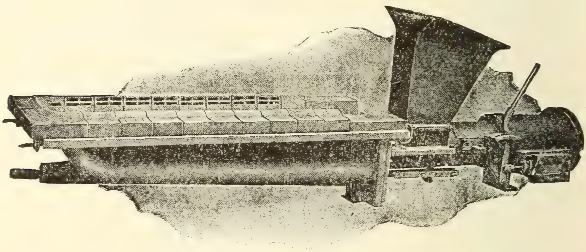


FIG. 107. JONES UNDER-FEED STOKER, HAVING A STEAM RAM.

Ques. 424.—In what way is it possible to successfully use automatic or mechanical stokers on marine boilers?

Ans.—By the use of liquid fuels, such as petroleum, blast-furnace oil, tar oil, etc.

Ques. 425.—Of what does petroleum consist?

Ans.—Petroleum consists practically of carbon, hydrogen, and oxygen, in the following proportions: Carbon, 85 per cent; hydrogen, 13 per cent, and oxygen, 2 per cent.

Ques. 426.—What is the heating value of 1 pound of petroleum?

Ans.—About 20,000 heat units, or about one-third more than the best coal.

Ques. 427.—How is petroleum fed to the furnaces?

Ans.—By being forced through nozzles having two or three holes, or annular spaces, from one of which the petroleum flows out, under pressure, while a jet of steam or compressed air issuing from another orifice catches the oil and "pulverizes" it into a fine spray, in which form it strikes the fire. The air for combustion is admitted through a third orifice, or if not thus supplied,

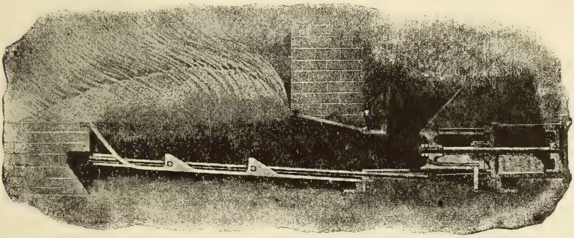


FIG. 108. SECTIONAL VIEW OF JONES UNDER-FEED STOKER.

the air for combustion is admitted by suitable orifices in the furnace front.

Ques. 428.—How is the furnace arranged for burning petroleum?

Ans.—A layer of broken fire-brick or asbestos is placed on the grate, and fire-brick screens, or bafflers, are placed in the way of the flame, thus providing a red-hot surface against which it impinges. Otherwise the combustion would be greatly hindered by the comparatively cool surfaces of the boiler-plates and tubes.

Oues. 429.—What agent has been found to be the best for pulverizing the petroleum and spraying it into the furnace?

Ans.—Compressed air, slightly heated.

Ques. 430—What is one of the disadvantages attending the use of steam for this purpose?

Ans.—The danger of the flame being extinguished by water that is sometimes carried over with the steam.

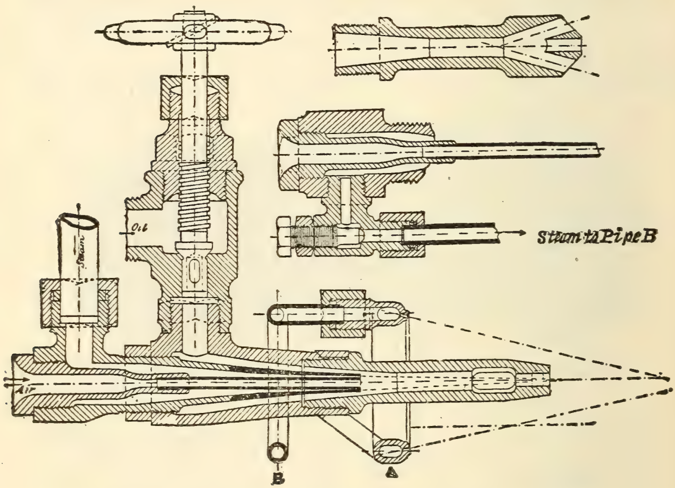


Fig. 109. Petroleum Burner for Boiler Furnace.

Ques. 431.—How is the oil supplied to the nozzles?

Ans.—By means of pumps that draw it from the bunkers and discharge it into a reservoir, and from thence it is fed to the burners.

Ques. 432.—What are the advantages in favor of petroleum fuel, especially for the marine service?

Ans.—First, superior evaporation, and, as a consequence, great reduction in the weight of fuel to be carried;

second, less space occupied by the fuel and ease of shipping it into the bunkers; third, reduction of stoke-hold force, also less space required in the stoke-hold; fourth, regularity of combustion and no reduction of power, due to cleaning fires, they being always clean and in a good condition; fifth, increased durability of boilers, owing to the fact that there are no variations of temperature, due to opening fire-doors, for coaling or cleaning; sixth, greater control over the expenditure of fuel, consequently less waste of steam at the safety valves, also less danger of a short supply of steam in case of a sudden demand upon the boilers.

Ques. 433.—What are some of the principal objections to its use on board of vessels?

Ans.—First, limited supply; second, vessels proceeding on long voyages could not, with present facilities, replenish their bunkers when required; third, danger of the generation of inflammable gases; fourth in war-ships the risk of possible loss of the fuel, in the event of injury to the bunker containing it.

Ques. 434.—Has the combination of coal and petroleum, in the same furnace, ever been attempted?

Ans.—Experiments along this line are being made in the British and other navies.

Ques. 435.—How are the furnaces fitted for this purpose?

Ans.—The same as for hand firing with coal, and in addition, a number of nozzles are placed in the front above the fire for injecting the petroleum over the incandescent coal.

Ques. 436.—Upon what does the efficiency of a steamship, or of a manufacturing establishment in which steam is used for power, largely depend?

Ans.—Upon the condition of the boilers and the care and labor expended for their preservation.

Ques. 437.—What was formerly one of the most dangerous and active agents in the deterioration of boilers, especially in the marine service?

Ans.—Corrosion of the boiler-plates and stays.

Ques. 438.—What was found, by a long series of experiments, to be the principal cause of this corrosion?

Ans.—The action of the fatty acids evolved by saponification from the heated tallow and vegetable oils, used at the time for the internal lubrication of the cylinders and valve-chests.

Ques. 439.—How were these oils carried into the boilers?

Ans.—In condensing systems, where the water of condensation was used for feed-water, the waste oil in the exhaust steam mingled with the feed-water and was carried into the boilers.

Ques. 440.—How has the danger from this source been largely obviated in late years?

Ans.—By the use of mineral oils for internal lubrication.

Ques. 441.—In what other way has the danger of corrosion been lessened?

Ans.—By the use of mild steel instead of iron plates in the construction of boilers. This steel is made by the

Seimens-Martin process, and is much stronger than iron and less liable to corrosive action.

Ques. 442.—Of what material are marine boilers now made entirely?

Ans.—Of steel, except the tubes, which are usually made of iron in the mercantile service. Steel tubes are used in war-ships. The furnaces and internal parts, that have to be welded or flanged, are made from specially soft steel plates.

Ques. 443.—What is the principal cause of corrosion in boilers at the present time?

Ans.—Oxidation of the plates, which results from contact with moisture and air, either carried in with the feed-water, or existing in the atmosphere when the boilers are empty.

Ques. 444.—What conditions must exist in order that corrosion shall take place from this cause?

Ans.—The simultaneous presence of both air and water, because neither dry air nor fresh water in which there is absolutely no air has any chemical action on steel or iron. Air dissolved in water is especially active, and the action is increased by the presence of various chlorides, such as magnesium and sodium.

Ques. 445.—Are there any other causes that tend toward the corrosion of boilers, internally?

Ans.—There are; for instance, hot sea-water, even when entirely deprived of air, has some action on steel and iron. It has been found that at the high temperatures now common in boilers, the chloride of magnesium contained in sea-water is decomposed by the heat and gives off hydrochloric acid, the evolution of acid being accelerated with increase of density.

Ques. 446.—Should sea-water be admitted to boilers if it is possible to prevent it?

Ans.—It should not; but if a portion is used, it is important that sufficient alkali, preferably lime, be admitted with the feed-water to render the water in the boilers slightly alkaline by the litmus test.

Ques. 447.—Does galvanic action, due to differences in the material used in the construction of the boilers, conduce towards corrosion?

Ans.—Galvanic action is probably a minor cause of corrosion.

Ques. 448.—What are some of the methods that may be employed for the prevention of corrosion in boilers?

Ans.—First, the admittance of air into the boilers while at work should be prevented as much as possible. This may be done by having a tank, called the feed-tank, into which the air-pumps may discharge its water, and from which the feed-pumps can draw their water for supplying the boilers. The feed-pumps should be independent pumps, which can be so regulated in speed as to be always fully supplied with water and never to empty the feed-tank and so suck in and discharge air into the boilers. Second, the complete exclusion of sea-water from the boilers if possible. The waste of feed-water should be made good by evaporators and a reserve of fresh water in tanks. Third, mineral oils, which consist of hydrocarbons only, should be used exclusively for lubrication of all internal parts of the engines and pumps requiring lubrication.

Ques. 449.—How may the injurious effects of galvanic action be neutralized?

Ans.—By the suspension of zinc slabs in various parts of the boiler, both below the water-line and also in the steam-space. Then if there be any galvanic action the zinc slabs will be attacked instead of the material of the boiler itself.

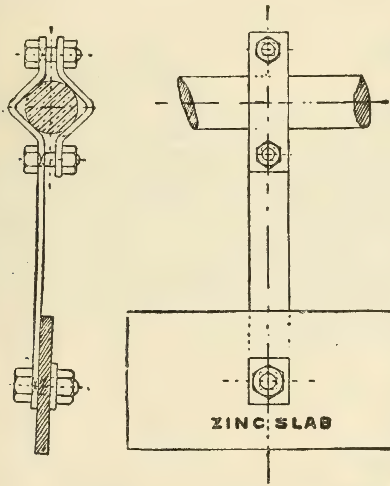


FIG. 110. METHOD OF SUSPENDING ZINC SLABS.

Ques. 450.—What is an important point to be observed when placing these zinc slabs?

Ans.—They should be in actual bright contact with the material of the boiler and they should be well distributed, so that every portion of the interior surface of the boiler is protected.

Ques. 451.—What is the theory of the action of these zinc slabs, in preventing galvanic corrosion?

Ans.—Zinc is an electro-positive metal, and it being suspended in the boiler causes the steel of the boiler to become electro-negative and thus any corrosive agent is induced to attack the zinc, leaving the steel uninjured.

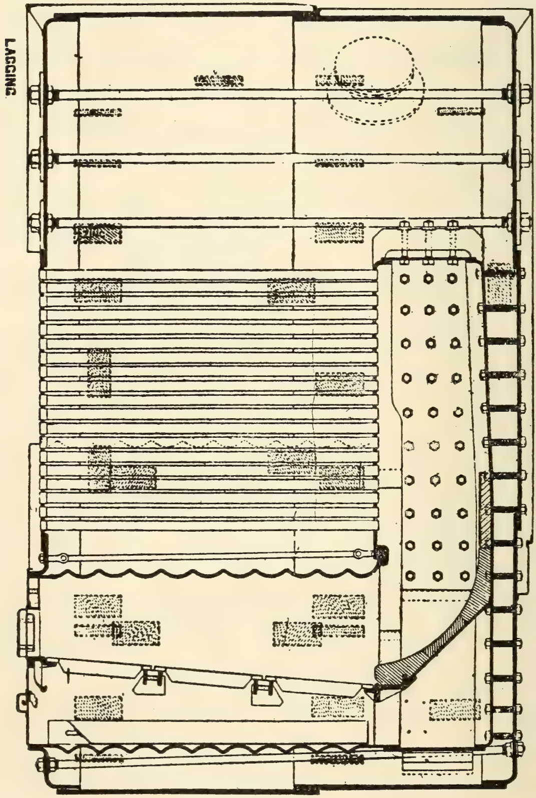


FIG. 111. SECTION OF MARINE BOILER, SHOWING LOCATION OF ZINC SLABS.

This preservative action can only take place when the boilers have water in them and the zinc slabs fitted in the steam-space act only when the boilers are completely filled with water.

CHAPTER VI

TYPES OF ENGINES—CLASSIFICATION

Ques. 452.—Into what three general classes may marine and stationary engines be divided?

Ans.—First, simple; second, compound; third, triple, or quadruple expansion.

Ques. 453.—What causes the piston of a steam-engine to move back and forth in the cylinder?

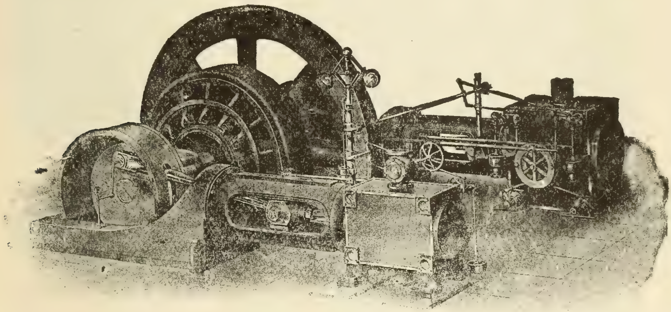


FIG. 112. CROSS COMPOUND DIRECT CONNECTED CORLISS ENGINE. ALLIS CHALMERS CO.

Ans.—The expansive force of the steam that is admitted alternately behind the piston, at either end of the cylinder.

Ques. 454.—Describe the action of the steam in a simple engine.

Ans.—In a simple engine the steam is used in but one cylinder, and from thence it is exhausted, either into the atmosphere or into a condensor.

Ques. 455.—What is the leading characteristic of a compound engine?

Ans.—In a compound engine the steam is made to do work in two or more cylinders before it is allowed to exhaust.

Ques. 456.—How is this accomplished?

Ans.—The compound engine is fitted with two, and in some cases with three cylinders. The cylinder into which steam at boiler pressure is admitted is termed the high-pressure cylinder and is the smallest of the group, in

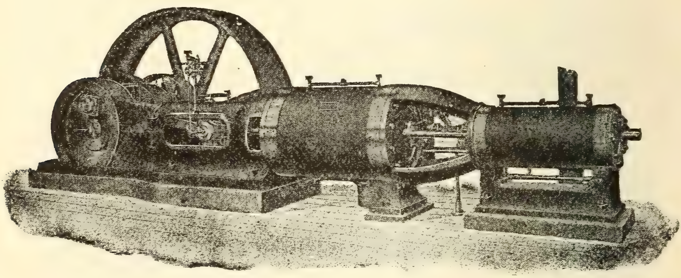


FIG. 113. TANDEM COMPOUND ENGINE, BUCKEYE ENGINE CO.

diameter. The exhaust passage (or receiver) from this cylinder leads directly to the valve-chest of another cylinder, larger in diameter, termed the low-pressure cylinder, and thus conducts the exhaust from the high to the low-pressure cylinder, wherein it again serves as working steam, and if the cylinders are properly proportioned for the pressure, the amount of work done in each cylinder will be the same.

Ques. 457.—How many kinds of compound engines are in use generally?

Ans.—Two kinds: First, the cross compound, in which the cylinders stand parallel, each having its individual cross-head, connecting rod, and valve-gear, and all connected to a common crank-shaft; second, tandem

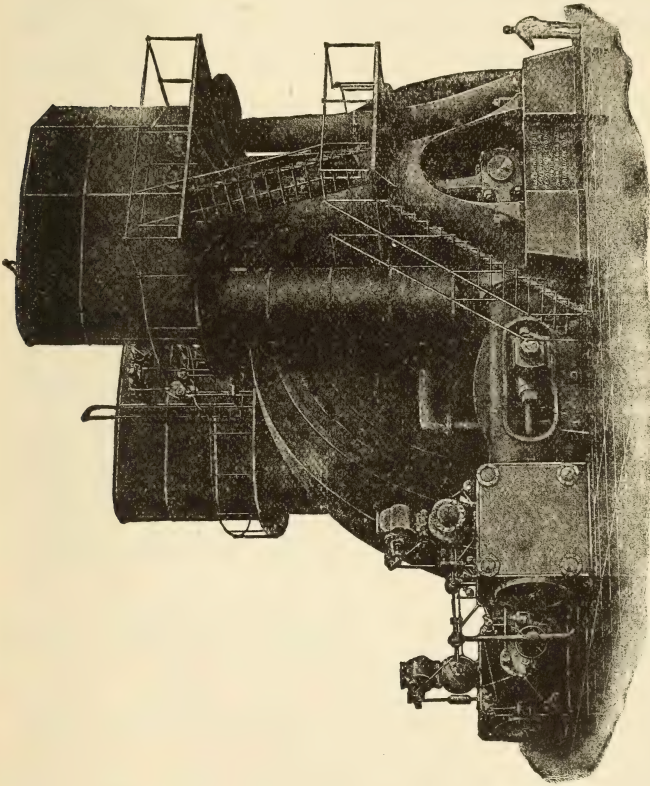


FIG 114. REYNOLDS COMBINED VERTICAL AND HORIZONTAL ENGINE, 12,000 HORSE-POWER CYLINDERS. 44x88x60.

compound, in which the cylinders are tandem to each other, and one piston rod, cross-head, connecting rod, and valve-gear is common to both, although each cylinder has its own valve or valves for controlling the admission and release of the steam.

Ques. 458.—What is implied in the expression "triple expansion?"

Ans.—Triple expansion means that the steam has been allowed to expand through three successive stages, doing

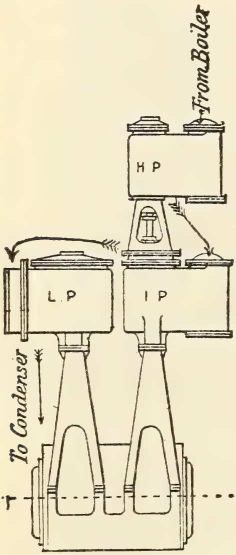


Fig. 115. Shows a Triple Expansion Engine in which the High Pressure is Tandem with the Intermediate Cylinder.

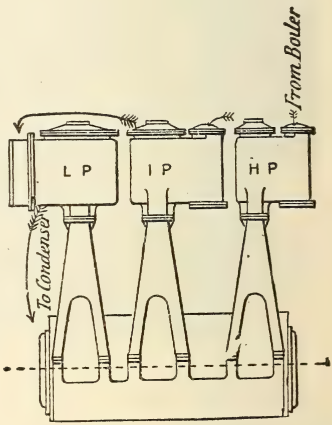


Fig. 115a. Shows the Ordinary Arrangement of Cylinders for a Triple Expansion Engine.

a fixed amount of work in each stage, before release occurs.

Ques. 459.—How many cylinders are required on a triple-expansion engine?

Ans.—Never less than three, and for large, high-speed engines it often becomes necessary to have two low-pressure cylinders, thus making a four-cylinder triple-expansion engine.

Ques. 460.—Are four cylinder triple-expansion engines much in use?

Ans.—They are in the marine service, and especially in the British navy, and they are also used to a large extent in the mercantile service.

Ques. 461.—Describe the action of the steam in a quadruple-expansion engine.

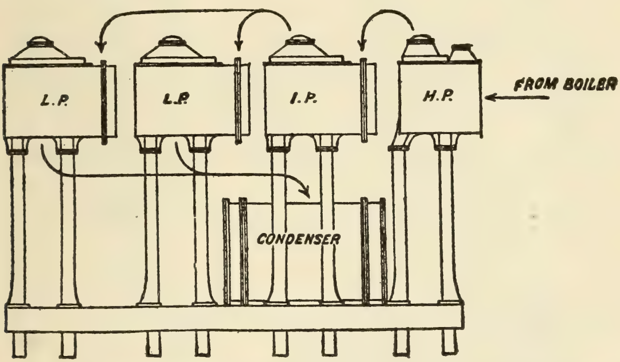


FIG. 116. ARRANGEMENT OF FOUR CYLINDER TRIPLE EXPANSION ENGINE FOR MARINE SERVICE.

Ans.—In a quadruple-expansion engine, the expansion of the steam is divided up into four stages by causing it to pass through four successive cylinders, termed respectively the high-pressure, first intermediate, second intermediate, and low-pressure. In some of the larger engines of this type there are two low-pressure cylinders, thus making five cylinders in all.

Ques. 462.—What pressures of steam are usually used in this type of engine?

Ans.—From 200 to 250 pounds per square inch.

Ques. 463.—What are some of the advantages that are to be gained in the use of steam by stage expansion?

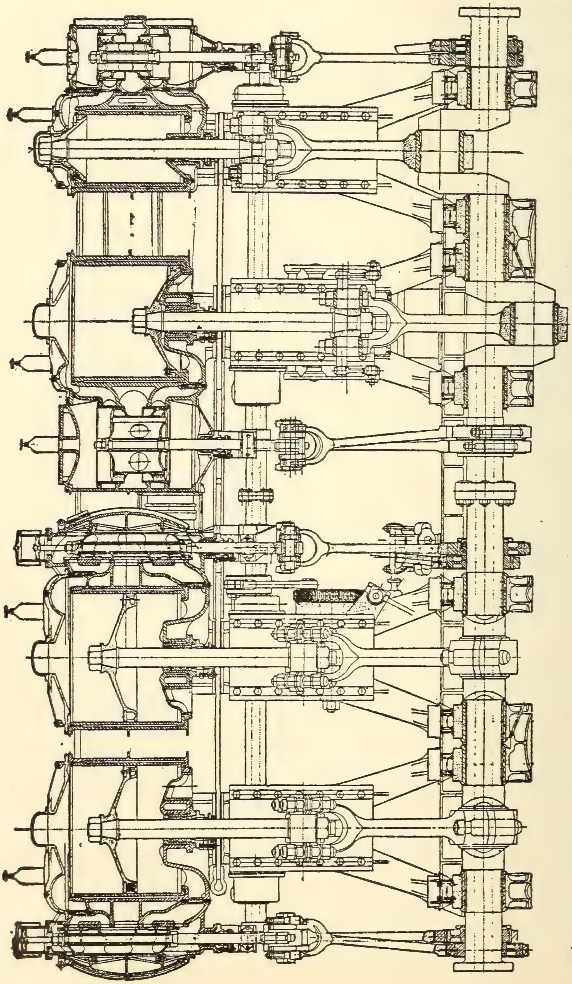


FIG. 117. SECTIONAL VIEW OF FOUR CYLINDER TRIPLE EXPANSION MARINE ENGINE FOR LARGE OCEAN-GOING STEAMER.

Ans.—First, that the cylinder into which steam directly from the boiler is admitted is never open to the cooling influence of the atmosphere, or condensor, hence there is not so much cooling and condensation of the entering steam; second, the steam that is condensed and reevaporated in the first cylinder reappears as working steam in the second cylinder; third, the loss from condensation in the second and third cylinders is also reduced, owing to the smaller range of temperature, between admission and exhaust in those cylinders.

Ques. 464.—What are the mechanical advantages of compound and triple-expansion engines, for heavy duty?

Ans.—First, the facility with which high rates of expansion may be carried out without bringing excessive strains and stresses on the framing of the engine; second, a greater uniformity of twisting moment on the shaft.

Ques. 465.—What are the usual ratios of cylinder volumes in compound and triple and quadruple-expansion engines?

Ans.—For compound engines 1 to 4 between high and low-pressure cylinders. For triple-expansion engines, the ratios are about 1, 3 and 7, for high, intermediate and low-pressure cylinders. For quadruple-expansion engines the ratios are as follows: 1, 2, 4½ and 10¼ for high-pressure, first intermediate, second intermediate and low-pressure respectively.

Ques. 466.—What is meant by the term receiver, as used in connection with the stage-expansion of steam?

Ans.—In the case of a compound engine the receiver is the whole of the space between the high-pressure piston, when at the end of its stroke, and the back of the low-pressure steam-valve, whether it be slide rotative, or piston-valve. In the case of a triple-expansion engine, the space between the piston at the end of its stroke and the back of the intermediate steam-valve is called the intermediate receiver, and the space between the inter-

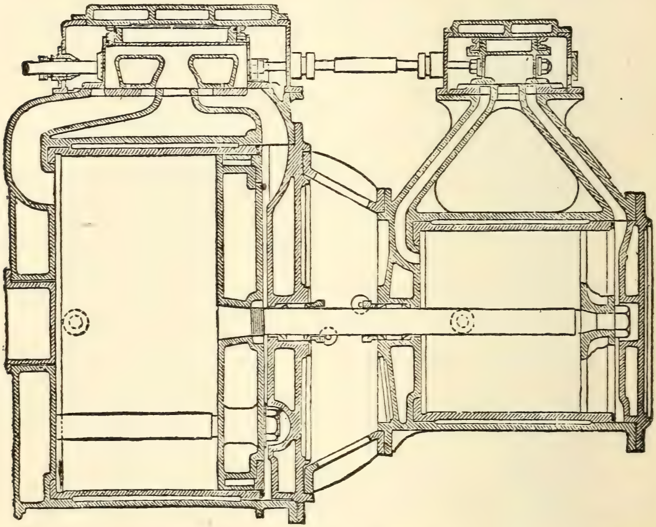


FIG. 118. SECTIONAL VIEW OF TANDEM COMPOUND CYLINDERS, SHOWING ARRANGEMENT OF STEAM CHESTS AND VALVES.

mediate piston at the end of its stroke and the low-pressure steam-valve is the low-pressure receiver.

Ques. 467.—What is the usual volume of these receivers in modern practice?

Ans.—After many experiments with large reservoirs as receivers, it has been found that all that is necessary is a comparatively large exhaust pipe from the exhaust orifice of the high-pressure cylinder to the steam inlet of the next lower pressure cylinder, it having been demonstrated that the volume of the exhaust passage and pipe from the high-pressure cylinder and the low-pressure valve-chest supplied sufficient space to allow for the compression that occurs between release from the high-pressure cylinder and admission to the low-pressure cylinder.

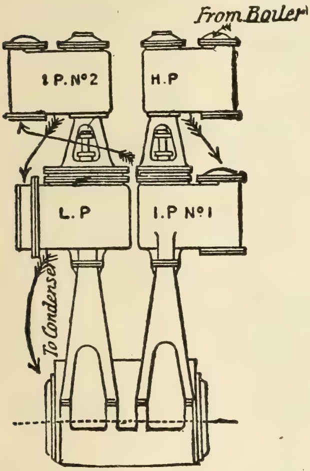


FIG. 119. TANDEM QUADRUPLE EXPANSION MARINE ENGINE SHOWING ARRANGEMENT OF CYLINDERS.

Ques. 468.—Does this law apply in the case of triple and quadruple-expansion engines?

Ans.—It does.

Ques. 469.—Upon what does the power of any stage-expansion engine depend?

Ans.—The power of a stage-expansion engine working at any given rate of expansion depends entirely upon the dimension of its low-pressure cylinder or cylinders, and is not affected by the size of its high-pressure cylinder, which latter, in fact, carries out but one stage in the expansion.

Ques. 470.—What does the capacity of the low-pressure cylinder or cylinders of such an engine require to be?

Ans.—The same as that of the whole of the cylinders of a simple engine of the same power, working at the same initial pressure and total ratio of expansion.

Ques. 471.—Why is this?

Ans.—For the reason that, since the initial pressures and ratios of expansion are the same in both engines, it follows that the terminal pressures and volumes must also be identical in both cases. In the simple engine the whole of the steam at the end of the stroke fills all of the cylinders, while in the compound engine it is contained in the low-pressure cylinder or cylinders only, hence the capacity of this cylinder must be equal to the capacity of all the cylinders of the simple engine.

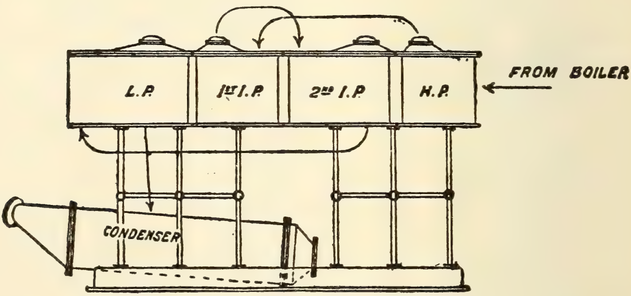


FIG. 119A. QUADRUPLE EXPANSION ENGINE, WITH CYLINDERS AS ORDINARILY ARRANGED—ARROWS SHOW COURSE TAKEN BY THE STEAM.

Ques. 472.—Why is it necessary in some cases to employ two low-pressure cylinders?

Ans.—For the reason that in very large engines one low-pressure cylinder would be too large and unwieldy, therefore it is divided into two equal parts.

Ques. 473.—Are compound and triple-expansion engines much in use outside of the marine service?

Ans.—They are to a large extent, owing to the great gain in economy over the simple engine. Practically all large manufacturing plants use them.

Ques. 474.—What other types of engines are in use in the marine service?

Ans.—The vertical walking-beam engine is largely in use on the lakes, bays, and rivers of the United States.

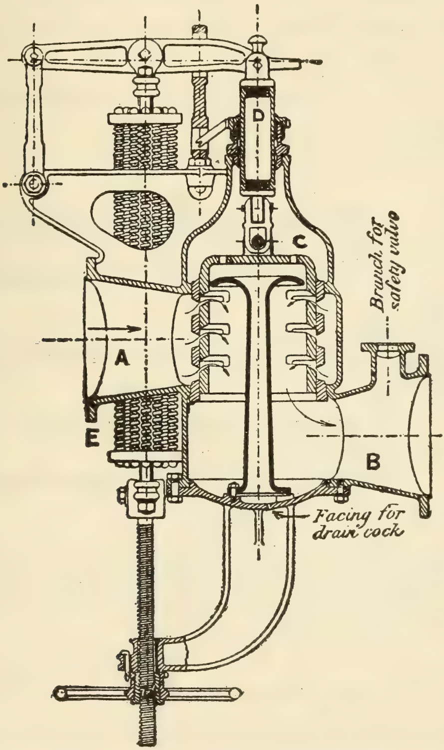


FIG. 120. BELLEVILLE REDUCING VALVE.

Ques. 475.—What is the leading characteristic of this type of engine?

Ans.—It has usually but a single cylinder, with a very long stroke in proportion to its diameter, the length of the stroke varying from 7 to 12 feet.

Ques. 476.—What pressures of steam are usually employed in beam engines?

Ans.—Owing to the fact that the steam is expanded in a single cylinder only, the pressure carried is low—50 to 60 pounds per square inch.

Ques. 477.—Mention another type of engine that is in common use on Western rivers.

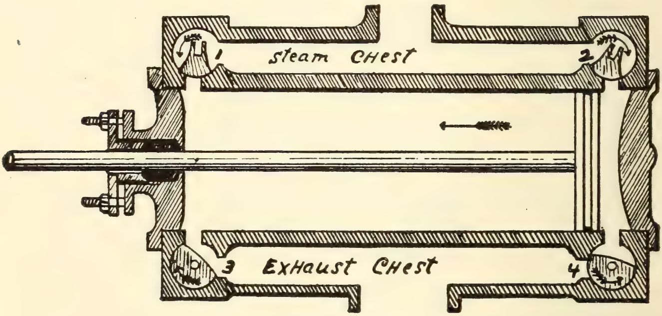


Fig. 121.

Fig. 121 is a sectional view of the cylinder, steam, and exhaust-chests. and the valve-chambers of a Corliss engine. 1 and 2 are the steam-valves and 3 and 4 the exhaust-valves. The valves work in cylindrical chambers accurately bored out, the face of the valve being turned off to fit steam tight. They are what is termed rotative valves, that is, they receive a semi-rotary motion from the wrist-plate, which in turn is actuated by the eccentric.

Ans.—The stern-wheel engine, consisting of a pair of engines, one cylinder on either side of the boat, and directly connected to the shaft of the stern-wheel. Like the beam engine, the stroke is long in proportion to the cylinder diameter.

Ques. 478.—Are these engines simple or compound?

Ans.—In former years simple engines were used altogether, but the later types are compound, either tandem or cross-compound.

Ques. 479.—What styles of valves and valve-gears are in use on these engines?

Ans.—Poppet-valves, actuated by long cam-driven levers, are the most generally used. Other styles of valves, such as rotative valves, common slide and piston-valves, are also quite frequently used.

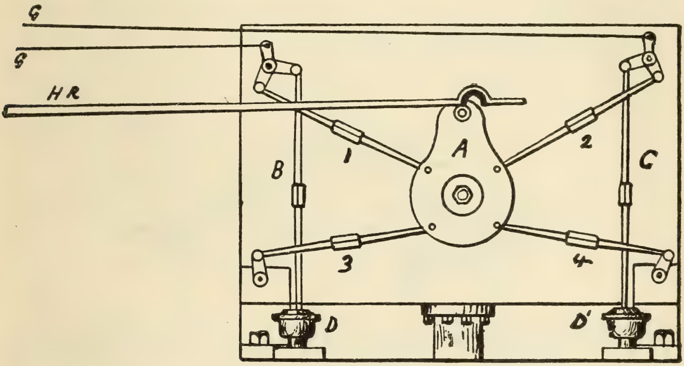


FIG. 122.

The valve-gear of a Corliss engine with a single eccentric is shown in Fig. 122. The connections of the exhaust-valves with the wrist-plate are positive, and the travel of these valves is fixed, being a constant quantity, but the connections of the steam-valves with the wrist-plate are detachable, being under the control of the governor.

Ques. 480.—What is meant in speaking of a four-valve engine?

Ans.—An engine having two steam-valves and two exhaust-valves located near each end of the cylinder.

Ques. 481.—What type of four-valve engine has met with great favor since its introduction?

Ans.—The Corliss engine, invented by Mr. Geo. H. Corliss, of Providence, R. I.

Ques. 482.—What advantage does the four-valve engine possess over the single-valve type?

Ans.—The advantage that each valve may be adjusted to a certain degree independently of the others, the steam-valves for admission and cut-off and the exhaust-valves for compression and release.

Ques. 483.—What is one of the oldest forms of valve, and one that is still used extensively, especially on marine engines?

Ans.—The D slide-valve.

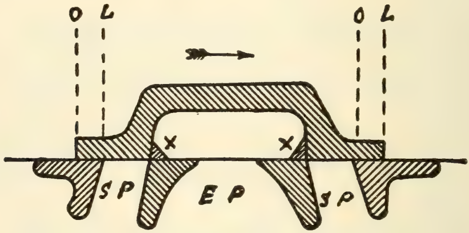


FIG. 123.

Fig. 123 represents a slide-valve at mid-travel. S P—S P are the steam-ports and E P is the exhaust-port; the projections marked x at each foot of the arch inside the valve represent inside lap, and may be added to or taken from the inside edges of the valve, according as more or less compression is desired. The dotted lines O L—O L represent outside lap.

Ques. 484.—What are the functions of the slide-valve?

Ans.—It controls the admission, expansion and release of the steam and the closure of the exhaust.

Ques. 485.—Upon what does the development of the full power of the engine and its efficient and economical use of steam, as well as its regular and quiet action, largely depend?

Ans.—Upon the correct adjustment of its valve or valves.

Ques. 486.—How is the slide-valve fitted to the cylinder?

Ans.—The slide-valve has a flat face and it works on the corresponding flat face of the cylinder. In the cylinder face there are three passages called ports, the two smallest, called steam-ports, leading to each end of the cylinder, and the larger one, called the exhaust-port, eading to either the receiver, condensor, or the atmosphere, as the case may be. The valve is contained in a steam-tight chest or casing, either cast with the cylinder,

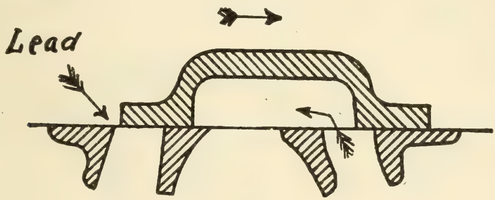


Fig. 124.

Fig. 124 shows the slide-valve in the position of lead—exhaust opening has also occurred at the opposite end of the cylinder. The arrows show the course of the steam, also the direction in which the valve is traveling.

or bolted to it. This casing or valve-chest is filled with live steam while the engine is working.

Ques. 487.—How must the slide-valve be constructed, in order that it may properly perform the four important functions of admission, cut-off, release, and exhaust closure?

Ans.—It must have lap and lead.

Ques. 488.—What is lap?

Ans.—Lap is the amount that the ends of the valve project over the edges of the ports when the valve is at mid-travel.

Ques. 489.—What is steam lap, or outside lap?

Ans.—The amount that the end of the valve projects over the outside edge of the steam-port.

Ques. 490.—What is inside or exhaust lap?

Ans.—The lap of the inside or exhaust edge of the valve over the inside edge of the port.

Ques. 491.—What is lead?

Ans.—The amount that the steam port is open when the piston is just commencing its stroke. This is the instant of admission.

Ques. 492.—When is the instant of cut-off?

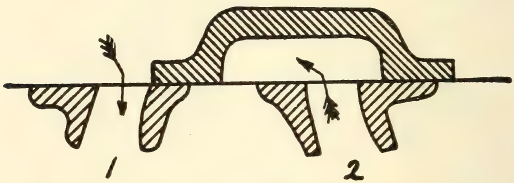


FIG. 125.

Fig. 125 shows the slide-valve at the end of its travel—full port opening.

Ans.—When the admission of steam to the cylinder is stopped by the steam edge of the valve closing the steam-port and the piston is pushed the balance of the stroke by the expansion of the steam admitted before cut-off occurred.

Ques. 493.—When is the instant of compression?

Ans.—When the two inside or exhaust edges of the valve coincide with the inner edges of the ports, the piston being near the end of its stroke and the valve at mid-travel.

Ques. 494.—When is the instant of release?

Ans.—When the inner edge of the valve commences to open the steam-port to the exhaust-passage.

Ques. 495.—What is the advantage gained by compression?

Ans.—A portion of steam is confined ahead of the piston, thus forming an elastic cushion to absorb the momentum of the piston and other moving parts connected with it and bring all to rest quietly at the end of the stroke.

Ques. 496.—How may this compression be increased or diminished?

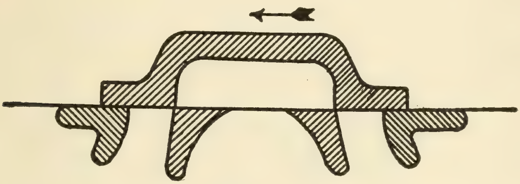


Fig. 126.

Fig. 126 illustrates the instant of cut-off. The valve is now traveling in the opposite direction.

Ans.—By adding to or taking away from the inside lap of the valve.

Ques. 497.—What is the object of giving a valve lead?

Ans.—The effect of lead is to cause the engine to be quick and not to lag at the beginning of the stroke. The live steam admitted through the lead opening also assists in forming a cushion for the piston at the end of the stroke.

Ques. 498.—Do the principles governing the adjustment and action of the slide-valve necessarily have to be applied in the adjustment and action of rotative, piston, and other forms of valves for controlling the distribution of steam in the cylinders of engines?

Ans.—They do. The same general principles apply in all cases.

Ques. 499.—How is motion generally imparted to the slide-valve or other types of valves?

Ans.—By means of an eccentric, which is simply a circular cast-iron or cast-steel sheave having a hole bored in it eccentrically with its own circumference, and large enough to permit of its being fitted on the engine shaft. The eccentric-sheave is either keyed on the shaft or held

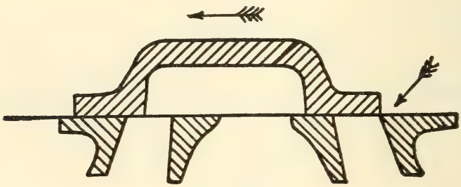


Fig. 127.

Fig. 127 shows the slide-valve at the instant of compression.

in its place by set-screws, and therefore revolves with the shaft. On the circumference of the eccentric, which is of sufficient width to present a good bearing surface, a ring, called the eccentric-strap, works, and attached to this ring is the eccentric-rod, which is either directly connected to the valve-rod, or valve-stem, or else imparts motion to the valve through the agency of a rocker-arm, and in many engines a link motion is used. The center of revolution of the eccentric being several inches apart from its center of formation, will, when the sheave revolves with the shaft, cause the eccentric to convert the rotary motion into a reciprocating motion, which through the agency of the rod is imparted to the valve or valves.

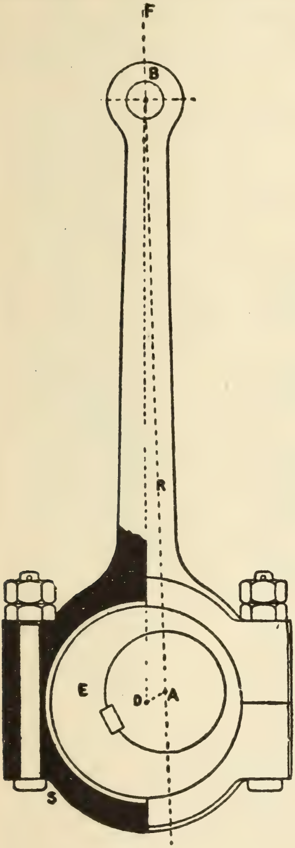


FIG. 128.

Fig. 128 shows an eccentric with its strap and rod. E is the sheave, the center of which is shown at D. A is the center of the shaft. The distance A D represents the throw of the eccentric and twice that distance equals the travel of the end B of the rod along the line A F. S is the eccentric strap

Ques. 500.—What is meant by the throw of an eccentric?

Ans.—The distance between the center of the eccentric-sheave and the center of the crank-shaft. This distance is also called the radius of eccentricity.

Ques. 501.—What is meant by eccentric position?

Ans.—The location of the highest point of the eccentric relative to the center of the crank-pin, expressed in degrees.

Ques. 502.—What is angular advance?

Ans.—The distance that the high point of the eccentric is set ahead of a line at right angles with the crank, in other words, the lap angle plus the lead angle.

Ques. 503.—If a valve had neither lap nor lead, what would be the position of the high point of the eccentric relative to the crank?

Ans.—It would be on a line exactly at right angles with the crank, as, for instance, the crank being at 0 degrees, the eccentric would stand at 90 degrees.

Ques. 504.—How is the reversing of modern marine engines usually effected?

Ans.—By means of the link motion, using two eccentrics.

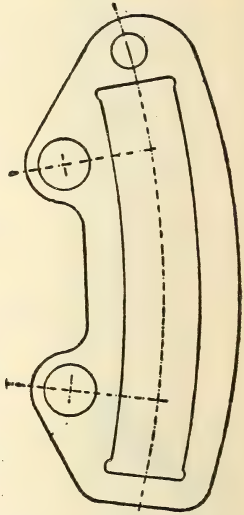


FIG. 129. SLOTTED LINK.

Ques. 505.—How many varieties of links are in use?

Ans.—Three, the slotted link, the solid-bar link and the double-bar link.

Ques. 506.—Describe the slotted link.

Ans.—It is a curved bar with a slot cut in it, in which the link-block is fitted. This link-block is attached to the valve-rod by a pin, about which an oscillating motion of the block occurs. Two projectoins are formed on one side of the link, to which the eccentric rods are connected.

Ques. 507.—Describe the solid-bar link.

Ans—The solid-bar link consists of a simple, curved, rectangular bar, with eyes formed at each end, for connecting the eccentric-rods. The solid bar passes through the block.

Ques. 508.—What is the general plan of the double-bar link?

Ans.—It consists of a pair of curved steel bars joined at the ends and kept a certain distance apart by distance pieces. Projecting pins are formed on the link-bars, two on each side, for the attachment of the eccentric-rods. The ends of the eccentric-rods are forked and contain each two adjustable bearings, which embrace the pins on each side of the link. The link-block is a steel or iron pin, sliding between the bars, and having projections on each

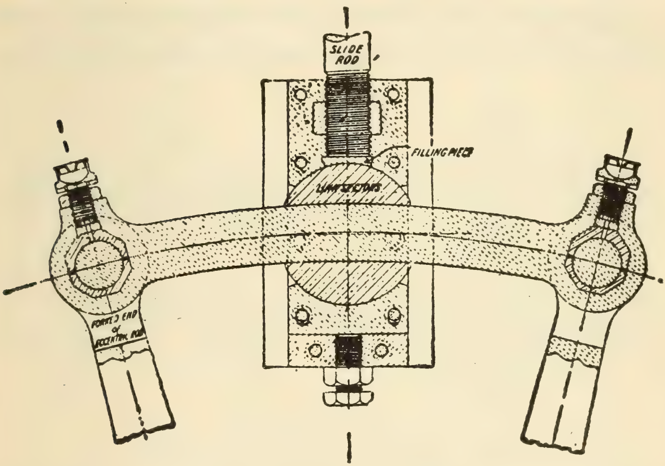


Fig. 130. Solid Bar Link.

side which embrace the link-bars and through which these bars slide, on adjustable gun-metal liners.

Ques. 509.—Why is it necessary that the link should be curved?

Ans.—For the reason that it is used not only for reversing the engine, but also for working steam expansively, and therefore its shape must be such that when the block is in any intermediate position the center of the travel of the valve will always be constant, otherwise the distribution of the steam to the two ends of the cylinder would not be evenly divided.

Ques. 510.—What is the slip of the link?

Ans.—A slight oscillating movement of the link on its block.

Ques. 511.—What is it that fixes the curvature of the link?

Ans.—The length of the eccentric-rod; that is, the curve of the link is a circular arc, of a radius equal to the

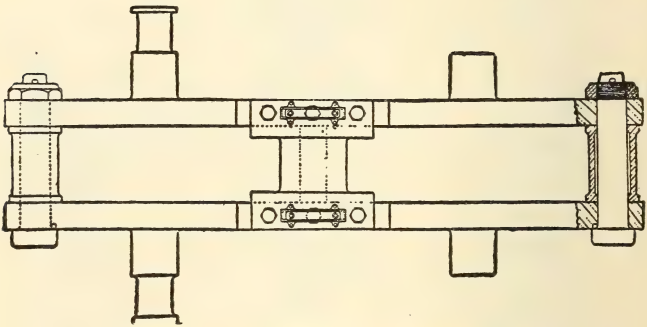


FIG. 131. PLAN VIEW OF DOUBLE-BARRED LINK.

distance between the center of the eccentric and center of the pin at the end of the rod.

Ques. 512.—Is there a type of reversing valve-gear that employs but one eccentric?

Ans.—There is, viz., the Marshall radial valve-gear.

Ques. 513.—It there a type of reversing valve-gear in which eccentrics are dispensed with?

Ans.—There is, viz., the Joy valve-gear, by which the motion of the valve is derived from the connecting rod, through the medium of a vibrating link, one end of which is jointed to the connecting rod while the other end is constrained to move in a horizontal or vertical direction by the action of a radius rod. This motion is horizontal if the engine is a vertical engine, or vertical if the engine is horizontal. One end of another rod works on a pin in the vibrating link and near the other end of this rod is a fulcrum carried by a pin attached to sliding blocks on each side, working in sectors, which are carried by the reversing shaft. Motion is communicated to the valve

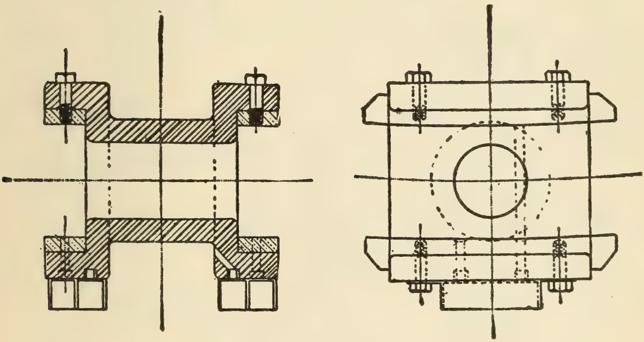


Fig. 132.

Fig. 132 shows details of the construction of the link-block for a double-barred link.

from a point in the last-mentioned rod beyond the fulcrum carried by the sectors attached to the reversing shaft.

Ques. 514.—How is the forward or backward movement of the engine effected with the Joy valve-gear?

Ans.—By inclining the sector on one or the other side of the center line of the reversing shaft and the point of cut-off and consequently the amount of expansion depends upon the amount of the inclination, the central position being mid-gear. The reversing arm moves these sectors to the required position. In large marine engines the reversing mechanism is operated by a small starting engine. On locomotives and small engines it is operated by hand.

Ques. 515.—Mention one of the advantages possessed by the Joy valve-gear, over the double eccentric and link motion.

Ans.—By this gear a constant lead is secured for all linked-up positions.

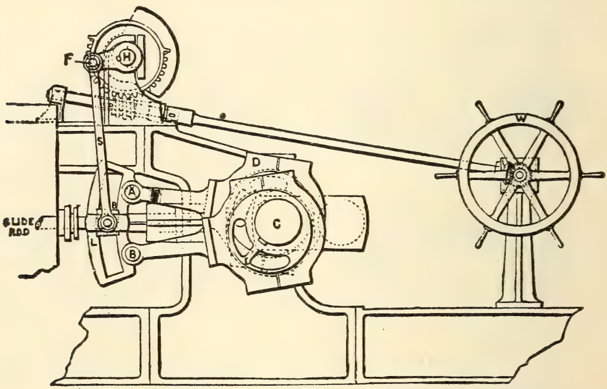


FIG. 133. STEVENSON LINK MOTION FOR MARINE ENGINE.

On the crank-shaft C there are keyed two eccentrics, one in the position to give ahead motion and the other in the position for astern motion. The eccentric rods are of equal length, and their ends are attached by working joints to the opposite ends of a curved link, L.

Ques. 516.—Is the Joy valve-gear much in use?

Ans.—It is applied to a large number of marine engines and locomotives.

Ques. 517.—How is the lifting valve-gear of the marine beam engine actuated?

Ans.—By curved cams keyed to a transverse shaft Four cams are fitted, two for steam and two for exhaust

Ques. 518.—How is the oscillating movement imparted to the transverse shaft?

Ans.—From rocker-arms, one on each end of the

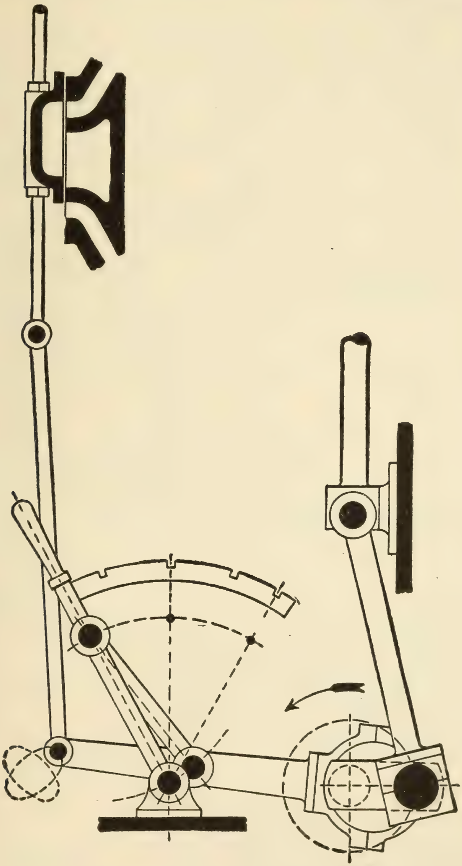


FIG. 134.

The Marshall Valve-gear. The single eccentric, turning with the **crank,** works the valve through a pivoted arm. The movement of the engine may be stopped or reversed by sliding the hand-lever on the notched quadrant. **The** loop paths show the movement of the valve rod-pin and also of the valve **in vertical** directions for ahead or backing motion.

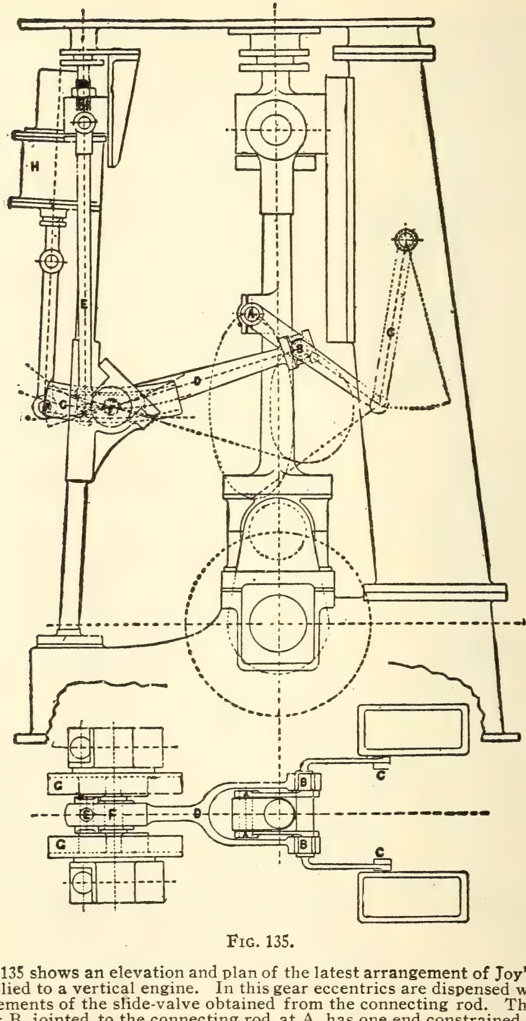


FIG. 135.

Fig. 135 shows an elevation and plan of the latest arrangement of Joy's valve-gear applied to a vertical engine. In this gear eccentrics are dispensed with, and the movements of the slide-valve obtained from the connecting rod. The vibrating link B, jointed to the connecting rod at A, has one end constrained to move horizontally by the action of the radius rod C. One end of another rod, D, works on a pin in the vibrating link B; near the other end is a fulcrum carried by a pin F, attached to sliding blocks on each side working in sectors G, which are carried by the reversing shaft, the center line of the sector passing through the center of the reversing shaft. From D the motion is communicated to the slide-valve rod by means of the link E, attached to a point K in the rod D beyond the fulcrum F.

The forward or backward movement of the engine is governed by inclining the sector on one or the other side of the horizontal center line, and the amount of expansion depends on the amount of the inclination, the exactly central or horizontal position being 'mid-gear.' The reversing arm F R moves these sectors to the required position, and its extremity R is connected to the starting engine H. The paths of the point A in the connecting rod, and also of the point B in the vibrating link, as the engine revolves, are indicated by dotted lines, as are also the extreme positions of the sector center lines for ahead and astern working respectively. The gear as drawn is in the stop position. By this gear a constant lead is secured for all linked-up positions, since when the piston is at the top or bottom of the stroke the pin F co-incides with the center of the reversing shaft, so that in this position any movement of the sectors does not affect the position of the slide-valve. The up and down motion of the point B therefore gives a constant movement of the valve equal to the *lap plus the lead*, while the horizontal motion sliding the block to and fro in the sectors adds the amount required for steam opening, this amount increasing with the angle of the sector to the horizontal.

transverse shaft, the pins of which are engaged by hooks in the eccentric-rods.

Ques. 519.—How are the poppet-valves of the Western river boat actuated?

Ans.—By cams very similar to those on the beam engine.

Ques. 520.—Describe the construction and action of a double-ported slide-valve.

Ans.—A double-ported slide-valve acts in a manner similar to a single-ported valve in the admission of steam, but in addition there is what is practically an inner valve, to which steam is admitted through passages formed in the body of the valve. There are also two inner ports in addition to the two ports at the ends of the cylinder, and these inner ports or passages also lead to and are in connection with the end ports.

Ques. 521.—What is the object in using a double-ported valve?

Ans.—To reduce the travel of the valve, which in large engines would be too great with a single-ported valve.

Ques. 522.—Are treble-ported valves used to any large extent?

Ans.—They are, on large marine engines, their action being on the same general principles as the double-ported slide-valve.

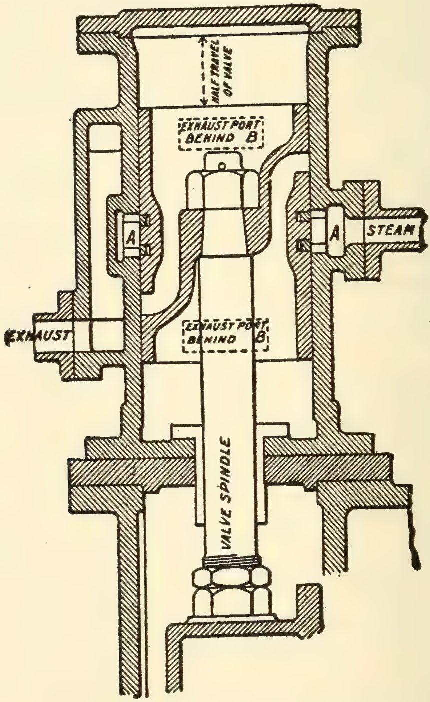


FIG. 136. JOY'S ASSISTANT CYLINDER.

This consists of a small cylinder and steam-piston attached to the valve-spindle. The cylinder has a central inlet for steam, A, and two exhaust-ports, B, one for each end, leading to a common exhaust-pipe, and the piston is so constructed that by its motion the operations of steam admission, cut-off, release and compression are performed on each side of the piston. The apparatus is, therefore, a small engine which exercises a force on the valve to move it up or down, and cushions steam at each end to absorb the momentum forces. These assistant cylinders give diagrams similar to that of an ordinary engine; they exert from 15 to 25 I. H. P. each for the sizes fitted in marine engines, and the amount of power developed can be adjusted by means of a valve on the steam-pipe. If the main valve be linked in, the assistant cylinder is also automatically similarly affected.

Ques. 523.—How is the pressure of the steam on the back of a large, flat slide-valve lessened and relieved?

Ans.—By relief packing rings.

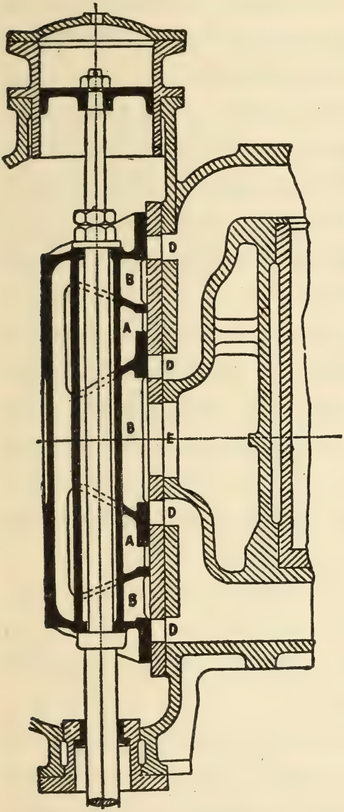


FIG. 137. DOUBLE-PORTED VALVE.

Ques. 524.—How are relief packing rings fitted?

Ans.—They are sometimes fitted on the back of the valve, but are generally fitted on the valve-chest cover, and are pressed out by springs so as to work steam-tight on a planed surface, either on the back of the valve or, on the inside of the cover, thus reducing the area on which the steam-pressure can act. The space inside the packing ring is connected to the condensor or the receiver of the succeeding engine.

Ques. 525.—Do relief rings work in a satisfactory manner?

Ans.—They do not, as a general thing, being troublesome to make efficient, and they also are difficult of adjustment.

Ques. 526.—What form of slide-valve has been found to give good satisfaction, especially on the high and intermediate cylinders of large marine engines?

Ans.—The piston slide-valve, consisting of two pistons connected together and working steam-tight in cylindrical chambers that contain the steam-ports. The face of each of the pistons corresponds to the face of the single-ported slide-valve, and performs the same functions.

Ques 527.—What means are provided in large vertical engines for preventing the weight of the slide-valve, rod, and link gear from bearing upon the eccentric?

Ans.—Balancing pistons, working in small steam-cylinders in the top end of the valve-casing.

Ques. 528.—What is meant by setting the valve, or valves of an engine?

Ans.—The adjustment and securing of the slide-valve in its proper position on the rod so as to secure the correct distribution of the steam in the cylinder. This also includes the fixing of the eccentric in its correct position on the shaft.

Ques. 529.—What is the first, or one of the first, moves in valve-setting?

Ans.—The rods and gear are first coupled together, and the crank is placed on the dead center.

Ques. 530.—What is the meaning of the expression dead center?

Ans.—An engine is on the dead center when the crank is in line with the piston-rod, that is, when the centers of the crank-shaft, crank-pin, and cross-head pin are exactly in line, so that the pressure of the steam on the piston exerts no turning moment on the shaft, but produces only direct thrust, subjecting the shaft to bending action only.

Ques. 531.—With the engine on the dead center and the rods and valve-gear all coupled up, what is the next move in valve-setting?

Ans.—The slide-valve, by means of screws and nuts on the valve-rod, is fixed in the proper position to give the required lead for the corresponding end of the cylinder. The shaft is then turned around until the crank is on the opposite dead point and the lead of the valve for that end of the cylinder is measured. If the amounts of lead at the opposite ends are different, the position of the slide-valve on the rod should be adjusted by means of the nuts and screws, until the leads are either equal, or differ by the desired amount. The valve should then be permanently secured on the rod, so that its position may not alter. This is called equalizing the lead.

Ques. 532.—If, after having gotten the lead equalized, it is found that there is too much or too little, how may it be decreased, or increased without altering the position of the valve on the rod?

Ans.—To decrease the lead, reduce the angular advance of the eccentric, and to increase the lead it is necessary to increase the angular advance.

Ques. 533.—What is the rule generally observed regarding the lead on large vertical engines?

Ans.—In vertical engines, owing to the weight of the moving parts, the lead on the lower end is generally made slightly greater than the lead on the upper end, and more exhaust lap is allowed. In such cases the valve is set on the rod to give the required difference between the two leads. Then, if the lead be too great or too small at both ends, the required change may be made by moving the eccentric ahead or back on the shaft.

Ques. 534.—Is the position of the eccentric on the shaft necessarily fixed on all types of engines?

Ans.—It is not. Many high-class stationary engines

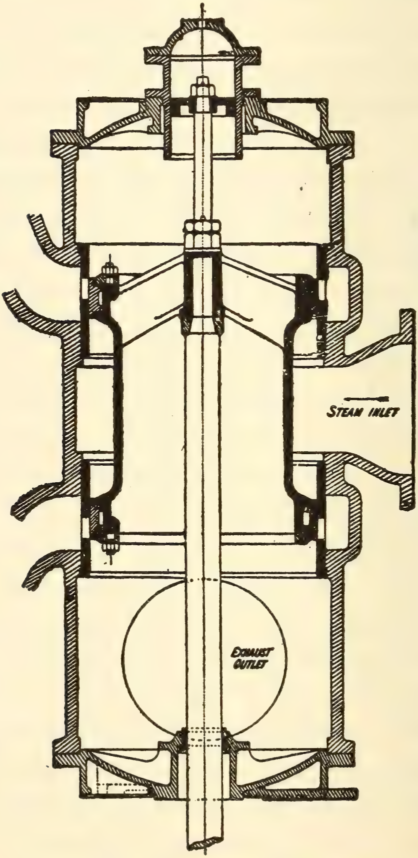


Fig. 138. Piston Valve.

are fitted with isochronol or inertia governors, which control the position of the eccentric and vary the point of cut-off according as the load on the engine is light or heavy, thus maintaining a regular speed.

Ques. 535.—What types of valves are used with isochronol governors?

Ans.—Slide-valves of various patterns; box-valves, in which the steam passes through the valve; piston valves, in which the steam either passes through or around the ends of the valve.

Ques. 536.—In all types of reciprocating engines the same factors affecting the distribution of the steam are present. What are they?

Ans.—Outside lap, affecting admission and cut-off, and inside lap, affecting release and compression.

Ques. 537.—How are these factors distributed in the four-valve type of engine?

Ans.—They are distributed among the four valves, each valve performing its own particular function in the distribution of the steam for the end of the cylinder to which it is attached.

Ques. 538.—What advantage is there connected with setting the valves of a four-valve engine, as compared with a single valve?

Ans.—Each valve may be adjusted to a certain degree independently of the others, thus, for instance, the steam-valves of a Corliss engine may be adjusted to cut off the steam at any point from the beginning up to one-half the stroke, without in the least affecting the release or compression, because these latter events are controlled by the exhaust-valves.

Ques. 539.—What is the first requisite in setting the valves of a Corliss engine?

Ans.—To place the crank on the dead center.

Ques. 540.—What is the next move?

Ans.—To adjust the length of the hook-rod, if it is adjustable; if not, then the length of the eccentric-rod, so that the wrist-plate will vibrate equal distances each

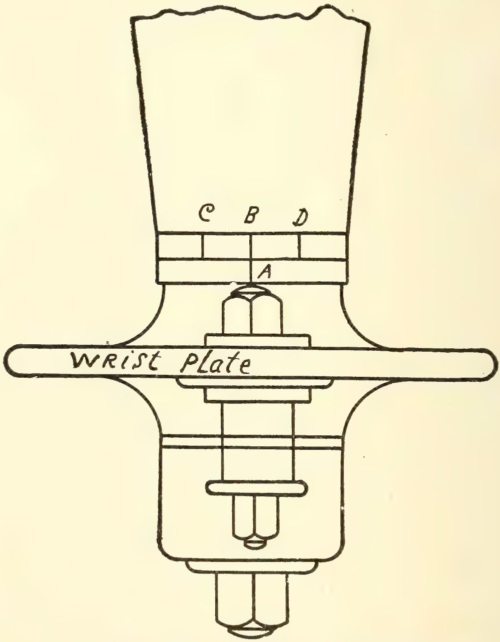


FIG. 139. WRIST PLATE OF CORLISS ENGINE.

way from its central position, which is marked on top of the hub.

Ques. 541.—How should the rocker-arm, that carries the eccentric-rod, and hook-rod be adjusted?

Ans.—The length of the eccentric-rod should be such that the rocker-arm will vibrate equal distances each way from a vertical position.

Ques. 542.—How may the vibration of the wrist-plate and rocker-arm be tested?

Ans.—By connecting the eccentric-rod and the hook-rod in their proper places, and turning the loose eccentric around on the shaft in the direction the engine is to run.

Ques. 543.—Having gotten these important adjustments correctly made, what is the next step in setting Corliss valves?

Ans.—Remove the back bonnets from the four valve

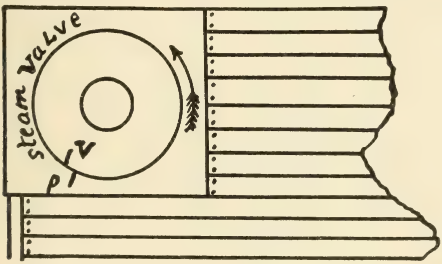


FIG. 140. STEAM-VALVE OF CORLISS ENGINE.

chests, and while neither the working edges of the valves nor the ports can be seen, yet certain marks will be found on the ends of the valves and corresponding marks on the faces of the chests, which serve as a guide in setting the valves.

Ques. 544.—Having removed the bonnets and found the marks, what is to be done next?

Ans.—Temporarily secure the wrist-plate in its central position by tightening one of the set-screws on the eccentric. Then connect the valve-rods to the wrist-plate and to the small crank-arms attached to the ends of the valves, adjusting their lengths so that the steam-valves will have from ¼ to $\frac{9}{16}$ inch lap, and the exhaust valves from $\frac{1}{32}$ to $\frac{3}{16}$ inch opening.

Ques. 545.—In adjusting the steam-valves, what particular detail should be carefully noted?

Ans.—The direction in which the valves turn to open should be noted. In most Corliss engines the arm of the small crank to which the valve-rod is connected, extends

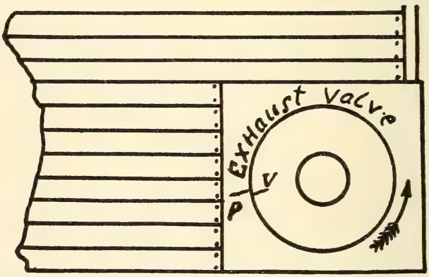


FIG. 141. EXHAUST-VALVE OF CORLISS ENGINE.

downwards from the valve-stem. This will cause the valve to move towards the wrist-plate in opening.

Ques. 546.—After the valve-rods have been properly adjusted as to length, what is the next move?

Ans.—Place the engine on the dead center—either center will do—and move the eccentric around on the shaft in the direction the engine is to run, until the eccentric is far enough ahead of the crank to allow the steam-valve for that end of the cylinder the proper amount of lead opening, which will vary according to the size of the engine. Then tighten the eccentric set screws and turn the engine around to the opposite center and note whether the lead is the same on both ends.

Ques. 547.—In case there is a difference in the lead for the two ends, how may it generally be equalized?

Ans.—By slightly altering the length of one of the valve-rods.

Ques. 548.—What is the next point to receive attention, in setting Corliss valves?

TABLE 8

LAP AND LEAD OF CORLISS VALVES

Size of Engine.	Lap of Steam Valve.	Lead Opening of Steam Valve.	Lead Opening of Exhaust Valve.
12 inches	1/4 inch	1/32 inch	1/32 inch
14 "	5/16 "	1/32 "	1/32 "
16 "	5/16 "	1/16 "	1/32 "
18 "	3/8 "	1/16 "	1/16 "
20 "	3/8 "	1/16 "	1/16 "
22 "	3/8 "	1/16 "	1/16 "
24 "	7/16 "	3/32 "	3/32 "
26 "	7/16 "	3/32 "	3/32 "
28 "	7/16 "	3/32 "	3/32 "
30 "	1/2 "	3/32 "	1/8 "
32 "	1/2 "	3/32 "	1/8 "
34 "	1/2 "	1/8 "	1/8 "
36 "	1/2 "	1/8 "	1/8 "
38 "	9/16 "	1/8 "	3/16 "
40 "	9/16 "	1/8 "	3/16 "
42 "	9/16 "	1/8 "	3/16 "

Ans.—The adjustment of the lengths of the rods extending from the governor to the releasing mechanism, so that the valves will cut off at equal points in the stroke.

Ques. 549.—How is this adjustment accomplished?

Ans.—By raising the hook-rod clear of the wrist-plate pin and with the bar provided for the purpose, move the wrist-plate to either one of its extreme positions, as shown by the marks on the hub, and, holding it in this position, adjust the length of the governor-rod for that steam-valve (which will then be wide open) so that the boss or roller which trips the releasing mechanism is just in contact, or within $\frac{1}{32}$ inch of it. Then move the wrist-plate to the other extreme of its travel and adjust the length of the other rod in the same manner.

Ques. 550.—How may the accuracy of this adjustment be tested?

Ans.—Raise the governor-balls to their medium position, or about where they would be when the engine is running at its normal speed, and block them there. Then having again connected the hook-rod to the wrist-plate, turn the engine around in the direction in which it is to run, and when the valve is released by the trip, measure the distance upon the guide that the cross-head has traveled from the end of the stroke. Now continue to turn the engine in the same direction until the other valve is released, and measure the distance that the cross-head has traveled from the opposite end of the stroke, and if these two distances are the same, the cut-off is equalized. If there is a difference, lengthen one rod and shorten the other until the point of cut-off is the same for both ends. The lengths of the dash-pot rods should also be adjusted, so that when the plunger is at the bottom of the dash-pot the valve-lever will engage the hook. The lock-nuts on all rods should then be securely tightened.

CHAPTER VII

CONDENSERS—AIR-PUMPS—SEA-WATER

Ques. 551.—What is the average composition of sea-water?

Ans.—Sea-water contains about $\frac{1}{32}$ part of its weight of solid matter, of which common salt (sodic chloride) is the principle constituent. The average composition of the solid matter in sea-water may be taken as follows:

Sodic chloride, or common salt	76	per cent
Magnesic chloride	10	"
Calcic sulphate, or gypsum	5	"
Magnesic sulphate	6	"
Carbonate of lime, and organic matter	3	"

Ques. 552.—Does the common salt in sea-water cause much trouble for the marine engineer?

Ans.—It does not, for the reason that it remains soluble in water at all temperatures, and there is no deposit of salt, except under extreme circumstances.

Ques. 553.—What is the principal scale-forming ingredient in sea-water?

Ans.—Sulphate of lime, or calcic sulphate. Deposit is also formed by sulphate of magnesia, although it is less objectionable than the lime deposit.

Ques. 554.—At what temperature does the sulphate of lime become insoluble in water and form a deposit on the boiler plates?

Ans.—At a temperature of 280 degrees to 295 degrees

Fahrenheit, corresponding to a pressure of 35 to 45 pounds pressure of steam by the gauge. As the temperature of the water rises, the other sulphates become insoluble, and at 350 degrees Fahrenheit, or 120 pounds gauge-pressure, sea-water is incapable of holding any sulphates in solution.

Ques. 555.—What other cause, besides a high temperature, tends to precipitate these salts?

Ans.—Increase of density, caused by evaporation of the water, even if the temperature remains about 212 degrees Fahrenheit. Sulphate of calcium is thus deposited at a density of $\frac{3}{32}$. Common salt does not crystallize out until a density of about $\frac{8}{32}$ is reached.

Ques. 556.—When was it possible to use sea-water for feeding boilers?

Ans.—In the early days of marine engineering, when a low-pressure (35 to 45 pounds) was carried, and the jet condenser was used, in which the steam was exhausted into the condensing chamber, where it came into actual contact with and was condensed by a jet of cold sea-water. The feed-water for the boilers was drawn from this mixture of sea-water and condensed steam, consequently a large quantity of sea-water was sent into the boilers, but as the temperature was low and the density was not allowed to exceed $\frac{2}{32}$, the salts were held in solution fairly well.

Ques. 557.—How was the increase of density prevented?

Ans.—By blowing off a portion of the denser boiler-water at stated times, and making up the loss by admitting a larger quantity of salt water. This was termed "brining the boiler."

Ques. 558.—What led to the introduction of the surface condenser?

Ans.—With the advent of high pressures, it was found impossible to prevent the deposit of scale, and all of its attendant evils. It was therefore found necessary to condense the exhaust steam without bringing it into actual contact with the condensing water, hence the surface condenser was designed.

Ques. 559.—Mention two of the principal advantages gained by the use of the surface condenser.

Ans.—First, by its use fresh feed-water is obtained for the boilers; second, the condition of the condensing water is of no importance, as regards the feed-water so that, no matter whether it is salt, muddy, acid, or otherwise impure, pure water is always obtained for the boilers, provided the condenser is maintained in good condition and no leakage is allowed to occur.

Ques. 560.—What is the meaning of the word vacuum?

Ans.—That condition existing within a closed vessel during the absence of all pressure, including atmospheric pressure.

Ques. 561.—How is a vacuum measured?

Ans.—It is measured in inches of a column of mercury contained within a glass tube a little more than 30 inches in height. having its lower end open and immersed in a small open vessel filled with mercury. The upper end of the glass tube is connected with the vessel in which the vacuum is to be produced. When no vacuum exists, the mercury will leave the tube and fill the lower vessel. When a vacuum is maintained within the condenser, or other vessel, the mercury will rise in the glass tube to a height corresponding to the degree of vacuum. If the mercury rises to a height of 30 inches it indicates a perfect vacuum, which means the absence of all pressure within the vessel, but this condition is never realized in practice, the nearest approach to it being about 28 inches.

Ques. 562.—Is the mercurial vacuum-gauge used in every-day practice?

Ans.—For purposes of convenience it is not generally used, it having been replaced by the Bourdon Spring-gauge, although the mercury-gauge is used for testing.

Ques. 563.—What is the advantage, from a purely economic standpoint, in allowing the exhaust steam to pass into a condenser in which a vacuum is maintained rather than to allow it to exhaust into the open air?

Ans.—In a non-condensing engine, that is, an engine in which the exhaust steam passes into the open air, the pressure of the atmosphere, amounting to 14.7 pounds per square inch at sea-level, is constantly in resistance to the motion of the piston. Therefore the exhaust or terminal pressure can not fall below the atmospheric pressure and is generally from 2 to 5 pounds above it, caused by the resistance of bends, and turns in the exhaust pipe, or other causes which tend to retard the free passage of the steam. On the other hand, if the steam were allowed to exhaust into a condenser in which a vacuum of 25 inches is being maintained, the terminal pressure or back pressure in resistance to the forward motion of the piston would be but 2.5 pounds, and if a vacuum of 28 inches existed in the condenser there would be practically no back pressure, thus making available for useful work the 14.7 pounds of steam which in the non-condensing engine was required to overcome the resistance of the atmospheric pressure.

Ques. 564.—Is it proper, then, to consider the vacuum in a condenser as power?

Ans.—The vacuum can not be considered as power at all. It occupies the anomalous position of increasing, by its presence, the capacity of the engine for doing work.

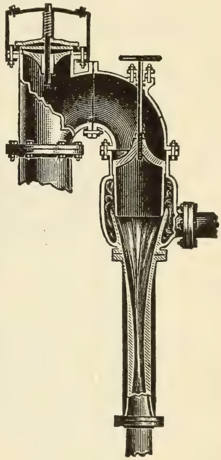


FIG. 142.
SIPHON CONDENSER.

Ques. 565.—How is the vacuum in a condenser usually maintained?

Ans.—By a pump called an air-pump, although a partial vacuum can be produced by the mere condensation of the exhaust steam as it enters the condenser, by allowing a spray of cold water to strike it. The steam when it first enters the condenser drives out the air and the vessel is filled with steam at a low pressure, which, when condensed, occupies about 1,600 times less space than it did before being condensed, hence a partial vacuum is produced. The action of the siphon injector is based upon this principle.

Ques. 566.—Describe the construction and action of the siphon condenser.

Ans.—The siphon condenser is a form of jet condenser in which no air-pump is used. In this type of condenser the supply of condensing water is drawn from outside pressure, either from an overhead tank, or other source,

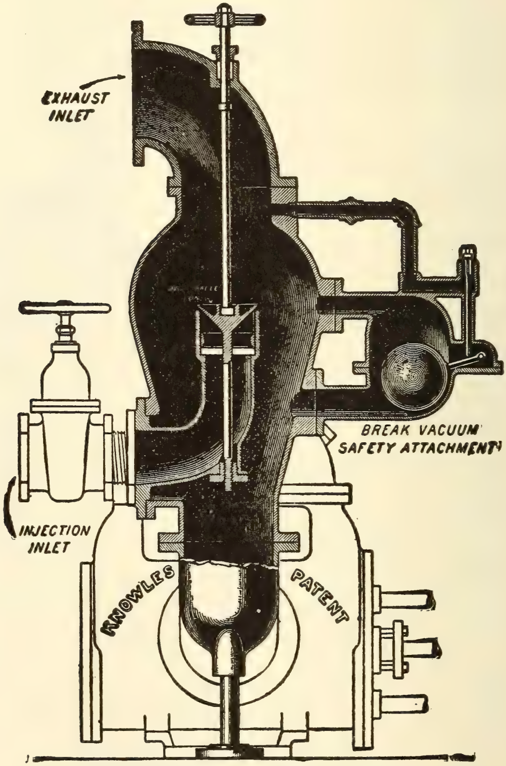


FIG. 143. KNOWLES JET CONDENSER.

and passing into an annular enlargement of the exhaust-pipe, is discharged downwards in the form of a cylindrical sheet of water, into a nozzle which gradually contracts. The exhaust steam, entering at the same time, is condensed and the contracting neck of the cone-shaped nozzle gradually brings the water to a solid jet and it rushes through the nozzle with a velocity sufficient to create a vacuum. This type of condenser can only be used where the discharge pipe has a perfectly free outlet.

Ques. 567.—Describe in general terms the construction and action of the jet condenser.

Ans.—The jet condenser is usually a vertical, cylindri-

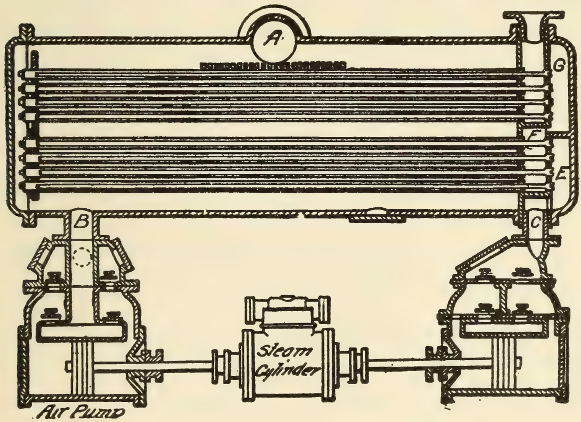


FIG. 144. SECTIONAL VIEW OF A SURFACE CONDENSER AND INDEPENDENT AIR AND CIRCULATING PUMPS.

cal, cast-iron vessel, made air-tight, and which receives the exhaust steam from the low-pressure cylinder. In modern plants, condenser-shells are often made of sheet steel in cylindrical shape, reenforced with stiffening rings. The exhaust steam enters at the top and the condensing water enters usually at the side, flowing in through the spraying nozzle, and, discharging through a large number of small holes, comes in contact with the steam in the form of spray, thus producing a quick condensation while falling to the bottom of the condenser, to be drawn off by the air-pump. A cock or valve is fitted in the injection pipe, for the purpose of regulating the supply of cooling water.

Ques. 568.—Why is an air-pump a necessary part of a reliable jet-condensing apparatus?

Ans.—The mixture of condensing water and condensed steam must be pumped away constantly, also the condensing water always contains a certain volume of air in solution, which may be liberated, either by boiling it or by reducing the pressure to which it is subjected. This air is liberated in the condenser, and if it is not pumped away regularly, it is liable to accumulate and spoil the vacuum.

Ques. 569.—How may the dimensions of a single-acting air-pump for a given sized engine be determined?

Ans.—In the solution of this problem, two factors must be considered: First, the total volume of the low-pressure cylinder; second, the density of the exhaust steam. The volume of the air-pump cylinder is then found by the following rule: Multiply the volume of the low-pressure cylinder in cubic feet by 3.5, and divide the product by the number of cubic feet contained in 1 pound weight of exhaust steam at the pressure at which it enters the condenser. This rule applies only to jet condensers.

Ques. 570.—Describe the construction and action of the surface condenser.

Ans.—The surface condenser. like the jet condenser.

is an air-tight iron or steel vessel, either cylindrical or rectangular in shape, but, unlike the jet condenser, it is fitted with a large number of brass or copper tubes of small diameter (generally about ⅝ inches), through which cold water is forced by a pump called a circulating

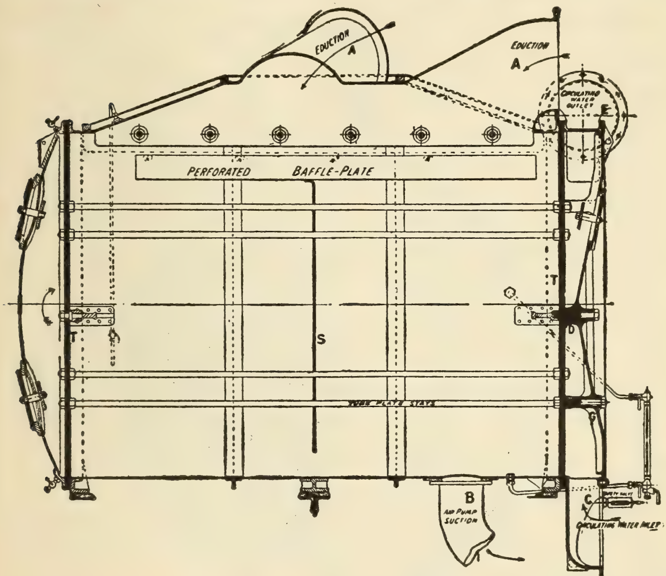


FIG. 145.

Side view of large cylindrical horizontal surface-condenser having two exhaust-inlets. The tubes are not shown. The steam enters at the orifices marked A, and is withdrawn, when condensed, through the orifice B by the air-pump. The circulating water enters at C, and is confined by the diaphragm D to the lower half of the tubes, and, having traversed these tubes, it returns through the upper half of the tubes, being finally discharged to the sea through the pipe E. T. T. are the tube-plates near the ends of the condenser casing.

pump. A vacuum is maintained in the body of the condenser by the air-pump, and the steam exhausting into this vacuum is condensed by coming in contact with the cool surface of the tubes. Or, as is often the case, the exhaust steam passes through the tubes instead of around them, and the cooling water is forced into and through the body of the condenser, the vacuum in this case being maintained in the tubes. The tubes may be placed either vertical or horizontal. When the steam is passed through the tubes, they are generally placed vertical, while, on the

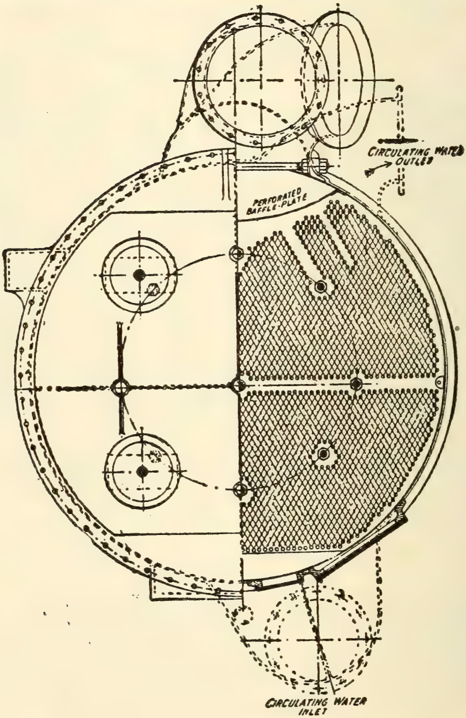


FIG. 146. END SECTIONAL VIEW OF CYLINDRICAL HORIZONTAL SURFACE CONDENSER, SHOWING A PORTION OF THE TUBES.

other hand, if the water circulates through them they are placed horizontal. The system of causing the water to circulate through the tubes, the steam surrounding them, is the more general.

Ques. 571.—How are the tubes generally arranged in a surface condenser?

Ans.—They are arranged in one or more systems, so that the condensing water passes through the condenser, usually twice, the coldest water entering at the bottom and coming in contact with the steam at its lowest temperature, and the warmest water at the top meeting the hottest steam. The exhaust steam enters at the top and after passing over the cold tubes is removed in the form of water, by the air-pump. The steam is directed in its downward course by baffle-plates, thus securing complete utilization of the cooling surface. A space is provided at the bottom of the condenser for the accumulation of the water of condensation below the cooling surface. The condenser casing or shell for naval vessels is either cast in brass or else built up from composition sheets, in order to save weight and prevent corrosion and galvanic action, which would be more liable to take place with an iron or steel shell.

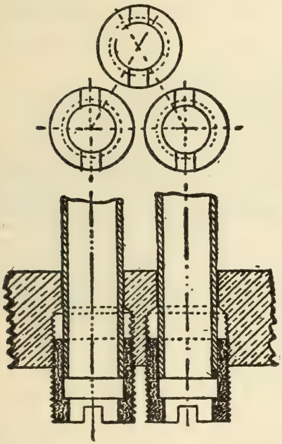


FIG. 147. DETAILS OF WICK AND GLAND PACKING FOR THE TUBES OF A SURFACE CONDENSER.

Ques. 572.—How are the tubes secured in their places?

Ans.—Brass or composition tube-plates are placed in the shell, near each end, sufficient space being left between the outside cover-plates and the tube-plates ...

the circulation of the cooling water. Into these plates, which are thick enough to furnish a good bearing for the tubes, the ends of the tubes are fitted and packed thoroughly tight, sometimes with a wood packing, sometimes with small screwed stuffing boxes with glands and followers, which tighten upon wick packing. The wood packing consists of a small soft wooden sleeve, which is forced into the small hole over the tube end in a dry state, and after becoming wet it swells and clamps the

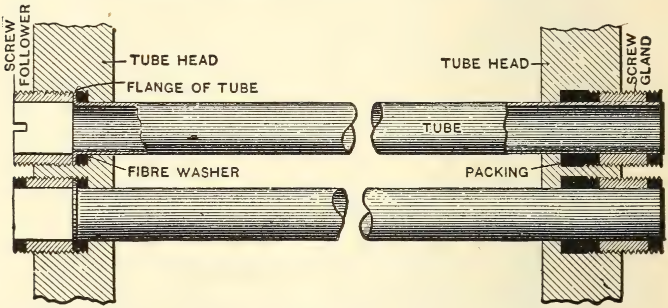


FIG. 148. METHOD OF PACKING TUBES OF A WORTHINGTON SURFACE CONDENSER.

One end of each tube is flanged and rigidly held in the tube head by means of a screw follower; the other end of the tube passes through an adjustable gland, which permits of free movement of the tube during expansion and contraction. This method of securing rigidly one end of the tube reduces the number of glands or stuffing-boxes to just one-half the number found in ordinary condensers. The glands can be readily removed and the packing replaced if it becomes leaky from long use.

tube, thus forming and preserving a tight joint so long as it is kept wet.

Ques. 573.—Which kind of packing is the most reliable for condenser tubes?

Ans.—The gland and wick, for the reason that it always remains tight, while on the other hand the wood packing will shrink and become loose if the condenser is out of service for a time.

Ques. 574.—What are the usual dimensions of the tubes of surface condensers?

Ans.—They are generally about $\frac{5}{8}$ inches in diameter, are made of brass, about $\frac{1}{20}$ of an inch thick, of a composition consisting of not less than 70 per cent of copper and not less than 1 per cent of tin, the remainder being zinc, the small quantity of tin being added to prevent galvanic action. The tubes are pitched not less than $\frac{31}{32}$

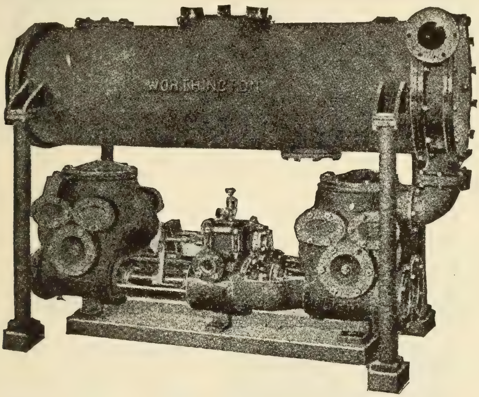


FIG. 149. WORTHINGTON SURFACE CONDENSER, WITH AIR AND CIRCULATING PUMP.

inches apart in order to allow sufficient material for the gland. They are zigzagged so as to occupy as small a volume as possible. Condenser tubes vary considerably in length, depending upon the size of the condenser, the usual length in large condensers being from 8 to 10 feet, while in some very large condensers the tubes are 14 or 15 feet in length. The tube-plates are about 1 inch thick, in order to provide sufficient depth for the gland and packing for the tubes.

Ques. 575.—What type of air-pump is generally used?

Ans.—The vertical single-acting air-pump has been

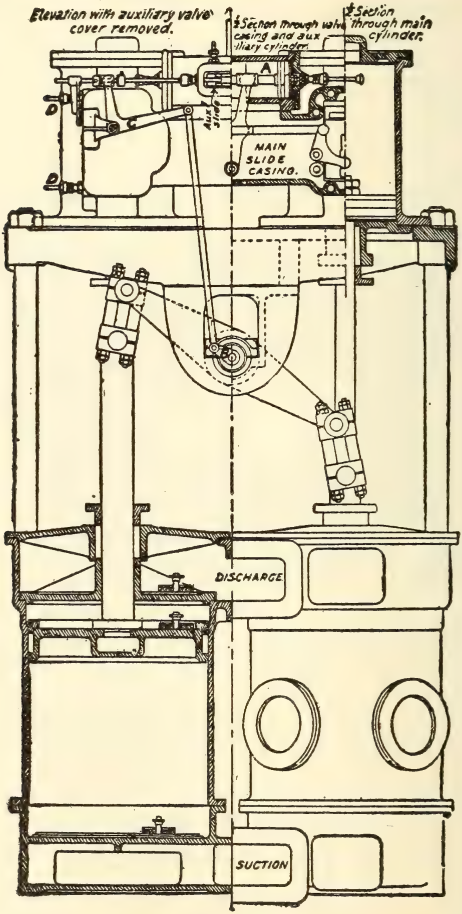


Fig. 150.

Section of Blake independent air-pump, fitted in many vessels, **including** several U. S. warships. There are two steam-cylinders and two single acting vertical air-pumps of the usual type. It works at slow speed and gives excellent results.

found to be the most efficient. In vertical engines the air-pump generally receives its motion from the cross-head of the engine, through the medium of a short walking-beam. There are, however, a great many engines fitted up with an independent air-pump and condenser, in which the air-pump is simply an ordinary double-acting steam-pump, having its own steam-cylinder, and may be operated independently of the engine, which is a great advantage, as there is not so much danger of the water from the condenser backing up into the cylinder in case of a sudden shut-down of the engine, which is liable to occur with a jet condenser.

Ques. 576.—Describe the parts of the vertical single-acting air-pump.

Ans.—It consists of the barrel, or cylinder, the suction-channel way at the bottom, the cover, with delivery-channel way and the hot well, the whole being made air-tight. The moving parts are the bucket, or piston, with its valves, the foot-valves and the head-valves.

Ques. 577.—Describe the arrangement of the air-pump in connection with the condenser.

Ans.—The suction-channel way is in connection with the lowest part of the condenser, in order that the water can be readily and completely removed from the condenser. It usually supports the foot-valves and all joints and valve-seat division-plates require to be fitted air-tight. The barrel is generally connected to a flange or facing of the suction-channel way, and it is constructed of composition or cast iron with a composition sleeve pressed in and bored out truly cylindrical, in order to form a smooth and durable working-cylinder for the bucket or piston, which is kept tight against the barrel, either by water-

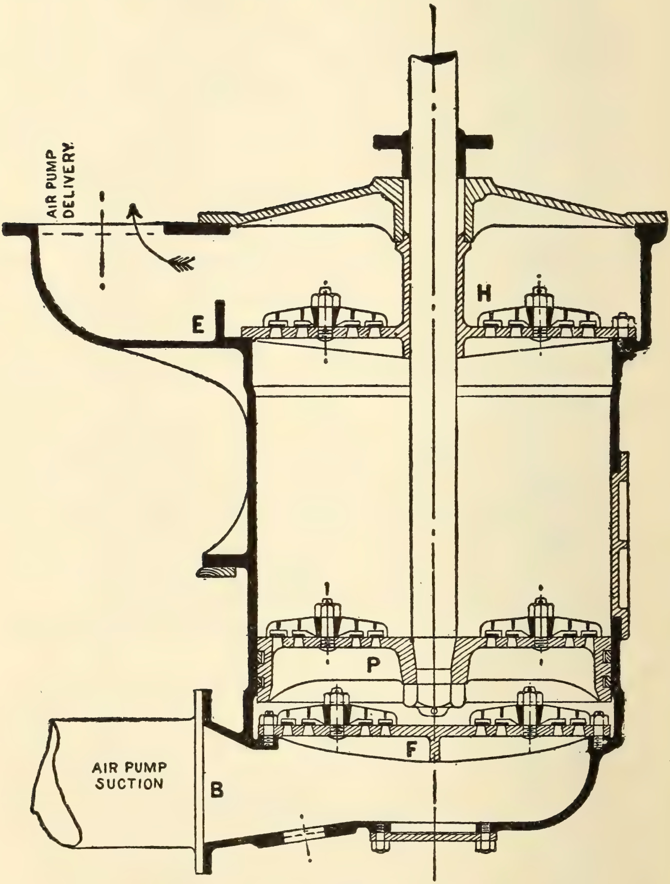


FIG. 151. SECTIONAL VIEW OF VERTICAL SINGLE ACTING AIR-PUMP.

grooves, or, more commonly, by packing, consisting of one or more split metallic packing rings. Sometimes fibrous soft packing, held in place and compressed by a follower ring, is used. A stuffing box is provided in the top cover, through which the piston-rod or trunk, as the case may be, has water-tight passage.

Ques. 578.—What kind of valves are used in air-pumps?

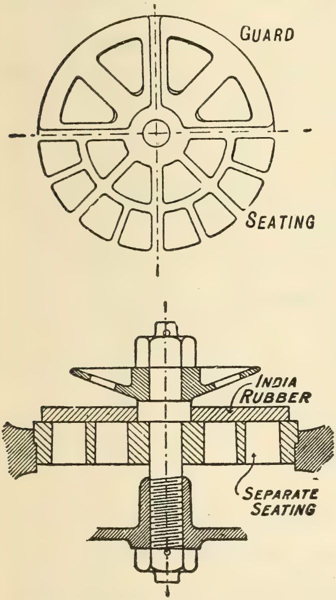


FIG. 152.
DETAILS OF RUBBER VALVE, VALVE-SEAT AND GUARD FOR AIR-PUMP.

Ans.—Rubber valves, either of hard or soft rubber, but since the introduction of mineral oil as a lubricant for the engine cylinders, it has been found that the ordinary rubber valves deteriorate under its influence, and metal valves are now largely coming into use, especially in the navies. They may be made of thin sheet metal, are light, and not affected by grease, if cleaned occasionally, and will last a long time. In form, air-pump valves are either single rectangular flaps that lift on one edge against a curved metallic guard, or else there are a number of smaller circular valves, lifting bodily from their seats, and secured to the seat by a central stud, which also carries a metal guard above the valve. The valve-seats are usually independent, being constructed of composition metal, and pressed into their places. They are divided into small spaces by gratings, so that the unsupported area of the valve may not be too large. The bucket carries the bucket-valves, which allow the air and water to pass through to the delivery side. Air-pump valves are sometimes fitted with spiral springs of bronze wire on top, to secure quick closing. The flap valves are clamped to the seat, on the stationary edge, by their curved guards.

Ques. 579.—How is the bucket or piston of the air-pump actuated?

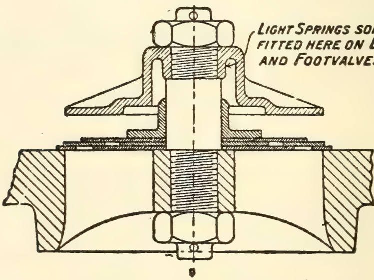


FIG. 153. SECTION OF METAL VALVE, VALVE-SEAT AND GUARD FOR AIR-PUMP.

Ans.—Either by a solid piston-rod, or by a hollow trunk, made entirely of composition, or covered by a composition sleeve. With the piston-rod type it is necessary to have a connecting rod and guides above the top cover of the air-pump, while the trunk type contains the connecting rod bearing in the trunk, near the bucket, and requires no extra guides.

Ques. 580.—What is the function of the hot well?

Ans.—It acts as a small reservoir, for the accumulation of the discharge-water from which the feed-pumps draw their supply. The later vessels in the English navy are fitted with "feed-tanks" in which the discharge from the air-pumps is allowed to accumulate, and from which the feed-pumps draw their supply of water for feeding the boilers. There is a feed-tank for each engine-room,

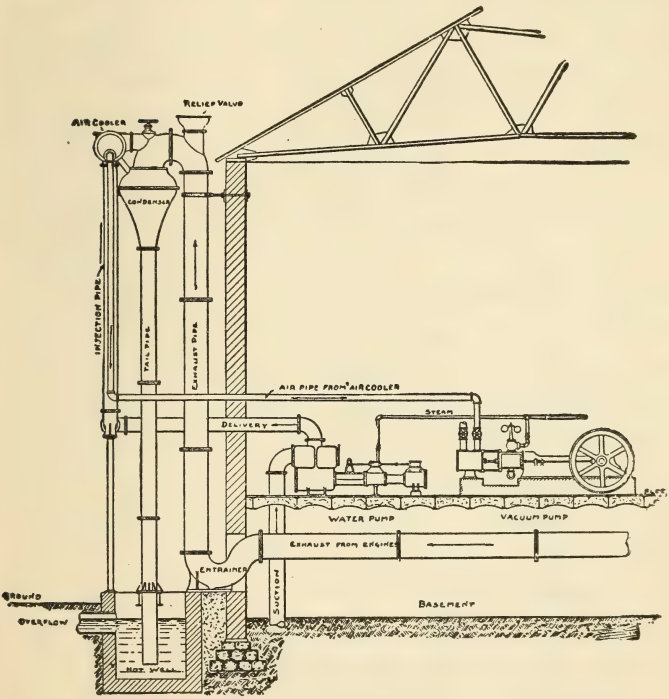


FIG. 154. WORTHINGTON CENTRAL CONDENSER FOR A LARGE STATIONARY PLANT, SHOWING PUMPS AND PIPING.

and they are connected by a pipe running between the two engine-rooms, fitted with a shut-off valve worked from either engine-room. These feed-tanks are fitted with glass water-gauges and zinc slabs.

Ques. 581.—What is the function of the circulating pump in connection with the surface condenser?

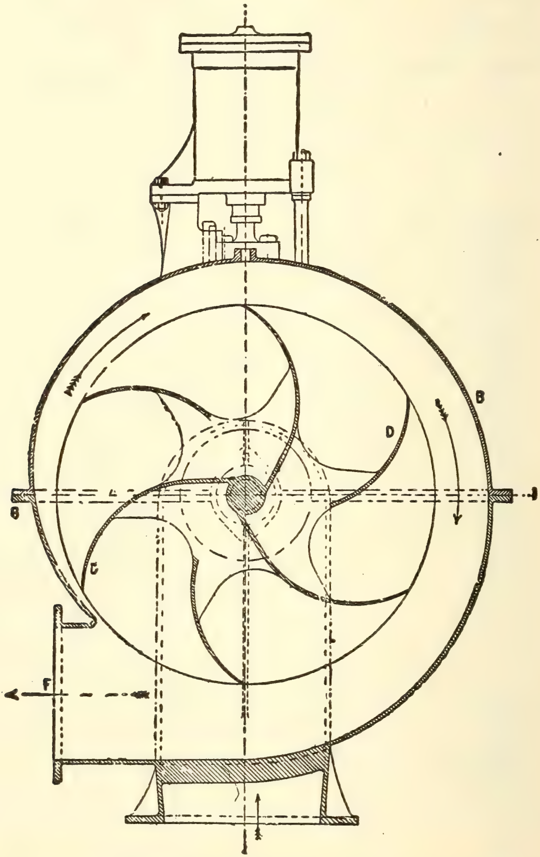


FIG. 155. TRANSVERSE SECTION OF A CENTRIFUGAL PUMP. B, CASING. D D, CURVED VANES.

Ans.—It either forces or draws the cooling water through the tubes or the body of the condenser.

Ques. 582.—What type of pump has been found to be best adapted to this work?

Ans.—The centrifugal pump worked by an independent auxiliary engine, for the reason that the pump works smoothly, there are no valves, and having a separate engine, it can be kept working and the condensers kept cool when the main engines are stopped, which is not the case with a pump that receives its motion from the main engines. Another great advantage possessed by the independent system is, that the speed may be regulated so as to supply the required quantity of water.

Ques. 583.—Describe the construction and action of the centrifugal circulating pump.

Ans.—The pump consists of an impeller wheel or fan revolving inside a casing. The impeller and casing are made of gun metal, and the spindle or shaft carrying the impeller is either cast of gun metal in one piece with the impeller, or formed separately of forged bronze and keyed to it. This spindle runs in lignum-vitae bearings and is lubricated with water. The impeller generally consists of a central web guiding the incoming water, with two side-plates that gradually approach each other as they near the circumference and between which runs a series of curved vanes. These vanes are curved away from the direction of rotation as they proceed from the boss to the circumference. The water enters the central part of the impeller through the inlet pipe and is thrown by the rapidly revolving vanes outwards and around into the casing which surrounds the circumference of the wheel. The casing is of gradually increasing area and leads to the delivery pipe, through which it is forced by the centrifugal action to the condenser, where, after traversing the tubes, it is discharged overboard. The casing is

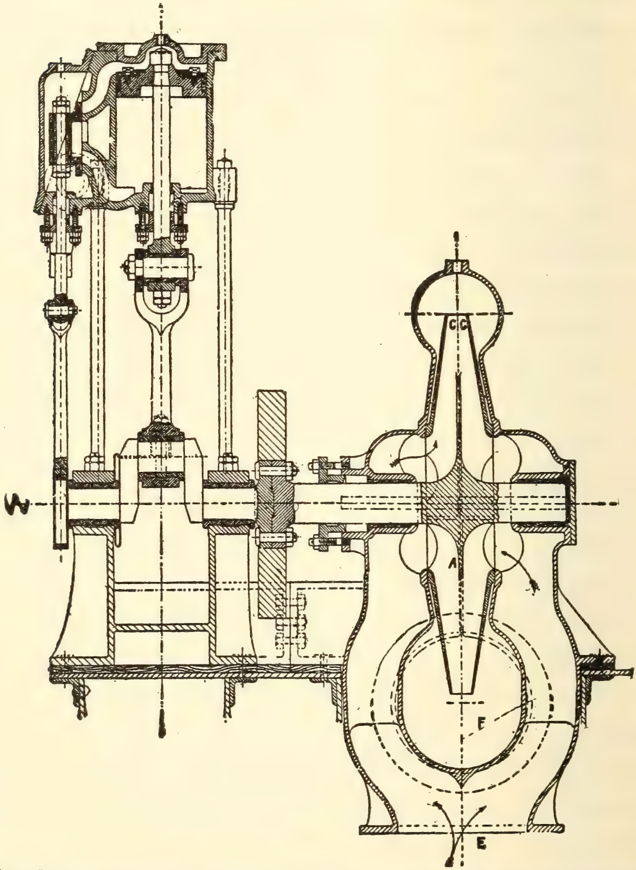


FIG. 156. LONGITUDINAL SECTION OF A CENTRIFUGAL PUMP. A, CENTRAL WEB C C, SIDE PLATES. E, INLET. F, DISCHARGE.

formed in two parts to enable the impeller to be inserted and also to facilitate inspection.

Ques. 584.—How is the quantity of water required to condense the exhaust steam of an engine determined?

Ans.—The quantity of cooling water required for a condensing system depends primarily upon the system, whether it is surface condensing or whether the condenser is a jet condenser. The surface condenser needs a greater quantity of water than does the jet condenser. This is due to the fact that in the surface condenser the water, not being mixed with the steam, can not absorb the heat so rapidly.

Ques. 585.—About how much more water does a surface condenser require than is needed by a jet condenser?

Ans.—About 15 per cent more.

Ques. 586.—What three factors determine the quantity of cooling water required?

Ans.—First, the density, temperature, and volume of the steam to be condensed in a given time; second, the temperature of the overflow and third, the temperature of the injection water. For instance, it may be desired to keep the overflow at as high a temperature as possible, for the purpose of feeding the boilers, or the temperature of the injection or cooling water varies greatly. It may be 35 degrees in the winter and 70 degrees in the summer. In the marine service the temperature of sea-water varies considerably, depending upon the locality, in the tropics the temperature of the sea-water in the summer being often as high as 85 degrees Fahrenheit.

Ques. 587.—What quantity of condensing water would be required in a jet condenser into which the exhaust steam under an absolute pressure of 7 pounds is passing, assuming the temperature of the cooling water to be 55 degrees and the temperature of the overflow to be 110 degrees?

Ans.—In these calculations the total heat in the steam must be considered. This means not only the sensible heat, but the latent heat also. Now in 1 pound weight of steam at 7 pounds absolute pressure the total heat is 1,135.9 heat units. The temperature of the overflow being 110 degrees, the total heat to be absorbed from each pound weight of steam in this case would be 1,135.9 — 110 = 1025.9 thermal units. The temperature of the condensing water being 55 degrees and the temperature of the overflow being 110 degrees, there will be 110 degrees—55 degrees=55 degrees of heat absorbed by each pound of cooling water passing into and through the condenser, and the number of pounds of water required to condense each pound weight of steam under these conditions will equal the number of times 55 is contained in 1,025.9, thus, $\frac{1025}{55} = 18.65$ pounds. Assuming the steam consumption of the engine to be 17 pounds per indicated horse-power per hour, then $17 \times 18.65 = 317.05$ pounds of water is required per horse-power per hour for condensing purposes.

Ques. 588.—How is the weight of cooling water required per hour determined, when the steam consumption per indicated horse-power per hour is not known?

Ans.—In this case the volume of steam exhausted per hour must be considered. Thus, assume the cylinder from which the steam is exhausted to be 24 × 48 inches and the revolutions per minute to be 80. The piston displacement will equal area of piston less one-half area of rod, multiplied by length of stroke. The area of a circle 24 inches in diameter = 452.39 square inches. Suppose the piston-rod to be 4.5 inches in diameter, its area is 15.904 square inches, one-half of which = 7.952 square

TABLE NO. 9

JET CONDENSING

QUANTITY OF INJECTION WATER PER REVOLUTION OF ENGINE.

INJECTION WATER 50° OVERFLOW 110°

Low-pressure Cylinder.	Single-cylinder, Water per Rev.		Two-cylinder, Water per Rev.		Three-cylinder, Water per Rev.	
	Lbs.	Galls.	Lbs.	Galls.	Lbs.	Galls.
20x36 inches..........	4.2	.5	3.9	.47	3.6	.43
22x36 "	5.1	.61	4.8	.57	4.4	.53
24x42 "	7.	.84	6.6	.79	6.	.72
26x42 "	8.3	1.	7.8	.93	7.2	.87
28x48 "	11.	1.45	10.4	1.24	9.5	1.14
30x48 "	12.6	1.52	11.7	1.41	10.8	1.3
32x54 "	16.2	1.95	15.	1.81	13.9	1.68
34x54 "	18.3	2.2	17.0	2.05	15.8	1.9
36x60 "	22.8	2.75	21.2	2.55	19.6	2.36
38x60 "	25.5	3.07	23.7	2.85	21.9	2.64
40x66 "	31.	3.73	28.8	3.45	26.7	3.2
44x66 "	37.5	4.51	34.8	4.2	32.2	3.8
48x72 "	48.5	5.84	45.	5.42	41.7	5.
52x72 "	57.	6.89	53.1	6.4	49.2	5.9
56x72 "	66.	7.9	61.5	7.41	57.	6.8
60x72 "	75.6	9.	70.5	8.5	65.3	7.8
64x72 "	85.	10.	80.	9.6	74.	8.9

(Table No. 9.—From Book on Compound Engines. By James Tribe, Detroit, Mich.)

inches. The effective area of the piston is therefore 452.39 — 7.952 = 444.4 square inches and the piston displacement equals 444.4 × 48 = 21,332.64 cubic inches. It is necessary in this calculation to express the total volume of steam exhausted per minute in cubic feet, therefore 21,332.64 ÷ 1,728 (number of cubic inches in a cubic foot) gives 12.34 cubic feet of piston displacement, and the engine running at a speed of 80 revolutions per minute will send into the condenser a volume of steam equal to twice the piston displacement multiplied by the number of revolutions per minute, expressed thus: 12.34 × 2 × 80 = 1,974.4 cubic feet per minute. Assuming the absolute pressure of the exhaust to be 7 pounds per square inch, the weight of 1 cubic foot of steam at 7 pounds absolute is .0189 pounds and the total weight of steam exhausted per minute would be 1,974.4 × .0189 = 37.3 pounds, and if 18.65 pounds of water is required to condense 1 pound weight of steam at 7 pounds absolute, the total weight of water required per minute in this case would be expressed as follows: 37.3 × 18.65 = 695.8 pounds, or per hour 695.8 × 60 = 41,748 pounds, equal to 5,029 gallons.

Ques. 589.—What quantity of condensing water would be required in a surface condenser, assuming the conditions to be the same as described in the answer to question 587?

Ans.—A surface condenser requires about 15 to 20 per cent more condensing water than a jet condenser does. It was seen in the answer referred to that 18.65 pounds of water were required to condense 1 pound weight of steam, therefore the quantity of water required by the surface condenser would be about 22 or 23 pounds for each pound of steam.

Ques. 590.—What provision is made on board of vessels for obtaining a supply of water for the condensers and for other purposes?

TABLE 10

AREAS AND CIRCUMFERENCES OF CIRCLES.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
.25	.049	.7854	15.5	188.692	48.694	31	754.769	97.389
.5	.1963	1.5708	16	201.062	50.265	31.25	766.992	98.175
1.0	.7854	3.1416	16.25	207.394	51.051	31.5	799.313	98.968
1.25	1.2271	3.9270	16.5	213.825	51.836	32	804.249	100.53
1.5	1.7671	4.7124	17	226.980	53.407	32.25	816.86	101.31
2	3.1416	6.2832	17.25	233.705	54.192	33	855.30	103.67
2.25	3.9760	7.0686	17.5	240.520	54.978	33.25	868.30	104.45
2.5	4.9087	7.8540	18	254.469	56.548	33.5	881.41	105.24
3	7.0686	9.4248	18.25	261.587	57.334	34	907.92	106.81
3.25	8.2957	10.210	18.5	268.803	58.119	34.25	921.32	107.60
3.5	9.6211	10.995	19	283.529	59.690	34.5	934.82	108.38
4	12.566	12.566	19.25	291.039	60.475	35	962.11	106.95
4.25	14.186	13.351	19.5	298.648	61.261	35.25	975.90	110.74
4.5	15.904	14.137	20	314.160	62.832	35.5	989.80	111.52
5	19.635	15.708	20.25	322.063	63.617	36	1017.8	113.09
5.25	21.647	16.493	20.5	330.064	64.402	36.25	1032.06	113.88
5.5	23.758	17.278	21	346.361	65.973	36.5	1046.35	114.66
6	28.274	18.849	21.25	354.657	66.759	37	1075.21	116.23
6.25	30.679	19.635	21.5	363.051	67.544	37.25	1089.79	117.01
6.5	33.183	20.420	22	380.133	69.115	37.5	1104.46	117.81
7	38.484	21.991	22.25	388.822	69.900	38	1134.11	119.38
7.25	41.282	22.776	22.5	397.608	70.686	38.25	1149.08	120.16
7.5	44.178	23.562	23	415.476	72.256	38.5	1164.15	120.95
8	50.265	25.132	23.25	424.557	73.042	39	1194.59	122.52
8.25	53.456	25.918	23.5	433.731	73.827	39.25	1209.95	123.30
8.5	56.745	26.703	24	452.390	75.398	39.5	1225.42	124.09
9	63.617	28.274	24.25	461.864	76.183	40	1256.64	125.66
9.25	67.200	29.059	24.5	471.436	76.969	40.25	1272.39	126.44
9.5	70.882	29.845	25	490.875	78.540	40.5	1288.25	127.23
10	78.540	31.416	25.25	500.741	79.325	41	1320.25	128.80
10.25	82.516	32.201	25.5	510.706	80.110	41.25	1336.40	129.59
10.5	86.590	32.986	26	530.930	81.681	41.5	1352.65	130.37
11	95.033	34.557	26.25	541.189	82.467	42	1385.44	131.94
11.25	99.402	35.343	26.5	551.547	83.252	42.25	1401.98	132.73
11.5	103.869	36.128	27	572.556	84.823	42.5	1418.62	133.51
12	113.097	37.699	27.25	583.208	85.608	43	1452.20	135.08
12.25	117.859	38.484	27.5	593.958	86.394	43.25	1469.13	135.87
12.5	122.718	39.270	28	615.753	87.964	43.5	1486.17	136.65
13	132.732	40.840	28.25	626.798	88.750	44	1520.53	138.23
13.25	137.886	41.626	28.5	637.941	89.535	44.25	1537.86	139.01
13.5	143.130	42.411	29	660.521	91.106	44.5	1555.28	139.80
14	153.938	43.982	29.25	671.958	91.891	45	1590.43	141.37
14.25	159.485	44.767	29.5	683.494	92.677	45.25	1608.15	142.15
14.5	165.130	45.553	30	706.860	94.248	45.5	1625.97	142.94
15	176.715	47.124	30.25	718.690	95.033	46	1661.90	144.51
15 25	182.654	47.909	30.5	730.618	95.818	46.25	1680.01	145.29

TABLE 10—*Continued.*

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
46.5	1698.23	146.08	62.25	3043.47	195.56	78	4778.37	245.04
47	1734.94	147.65	62.5	3067.96	196.35	78.25	4809.05	245.83
47.25	1753.45	148.44	63	3117.25	197.92	78.5	4839.83	246.61
47.5	1772.05	149.22	63.25	3142.04	198.71	79	4901.68	248.19
48	1809.56	150.79	63.5	3166.92	199.50	79.25	4932.75	248.97
48.25	1828.46	151.58	64	3216.99	201.06	79.5	4963.92	249.76
48.5	1847.45	152.36	64.25	3242.17	201.85	80	5026.56	251.33
49	1885.74	153.93	64.5	3267.46	202.68	80.5	5089.58	252.90
49.25	1905.03	154.72	65	3318.31	204.20	81	5153.00	254.47
49.5	1924.42	155.50	65.25	3343.88	204.99	81.5	5216.82	256.04
50	1963.50	157.08	65.5	3369.56	205.77	82	5281.02	257.61
50.25	1983.18	157.86	66	3421.20	207.34	82.5	5345.62	259.18
50.5	2002.96	158.65	66.25	3447.16	208.13	83	5410.62	260.75
51	2042.82	160.22	66.5	3473.23	208.91	83.5	5476.00	262.32
51.25	2062.90	161.00	67	3525.66	210.49	84	5541.78	263.89
51.5	2083.07	161.79	67.25	3552.01	211.27	84.5	5607.95	265.46
52	2123.72	163.36	67.5	3578.47	212.06	85	5674.51	267.04
52.25	2144.19	164.14	68	3631.68	213.63	85.5	5741.47	268.60
52.5	2164.75	164.19	68.25	3658.44	214.41	86	5808.81	270.17
53	2206.18	166.50	68.5	3685.29	215.20	86.5	5876.55	271.75
53.25	2227.05	167.29	69	3739.28	216.77	87	5944.66	273.32
53.5	2248.01	168.07	69.25	3766.43	217.55	87.5	6013.21	274.89
54	2290.22	169.64	69.5	3793.67	218.34	88	6082.13	276.46
54.25	2311.48	170.43	70	3848.46	219.91	88.5	6151.44	278.03
54.5	2332.83	171.21	70.25	3875.99	220.70	89	6221.15	279.60
55	2375.83	172.78	70.5	3903.63	221.48	89.5	6291.25	281.17
55.25	2397.48	173.57	71	3959.20	223.05	90	6371.64	282.74
55.5	2419.22	174.35	71.25	3987.13	223.84	90.5	6432.62	284.31
56	2463.01	175.92	71.5	4015.16	224.62	91	6503.89	285.88
56.25	2485.05	176.71	72	4071.51	226.19	91.5	6573.56	287.46
56.5	2507.19	177.5	72.25	4099.83	226.98	92	6647.62	289.03
57	2551.76	179.07	72.5	4128.25	227.75	92.5	6720.07	290.60
57.25	2574.19	179.85	73	4185.39	229.34	93	6792.92	292.17
57.5	2596.72	180.64	73.25	4214.11	230.12	93.5	6866.16	293.74
58	2642.08	182.21	73.5	4242.92	230.91	94	6939.79	295.31
58.25	2664.91	182.99	74	4300.85	232.48	94.5	7013.81	296.88
58.5	2687.83	183.78	74.25	4329.95	233.26	95	7088.23	298.45
59	2733.97	185.35	74.5	4359.16	234.05	95.5	7163.04	300.02
59.25	2757.19	186.14	75	4417.87	235.62	96	7238.25	301.59
59.5	2780.51	186.92	75.25	4447.37	236.40	96.5	7313.80	303.16
60	2827.44	188.49	75.5	4476.97	237.19	97	7389.81	304.73
60.25	2851.05	189.28	76	4536.37	238.76	97.5	7466.22	306.30
60.5	2874.76	190.06	76.25	4566.36	239.55	98	7542.89	307.88
61	2922.47	191.64	76.5	4596.35	240.33	98.5	7620.09	309.44
61.25	2946.47	192.42	77	4656.63	241.90	99	7697.70	311.02
61.5	2970.57	193.21	77 25	4686.92	242.69	99.5	7775.63	312.58
62	3019.07	194.78	77.5	4717.30	243.47	100	7854.00	314.16

Ans.—All holes in the hull of a ship below the water-line for the supply or discharge of condensing water, or for any other purpose, are fitted with valves having long spindles which are brought inside the vessel through stuffing boxes, in order that the valves may be worked from inboard. The circulating pumps take their suction from a large screw-down inlet valve on the bottom of the ship, while the discharge is through similar valves on the ship's side.

Ques. 591.—What type of valve is largely used for this purpose?

Ans.—The Kingston sea-valve. Strainers are placed over all inlets, to prevent the entrance of weeds and other impurities.

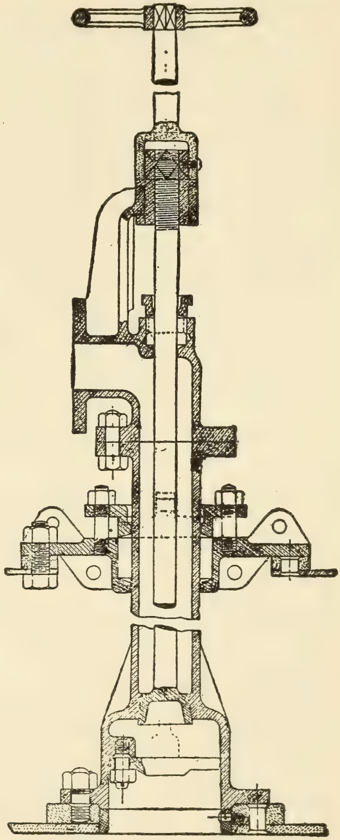


FIG. 157. SEA-VALVE.

CHAPTER VIII

AUXILIARY MACHINERY AND FITTINGS

Ques. 592.—Besides the air and circulating pumps, what other pumps are required in well-equipped steam plants, or aboard steam-ships?

Ans.—Boiler feed-pumps, fire-service, pumps for hydraulic elevators, and other service requiring water-pressure, and in addition, on ship-board, pumps are required for emptying the bilges and tanks and for supplying water for washing the decks, evaporator service and for sanitary purposes.

Ques. 593.—Is there a special pump provided for each service?

Ans.—Not in all cases, but one pump may be connected in such a manner as will permit of its being used alternately for several different purposes. However, a special pump is, or at least should always be provided for feeding the boilers. Also a special bilge-pump is usually supplied, for the reason that it handles very dirty water, that should not be passed through any other pipe system. In small vessels one pump (the donkey) usually serves for nearly all purposes, including auxiliary boiler-feed, and on Western river steamers an independent pump (the doctor) having a steam-cylinder and walking-beam, drives a system of pumps for feed, fire and bilge-pumping service.

Ques. 594.—What special features should appertain to the boiler feed-pump?

Ans.—It should be simple, durable, of great strength and ample capacity to insure regular and reliable service under the most severe conditions. It is always best to have the main and auxiliary feed-pumps duplicates of each other if possible, for the reason that in cases of emergency the different parts are interchangeable. In the marine service the main feed-pump draws its supply of water from the hot well, feed-heater or the feed-tank, as the case may be. The auxiliary or duplicate feed-pump may be arranged so as to draw from either of these sources, and also from the sea, thus making provision for emergency.

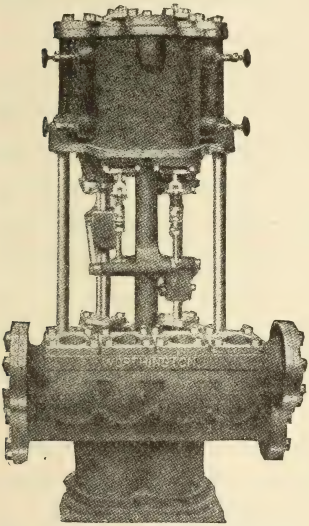


FIG. 158. THE WORTHINGTON BOILER-FEED PUMP, ADMIRALTY PATTERN, FOR 250 POUNDS PRESSURE.

Ques. 595.—Where should the feed-pumps be located?

Ans.—As near to the boiler-room as possible, in order that the engineer in charge of the boilers may have full control of the feed-water supply. On board of vessels, when the feed-pump is worked from the main engine, the auxiliary, or injector is usually placed in the stoke-hold.

Ques. 596.—What type of boiler feed-pump has been found to be the most reliable for all kinds of service?

Ans.—The double acting steam-pump, working independently of all other machinery. The horizontal variety is principally used for land service, while on board steam vessels the vertical type is preferred, for the reason that it occupies less floor space. In both the horizontal and vertical types, the water valve-chambers have removable covers, allowing a ready access to the valves and valve-seats. The steam-valves of these pumps are actuated in various ways. In the duplex variety, which consists of two pumps combined into one, the steam-valve of one side is moved from the piston-rod of the other, and vice versa, while with a pump having but a single steam-cylinder, the steam-valve is worked by a tappet action from its own piston-rod.

Ques. 597.—What two varieties of feed-pumps are largely in use on ocean steamers?

Ans.—The Weir vertical double-acting steam-pump and the Belleville, which is built either vertical or horizontal. In the Weir pump the water-valves are a series of small cones milled out of solid metal and give a large area of opening with a slight lift. The steam-valve arrangement of the Weir pump is rather complicated and requires to be maintained in perfect condition, to insure good service. It consists of a main valve for distributing steam to the cylinder and an auxiliary valve for distributing steam to work the main valve. The main valve moves horizontally from side to side, being driven by steam admitted and exhausted from each end alternately. The auxiliary valve is actuated by a lever with a fixed fulcrum worked by the piston-rod of the pump. This auxiliary valve moves on a flat face on the back of the main valve and in a direction at right angles to the latter. Both the main and auxiliary valves are simply slide valves, but the main valve is half round, the round side working on the correspondingly shaped cylinder port-seat, while the back of the valve is flat and forms the seat for the auxiliary valve. Both ends of the main valve are lengthened, so as to project beyond the port face and are turned cylindrical, with flat ends. Caps are fitted on each of these ends, forming cylinders which are closed at the mouths by the flat ends of the main valve, which act as pistons, the length of stroke

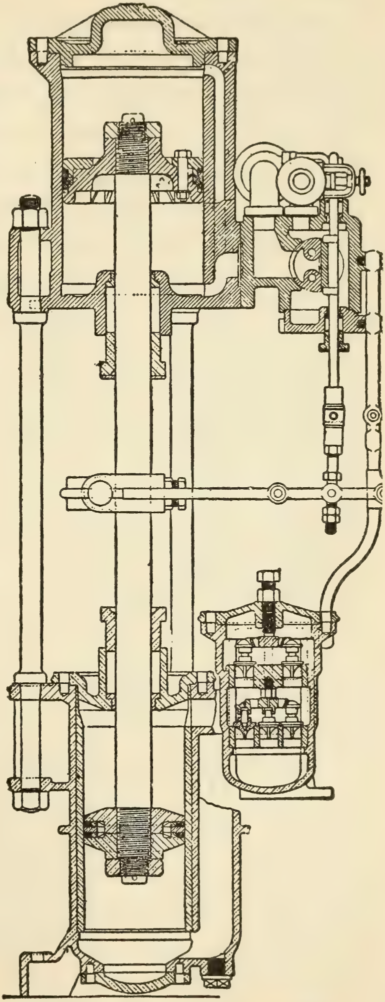


FIG. 159. WEIR'S FEED-PUMP FOR MARINE SERVICE.

that the piston can make being the full travel of the valve. The auxiliary valve-seat has three ports, the center one being the exhaust and the two side ports being steam-passages leading through the piston ends of the main valve. The right-hand cylinder port-passage is led through the left-hand end of the piston and the left-hand passage leads to the other end. These ports admit steam to the two small caps or cylinders at each end of the valve alternately, by which it is thrown from side to side. Besides the ports already referred to, there are two other ports formed on the auxiliary valve-seat leading to and corresponding to two ports on the half-round seat of the main valve. These ports are for the purpose of admitting steam to the top and bottom of the main cylinder, and are arranged on the auxiliary valve-seat to cut off steam before the end of the stroke, and so reduce the speed of the piston, but the expansion chambers at each end of the main valve are fitted with by-passes to admit steam for the full stroke when so desired. This may be necessary when starting the pump, as then the water-cylinder may be full of water. These by-passes are formed by notches cut in the edges of the caps and may be opened or closed by turning the caps by means of spindles provided at each side of the valve-chest, and thus give a definite cut-off. There are separate by-passes for the up and down strokes, and the silent working of the pump depends upon the proper adjustment of these by-passes.

Ques. 598.—Describe the action of the Belleville feed-pump.

Ans.—The pump is double-acting, having an ordinary flat slide-valve without lap, worked by a curved lever, which is moved at each end of the stroke, by a projection or lug on the piston-rod. The steam-ports are arranged at each end of the cylinder in such a manner as to admit the steam uniformly all around the cylinder circumference, and not at the top only, which prevents bending forces on the rod. The steam-pressure remains constant, therefore, until near the end of the stroke, when the projection strikes the valve-lever and commences to close the

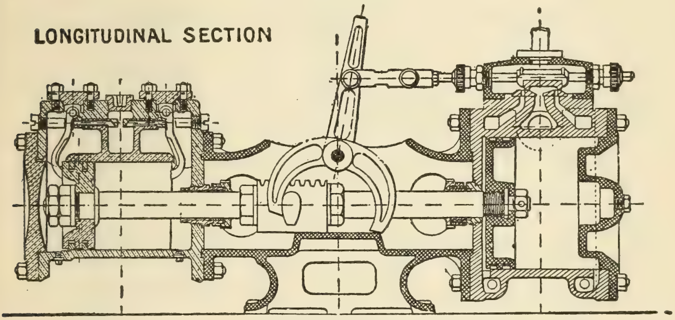


Fig. 160. Belleville Feed-pump.

steam-valve, so that the steam-pressure falls and the motion would cease, but for special provisions. Before the piston can commence the return stroke, it is necessary that the valve should not only be closed but pushed sufficiently far over to reopen for steam on the other side. To enable the steam already in the cylinder to complete the stroke and throw the valve over to the opposite side, an orifice is provided at each end of the water-cylinder, closed by levers and communicating with the suction-chamber, so that when the water-piston nears the end of its stroke, it strikes one of these levers and opens the orifice to the suction-chamber, thus causing the pressure in the water-cylinder to fall, and the steam, although cut off, is enabled by its expansive force to push the piston to the end of the stroke and reverse the valve. When motion begins in the opposite direction the water-valves are a series of small valves, generally eight in number, at each end, four for suction and four for discharge. Small holes about $\frac{1}{16}$ inch in diameter, are made through the levers into

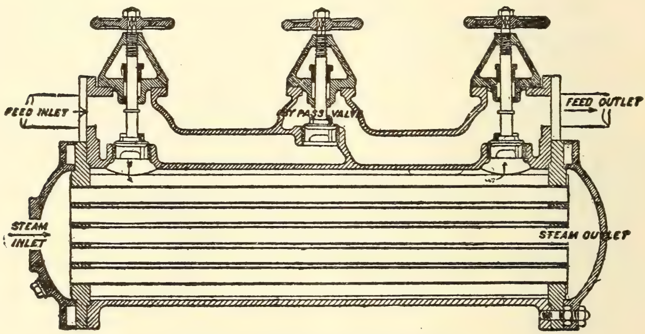


FIG. 161. KIRKALDY'S FEED-HEATER.

the passage leading to the suction chamber, so that a small quantity of water is always escaping from the water-cylinder, which causes the pump to keep slowly in motion, even when the feed-valves on the boilers are closed.

Ques. 599.—Are feed-water heaters much in use in the marine service?

Ans.—They are largely used in the mercantile service, and results justify their adoption.

Ques. 600.—Describe the construction and operation of Kirkaldy's feed-heater.

Ans.—It is constructed along lines similiar to a surface condenser, having tubes rolled into tube-plates in the ordinary manner, the whole surrounded by an outside shell, leaving spaces at each end between the tube-plates and end-covers. The feed-water does not mix with the heating steam, but is drawn through the tubes, on the

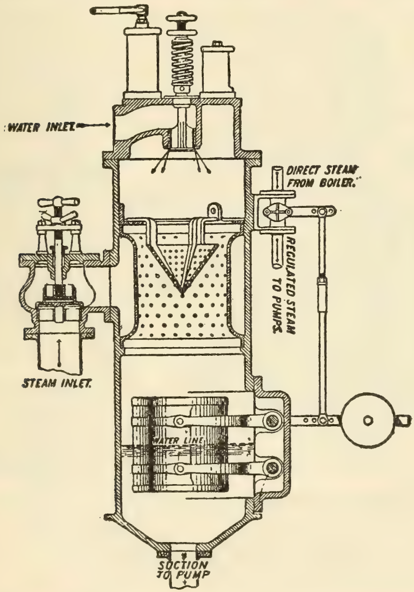


FIG. 162. WEIR'S FEED-HEATER AND REGULATOR.

outside of which is the steam, which is usually the exhaust from various auxiliary engines, or it may be drawn from the boilers. By-pass valves are fitted, so that when necessary the feed-water can be passed direct, without passing through the heater.

Ques. 601.—Describe the construction and operation of Weir's feed-heater and regulator.

Ans.—It takes steam from the final receiver of the engine after it has done most of its work. The steam enters the heating chamber through a circular perforated ring and there mixes with the cold feed-water, which is admitted through the spring-loaded valve on the cover.

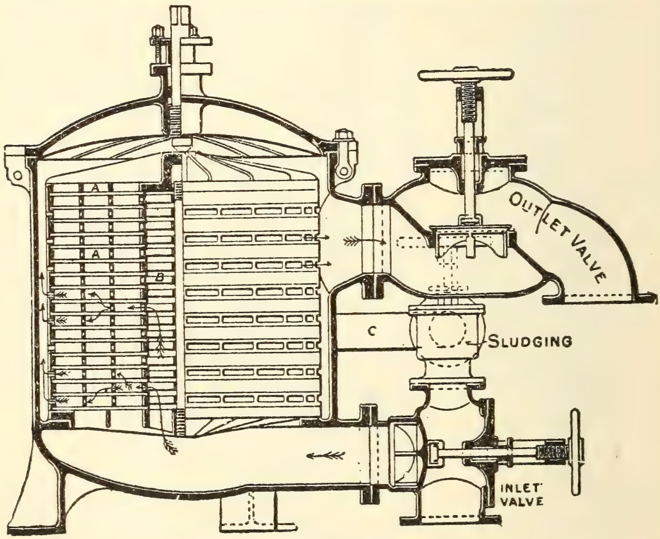


FIG. 163. THE HARRIS GREASE FILTER.

The heated water falls to the bottom of the heater, from whence it is removed by the feed-pump. A galvanized iron float is fitted to the bottom of the heater, which communicates by means of levers with the steam-valve leading to the feed-pump, thus keeping the water-level constant in the heater and preventing the pumps from drawing air.

Ques. 602.—What provision is made on board steam-vessels for the prevention of oil or grease passing into the boilers along with the feed-water?

Ans.—Numerous types of grease-filters are in use. In the Harris grease-filter the feed-water is caused to pass through a series of gratings, on each of which is fitted one or two sheets of filtering material, consisting of toweling or flannel, supported by wire gauze. When the cloths become dirty they are cleaned by a steam jet, and washed off by a reverse current of water.

Ques. 603.—What is the object of placing a governor on an engine?

Ans.—To maintain regularity of speed of the engine when the load is varied from any cause.

Ques. 604.—Upon what principle do the most of the governors for land engines operate?

Ans.—Upon the principle of centrifugal force causing two balls or weights, each suspended or attached to a lever swinging on a fulcrum, fixed near the top of a vertical revolving spindle, to fly outward as the speed increases; and the force of gravitation which acts in the opposite direction as the speed decreases. The outward movement of the balls or weights is utilized to either close the throttle or shorten the point of cut-off, while the inward movement has the opposite effect.

Ques. 605.—Are governors required on marine engines?

Ans.—They are, for the reason that in a marine engine considerable diminution in resistance may ensue in rough or stormy weather, from the pitching motion of the vessel, which causes the propellers to rise partly out of the water, thus causing what is technically known as "racing of the engines."

Ques. 606.—Is the centrifugal type of governor suitable for marine service?

Ans.—It is not, for the reason that the forces acting upon the balls or weights would be affected by the motion of the ship and the action would be irregular. Other forms of governors for marine engines are in use with various degrees of success, but all, or nearly all of them, possess the one defect of requiring an increased speed of the engine to cause them to act, and even then their action is sluggish, the throttle-valve being generally closed after the racing is over.

Ques. 607.—What type of marine governor is likely to prove the most successful in marine service for the prevention of "racing?"

Ans.—A governor that acts by variations of pressure at the stern of the vessel near the propeller, and not from engine-speed variations. Racing being caused by diminished immersion of the propeller, it is accompanied by a diminution of pressure of water at that part, which can be utilized to actuate the throttle-valve. Such governors may therefore anticipate and prevent any increase of speed due to the above cause, although they would have no effect in case of a serious increase of speed, due to such an accident as a broken shaft or propeller.

Ques. 608.—Describe Dunlop's governor, which is of the latter type.

Ans.—It consists of a sea-cock at the stern of the ship, opening into an air-vessel or air-chamber, so constructed that, by opening the sea-cock, water flows into the air-vessel and compresses the air contained therein to a pressure equivalent to the head of water outside the ship. From the top of the air-chamber a pipe is led to the under side of an air-tight elastic diaphragm, forming part of an apparatus in the engine-room. On the upper side of the diaphragm is a spiral spring, with means of adjusting its compression to balance the air pressure below the diaphragm. From the center of the diaphragm a connection is made to the slide-valve of a small steam-cylinder so constructed that its piston moves in exact accordance with the movements of the diaphragm. This steam-piston is connected by suitable gear to the throttle-valve of the engine whose speed is to be controlled. The action is as follows: The sea-cock being open, any variation of head of water outside the ship is accompanied by an inflow or outflow of water through it and consequently a variation in the pressure of the air contained in the air-chamber, and also under the diaphragm of the engine-room apparatus, causing the diaphragm to move through such part of its travel as is requisite to enable the compression of spring and the air-pressure to balance each other again. Every movement of the diaphragm is followed by a corresponding movement of the governor steam-piston, and consequently of the throttle-valve of the engines under control, the time taken between the variation in the head of water at the stern of the ship and the moving of the throttle-valve being practically nothing. The governor therefore anticipates any increase in the speed of the engines due to the propeller rising out of the water and does not depend upon a variation in speed of the engines to be controlled, before it acts. By adjusting the balance between the spring and the air-pressure under the diaphragm the diaphragm begins to fall and the throttle-valve to close, when the tips of the propeller-blades rise

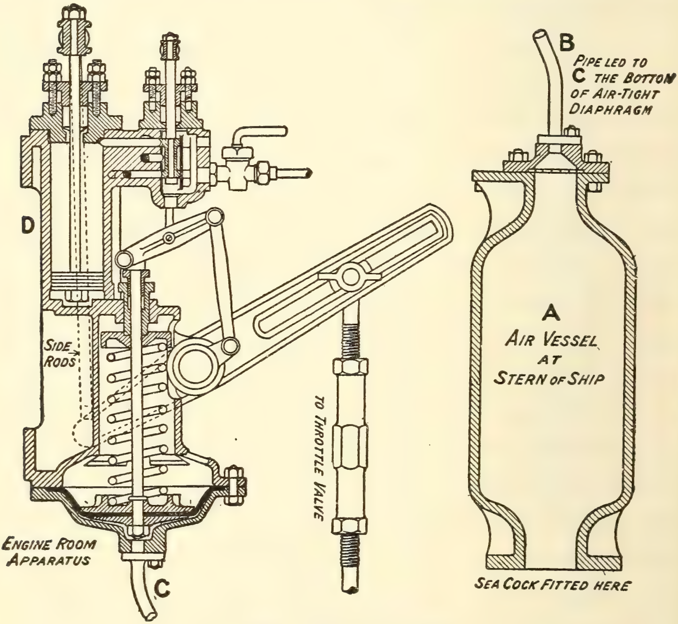
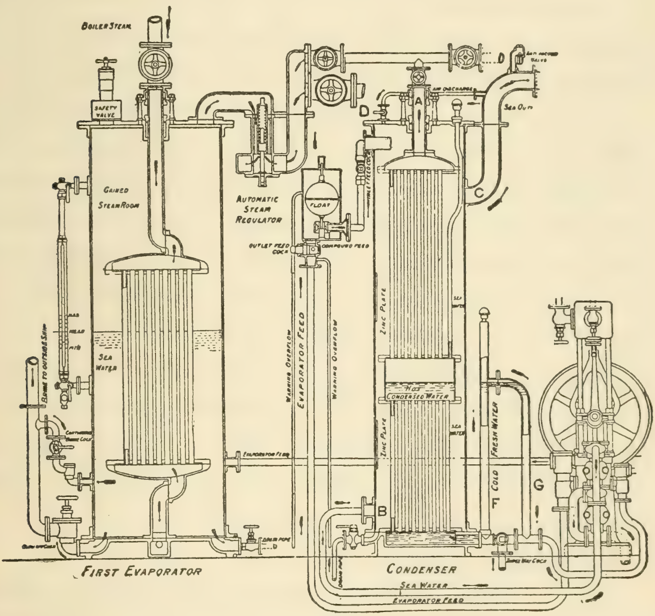


FIG. 164. DUNLOP'S GOVERNOR.

to any desired distance above the surface of the water. The air-vessel should be fitted as far aft in the screw-tunnel as possible, the hole through the side of the vessel being placed about one-fourth the diameter of the propeller below the level of the center of the shaft. The reports of the action of this governor in the mercantile marine are very satisfactory. It is fitted in the "Campania," "Paris," and many other vessels.

Ques. 609.—How is the fresh water needed on board ship for drinking, washing, culinary purposes, and for making up for the waste of feed-water for the boilers and for various other purposes, obtained?



NORMANDY'S EVAPORATOR.

Ans.—By means of evaporators and distillers. The evaporators are really small boilers, with heat obtained from steam passing through tubes, while the water to be evaporated surrounds the tubes. There is no coal used in these boilers, the steam being obtained from the main boilers. The vapor produced is conducted to the distilling apparatus, where it is condensed into fresh drinking water, and a portion of it goes to the condensers for the purpose of making up the deficiency of boiler feed-water. The condensed primary steam is returned to the boilers.

Ques. 610.—Describe Normandy's evaporator.

Ans.—In this type of evaporator the tubes are all straight and rolled into tube-plates at their ends. The steam from the main boilers enters these tubes through a pipe at the top and evaporates the surrounding sea-water contained in the shell, and is itself condensed and passes out through the bottom, returning to the boilers. The vapor generated outside the tubes is conveyed by a valve and pipe, either to the auxiliary condenser for feed-water make-up, or else to the distilling condensers for the production of drinking water. The resulting scale is deposited in the evaporator, from whence it is cleaned at intervals. The sea-water for the evaporator is supplied by a pump. It takes its supply from a feed-box containing a float which maintains a constant level in the feed-box.

Ques. 611.—Describe Normandy's condenser.

Ans.—The steam from the evaporator enters the condenser through a pipe at the top and passes downwards through two series of tubes, the upper set being the condensing and the lower the cooling tubes. These tubes are surrounded by a casing, which is kept filled with cold sea-water that enters at the bottom and flows out at the top through an overflow pipe that is connected to the casing at a point a short distance below the top and is then carried to some distance above the top of the chamber before discharging overboard. By means of this arrangement the hottest sea-water is not discharged overboard, but instead may be used in the evaporator, in connection with the condenser, and thus promote economy of evaporation. An air-pipe is fitted to allow the air evolved from the condensing water in the casing by heat to pass into the overflow pipe leading to the sea. The condensed water rises from the lower chamber through a stand-pipe connected at the bottom and overflows from this pipe into and down another pipe leading to the suction of a small steam donkey pump, which pumps it into test-tanks, from whence it flows by gravity to the water-tanks in the hold of the vessel. By this arrangement the cooling tubes of the condenser are always kept full of water and the fresh water is drawn off cold.

Ques. 612.—On vessels carrying cargoes of fresh meat and other perishable articles that are affected by the heat, what provision is made for their preservation?

Ans.—Various types of refrigerating machinery are in use, some using the cold-air system, others the carbonic-acid system, and a few of the smaller ships are fitted with machines for making ice only.

Ques. 613.—Describe the cold-air system.

Ans.—The machine consists of a tandem compound engine having piston slide-valves both on the same valve-rod and worked by a single eccentric. This engine supplies the motive power of the apparatus. Two air-cylinders, one called the compressing cylinder and the other one the expanding cylinder, are placed side by side and in line with the low-pressure cylinder of the engine. These air-cylinders are double acting, the pistons receiving their motion from the crank-shaft driven by the engine. The action of the device is simple and is as follows: The revolving shaft, through the medium of connecting rods and guides, moves the pistons up and down. Air is drawn into the compressing cylinder through inlet-valves from the surrounding atmosphere or from the cold room. It is compressed on the return stroke of the piston and passes into the cooling chamber, which is constructed similar to a surface condenser, having a pump to circulate the cooling sea-water through it. The work done thus far appears as heat in the air and this heated air, passing through the tubes of the air-cooler, is cooled by the circulating water and is then led to the valve-chamber of the expanding cylinder. The valve arrangement of this cylinder consists of a slide-valve and an expansion valve working on the back of the slide-valve. This arrangement supplies a means of sharply cutting off the inlet of air when it enters the expanding cylinder. The compressing cylinder is provided with a water-jacket through which the circulating pump delivers the cooling water on its way from the air-cooler to the sea. The slide-valves are so arranged in the expanding cylinder that when the proper quantity of air is admitted the supply is cut off and during the remainder of the stroke the air expands and therefore does work on the piston and heat is expended in the process in exactly the converse manner to the generation of heat in the compressing cylinder. As, however, the air has been deprived of its surplus heat

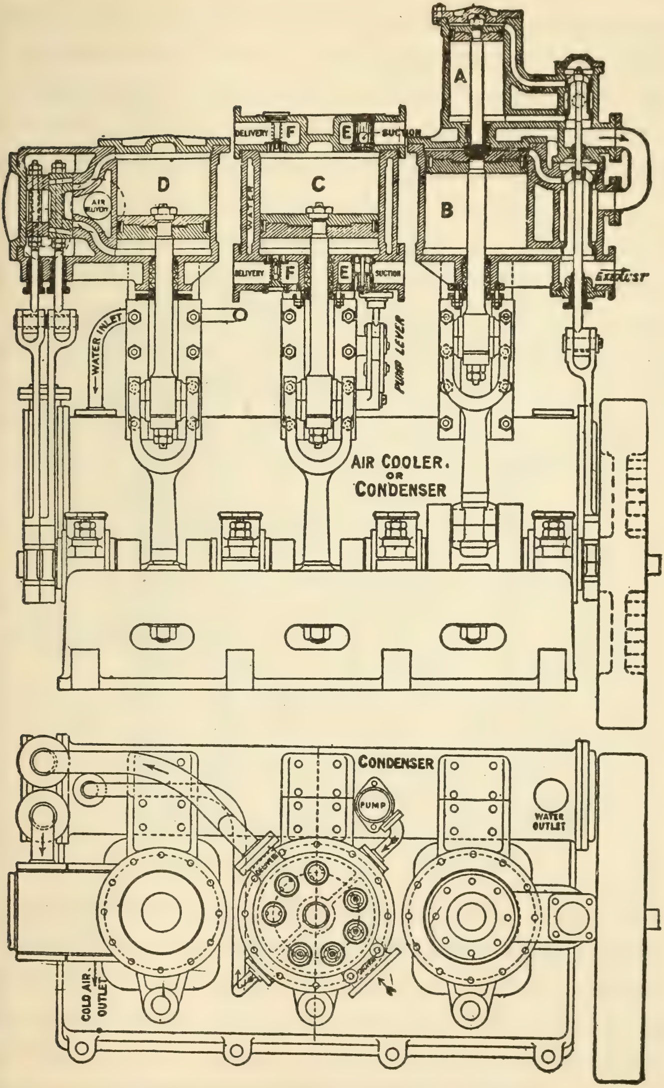


FIG. 165. COLD-AIR SYSTEM OF REFRIGERATION.

in the cooling chamber, the heat equivalent of the work it does in the expanding cylinder is absorbed from itself and the result is a considerable lowering of its temperature. This cold air is then exhausted through the orifice of the slide-valve in the usual manner, and conducted first to the

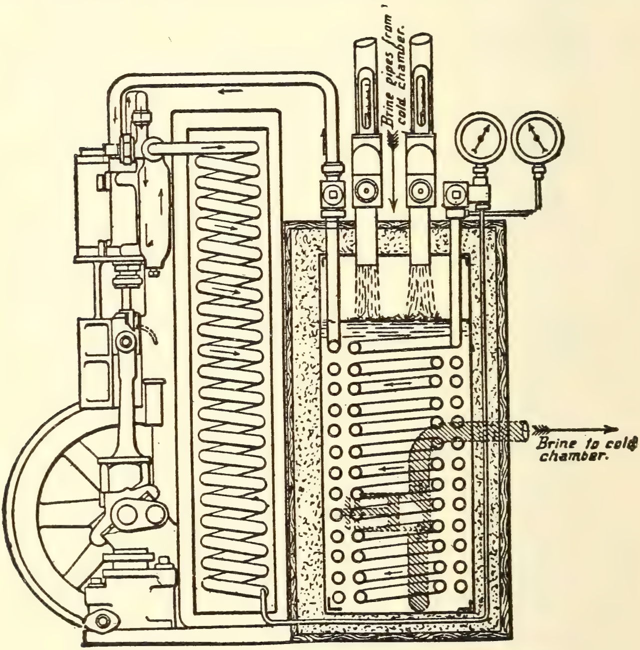


FIG. 166. CARBONIC-ACID SYSTEM OF REFRIGERATION.

"snow-box" a small accessible chamber in which the snow formed from the moisture is deposited, and from thence to the cold chamber, in which the supply of meat or provisions is kept and where it displaces air of a higher temperature. The refrigerating chamber is insulated by lagging its bulkheads, ceiling, and floor with silicate cotton or other non-conductor, a teak lining being fitted over this to form the inside surface.

Ques. 614.—Describe the carbonic-acid system.

Ans.—A very successful and efficient device is the carbonic-anhydride system of Messrs. J. & E. Hall, in which carbonic anhydride is passed round continually in the circuit. The apparatus consists of three parts: a compressor, a condenser, and an evaporator. The compressor draws in heated and expanded gas from the evaporator and compresses it. The compressed gas then passes to a condenser, consisting of coils in which the warm compressed gas is cooled and liquefied by reduction of temperature caused by the action of the cooling sea-water. From the condenser the cool liquid carbonic anhydride is conveyed into the evaporator consisting of coils, where it vaporizes and expands, absorbing heat in the process and cooling the surrounding brine, which is in contact with the coils. This cold brine is circulated by a small pump to the refrigerating chamber, where it is conducted through a long series of rows of cooling pipes, termed "grids," which are placed at the roof of the chamber. The cold-brine "grids" in this position set up a circulation of air, the cold air descending and being replaced by air not so cold, which is cooled in its turn. Any moisture in the air is condensed on the "grids" and appears as frost on the pipes. The theory of the action of this system is as follows: Under atmospheric pressure the liquid CO_2 would evaporate at a temperature of 120 degrees Fahrenheit below zero, but its temperature of evaporation rises with the pressure, in a similar manner as water. At a pressure of 500 pounds per square inch it boils at a temperature of 30 degrees Fahrenheit so that cold water may be used to supply the heat for boiling it. The pressure in the evaporator is therefore regulated to the required temperature of the cooling water, so that a considerable pressure is necessary in the evaporator. The compressor draws the gas from the evaporator and compresses it to the liquefying pressure, the heat due to the compression being absorbed by the cooling water in the condenser coils and the gas in these coils becomes liquid before its exit. The liquid is then boiled in the evaporator coils, cooling the surrounding brine by the heat absorbed during evaporation. The compressor gland is made tight by cupped leathers with glycerine forced between them at a higher pressure than that in the compressor, so that no escape of gas can take place. The carbonic anhydride is supplied in steel cylinders to replenish the supply.

Ques. 615.—What types of dynamos are used on board ships for generating electric current for internal illumination and for working search-lights and motors?

Ans.—They are usually of the two-pole type, direct driven and carried on an extension of the engine-bed. They have drum armatures and the field-magnets are compound wound, to give a constant pressure of 80 or 100 volts for any current from zero to the maximum, while the speed is maintained constant. The usual speed is 320 revolutions per minute. The machines are connected to a switchboard located in a central position, from which the current is distributed to the various circuits for lighting, motors, etc. This board is so arranged that a circuit can be quickly changed from one machine to another, but no circuit can receive current from two

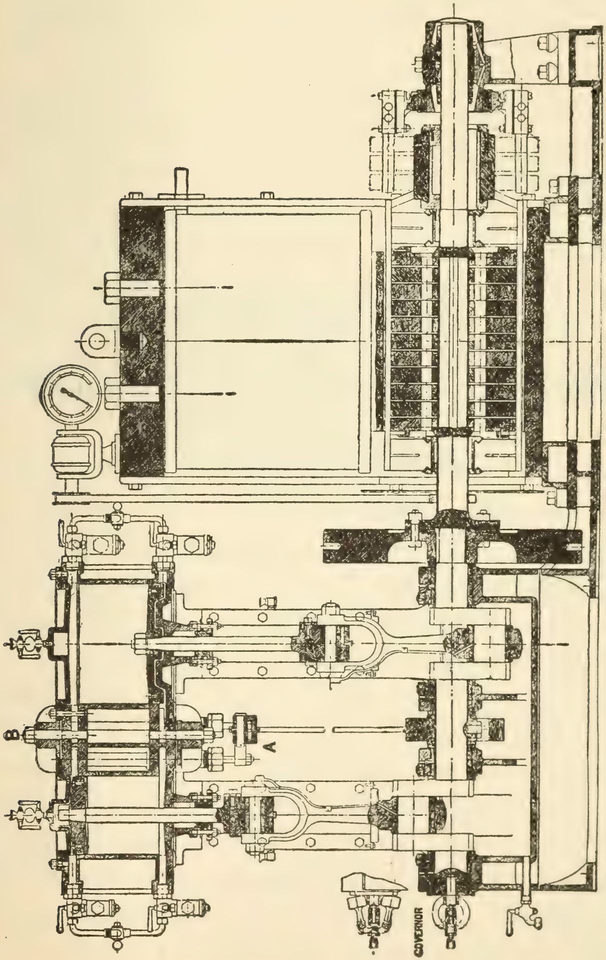


FIG. 167. ENGINES AND DYNAMO FOR MARINE SERVICE.

machines at the same time. The most recently fitted dynamos for the marine service are of the iron-clad type, the field coils and the armature being almost entirely surrounded by iron, to reduce to a minimum the leakage of magnetic lines of force which may affect compasses or chronometers in the neighborhood.

Ques. 616.—How are these dynamos usually driven?

Ans.—By vertical two-cylinder engines, generally compounded, although in some ships, where the steam-pressure is low, the engines are simple. All parts are carefully balanced and a heavy fly-wheel is fitted on the engine-shaft, at the dynamo end, which conduces to steady running. The speed is regulated by an isochronal governor fitted on the shaft.

Ques. 617.—Describe the construction of the armature.

Ans.—The armature-core is built up of thin disks of soft iron slipped over metal sleeves, which are keyed on the shaft. The disks are insulated from each other by thin sheets of asbestos paper, to prevent loss of energy and heating due to eddy currents, and are kept in place by clamping-plates and end-nuts. The conductors on the armature, which carry the current, are made up of copper wires, twisted together, and pressed to a rectangular section. They are insulated by a covering of varnished tape. Usually two lengths of bars are used. They are placed around the periphery of the armature, longitudinally, long and short bars alternating, their ends overhanging the core. All the ends at one end of the armature project the same distance. Projections are fitted into the core at intervals, which drive the conductor-bars. These projections are insulated by mica slips. The bars are kept in place by bands of steel or bronze binding wire, tightly wound on and soldered. Mica strips are placed under the bands to prevent injury to the insulation of the bars. Each bar is connected at each end by bent copper strips to another bar almost diametrically opposite to it, so that the whole of the bars and end-connections form one closed circuit. The projecting end of each long bar is also connected to the nearest commutator segment, the number of segments being equal to the number of long

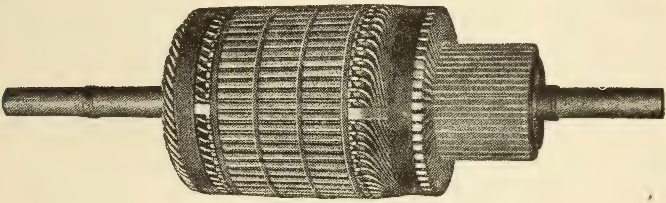


FIG. 168. ARMATURE

bars. Two or more pairs of brushes bear on the commutator, to collect the current, so that any brush may be lifted off without interrupting the circuit.

Ques. 618.—Describe the construction of the field-magnet coils.

Ans.—The field-magnet winding consists of shunt and series coils wound on a frame which fits over the upper pole-piece. The shunt coils are of small wire and high resistance. The ends of the wire are connected to the machine terminals. The greater part of the magnetism is due to these coils, so that at full speed, and when no current is being taken from the machine, the electric pressure is normal, that is, 80 or 100 volts. The series coils are formed of thick copper bars and convey the whole current generated. They provide additional magnetism, proportional to the current flowing in them, and so compensate for the additional

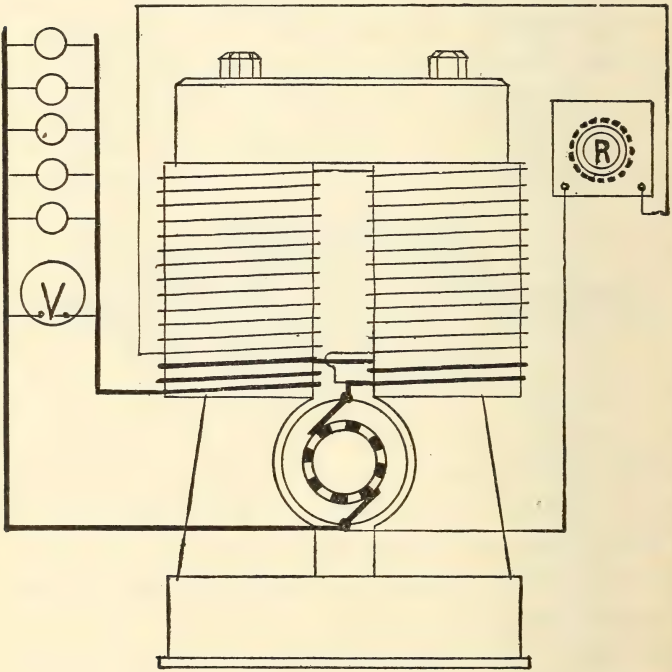


FIG. 169. COMPOUND WOUND DYNAMO.

pressure required to force this current through the machine. By the combination of the two sets of coils, the pressure is thus independent of the current, so long as the speed is constant. In the largest machines there are two distinct armature windings laid on side by side, the bars of the two windings alternating, as also do their respective commutator segments. The two windings are connected in parallel by the brushes, which all have a bearing rather wider than the angular width of two commutator segments.

Ques. 619.—In order to obtain satisfactory working, what should be done with the commutator occasionally?

Ans.—It should be turned up, by using a lathe slide-rest clamped to the bed-plate and running the engines as slowly as possible, and after turning, the commutator should be polished. This truing up is necessary in order to remove any flat places which are liable to form on the segments. The brushes also should be carefully filed to fit the commutator curve. The brushes must be carefully set in the holders, with all the tips of each set in a line, and the tips of the two sets bearing simultaneously on diametrically opposite commutator segments. Generally two segments are marked at their ends, with crosses, to assist in this adjustment.

Ques. 620.—How is the electric current carried to the different parts of the ship?

Ans.—By wires of the best copper, thoroughly insulated and protected from injury by being placed in wooden mouldings, or what is still better, iron tubes lined with insulating material. The junction boxes have safety fuses and connections, arranged in incombustible porcelain or lava blocks.

Ques. 621.—How are the lamps and motors arranged?

Ans.—The lamps are attached to substantial supports with good protection to the insulation of the wires at their connection. For exposed places extra globes or wire screens are provided to prevent breaking of the bulbs. The motors are fitted on substantial foundations, with switches for handling in convenient positions. The use of electric motors is becoming more and more general on board vessels as their convenience and freedom from waste is known. They can be used for working ventilating fans, etc., in confined spaces where the heat of steam would be objectionable. They also avoid the waste due to condensation, radiation and leakage in pipes, require very little attention when running and are always ready for starting.

Ques. 622.—What facilities are provided for pumping the water out of steam-ships in case of a serious leak?

Ans.—All steam-ships, including war-vessels, were formerly fitted with bilge-pumps worked direct from the main engines, and this is still the common practice in the mercantile marine. In addition to these pumps, the circulating pumps are fitted with bilge as well as sea connections, and in some of the larger vessels there are four centrifugal pumps which can be used for pumping out the bilges, each of these pumps having a capacity of at least 1,200 tons of water per hour.

Ques. 623.—What are some of the requirements of a reliable bilge-pumping outfit?

Ans.—The pump itself should be close to the bilge, but the engine for working it should if possible be at a high level, so as to be out of the reach of the water in case of its rising rapidly. Another point that should be kept in view is the provision of large engine-power for working the pumps. The valves for changing the suction of the centrifugal pumps from the sea to the bilge are, or at least should be, arranged to be worked from the starting platform, and to enable this to be done quickly in case of need, the valves in the sea and bilge-suction pipes

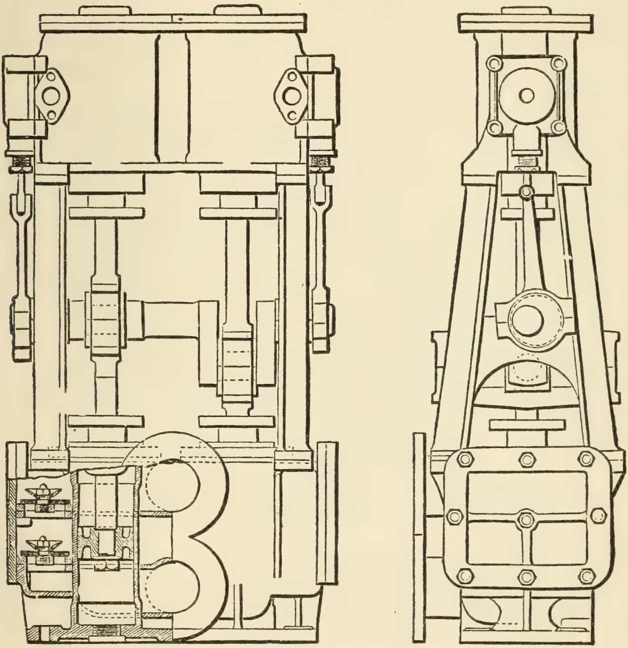


FIG. 170. FIRE AND BILGE PUMPS.

are often coupled together so that they may be worked by a single lever.

Ques. 624.—Describe the type of fire and bilge-pumping engines that are used to a large extent in the English navy.

Ans.—Each pumping engine consists of two double-acting pumps and two steam-cylinders, fitted with slide-valves, having very little lap, to insure the engines starting readily from any position of the cranks, economy in the use of steam being in these cases a minor consideration. In the large battle-ships and cruisers there are four of these pumps, two in each engine-room, each one of the four having a capacity of 80 to 120 tons of water per hour. The pumps are large enough to remove these quantities of water at a speed not exceeding 60 revolutions per minute, with a steam-pressure of two-thirds the maximum boiler-pressure, and they form a means of pumping water out of the ship, auxiliary to the main circulating pumps. They can be used for either fire service or for clearing the bilges of water.

Ques. 625.—Describe Friedmann's bilge-ejector.

Ans.—This apparatus is a modification of Giffard's injector, the number of nozzles being increased so as to give the steam several suction orifices instead of one. The steam is conducted to a tuyere about one-half the diameter of the steam-pipe, and then passes successively through a series of intermediate tuyeres, through which the water is drawn from the hold and expelled from the ship through the discharge. The device occupies little space and has considerable capacity, but its consumption of steam is large.

Ques. 626.—Describe the suction and discharge arrangements of fire and bilge pumps.

Ans.—They are fitted with separate suction-pipes leading to the following parts of the vessel: Forward and after ends of engine-room, with a continuation to the screw tunnel from the latter, main engine save-all, each boiler compartment, the main suction-pipe, salvage system of the vessel and to the sea. The valve-boxes and pipes are so arranged that each pump can draw from any of these parts. The pumps deliver water either overboard direct, to the engine-room or to the fire-main, a large air-vessel being fitted in connection with the latter.

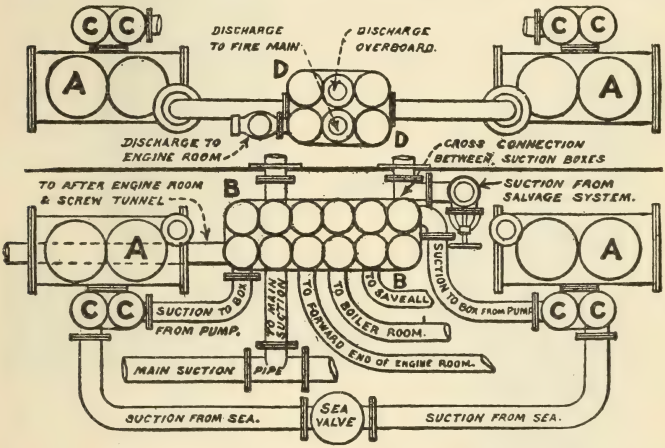


FIG. 171. SUCTION AND DISCHARGE ARRANGEMENTS OF FIRE AND BILGE PUMPS.
A A A A, pumps; B B, directing valve-boxes; C C, shut-off valves from the sea, and bilge directing valve-box respectively; D D, directing valves for discharge, either to fire main, overboard or to engine-room.

Ques. 627.—How is the fire-main arranged?

Ans.—The fire-main is a pipe extending fore and aft in the ship, with branches leading to different parts as required. Delivery-valves, with screwed nozzles for hose-connections, are located at various points in the fire-main. Non-return valves are fitted at the junction of delivery-pipes from the pumping engines.

CHAPTER IX

THE INDICATOR—PRINCIPLES OF THE INDICATOR

Ques. 628.—By whom was the indicator invented and first applied to the steam-engine?

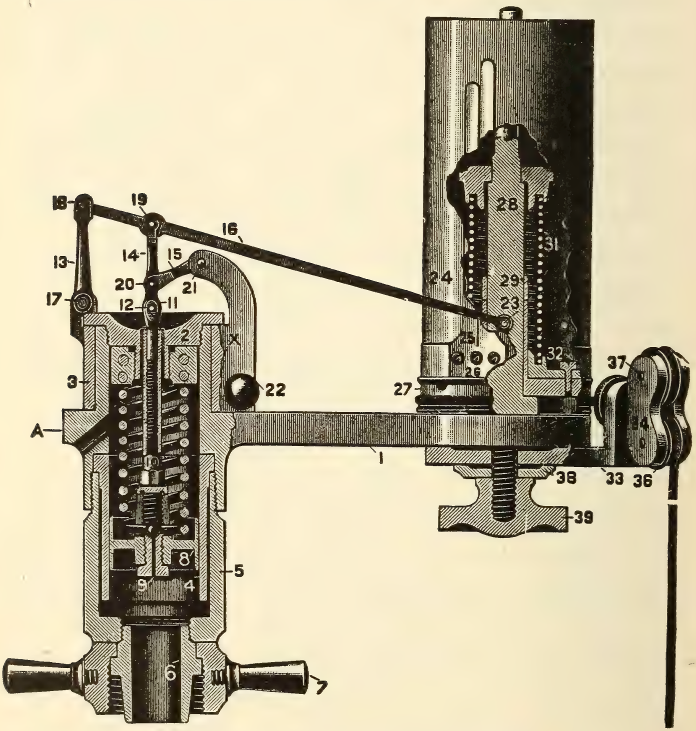


Fig. 172. Sectional View Crosby Indicator.

Ans.—The indicator was invented and first applied to the steam-engine by James Watt, whose restless genius was not satisfied with a mere outside view of his engine as it was running, but he desired to know more about the action of the steam in the cylinder, its pressure at different portions of the stroke, the laws governing its expansion after being cut off, etc. Watt's indicator, although crude in its design and construction, contained embodied within it all of the principles of the modern instrument.

Ques. 629.—What are the principles governing the action of the indicator?

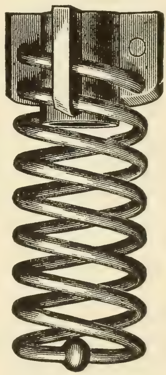


Fig. 173.
Crosby Indicator Spring.

Ans.—First, the pressure of the steam in the engine-cylinder throughout an entire revolution, against a small piston in the cylinder of the indicator, which in turn is controlled or resisted in its movement by a spring of known tension, so as to confine the stroke of the indicator piston within a certain small limit. Second, the stroke of the indicator piston is communicated by a multiplying mechanism of levers and parallel motion to a pencil moving in a vertical straight line, the distance through which the pencil moves being governed by the pressure in the engine-cylinder and the tension of the spring. Third, by the intervention of a reducing mechanism and a strong cord, the motion of the piston of the engine throughout an entire revolution is communicated to a small drum attached to and forming a part of the indicator. The movement of the drum is rotative and in a direction at right angles to the movement of the pencil. The forward stroke of the engine-piston causes the drum to rotate through part of a revolution and at the same time a clock-spring connected within the drum is wound up. On the return stroke the motion of the drum is reversed, and the tension of the spring returns the drum to its original position and also keeps the cord taut.

Ques. 630.—Describe in general terms the construction of an indicator.

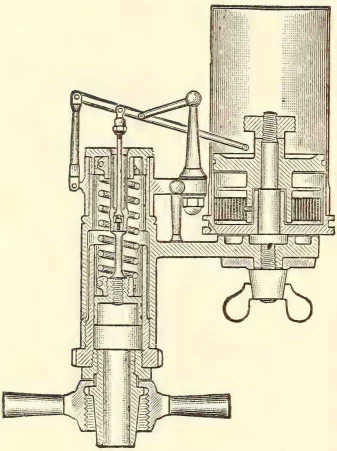


Fig. 174.
Sectional View Thompson Indicator.

Ans.—An indicator consists of a small cylinder, open to the atmosphere at the top and having its bottom end connected by suitable pipes and stop-cocks to both ends of the engine-cylinder in such a manner that the steam-pressure in either end may be caused to act upon the indicator piston, as required. The cylinder of the indicator stands vertical, and is of a known area, usually about one square inch. It contains a piston, upon which the steam acts only on the under side, the top of the cylinder being open to the atmosphere. The length of stroke of this piston is regulated and controlled by a steel spiral spring of known tension, which acts in resistance to the pressure of the steam. When the cock connecting the cylinders of the engine and indicator is closed, both ends of the indicator cylinder are open to atmospheric pressure, and the pencil, which is connected to the piston by a system of levers, stands at its neutral position.

Ques. 631.—Describe the construction and action of the spiral spring in connection with the indicator piston.

Ans.—These springs are made of different tensions in order to be suitable to different steam-pressures and speeds, and are numbered 20, 40, 60, etc., the number meaning that a pressure per square inch in the engine-cylinder corresponding to the number on the spring will cause a vertical movement of the pencil through a distance of one inch. Thus, if a No. 20 spring is used and the pressure in the cylinder at the commencement of the stroke is 20 pounds per square inch, the pencil will be raised one inch, or if the pressure is 30 pounds, the pencil will travel 1½ inch, and if there is a vacuum of 20 inches in the condenser, the pencil will drop ½ inch below the atmospheric line for the reason that 20 inches of vacuum correspond to a pressure of about 10 pounds less than atmospheric pressure or an absolute pressure of about 4 pounds. If a 60 spring is used a pressure of 60 pounds in the engine-cylinder will be required to raise the pencil one inch, or 90 pounds to raise it 1½ inch.

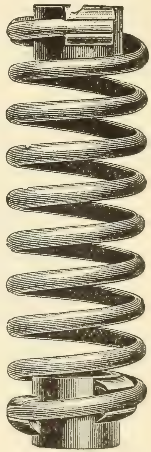


FIG. 175.
THOMPSON INDICATOR SPRING.

Ques. 632.—Are these springs placed inside the cylinder in all types of indicators?

Ans.—The Ashcroft Manufacturing Company of New

York, makers of the well-known Tabor indicator, have recently introduced a new feature in indicator work by connecting the spring on top of the cylinder and in plain

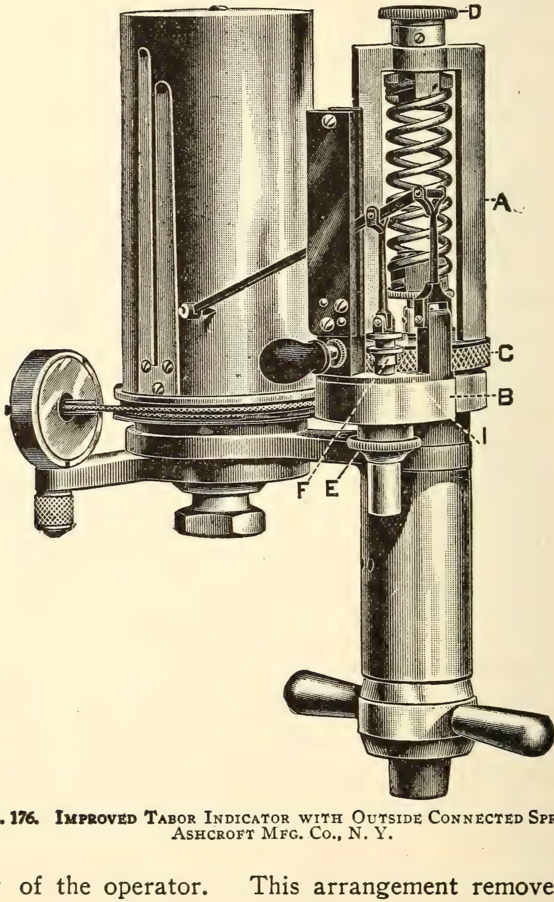


FIG. 176. IMPROVED TABOR INDICATOR WITH OUTSIDE CONNECTED SPRING. ASHCROFT MFG. CO., N. Y.

view of the operator. This arrangement removes the spring from the influence of direct contact with the steam, and it is subject only to the temperature of the surrounding atmosphere. It is claimed that as a result of this the accuracy of the spring is insured and that no allowance need to be made in its manufacture for expansion caused by the high temperature to which it is subject when located within the cylinder. Another good feature of this design is, that the spring can be easily removed without disconnecting any one part of the instrument in case it is desired to change springs.

Ques. 633.—What precautions should be observed in attaching the indicator to an engine-cylinder?

Ans.—The main requirements in these connections are that the holes shall not be drilled near the bottom of the cylinder where water is likely to find its way into the pipes, neither should they be in a location where the inrush of steam from the ports will strike them directly, nor where the edge of the piston is liable to partly cover them when at its extreme travel. An engineer before he undertakes to indicate an engine shoul l satisfy himself that all these requirements are fulfilled. Otherwise he is not likely to obtain a true diagram. The cock supplied with the indicator is threaded for one-half inch pipe, and unless the engine has a very long stroke it is the practice to bring the two end connections together at the side or top of the cylinder and at or near the middle of its length, where they can be connected to a three-way cock. The pipe connections should be as short and as free from elbows as possible, in order that the steam may strike the indicator piston as nearly as possible at the same moment that it acts upon the engine-piston. These pipes should always be thoroughly blown out and cleaned, by allowing the steam to blow through the open three-way cock during several revolutions of the engine before connecting the indicator. If this is not done there is a moral certainty that dirt and grit will get into the cylinder of the indicator and cause it to work badly and give diagrams that are misleading.

Ques. 634.—How is an indicator diagram or card drawn?

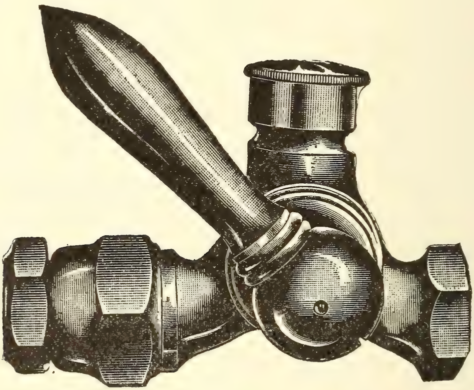


FIG. 177. THREE-WAY COCK.

Ans.—To the outside of the drum a piece of blank paper of suitable size is attached and held in place by two clips. Upon this paper the pencil in its motion up and down traces a complete diagram of the pressures and other interesting events transpiring within the engine-cylinder during the revolution of the engine. In fact, the diagram traced upon the paper is the compound result of two concurrent movements. First, that of the pencil caused by the pressure of the steam against the indicator piston; second, that of the paper drum caused by, and coincident with the motion of the engine-piston.

Ques. 635.—How is the atmospheric line drawn?

Ans.—By holding the pencil to the paper, and causing the drum to be rotated, when the pencil stands at its neutral position, that is with the steam shut off from the indicator cylinder.

Ques. 636.—What is meant by the term atmospheric line?

Ans.—The atmospheric line is a horizontal line drawn on the diagram and means the line of atmospheric pressure. If the engine is a non-condensing engine the pencil in tracing the diagram will, or at least should not fall below the atmospheric line at any point, but will on the return stroke trace a line called the line of back pressure at a distance more or less above the atmospheric line and very nearly parallel with it. If the engine is a condensing engine the pencil will drop below the atmospheric line while tracing the line of back pressure on the diagram, and the distance this line is below the atmospheric line will depend upon the number of inches of vacuum in the condenser.

Ques. 637.—Is the atmospheric line a necessary part of an indicator diagram?

Ans.—The atmospheric line is a very important factor in the study of the diagram.

Ques. 638.—How are the dimensions of the diagram regulated?

Ans.—It is a convenient practice to select a spring numbered one-half of the boiler-pressure as, for instance, suppose gauge-pressure or boiler-pressure is 200 pounds per square inch, then a 100 spring would give a diagram 2 inches in height, which is a convenient height. As to the length of the diagram, this is regulated by adjustment

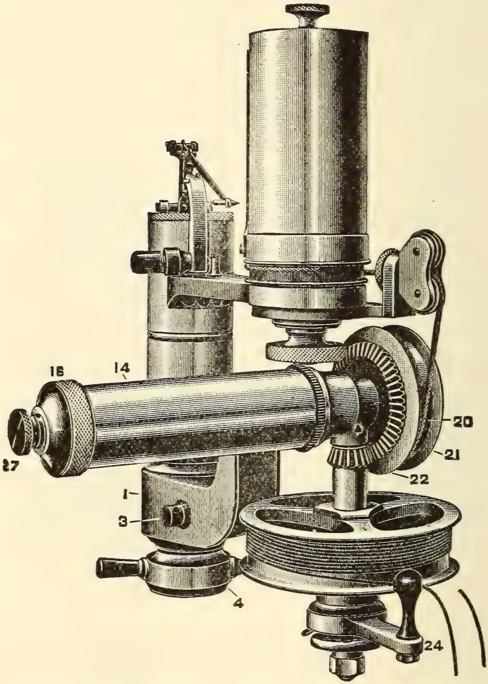


FIG. 178. CROSBY REDUCING WHEEL ATTACHED TO INDICATOR.

of the cord in its travel, by means of the reducing wheel. Any length of diagram up to four inches may be obtained, but two and a half to three inches is a very good length for analysis.

Ques. 639.—How is the motion of the crosshead of the engine reduced and utilized for rotating the drum of the indicator?

Ans.—There are various mechanisms used for this purpose. Probably the only practically universal

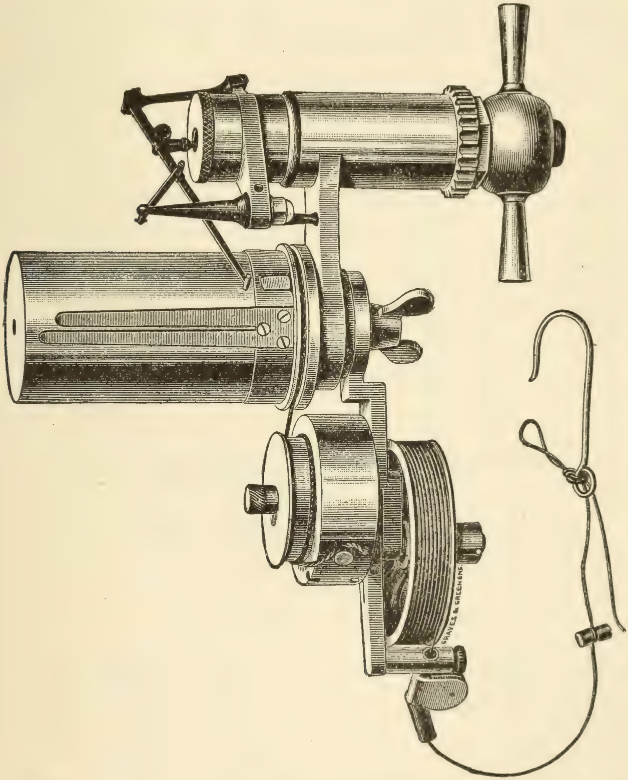
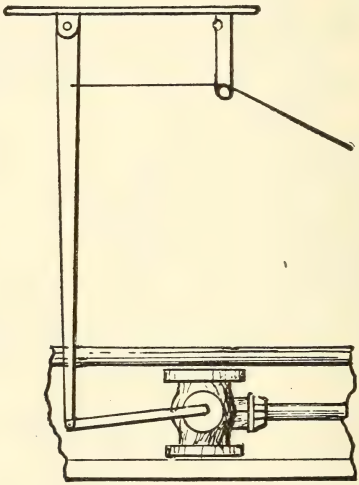


Fig. 179. Thompson Indicator with Reducing Wheel Attached.

mechanism for reducing the motion of the crosshead is the reducing wheel, a device in which, by the employment of gears and pulleys of different diameters, the motion is reduced to within the compass of the drum, and the device is applicable to almost any make of engine, whether of high or low speed. Some makers of indicators attach the reducing wheel directly to the indicator, thus producing a neat and very convenient arrangement.

Ques. 640.--Describe the construction of the wooden pendulum for reducing the motion.

Ans.—It consists of a flat strip of pine or other light



WOODEN PENDULUM, REDUCING MOTION.

wood of a length not less than one and a half times the stroke of the engine, and if made longer it will be better. It should be from ¾ to ⅞ inch thick and have an average width of about 4 inches. If the engine to be indicated is horizontal the bar or pendulum is to be pivoted at a fixed point directly above and in line with the side of the cross-head, as that is generally the most convenient point of attachment. The pivot can be fixed to a permanent standard bolted to the frame of the engine or it may be secured to the ceiling of the room or even to a post fastened to the floor. If the engine is vertical the bar can be pivoted to the wall of the room or a strong post firmly secured to the floor. The connection with the crosshead is best accomplished by means of a short bar or link. A convenient length for this bar is one-half the stroke of the engine.

Ques. 641.—When the short bar is one-half the length of the stroke, how is the correct point for the location of the pivot for the pendulum found?

Ans.—Place the engine on the center with the crosshead at the end of the stroke towards the crank. Then having previously bored a hole for the pivot in one end of the pendulum bar and in the other end a hole for connecting with the link, suspend the pendulum by a temporary pin, as a large wood screw, directly above and in line with the stud or bolt hole which has previously been tapped into the crosshead at any convenient point. The pendulum should be temporarily suspended at such a height that when it hangs perpendicular the hole in its lower end will line up accurately with the hole or stud in the crosshead. Now swing the pendulum in either direction a distance equal to the length of the link (one-half the stroke of the engine) from the crosshead connection and note the distance that the bottom hole is above a straight edge laid horizontal and in line with the center of the stud in the crosshead. This will give the total vibration of the free end of the link from a line parallel with the line of the engine and the permanent location of the pivot should be one-half of this distance below the temporary point of suspension. This will allow the link to vibrate equally above and below the center of its connection with the crosshead.

Ques. 642.—How is the correct point of attachment of the cord to the pendulum found?

Ans.—The cord can be attached to the pendulum at a point near the pivot, which will give the desired length of diagram. This point can be determined by multiplying the length of the pendulum by the desired length of diagram and dividing the product by the stroke. For convenience these terms should be expressed in inches. Thus, assume stroke of engine to be 48 inches, length of pendulum 1½ times length of stroke = 72 inches. Desired length of diagram 3 inches. Then $72 \times 3 \div 48 = 4.5$ inches, which is the distance from center of pivot to point of connection for the cord. This can be either a small hole bored through the pendulum or a wood screw to which the cord can be attached. From this point the cord should be led over a guide pulley located at such height that when the pendulum is vertical the cord will leave it at right angles. After leaving the guide pulley the cord can be carried at any angle desired.

Ques. 643.—How should the indicator be cared for?

Ans.—The indicator should be cleaned and oiled both before and after using. The best material for wiping it is a clean piece of old soft muslin of fine texture, as there is not so much liability of lint sticking to or getting into the small joints. Use good clock oil for the joints and springs, and before taking diagrams it is a good practice to rub a small portion of cylinder oil on the piston and the inside of the cylinder, but when about to put the instrument away these should be oiled with clock oil also.

Ques. 644.—How may the cord be adjusted to proper length?

Ans.—None but the best cord should be used for connecting the paper drum with the reducing motion, as a cord that is liable to stretch will cause trouble. After the indicator has been screwed on to the cock connecting with the pipe, the cord must be adjusted to the proper length before hooking it on to the drum. This must be done while the engine is running, by taking hold of the loop on the cord connected with the reducing motion with one hand, and with the other hand grasp the hook on the short cord attached to the drum, then by holding the two ends near each other during a revolution or two it will be seen whether the long cord needs to be shortened or lengthened.

Ques. 645.—What precautions are necessary in regard to the paper and pencil in order to secure a truthful diagram?

Ans.—Care should be exercised in placing the paper on the drum to see that it is stretched tight and firmly held by the clips. The pencil point having been first sharpened by rubbing it on a piece of fine emery cloth or sand paper should be adjusted by means of the pencil stop with which all indicators should be provided, so that it will have just sufficient bearing against the paper to make a fine, plain mark. If the pencil bears too hard on the paper it will cause unnecessary friction and the diagram will be distorted. The best method of ascertaining this fact and also whether the travel of the drum is equally divided between the stops, is to place a blank diagram on the drum, connect the cord and while the engine makes a revolution hold the pencil against the paper. Then unhook the cord, remove the paper and if the travel of the drum is not divided correctly it can be changed.

Ques. 646.—Describe the process of taking an indicator diagram.

Ans.—Place a fresh blank on the drum, being careful to keep the pencil out of contact with it, connect the cord, open the cock admitting steam to the indicator and after the pencil has made a few strokes to allow the cylinder to become warmed up, then gently swing it around to the paper drum and hold in there while the engine makes a complete revolution. Then move the pencil clear of the paper, close the cock and unhook the cord. Now trace the atmospheric line by holding the pencil against the paper while the drum is revolved by hand. This method of tracing the atmospheric line is preferable to that of tracing it immediately after closing the cock and while the drum is still being moved by the engine, for the reason that there is not so much liability of getting the atmospheric line too high owing to the presence of a slight pressure of steam remaining under the indicator piston for a second or two just after closing the cock; also the line drawn by hand will be longer than one drawn while the drum is moved by the motion of the engine and will therefore be more readily distinguished from the line of back pressure.

Ques. 647.—What other details should be observed in the taking of indicator diagrams?

Ans.—As soon as the diagrams are taken the following data should be noted upon them: The end of the cylinder, whether head or crank; boiler-pressure, and time when taken. Other data can be added afterwards.

Ques. 648.—What needed changes in the cut-off of a Corliss engine, as shown by a diagram, may be made while the engine is running?

Ans.—If the engine is an automatic cut-off of the Corliss type and the point of cut-off on one end does not coincide with the other, the difference can generally be adjusted while the engine is running by changing the length of the rods extending from the governor to the tripping device. These rods are, or should be fitted with right and left threads on the ends for this purpose. Any changes in the valves, such as giving them more lead, compression, etc., and which necessitates changing the length of the reach rods connecting them with the wrist plate, will have to be made while the engine is stopped, although with slow-speed engines and the exercise of caution it is possible to make alterations in these rods while the engine is running.

Ques. 649.—What important details will a truthful indicator diagram show?

Ans.—First, the pressure of the steam against the piston of the engine at any point in the stroke during a complete revolution; second, diagrams from a condensing engine show the amount of vacuum that is being maintained in the condenser, measured from the line of perfect vacuum; third, the point of cut-off is clearly shown, also the point in the return stroke at which compression begins; fourth, the expansion curve, and how near it approaches the theoretical expansion curve; fifth, any fault in the setting of the valves is clearly shown on the diagram; sixth, diagrams taken from the different cylinders of a compound or stage expansion engine may be combined in such a manner as to show whether or not the cylinders are properly proportioned, and whether the steam is being distributed correctly.

Ques. 650.—What is absolute pressure?

Ans.—Pressure reckoned from a perfect vacuum. It equals the boiler-pressure plus the atmospheric pressure.

Ques. 651 —What is boiler-pressure or gauge-pressure?

Ans.—Pressure above the atmospheric pressure as shown by the steam gauge.

Ques. 652.—What is initial pressure?

Ans.—Pressure in the cylinder at the beginning of the stroke.

Ques. 653.—What is meant by terminal pressure (T. P.)?

Ans.—The pressure that would exist in the cylinder at the end of the stroke provided the exhaust valve did not open until the stroke was entirely completed. It may be graphically illustrated on the diagram by extending the expansion curve by hand to the end of the stroke. It is found theoretically by dividing the pressure at point of cut-off by the ratio of expansion. Thus, absolute pressure at cut-off=100 pounds, ratio of expansion=5; then 100÷5=20 pounds, absolute terminal pressure.

Ques. 654.—What is mean effective pressure (M. E. P.)?

Ans.—The average pressure acting upon the piston throughout the stroke minus the back pressure.

Ques. 655.—What is back pressure?

Ans.—Pressure which tends to retard the forward stroke of the piston. Indicated on the diagram from a non-condensing engine by the height of the back pressure line above the atmospheric line. In a condensing engine the degree of back pressure is shown by the height of the back pressure line above an imaginary line representing the pressure in the condenser corresponding to the degree of vacuum in inches, as shown by the vacuum gauge.

Ques. 656.—What is total or absolute back pressure?

Ans.—Total or absolute back pressure, in either a condensing or non-condensing engine, is that indicated on the diagram by the height of the line of back pressure above the line of perfect vacuum.

Ques. 657.—How is the line of perfect vacuum drawn on an indicator diagram?

Ans.—The line of perfect vacuum is drawn parallel with the atmospheric line and at a distance below the latter, representing 14.7 pounds, as measured by the scale corresponding to the spring that was used in taking the diagram. Different scales are supplied for the different springs used.

Ques. 658.—What is meant by ratio of expansion?

Ans.—The proportion that the volume of steam in the cylinder at point of release bears to the volume at cut-off. Thus, if the point of cut-off is at one-fifth of the stroke, and release does not take place until the end of the stroke, the ratio of expansion, or in other words, the number of expansions, is 5. When the T. P. is known the ratio of expansion may be found by dividing the initial pressure by the T. P.

Ques. 659.—What is meant by wire drawing?

Ans.—When through insufficiency of valve opening, contracted ports or throttling governor, the steam is prevented from following up the piston at full initial pressure until the point of cut-off is reached, it is said to be wire drawn. It is indicated on the diagram by a gradual inclination downwards of the steam line from the admission line to the point of cut-off. Too small a steam pipe from boiler to engine will also cause wire drawing and fall of pressure.

Ques. 660.—What is condenser pressure?

Ans.—Condenser pressure may be defined as the pressure existing in the condenser of an engine, caused by the lack of a perfect vacuum. As, for instance, with a vacuum of 25 inches there will still remain the pressure due to the 5 inches which is lacking. This will be about 2.5 pounds.

Ques. 661.—What is absolute zero?

Ans.—Absolute zero has been fixed by calculation at 461.2 degrees below the zero of the Fahrenheit scale.

Ques. 662.—What is piston displacement?

Ans.—The space or volume swept through by the piston in a single stroke. Found by multiplying the area of piston by length of stroke.

Ques. 663.—What is piston clearance?

Ans.—The distance between the piston and cylinder head when the piston is at the end of the stroke.

Ques. 664.—What is steam clearance, ordinarily termed clearance?

Ans.—The space between the piston at the end of the stroke and the valve face. It is reckoned in per cent of the total piston displacement.

Ques. 665.—What is the meaning of the expression horse-power as applied to a steam-engine?

Ans.—33,000 pounds raised one foot high in one minute of time.

Ques. 666.—What is indicated horse-power (I. H. P.)?

Ans.—The horse-power as shown by the indicator diagram. It is found as follows: Area of piston in square inches × M. E. P. × piston speed in feet ÷ 33,000.

Ques. 667.—What is meant by the term piston speed?

Ans.—The distance in feet traveled by the piston in one minute. It is the product of twice the length of stroke expressed in feet multiplied by the number of revolutions per minute.

Ques. 668.—What is net horse-power?

Ans.—I. H. P. minus the friction of the engine

Ques. 669.—What is compression?

Ans.—The action of the piston as it nears the end of the stroke, in reducing the volume and raising the pressure of the steam retained in the cylinder ahead of the piston by the closing of the exhaust valve.

Ques. 670.—What is Boyle's law of expanding gases?

Ans.—"The pressure of a gas at a constant temperature varies inversely as the space it occupies." Thus, if a given volume of gas is confined at a pressure of 50 pounds per square inch and it is allowed to expand to twice its volume, the pressure will fall to 25 pounds per square inch.

Ques. 671.—What is an adiabatic curve?

Ans.—A curve representing the expansion of a gas which loses no heat while expanding. Sometimes called the curve of no transmission.

Ques. 672.—What is an isothermal curve?

Ans.—A curve representing the expansion of a gas having a constant temperature but partially influenced by moisture, causing a variation in pressure according to the degree of moisture or saturation. It is also called the theoretical expansion curve.

Ques. 673.—What is the expansion curve?

Ans.—The curve traced upon the diagram by the indicator pencil showing the actual expansion of the steam in the cylinder.

Ques. 674.—What is power?

Ans.—The rate of doing work, or the number of foot pounds exerted in a given time.

Ques. 675.—What is the unit of work?

Ans.—The foot pound, or the raising of one pound weight one foot high.

Ques. 676.—Define the first law of motion.

Ans.—All bodies continue either in a state of rest or of uniform motion in a straight line, except in so far as they may be compelled by impressed forces to change that state.

Ques. 677.—What is work?

Ans.—Mechanical force or pressure can not be considered as work unless it is exerted upon a body and causes that body to move through space. The product of the pressure multiplied by the distance passed through and the time thus occupied is work.

Ques. 678.—What is momentum?

Ans.—Force possessed by bodies in motion, or the product of mass and density.

Ques. 679.—What is the meaning of the word dynamics?

Ans.—The science of moving powers or of matter in motion, or of the motion of bodies that mutually act upon each other.

Ques. 680.—What is force?

Ans.—That which alters the motion of a body or puts in motion a body that was at rest.

Ques. 681.—What is the maximum theoretical duty of steam?

Ans.—The maximum theoretical duty of steam is the product of the mechanical equivalent of heat, viz., 778 foot pounds multiplied by the total heat units in a pound of steam. Thus, in one pound of steam at 212 degrees reckoned from 32 degrees the total heat equals 1,146.6 heat units. Then $778 \times 1{,}146.6 = 892{,}054.8$ foot pounds = maximum duty.

Ques. 682.—What is steam efficiency?

Ans.—Steam efficiency may be expressed as follows:

$\frac{\text{Heat converted into useful work}}{\text{Heat expended}}$ and maximum efficiency can only be attained by using steam at as high an initial pressure as is consistent with safety, and at as large a ratio of expansion as possible.

Ques. 683.—What is meant by the term efficiency of the plant as a whole?

Ans.—Efficiency of the plant as a whole includes boiler and engine efficiency, and is to be figured upon the basis of $\frac{\text{Heat converted into useful work}}{\text{Calorific or heat value of fuel}}$

Ques. 684.—What is the horse-power constant of an engine?

Ans.—The horse-power constant of an engine is found by multiplying the area of the piston in square inches by the speed of the piston in feet per minute and dividing the product by 33,000. It is the power the engine would develop with one pound mean effective pressure. To find the horse-power of the engine, multiply the M. E. P. of the diagram by this constant.

Ques. 685.—What is meant by the expression steam consumption per horse-power per hour?

Ans.—The weight in pounds of steam exhausted into the atmosphere or into the condenser in one hour divided by the horse-power developed. It is determined from the diagram by selecting a point in the expansion curve just previous to the opening of the exhaust-valve and measuring the absolute pressure at that point. Then the piston displacement up to the point selected, plus the clearance space, expressed in cubic feet, will give the volume of steam in the cylinder, which multiplied by the weight per cubic foot of steam at the pressure as measured will give the weight of steam consumed during one stroke. From this should be deducted the steam saved by compression as shown by the diagram, in order to get a true measure of the economy of the engine. Having thus determined the weight of steam consumed for one stroke, multiply it by twice the number of strokes per minute and by 60, which will give the total weight consumed per hour. This divided by the horse-power will give the rate per horse-power per hour.

Ques. 686.—What is cylinder condensation and reëvaporation?

Ans.—When the exhaust-valve opens to permit the exit of the steam there is a perceptible cooling of the walls of the cylinder, especially in condensing engines when a high vacuum is maintained. This results in more or less condensation of the live steam admitted by the opening of the steam-valve; but if the exhaust-valve is caused to close at the proper time so as to retain a portion of the steam to be compressed by the piston on the return stroke, a considerable poi tion of the water caused by condensation will be reëvaporated into steam by the heat and consequent rise in pressure caused by compression.

Ques. 687.—What are ordinates, as applied to indicator diagrams?

Ans.—Parallel lines drawn at equal distances apart across the face of the diagram and perpendicular to the atmospheric line. They serve as a guide to facilitate the measurement of the average forward pressure throughout the stroke, or the pressure at any point of the stroke if desired.

Ques. 688.—What is a throttling governor?

Ans.—A governor that is used to regulate the speed of engines having a fixed cut-off. The governor controls the position of a valve in the steam-pipe, opening or closing it according as the engine needs more or less steam in order to maintain a regular speed.

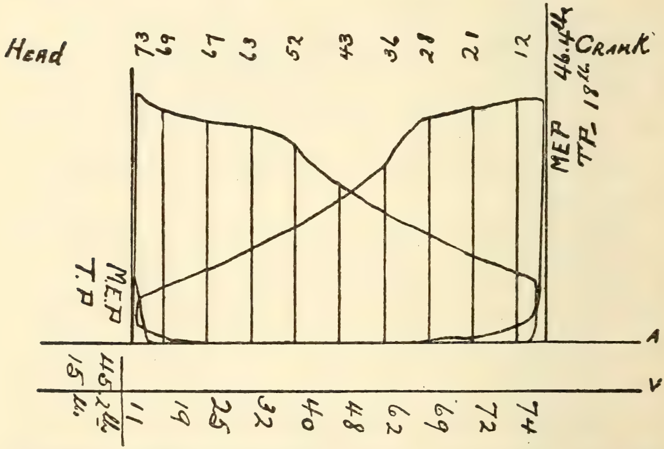


FIG. 180. ILLUSTRATING THE PROCESS OF OBTAINING THE MEAN EFFECTIVE PRESSURE BY MEANS OF ORDINATES.

Ques. 689.—What is an automatic or variable cut-off engine?

Ans.—In engines of this type the full boiler pressure is constantly in the valve chest and the speed of the engine is regulated by the governor controlling the point of cut-off, causing it to take place earlier or later according as the load on the engine is lighter or heavier.

Ques. 690.—What is a fixed cut-off?

Ans.—This term is applied to engines in which the point of cut-off remains the same regardless of the load, the speed being regulated by a throttling governor.

Ques. 691.—What is an adjustable cut-off?

Ans.—One in which the point of cut-off may be regulated or adjusted by hand by means of a hand wheel and screw attached to the valve stem, the supply of steam being regulated by a throttling governor.

Ques. 692.—What is an isochronal or shaft governor?

FIG. 181. INDICATOR DIAGRAM TAKEN FROM A CONDENSING ENGINE.

A, atmospheric line. V, line of perfect vacuum. B to D, admission line. D to E, steam line. E, point of cut-off. E to F, expansion line. F to G, exhaust. G to C, line of back pressure; and from C to B shows compression.

Ans.—This device in which the centrifugal and centripetal forces are utilized, as in the fly-ball governor, is generally applied to automatic cut-off engines having reciprocating or slide valves. It is attached to the crank shaft and its function is to change the position of the eccentric, which is free to move across the shaft within certain prescribed limits, but is at the same time attached to the governor. The angular advance of the eccentric is thus increased or diminished: in fact is entirely under the control of the governor, and cut-off occurs earlier or later according to the demands of the load on the engine.

Ques. 693.—If the valves of an engine are properly adjusted and the distribution of the steam is approximately correct, what particular features should characterize an indicator diagram taken from it?

Ans.—First, the admission line at the beginning of the stroke should be perpendicular to the atmospheric line; second, the steam line, as it is called, extending from the beginning of the stroke to the point of cut-off, should be

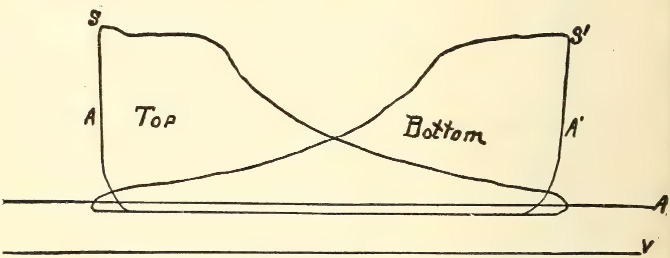


FIG. 182. DIAGRAM SHOWING INSUFFICIENT LEAD.

parallel with the atmospheric line; third, the point of cut-off should be sharply defined; fourth, the expansion curve, extending from the point of cut-off to the point of release, should conform as near as possible with the isothermal curve, which can easily be applied to any diagram; fifth, the exhaust line, extending from point of release to that point in the return stroke where compression begins, should be parallel with and practically coincident with the atmospheric line, if the engine is non-condensing, or if the engine be a condensing engine, this line should approach within a few pounds of the line of perfect vacuum.

Ques. 694.—If the admission line inclines inward from the perpendicular, what defect in the valve setting is indicated?

Ans.—Insufficient lead.

Ques. 695.—How is wire drawing of the steam detected by the indicator diagram?

Ans.—By the downward inclination of the steam line toward the point of cut-off.

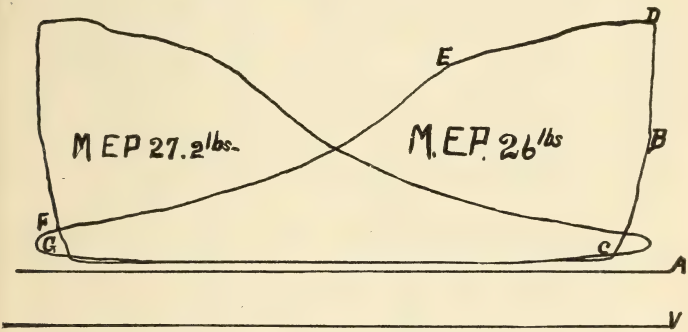


FIG. 183. DIAGRAM SHOWING EFFECTS OF WIRE DRAWING THE STEAM.

Ques. 696.—What is a very necessary factor in the calculation of the horse-power of an engine as shown by a diagram taken from it?

Ans.—The mean effective pressure.

Ques. 697.—How is the M. E. P. of a diagram ascertained?

Ans.—There are two methods commonly used. First, by means of ordinates, and secondly, by the use of the planimeter.

Ques. 698.—Describe the method of finding the M. E. P. by ordinates.

Ans.—The process consists in drawing any convenient number of vertical lines perpendicular to the atmospheric line across the face of the diagram, spacing them equally, with the exception of the two end spaces, which should be one-half the width of the others, for the reason that the ordinates stand for the centers of equal spaces. This is an important matter, and should be thoroughly under-

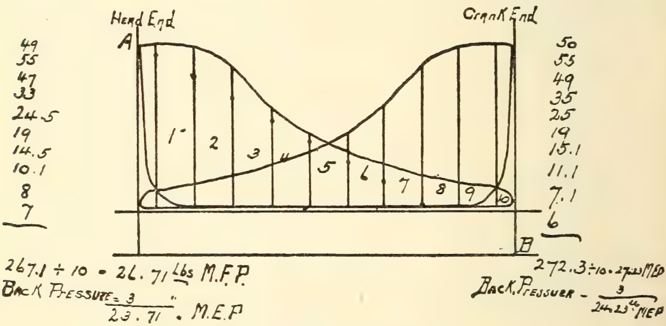


FIG. 184. FINDING M. E. P.

stood, because if the spaces are all made of equal width, and measurements are taken on the ordinates, the results will be incorrect, especially in the case of high initial pressure and early cut-off, following which the steam undergoes great changes. If the spaces are all made equal, the measurements will require to be taken in the middle of them, and errors are liable to occur, whereas if spaced as before described, the measurements can be made on the ordinates, which is much more convenient and will insure correct results. Any number of ordinates can be drawn, but ten is the most convenient and is amply sufficient, except in case the diagram is excessively long.

Ques. 699.—Having succeeded in drawing the ordinates across the face of the diagram, what is the next step?

Ans.—The pressure represented by each line is measured from the exhaust line to the steam line, and so on,

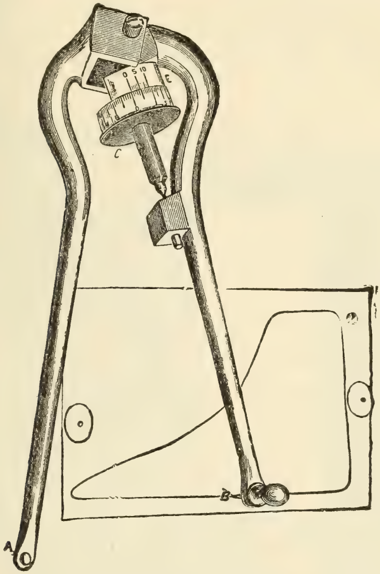


FIG. 185. PLANIMETER.

along the expansion curve throughout the length of the diagram, using for this purpose the scale adapted to the spring used, and having thus obtained measurements on each line, add all together and divide the sum total by the number of lines, which will give the mean forward pressure. To obtain the mean effective pressure, deduct the back pressure, which is represented by the distance of the exhaust line above the atmospheric line in a non-condensing engine, and in a condensing engine the back pressure is measured from the line of perfect vacuum.

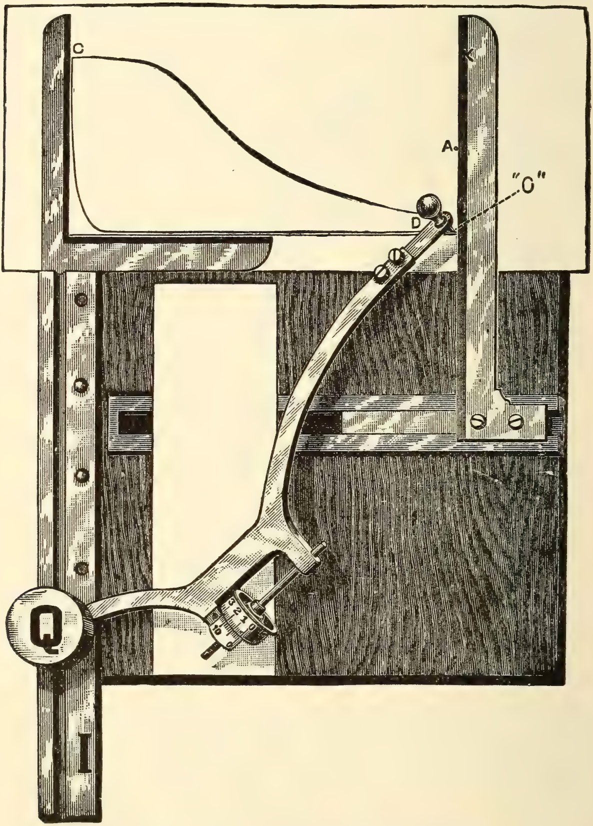


Fig. 186. Coffin Averager or Planimeter.

Ques. 700.—What is a planimeter?

Ans.—The planimeter is an instrument which will accurately measure the area of any plane surface, no matter how irregular the outline or boundary line is.

Ques. 701.—What is the main requirement in ascertaining the M. E. P. of a diagram?

Ans.—The prime requisite in making power calculations from indicator diagrams is to obtain the average height or width of the diagram, supposing it were reduced to a plain parallelogram instead of the irregular figure which it is.

Ques. 702.—What advantage is gained by using the planimeter in measuring diagrams?

Ans.—It shows at once the area of the diagram in square inches and decimal fractions of a square inch, and when the area is thus known it is an easy matter to obtain the average height by simply dividing the area in inches by the length of the diagram in inches. Having ascertained the average height of the diagram in inches or fractions of an inch the mean or average pressure is found by multiplying the height by the scale. Or the process may be made still more simple by first multiplying the area, as shown by the planimeter in square inches and decimals of an inch, by the scale and dividing the product by the length of the diagram in inches. The result will be the same as before, and troublesome fractions will be avoided.

Ques. 703.—Having obtained the M. E. P., as shown by the diagram, how may the horse-power developed by the engine be ascertained?

Ans.—The area of the piston (minus one-half the area of rod) multiplied by the M. E. P., as shown by the diagram, and this product multiplied by the number of feet traveled by the piston per minute (piston speed) will give the number of foot pounds of work done by the engine each minute, and if this product be divided by 33,000, the quotient will be the indicated horse-power (I. H. P.) developed by the engine.

Ques. 704.—Mention two important factors in calculations of steam consumption.

Ans.—In calculating the steam consumption of an engine, two very important factors must not be lost sight of, viz., clearance and compression. Especially is this the case in regard to clearance when there is little or no compression, for the reason that the steam required to fill the clearance space at each stroke of the engine is practically wasted, and all of it passes into the atmosphere or the condenser, as the case may be, without having done any useful work except to merely fill the space devoted to clearance. On the other hand, if the exhaust valve is closed before the piston completes the return stroke, the steam then remaining in the cylinder will be compressed into the clearance space and can be deducted from the total volume which, without compression, would have been exhausted at the terminal pressure.

Ques. 705.—When, owing to light load and early cut-off, the expansion curve drops below the line of back pressure, how must the area of the diagram be calculated?

Ans.—The area of the loop below the back pressure line must be subtracted from the remainder of the diagram. If the planimeter is used, the instrument will make the subtraction automatically, but if the diagram is divided into parts by ordinates, the pressure shown by the ordinates in the lower loop must be subtracted from that shown by the loop above the back pressure line in order to ascertain the M. E. P. or average pressure.

Ques. 706.—What is meant by the adiabatic curve?

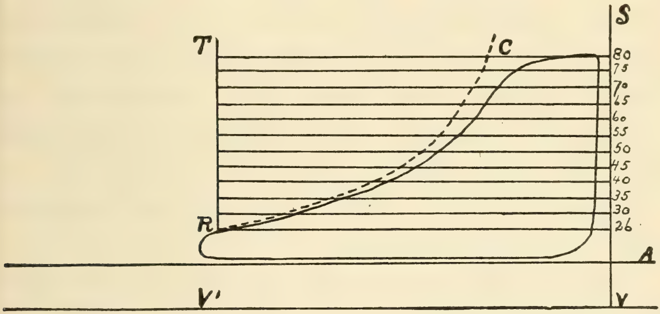


FIG. 187.

The dotted line R C shows what the true adiabatic curve would be on the diagram, provided it could be realized.

Ans.—If it were possible to so protect or insulate the cylinder of a steam engine that there would be absolutely no transmission of heat either to or from the steam during expansion, a true adiabatic curve or "curve of no transmission" might be obtained. The closer the actual expansion curve of a diagram conforms to such a curve, the higher will be the efficiency of the engine as a machine for converting heat into work.

CHAPTER X

THE STEAM TURBINE—FUNDAMENTAL PRINCIPLES

Ques. 707.—What are the basic principles governing the action of steam turbines?

Ans.—There are wo fundamental principles upon which all steam turbines operate, viz., reaction and impulse. In some types of turbines the reaction principle alone is utilized, and in others the impulse, while in still others, and probably the most successful ones, both principles are combined.

Ques. 708.—In what general direction does the steam flow when used in a turbine?

Ans.—Parallel with the shaft or rotor, and also in a screw-like direction around it. This definition does not apply, however, to turbines of the purely impulse type, like the De Laval, for instance.

Ques. 709.—What causes the rotor to revolve?

Ans.—The action of the steam, coming, as it does, with tremendous velocity and great force against the small buckets or vanes with which the rotor is fitted, causes it to revolve, and as there is a continuous current of steam passing into the cylinder, the motion is continuous.

Ques. 710.—What law of turbo-mechanics governs the relation of bucket-speed, and fluid or steam speed?

Ans.—For purely impulse-wheels, bucket-speed equals one-half of jet-speed. For reaction wheels, bucket-speed equals jet-speed.

Ques. 711.—With what velocity would steam of 100 pounds pressure discharge into a vacuum of 28 inches?

Ans.—The theoretical velocity would be 3,860 feet per second.

Ques. 712.—What amount of energy would a cubic foot of steam under 100 pounds pressure exert if allowed to discharge into a vacuum of 28 inches?

Ans.—59,900 foot pounds.

Ques. 713.—Does the steam impinge against the first rows or sections of buckets at full pressure?

Ans.—In turbines of the Parsons type, the initial pressure of the steam is practically boiler-pressure, but it gradually falls as it passes on through the cylinder, which becomes larger in diameter as the exhaust end is approached. In other types of turbines, the steam is admitted to and directed against the blades or buckets, through expanding nozzles, and by the time it strikes the first stage, or section of moving vanes, the pressure has fallen to one-third or less of the original boiler-pressure, but the velocity is very great.

Ques. 714.—In what particular respect does the steam turbine appear to possess an advantage over the reciprocating engine, in the use of steam?

Ans.—The turbine, if designed along correct lines, is capable of utilizing in the highest degree one of the most valuable properties of steam, viz., velocity.

Ques. 715.—Give an example of the great increase in the amount of work performed by an agent when velocity is one of the factors made use of.

Ans.—Suppose that a man is standing within arm's length of a heavy plate-glass window and that he holds in his hand an iron ball weighing 10 pounds. Suppose the man should place the ball against the glass and press the same there with all the energy he is capable of exerting. He would make very little, if any, impression upon the glass. But suppose that he should walk away from the window a distance of 20 feet, and then exert the same amount of energy in throwing the ball against the glass, a different result would ensue. The velocity with which the ball would impinge against the surface of the glass would no doubt ruin the window. Now, notwithstanding the fact that weight, energy, and time involved were exactly the same in both instances, yet a much larger amount of work was performed in the latter case, owing to the added force imparted to the ball by the velocity with which it impinged against the glass.

Ques. 716.—Describe the construction and action of the De Laval steam turbine.

Ans.—The De Laval steam turbine is termed by its builders a high-speed rotary steam-engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam-jet. There are no stationary or guide-blades, the angular position of the nozzles giving direction to the jet. The nozzles are placed at an angle of 20 degrees to the plane of motion of the buckets. The heat energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 feet per second. To attain the maximum of efficiency, the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 feet per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by

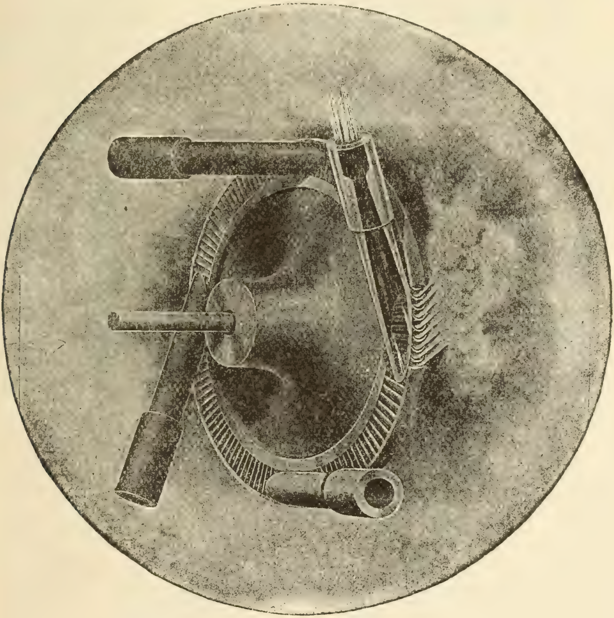


FIG. 188. THE DE LAVAL TURBINE WHEEL AND NOZZLES.

such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 feet per second.

Ques. 717.—Describe the action of the steam in its passage through the De Laval diverging nozzle.

Ans.—It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet of steam

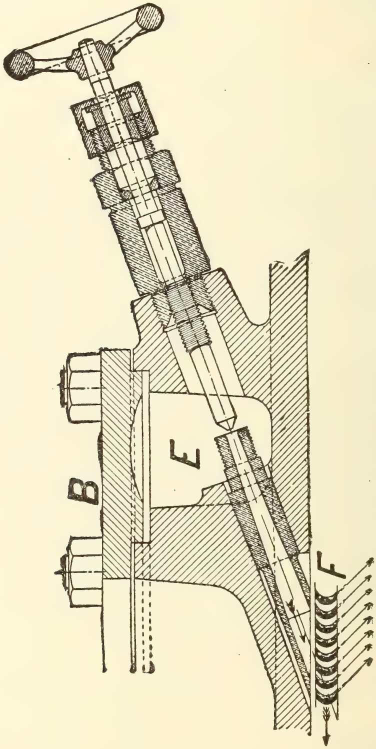


Fig. 189. De Laval Nozzle, Sectional View.

issuing from the nozzle is equal to the amount of energy that would be developed if an equal volume of steam were allowed to adiabatically expand behind the piston of a reciprocating engine, a condition, however, which for obvious reasons has never yet been attained in practice with the reciprocating engine. But with the divergent nozzle the conditions are different.

Ques. 718.—What is the usual speed of the De Laval steam-turbine wheel?

Ans.—From 10,000 to 30,000 revolutions per minute, according to the size of the machine.

Ques. 719.—How are the difficulties attending such high velocities overcome?

Ans.—By the long, flexible shaft and the ball and socket type of bearings, which allow of a slight flexure of the shaft in order that the wheel may revolve about its center of gravity rather than the geometrical center or center of position. All high-speed parts of the machine are made of forged nickel steel of great tensile strength.

Ques. 720.—How is the speed of the De Laval turbine-wheel and shaft reduced and transmitted for practical purposes?

Ans.—By a pair of very perfectly cut spiral gears, usually made 10 to 1. These gear-wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90 degrees to each other. This arrangement insures smooth running and at the same time checks any tendency of the shaft towards end-thrust, thus dispensing with a thrust bearing.

Ques. 721.—How are the buckets made and fitted to the De Laval wheel?

Ans.—The buckets are drop-forged and made with a bulb shank, fitted in slots, that are milled in the rim of the wheel.

Ques. 722.—How many buckets are there?

Ans.—The number of buckets varies according to the capacity of the machine. There are about 350 buckets

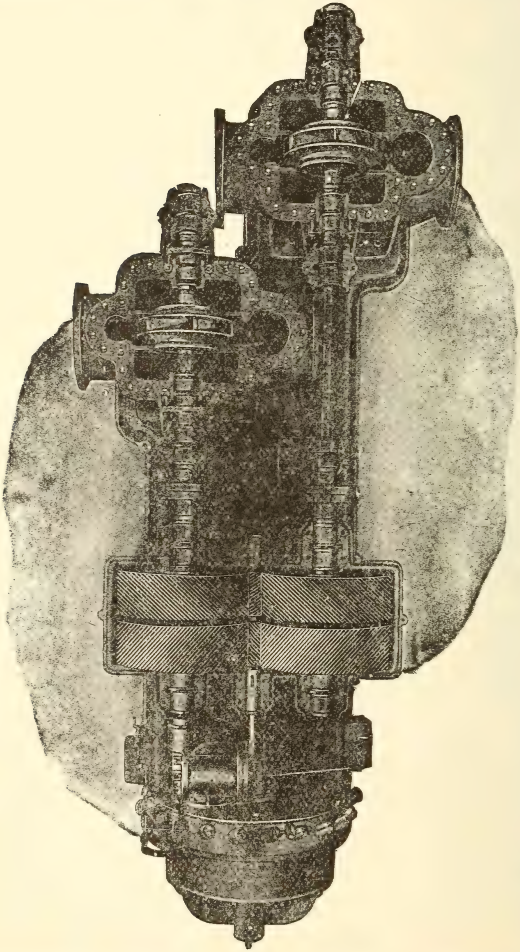


Fig. 190 shows a 110 H. P. De Laval turbine and rotary pump with the upper half of the gear case and field frame removed for purposes of inspection. The slender shaft is seen projecting from the center of the turbine case, and upon this shaft are shown the small pinions meshing into the large spiral gears upon the two pump shafts.

on a 300 horse-power wheel, which is the largest size built up to the present time.

Ques. 723.—How many of the diverging nozzles are fitted to each wheel?

Ans.—The number of these nozzles depends upon the size of the machine, ranging from one to fifteen. They are generally fitted with shut-off valves by which one or more nozzles can be cut out when the load is light. This

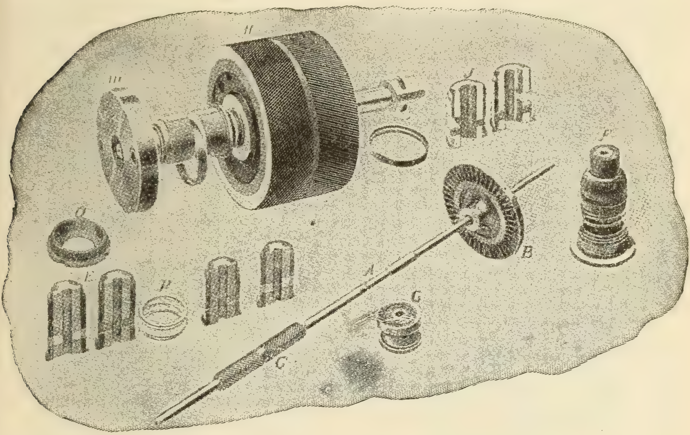


FIG. 191. WORKING PARTS OF THE DE LAVAL STEAM TURBINE.

A.—Turbine shaft.
B.—Turbine wheel.
C.—Pinion.
D.—Pinion bearing, two parts.
E.—Pinion bearing, two parts.
F.—Wheel bearing with spring.
G.—Flexible bearing.
H.—Gear wheel.
I.—Gear wheel shaft.
J.—Gear wheel bearing, two parts.
K.—Oil ring.
L.—Gear wheel bearing in position.
M.—Coupling.
N.—Centrifugal governor.
O.—Gland adjusting nut.
P.—Adjusting nut for flexible bearing

renders it possible to use steam at boiler-pressure, no matter how small the volume required for the load. This is a matter of great importance, especially where the load varies considerably, as, for instance, there are plants in which during certain hours of the day a 300 horse-power machine may be taxed to its utmost capacity and during certain other hours the load on the same machine may drop to 50 horse-power. In such cases the number of nozzles in action may be reduced by closing the shut-off valves until the required volume of steam is admitted to the wheel. This adds to the economy of the machine. After passing through the nozzles, the steam, as elsewhere explained, is now completely expanded, and in impinging on the buckets its kinetic energy is transferred to the turbine wheel. Leaving the buckets, the steam now passes into the exhaust-chamber, and out through the exhaust-opening, to the condenser or atmosphere, as the case may be.

Ques. 724.—How is the speed of this turbine regulated?

Ans.—The governor is of the centrifugal type, although differing greatly in detail from the ordinary fly-ball governor. It is connected directly to the end of the gear-wheel shaft.

Ques. 725.—Describe the methods of lubricating the bearings on the De Laval turbine.

Ans.—The main shaft and dynamo bearings are ring-oiling. The high-speed bearings on the turbine shaft are fed by gravity from an oil-reservoir, and the drip-oil is collected in the base and may be filtered and used again.

Ques. 726.—What can be said regarding the steam-consumption of this turbine?

Ans.—Efficiency tests of the De Laval turbine show a high economy in steam-consumption, as, for instance, a test made by Messrs. Dean and Main, of Boston, Mass., on a 300 horse-power turbine, using saturated steam at about 200 pounds pressure per square inch and developing 333 brake horse-power, showed a steam-consumption of 15.17 pounds per brake horse-power, and the same machine, when supplied with superheated steam and carrying a load of 352 brake horse-power, consumed but

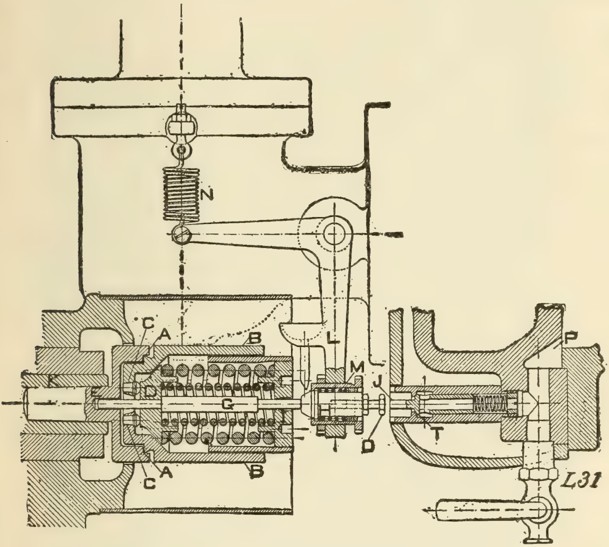


FIG. 192. THE DE LAVAL STEAM TURBINE GOVERNOR.

Two weights B are pivoted on knife edges A with hardened pins C, bearing on the spring seat D. E is the governor body fitted in the end of the gear wheel shaft K and has seats milled for the knife edges A. It is afterwards reduced in diameter to pass inside of the weights and its outer end is threaded to receive the adjusting nut I, by means of which the tension of the spring, and through this the speed of the turbine, is adjusted. When the speed accelerates, the weights, affected by centrifugal force, tend to spread apart, and pressing on the spring seat at D push the governor pin G to the right, thus actuating the bell crank L and cutting off a part of the flow of steam.

13.94 pounds per brake horse-power. These results compare most favorably with those of the highest type of reciprocating engines.

Ques. 727.—Since the steam is used in but a single stage or section of buckets in the De Laval turbine, why such good economy in the use of steam?

Ans.—The static energy in the steam as it enters the nozzles is converted into kinetic energy by its passage through the divergent nozzles, and the result is a greatly increased volume of steam leaving the nozzles at a tremendous velocity, but at a greatly reduced pressure—practically exhaust pressure—impinging against the buckets of the turbine wheel and thus causing it to revolve.

TABLE No. 11

CAPACITIES AND SPEED OF DE LAVAL TURBINES

Horse Power.	Revolutions Turbine Shaft.	Revolutions Main Shaft.	Approximate Weight, Pounds.
5	30,000	3,000	330
10	24,000	2,400	650
20	20,000	2,000	1,250
75	16,400	1,500	5,000
110	13,000	1,200	8,000
225	11,060	900	15,000
300	10,500	900	20,000

Ques. 728.—Describe in general terms the Curtis steam-turbine.

Ans.—The Curtis turbine is built by the General Electric Company at their works in Schenectady, N. Y., and Lynn, Mass. The larger sizes are of the vertical type, and those of small capacity are horizontal. In the vertical type the revolving parts are set upon a vertical shaft, the diameter of the shaft corresponding to the size of the machine. The shaft is supported by and runs upon a step-bearing at the bottom. This step-bearing consists of two cylindrical cast-iron plates bearing upon each other and having a central recess between them into which lubricating oil is forced under pressure by a steam or electrically driven pump, the oil passing up from

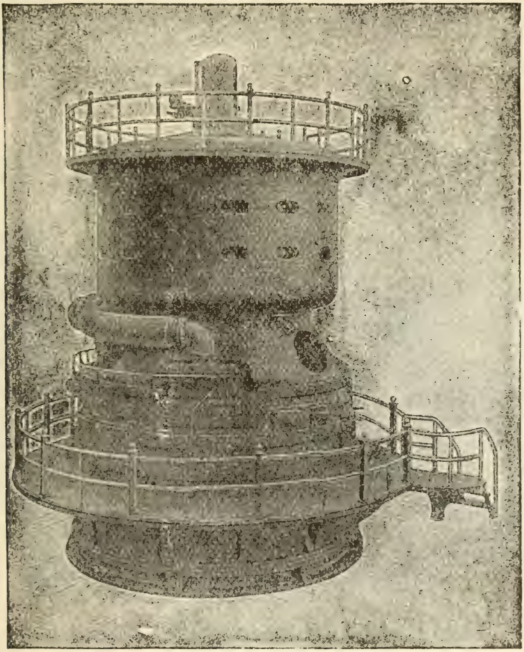


FIG. 193. 5,000 K. W. CURTIS STEAM TURBINE DIRECT CONNECTED TO 5,000 K. W. THREE-PHASE ALTERNATING CURRENT GENERATOR.

beneath. A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step-bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as the step-bearing pumps have proven, after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings, one just above the step, one between the turbine and generator, and the other near the top. These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end-thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum. The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades, bolted to the inner walls of the cylinder or casing.

Ques. 729.—What is the diameter of the vertical shaft for a 5,000 kilowatt turbine and dynamo?

Ans.—Fourteen inches.

Ques. 730.—How is the heat energy in the steam imparted to the wheel of the Curtis turbine?

Ans.—Both by impulse and reaction. The steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine the steam enters the initial set of nozzles at boiler-pressure, say 180 pounds. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 pounds, from which it further expands to atmospheric pressure in passing

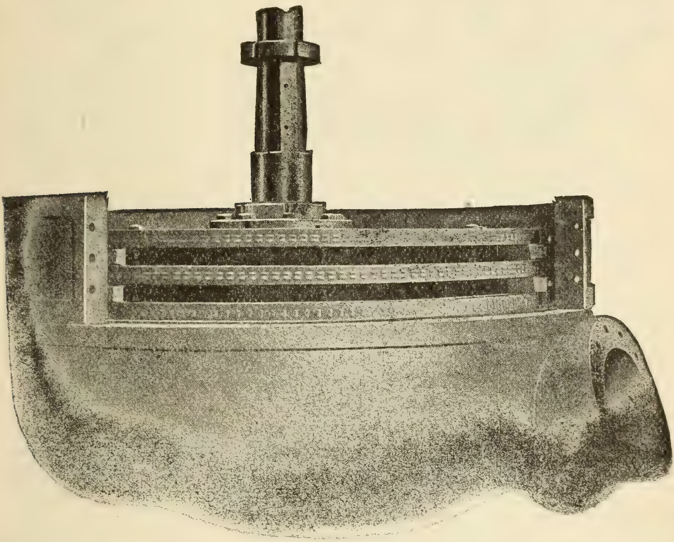


FIG. 194. ONE STAGE OF A 500 K. W. CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION.

through the wheels and intermediates. From the pressure in the first stage the steam again expands through the larger area of the second stage nozzles to a pressure slightly greater than the condenser vacuum at the entrance to the second set of moving blades, against which it now impinges and passes through, still doing work, due to velocity and mass. From this stage the steam passes to the condenser. If the turbine is a four-stage machine and the initial pressure is 180 pounds, the pressure at the different stages would be distributed in

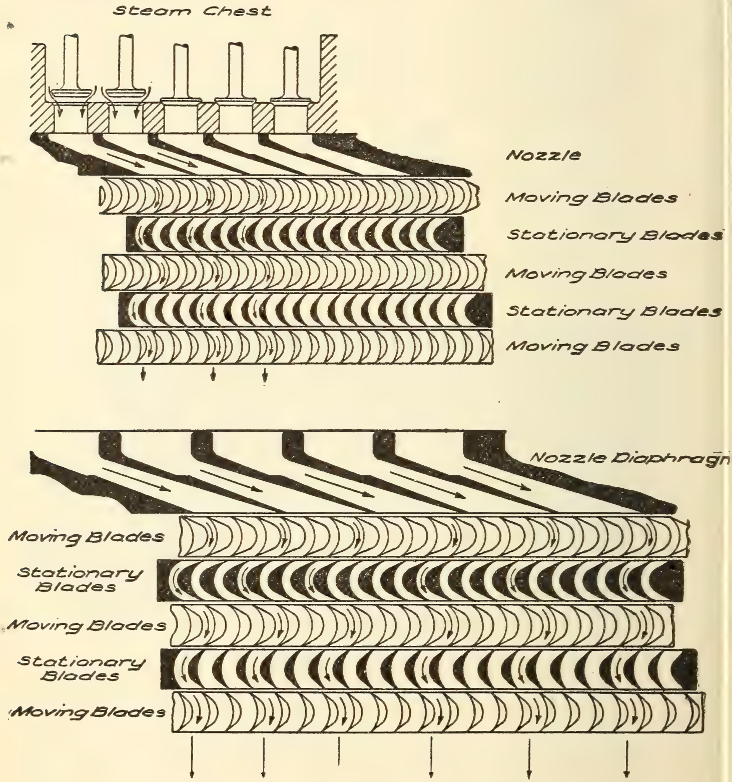


FIG. 195.

Diagram of the nozzles, moving blades and stationary blades of a two-stag Curtis steam turbine. The steam enters the nozzle openings at the top, controlled by the valves shown, two of the valves are open, and the course of the steam through the first stage is indicated by the arrows.

about the following manner: Initial pressure, 180 pounds; first stage, 50 pounds: second stage, 5 pounds:

third stage, partial vacuum, and fourth stage, condenser vacuum.

Ques. 731.—What are the diameters of the wheels?

Ans.—The diameters of the wheels vary according to the size of the machine, that of a 5,000 kilowatt unit being 13 feet.

Ques. 732.—What amount of clearance is there between the revolving and stationary blades?

Ans.—The clearance between the revolving and stationary blades is from $\frac{1}{32}$ to $\frac{1}{16}$ inch, thus reducing the wastage of steam to a very low percentage.

Ques. 733.—Describe the action of the steam in a two-stage Curtis turbine.

Ans.—The steam enters the nozzle openings at the top through valves that are controlled by the governor. After passing successively through the different sets of moving blades and stationary blades in the first stage, the steam passes into the second steam-chest. The flow of steam from this chamber to the second stage of buckets is also controlled by valves, but the function of these valves is not in the line of speed-regulation, but for the purpose of limiting the pressure in the stage-chambers, in a manner somewhat similar to the control of the receiver pressure in a two-cylinder or three-cylinder compound reciprocating engine. The valves controlling the admission of steam to the second and later stages differ from those in the first group in that they partake more of the nature of slide-valves and may be operated either by hand or automatically; in fact, they require but very little regulation, as the governing is always done by the live-steam admission-valves. As previously stated, the steam first strikes the moving blades in the first stage of a two-stage machine at a pressure of about 15 pounds

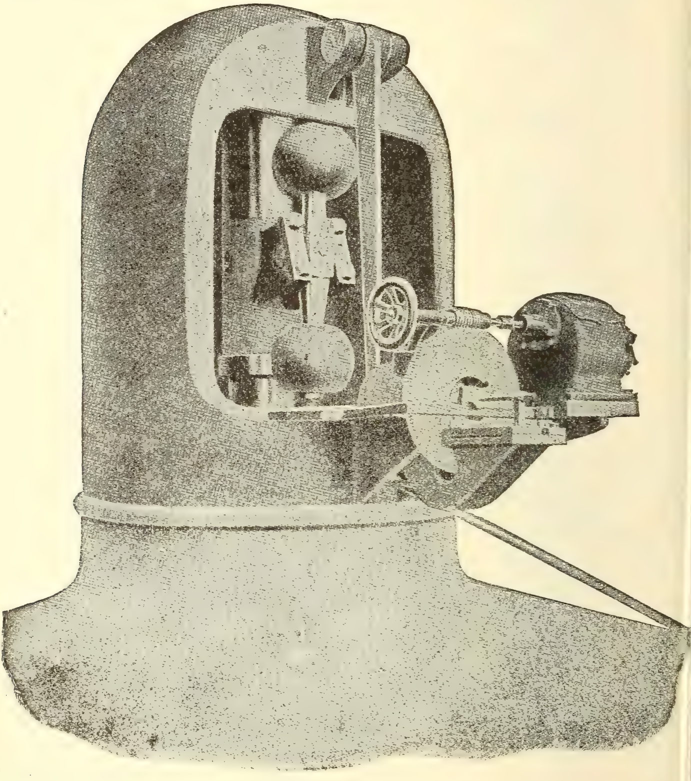


FIG. 196. GOVERNOR FOR 5,000 K. W. TURBINE.

above atmospheric pressure, but with great velocity. From this wheel it passes to the set of stationary blades between it and the next lower wheel. These stationary blades change the direction of flow of the steam and cause it to impinge against the buckets of the second wheel at the proper angle.

Ques. 734.—How is speed-regulation accomplished in the Curtis steam turbine?

Ans.—The governing of speed is accomplished in the first set of nozzles, and the control of the admission-valves here is effected by means of a centrifugal governor attached to the top end of the shaft. This governor, by

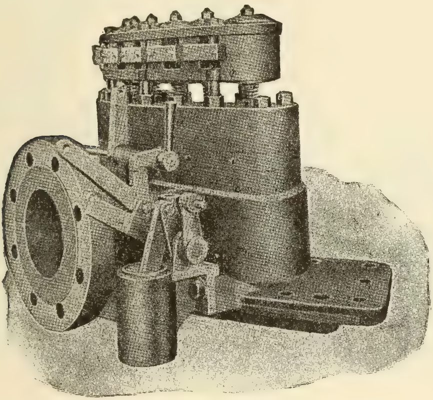


FIG. 197. ELECTRICALLY OPERATED VALVE.

a very slight movement, imparts motion to levers, which in turn work the valve mechanism. The admission of steam to the nozzles is controlled by piston-valves which are actuated by steam from small pilot-valves which are in turn under the control of the governor. Speed-regulation is effected by varying the number of nozzles in flow, that is, for light loads fewer nozzles are open and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges against the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

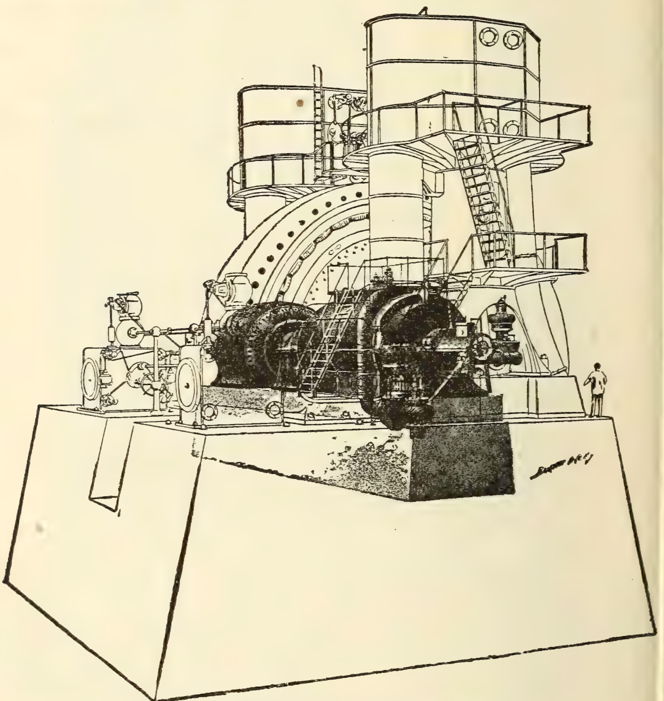


FIG. 198. 5,000 KILOWATT GENERATING UNITS.

Comparison of space occupied and size of foundations. Modern Engine Type Unit and a Westinghouse-Parsons Turbine Type Unit of similar rating and overload capacity.

Ques. 735.—What great advantage does the steam-turbine as a prime mover for an electric generator possess over the reciprocating engine?

Ans.—The advantage of a high speed of revolution.

whereby there can be a great reduction in the size, weight, and cost of the direct-driven generator.

Ques. 736.—Give approximately the over-all dimensions of a Westinghouse-Parsons turbo-generator unit of 5,500-kilowatt, 11,000 volt capacity, of the revolving field type, speed 750 revolutions per minute, vacuum to be 27½ inches.

Ans.—Length 47 feet, width 13 feet, and height 14 feet to top of gallery-ring.

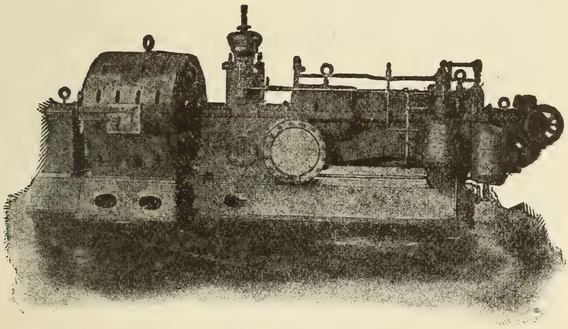


FIG. 199. GENERAL VIEW OF A 400 K. W. TURBINE GENERATOR UNIT.

Ques. 737.—What amount of floor-space would a reciprocating engine and direct-connected generator of equal capacity with the above occupy?

Ans.—The generator would be 42 feet in extreme diameter, its weight would be 445 tons (speed to be 75 revolutions per minute) and it, together with the four-cylinder piston engine, would fill a space 40 feet wide by 60 feet long, and tower 45 feet in height.

Ques. 738.—Describe in general terms the construction and principles of operation of the Westinghouse-Parsons steam-turbine.

Ans.—The Westinghouse-Parsons steam-turbine is fundamentally based upon the invention of Mr. Charles A. Parsons, who, while experimenting with a reaction turbine constructed along the lines of Hero's engine, conceived the idea of combining the two principles, reaction

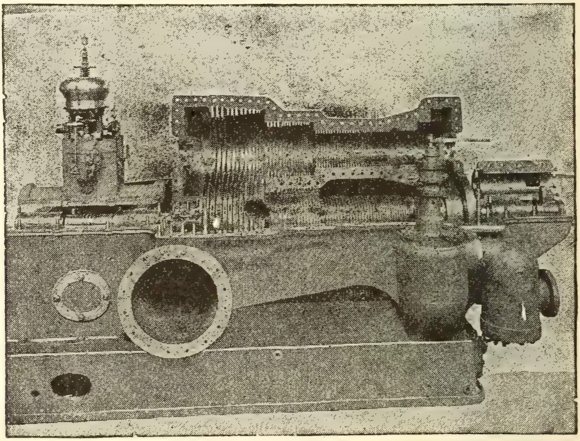


FIG. 200. Shows a 600 H. P. machine with the upper half of the cylinder, or stator as it is termed, thrown back for inspection.

and impulse, and also of causing the steam to flow in a general direction parallel with the shaft of the turbine. This principle of parallel flow is common to all four types of turbines, but is perhaps more prominent in the Westinghouse-Parsons and less so in the De Laval. The cylinder, or stator, as it is termed, is divided longitudinally into an upper and a lower half flanged and bolted together. There are three sections or drums, gradually increasing in diameter from the inlet to the third and last group of blades. This arrangement may be likened in some measure to the triple-compound reciprocating engine.

Ques. 739.—Describe the arrangement of the blades or buckets in the Westinghouse-Parsons steam-turbine.

Ans.—There are two kinds of blades, viz., stationary blades and moving blades, but they are similar in shape, being of the same curvature. These blades are made of hard drawn material, and are set into their places and secured by a caulking process. The stationary blades project from the inside surface of the cylinder, while similar rows of moving blades project from the surface of the rotor, or revolving drum. When the upper half of the cylinder is in position each row of stationary blades fits in between two corresponding rows of moving blades.

Ques. 740.—Are these blades all of the same length?

Ans.—They are not. The length varies from ½ inch for the shortest to 7 inches for the longest, according to their location. The shortest blades are placed at the steam end of each section and the longest blades are placed at the opposite end.

Ques. 741.—What is the clearance between the blades as they stand in the rows?

Ans.—The clearance between the blades as they stand in the rows is ⅛ inch for the smallest size blades and ½ inch for the larger ones, gradually increasing from the inlet to the exhaust. In the 5,000 kilowatt machine the clearance at the exhaust end between the rows of blades is 1 inch.

Ques. 742.—What is the general direction taken by the steam in its passage through the Westinghouse-Parsons turbine?

Ans.—The steam entering at the smaller end of the cylinder presses first against the shortest blades and then passes on through in the form of spiral or screw line about the rotor, continually pressing against new and gradually lengthening blades, thus doing work by reason of its velocity.

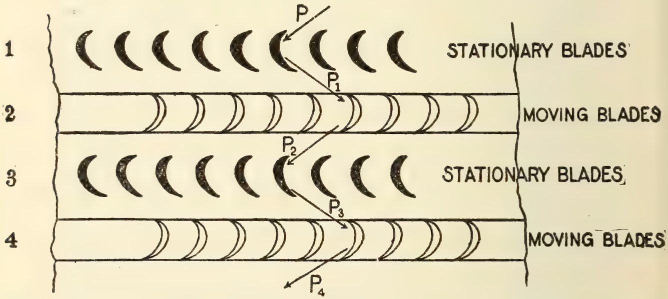


FIG. 201. SECTIONAL VIEW OF FOUR ROWS OF BLADES, OF A WESTINGHOUSE-PARSONS TURBINE.

Ques. 743.—As steam presses equally in all directions, is there not a very heavy end-thrust exerted by the rotor?

Ans.—There is not. The pressure in either direction is perfectly balanced by means of balancing pistons placed on the steam end of the rotor. The diameters of these pistons correspond to the diameters of the different drums or sections.*

Ques. 744.—About what is the velocity of the steam in the Parsons turbine?

*The theory and action of these balancing pistons is fully and completely described in Swingle's "Twentieth Century Hand Book for Engineers and Electricians."

Ans.—The highest velocity does not exceed 600 feet a second.

Ques. 745.—About what amount of pressure is exerted upon each blade by the steam?

Ans.—The steam-thrust on each blade is said to be equal to about 1 ounce avoirdupois.

Ques. 746.—With such a very light pressure upon

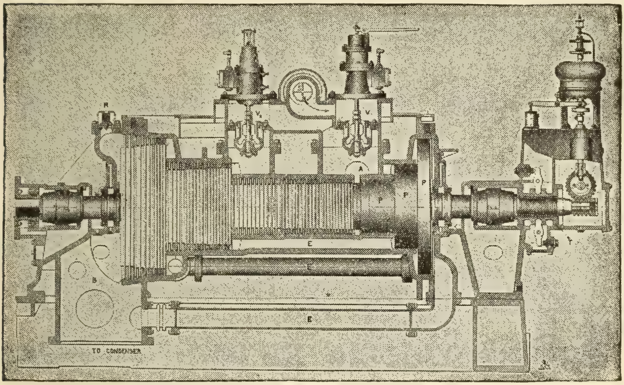


FIG. 202. SECTIONAL VIEW OF A WESTINGHOUSE-PARSONS TURBINE, SHOWING ARRANGEMENT OF BALANCING PISTONS P. P. P.

each blade, why is it that this turbine is capable of developing power?

Ans.—Because of the large number of blades; as, for instance, taking a 400 kilowatt machine, there are 16,095 moving blades and 14,978 stationary blades, a total of 31,073.

Ques. 747.—How are the clearances preserved?

Ans.—A rigid shaft and thrust or adjustment bearing accurately preserves the clearances.

Ques. 748.—Describe the construction and action of the bearings.

Ans.—The bearings are constructed along lines differing from those of the ordinary reciprocating engine. The bearing proper is a gun-metal sleeve that is prevented from turning by a loose-fitting dowell. Outside of this sleeve are three concentric tubes having a small clearance between them. This clearance is kept constantly filled with oil supplied under light pressure, which permits a vibration of the inner shell or sleeve and at the same time tends to restrain or cushion it. This arrangement allows the shaft to revolve about its axis of gravity instead of the geometrical axis, as would be the case if the bearing were of the ordinary construction. The journal is thus to a certain degree a floating journal, free to run slightly eccentric according as the shaft may happen to be out of balance.

Ques. 749.—How is the power of the Westinghouse-Parsons turbine transmitted to the dynamo, or other machine to be run?

Ans.—A flexible coupling is provided, by means of which the power of the turbine is transmitted to the dynamo or other machine it is intended to run. The oil from all the bearings drains back into a reservoir, and from there it is forced up into a chamber, where is forms a static head, which gives a constant pressure of oil on all the bearings.

Ques. 750.—How is the speed governed?

Ans.—The speed of the Westinghouse-Parsons turbine is regulated by a fly-ball governer constructed in such manner that a very slight movement of the balls serves to produce the required change in the supply of steam. The ball levers swing on knife edges instead of pins. The governor works both ways, that is to say, when the levers are oscillating about their mid position a head of steam corresponding to full load is being admitted to the turbine, and a movement from this point, either up or down, tends to increase or to decrease the supply of steam.

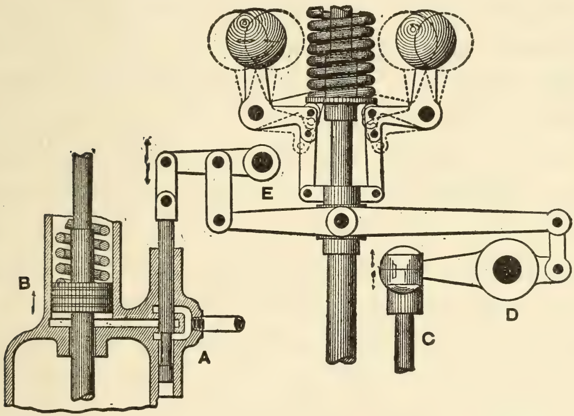


FIG. 203. SECTION OF WESTINGHOUSE-PARSONS TURBINE GOVERNOR.

Ques. 751.—What can be said of the efficiency of the Westinghouse-Parsons steam-turbine?

Ans.—Under test a 400 kilowatt Westinghouse-Parsons steam-turbine, using steam at 150 pounds initial pressure and superheated about 180 degrees, consumed 11.17 pounds of steam per brake horse-power hour at full load. The speed was 3,550 revolutions per minute and the vacuum was 28 inches. With dry saturated steam the consumption was 13.5 pounds per brake horse-power hour at full load, and 15.5 pounds at one-half load. A 1,000 kilowatt machine, using steam of 150 pounds pressure and superheated 140 degrees, exhausting into a vacuum of 28 inches, showed the very remarkable economy of 12.66 pounds of steam per electrical horse-power per hour. A 1,500 kilowatt Westinghouse-Parson turbine, using dry saturated steam of 150 pounds pressure with 27 inches vacuum, consumed 14.8 pounds steam per electrical horse-power hour at full load, and 17.2 pounds at one-half load.

Ques. 752.—What efficiency does the Curtis turbine show in the use of steam?

Ans.—A 600 kilowatt Curtis turbine operating at 1,500 revolutions per minute, with steam at 140 pounds gauge-pressure and 28.5 inches vacuum, showed a steam-consumption as follows, steam superheated 150 degrees: At full load, 12.5 pounds per electrical horse-power per hour; at half load, 13.25 pounds per electrical horse-power per hour; at one-sixth load, 16.2 pounds per electrical horse-power per hour, and at one-third overload, 12.4 pounds per electrical horse-power per hour.

Ques. 753.—Describe in brief terms the Hamilton-Holzwarth steam-turbine.

Ans.—The Hamilton-Holzwarth steam-turbine is based upon and has been developed from the designs of Prof. Rateau, and is being manufactured in this country by the Hooven-Owens-Rentschler Company, of Hamilton, Ohio. It is horizontal and placed upon a rigid bed-plate of the box pattern. All steam, oil and water-pipes are within and beneath this bed-plate, as are also the steam-inlet-valve and the regulating and by-pass valves. The smaller sizes of this turbine are built in a single casing or cylinder, but for units of 750 kilowatts and larger the revolving element is divided into two parts, high and low pressure. This turbine resembles the Westinghouse-Parsons turbine in some respects, prominent of which is that it is a full-stroke turbine, that is, that the steam flows through it in one continuous belt or veil in screw line, the general direction being parallel with the shaft. But, unlike the Parsons type, the steam in the Hamilton-Holzwarth turbine is made to do its work only by impulse, and not by impulse and reaction combined. It might thus be termed an action turbine.

Ques. 754.—Describe the interior construction of this turbine.

Ans.—The interior of the cylinder is divided into a series of stages by stationary disks which are set in grooves in the cylinder and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore. There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. Between each two stationary disks there is located a running wheel, and the clearance between the running vanes and the stationary vanes is made as slight as is consistent with safe practice.

Ques. 755.—Describe the construction of the running vanes and the action of the steam upon them.

Ans.—The running vanes conform in section somewhat to the Parsons type, but the action of the steam upon them and also within the stationary vanes is different. The expansion of the steam and consequent development of velocity takes place entirely within the stationary vanes, which also change the direction of flow of the steam and distribute it in the proper manner to the vanes of the running wheels, which, according to the claims of the makers, the steam enters and leaves at the same pressure, thus allowing the wheel to revolve in a uniform pressure.

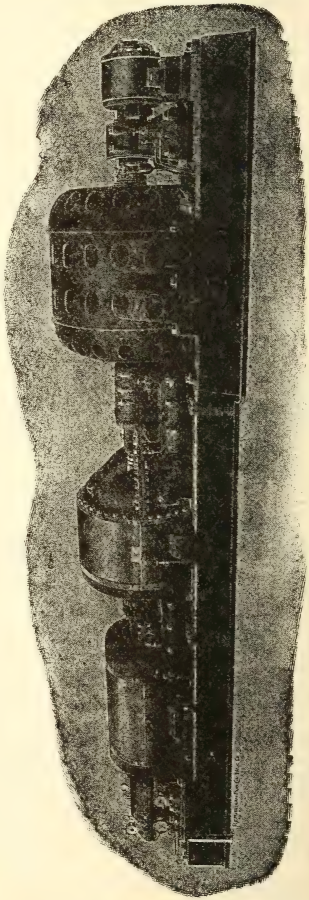


FIG. 204. GENERAL VIEW OF A HAMILTON-HOLZWARTH STEAM-TURBINE.

Ques. 756.—What provision is made in the Hamilton-Holzwarth turbine for maintaining the velocity of the steam as it expands?

Ans.—The first stationary disk of the low-pressure turbine has guide-vanes all around its circumference, so that the steam enters the turbine in a full cylindrical belt, interrupted only by the guide-vanes. To provide for the increasing volume as the steam expands in its course through the turbine, the areas of the passages through the distributers and running vanes must be progressively enlarged. The gradual increase in the dimensions of the stationary vanes permits the steam to expand within them, thus tending to maintain its velocity, while at the same time the vanes guide the steam under such a small angle that the force with which it impinges against the vanes of the next running wheel is as effective as possible. The curvature of the vanes is such that the steam while passing through them will increase its velocity in a ratio corresponding to its operation.

Ques. 757.—Describe the method of regulating the speed of this turbine.

Ans.—The governor is of the spring and weight type, adapted to high speed, and is designed especially for turbine governing. It is directly driven by the turbine-shaft, revolving with the same angular velocity. Its action is as follows: Two disks keyed to the shaft, drive, by means of rollers, two weights sliding along a cross-bar placed at right angles through the shaft and compressing two springs against two nuts on the cross-bar. Every movement of the weights, caused by increasing or decreasing the angular velocity of the turbine-shaft, is transmitted by means of levers to a sleeve which actuates the regulating mechanism. These levers are balanced so that no back pressure is exerted upon the weights. The whole governor is closed in by the disks, one on each side, and a steel ring secured by concentric recesses to the disks. In order to decrease the friction within the governor and regulating mechanism, thrust ball-bearings and frictionless roller-bearings are used.

Ques. 758.—Describe the action of the steam within the Hamilton-Holzwarth steam-turbine.

Ans.—After leaving the steam-separator that is located beneath the bed-plate, the steam passes through the inlet or throttle-valve, the stem of which extends up through the floor near the high-pressure casing and is protected by a floor-stand and equipped with a hand wheel. The steam now passes through the regulating valve, which will be described later on. From this valve it is led through a curved pipe to the front head of the high-pressure casing or cylinder. In this head is a ring channel into which the steam enters, and from whence it flows through the first set of stationary vanes.

Ques. 759.—Describe the action of the steam as it passes through the first set of stationary vanes.

Ans.—In these vanes the first stage of expansion occurs, the velocity of the flow is accelerated, and the direction of flow is changed by the curve of the vanes in such manner that the steam impinges against the vanes of the first running wheel at the proper angle and in a full cylindrical belt, imparting by impulse a portion of its energy to the wheel.

Ques. 760.—What takes place in the course of the steam after leaving the first running wheel?

Ans.—Passing through the vanes of this wheel, the steam immediately enters the vanes of the second stationary disk, which are larger in area than those of the first, and here occurs the second stage of expansion, another acceleration of velocity, and also the proper change in direction, and the steam leaves this distributer and impinges against the vanes of the second running wheel. This cycle is repeated throughout the several stages of the turbine, a certain percentage of the heat energy in the steam being imparted by impulse to each wheel and thence to the turbine-shaft. From the last running wheel the steam is led through receiver pipes to the front head of the low-pressure cylinder, or, if there is but one cylinder, directly to the condenser or the atmosphere.

Ques. 761.—Describe the construction and location of the regulating valve.

Ans.—The regulating valve is located beneath the bed-plate. One side of it is connected by a curved pipe with the front head of the high-pressure cylinder and the other side is connected with the inlet-valve. The regulating valve is of the double-seated poppet-valve type. Valves and valve-seats are made of tough cast steel, to avoid corrosion as much as possible, and the valve-body is made of cast iron.

Ques. 762.—Describe the by-pass regulating valve.

Ans.—This valve is also a double-seated poppet-valve and is located immediately below the regulating valve and forming a part of it. Thus the use of a second stuffing box for the stem of this valve is avoided. The function of this valve is to control the volume of the live-steam supply that flows directly to the by-pass nozzles in the front head of the low-pressure casing.

Ques. 763.—How is the main regulating valve operated?

Ans.—The main regulating valve is not actuated directly by the governor, but by means of the regulating mechanism.

Ques. 764.—Describe the construction and operation of the regulating mechanism of the Hamilton-Holzwarth steam-turbines.

Ans.—The construction and operation of this regulating mechanism is as follows: The stem of the regulating valve is driven by means of bevel gears by a shaft that is supported in frictionless roller-bearings. On this shaft there is a friction wheel that the governor can slide across the face of a continuously revolving friction disk by means of its sleeve and bell-crank lever. This revolving disk is keyed to a solid shaft which is driven by a coupling from a hollow shaft. This hollow shaft is driven by the turbine-shaft through the medium of a worm gear. The solid shaft, with the continuously revolving friction disk, can be slightly shifted by the governor sleeve so that the two friction disks come into contact when the sleeve moves, that is, when the angular velocity changes. If this change is relatively great, the sleeve will draw the periodically revolving friction disk far from the center of the always revolving one, and this disk will quickly drive the stem of the regulating valve and the flow of steam will thus be regulated. As soon as the angular velocity falls below a certain percentage of the normal speed, the driving friction disk is drawn back by the governor, the regulating valve remains open and the whole regulating mechanism rests or stops, although the shaft is still running.

Ques. 765.—Under what conditions will this governor shut down the turbine?

Ans.—Should the angular velocity of the shaft reach a point 2.5 per cent higher than normal, the governor will shut down the turbine. If an accident should happen to the governor, due to imperfect material or breaking or weakening of the springs, the result would be a shut-down of the turbine.

Ques. 766.—How may the speed of this turbine be changed, while running, if necessary?

Ans.—In order to change the speed of the turbine while running, which might be necessary in order to run the machine parallel with another prime mover, a spring balance is provided, attached to the bell-crank lever of the regulating mechanism. The hand-wheel of this spring balance is outside of the pedestal for regulating mechanism and near the floor-stand and hand-wheel. With this spring balance the speed of the turbine may be changed 5 per cent either way from normal.

Ques. 767.—What is the best method of disposing of the exhaust steam of steam-turbines?

Ans.—As in the case of the reciprocating engine, the highest efficiency in the operation of the steam-turbine is obtained by allowing the exhaust steam to pass into a condenser, and experience has demonstrated that it is possible to maintain a higher vacuum in the condenser of a turbine than in that of a reciprocating engine. This is due, no doubt, to the fact that in the turbine the steam is expanded down to a much lower pressure than is possible with the reciprocating engine.

Ques. 768.—What type of condensing apparatus is best adapted to steam-turbines?

Ans.—The condensing apparatus used in connection with steam-turbines may consist of any one of the modern improved systems, and as no cylinder-oil is used within the cylinder of the turbine, the water of condensation may be returned to the boilers as feed-water. If the condensing water is foul or contains matter that would be injurious to the boilers, a surface condenser should be used. If the water of condensation is not to be used in the boilers, the jet system may be employed.

Ques. 769.—What percentage of gain may be effected by allowing the exhaust steam from the turbine to pass into a good condenser?

Ans.—As an instance of the great gain in economy effected by the use of the condenser in connection with the steam-turbine, a 750 kilowatt Westinghouse-Parsons turbine, using steam of 150 pounds pressure, not superheated and exhausting into a vacuum of 28 inches, showed a steam consumption of 13.77 pounds per brake horse-power per hour, while the same machine operating non-condensing consumed 28.26 pounds of steam per brake horse-power hour. Practically the same percentage in economy effected by condensing the exhaust applies to the other types of steam-turbines.

Ques. 770.—About what is the additional cost of operating a complete condensing outfit in connection with a steam-turbine plant?

Ans.—With reference to the relative cost of operating the several auxiliaries necessary to a complete condensing outfit, the highest authorities on the subject place the power consumption of these auxiliaries at from 2 to 7 per cent of the total turbine output of power. A portion of this is regained by the use of an open heater for the feed-water, into which the exhaust steam from the auxiliaries may pass, thus heating the feed-water and returning a part of the heat to the boilers.

Ques. 771.—What precautions must be observed in the operation of a condensing outfit in order to obtain the highest efficiency?

Ans.—A prime requisite to the maintenance of high vacuum, with the resultant economy in the operation of the condensing apparatus, is that all entrained air must be excluded from the condenser. There are various ways in which it is possible for air to find its way into the condensing system. For instance, there may be an improperly packed gland, or there may be slight leaks in the piping, or the air may be introduced with the condensing water. This air should be removed before it reaches the condenser, and it may be accomplished by means of the "dry" air-pump.

Ques. 772.—Describe some of the leading characteristics of the dry air-pump.

Ans.—This dry air-pump is different from the ordinary air-pump that is used in connection with most condensing systems. The dry air-pump handles no water, the cylinder being lubricated with oil in the same manner as the steam-cylinder. The clearances also are made as small as possible. These pumps are built either in one or two stages.

Ques. 773.—What particular features would be required in the design of a compound or stage-expansion reciprocating engine, in order to develop a high vacuum, for instance as high as 28.5 inches?

Ans.—In comparing the efficiency of the reciprocating engine and the steam-turbine it is not to be inferred that reciprocating engines would not give better results at high vacuum than they do at the usual rate of 25 to 26 inches, but to reach and maintain the higher vacuum of 28 to 28.5 inches with the reciprocating engine would necessitate much larger sizes of the low-pressure cylinder, as also the valves and exhaust pipes, in order to handle the greatly increased volume of steam at the low-pressure demanded by high vacuum.

Ques. 774.—What advantage has the turbine over the reciprocating engine, in the disposal of its exhaust steam?

Ans.—The steam-turbine expands its working steam to within 1 inch of the vacuum existing in the condenser, that is, if there is a vacuum of 28 inches in the condenser there will be 27 inches of vacuum in the exhaust end of the turbine cylinder. On the other hand, there is usually a difference of 4 or 5 inches (2 to 2.5 pounds) between the mean back pressure in the cylinder of a reciprocating condensing engine and the absolute back pressure in the condenser.

Ques. 775.—Mention the two principal sources of economy that the steam-turbine possesses in a high degree.

Ans.—Two of the main sources of economy that the steam-turbine possesses in a much higher degree than does the reciprocating engine are: First, its adaptability for using superheated steam, and second, the possibility of maintaining a higher degree of vacuum.

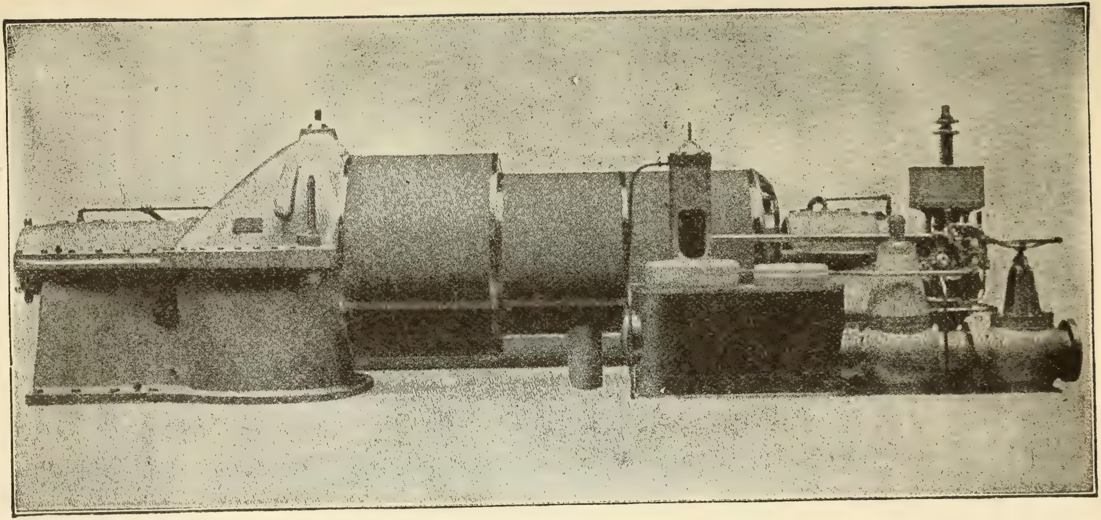


FIG. 205. THE ALLIS CHALMERS STEAM TURBINE.

Ques. 776.—What can be said of the steam turbine, regarding friction of rubbing parts, such as reciprocating pistons, cross-heads, etc?

Ans.—There are no rubbing surfaces in the turbine except the bearings of the rotor.

Ques. 777.—Of what type is the Allis Chalmers steam-turbine?

Ans.—It is of the reaction, or Parsons type, with a number of modifications in details of construction.

Ques. 778.—Give an elementary description of the "Parsons" steam-turbine.

Ans.—It consists essentially of a fixed casing, or cylinder, usually arranged in three stages of different diameters, that of the smallest diameter being at the high-pressure, or admission end, and that of the largest diameter at the low-pressure or exhaust end of the casing.

Inside of this casing is a revolving drum, or rotor, the ends of which are extended in the form of a shaft, and carried in two bearings, just outside each end of the cylinder.

Ques. 779.—What causes the drum to revolve within the cylinder?

Ans.—The drum is fitted with a large number of small curved blades, or paddles arranged in straight rows around its circumference. The blades in each stage, or step, are also arranged in groups of increasing length, those at the beginning of each larger stage being shorter than those at the end of the preceding stage, the change being made in such a manner that the correct relation of blade length to drum diameter is secured. These rows of revolving blades fit in and run between corresponding rows of stationary blades that project from the walls of the cylinder. These stationary blades have the same curvature as the revolving blades, but are set so that the curves incline in the opposite direction to those of the revolving blades. The steam entering the cylinder at the smallest or first stage, is deflected in its course by the first row of stationary blades, and immediately impinges with a pressure but slightly reduced from boiler pressure, against the first row of revolving blades. It then passes

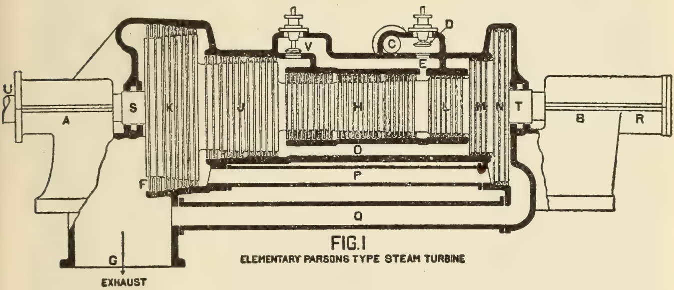


Fig. 206.

Main bearings, A and B. Thrust bearing, R. Steam pipe, C. Main throttle valve, D, which is balanced, and operated by the governor. Steam enters the cylinder through passage E, passes to the left through the alternate rows of stationary and revolving blades, leaving the cylinder at F and passes into the condenser, or atmosphere through passage G. H, J and K are the three steps or stages of the machine. L, M and N are the three balance pistons. O, P and Q are the equalizing passages, connecting the balance pistons with the corresponding stages.

to the next row of stationary blades, which again deflect its course so as to cause it to strike the next row of moving blades at the proper angle. Thus the continual pressure and reaction of the steam against the curved surfaces of the moving blades causes the drum, or rotor to revolve.

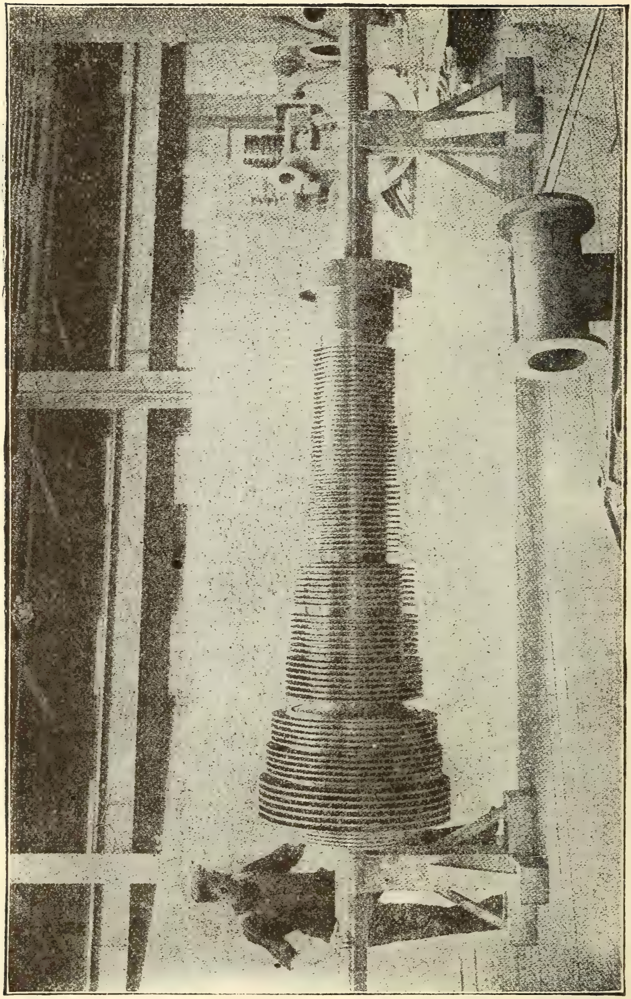


FIG. 207. SPINDLE OR ROTOR, ALLIS CHALMERS STEAM TURBINE.
The rings which carry the blades are pressed on.

Ques. 780.—Does not the action of the steam against the revolving blades tend to produce a strong end thrust?

Ans.—It does—but this thrust is neutralized by three "balance-pistons" so called, which are fitted upon the revolving drum at the high-pressure end of the cylinder. The diameter of each "piston" corresponds with the diameter of that stage of the cylinder with which it is connected by an equalizing passage which permits the steam to act upon it, and thus balance the thrust.

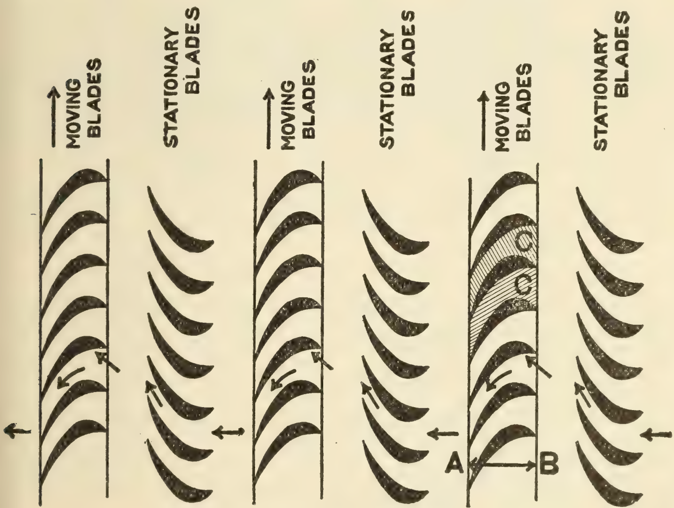


Fig. 208.

Fig. 208 showing arrangement of blading and course of the steam in Parsons steam turbine.

Ques. 781.—Do the revolving blades come in contact with the stationary parts?

Ans.—They do not. The high speeds which are necessary in the steam turbine prohibit any continuous contact between moving and stationary parts, except in the lubricated bearings.

Ques. 782.—How much clearance is allowed between the moving and stationary parts in the "Parsons" steam-turbine?

Ans.—The tips of the revolving blades just clear the walls of the cylinder, and the tips of the stationary blades just clear the surface of the rotor.

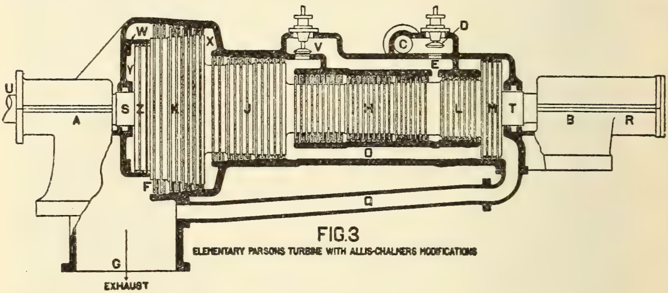


FIG. 209.

Sectional view of elementary Parsons steam turbine, with Allis Chalmers modifications. L and M are the two balance pistons at the high pressure end. Z is a smaller balance piston placed in the low pressure end, yet having the same effective area as did the larger piston N shown in Fig. 206. O and Q are the two equalizing passages for pistons L and M. Passage P is omitted in this construction and balance piston Z is equalized with the third stage pressure at Y. Valve V is a by-pass valve to allow of live steam being admitted to the second stage of the cylinder in case of a sudden overload. This by-pass valve is the equivalent of the by-pass valve used to admit live steam to the low pressure cylinder of a compound reciprocating engine. Valve V is arranged to be operated, either by the governor or by hand, as the conditions may require. Frictionless glands made tight by water packing are provided at S and T where the shaft passes out of the cylinder. The shaft is extended at U and connected to the generator shaft by a flexible coupling.

Ques. 783.—How are the clearances between the edges of the revolving and stationary blades preserved?

Ans.—The position of the drum, as regards end play, is definitely fixed by means of a small "thrust bearing" provided inside the housing of the main bearing.

This so-called thrust bearing can be adjusted to locate, and hold the revolving spindle or rotor in such position as will allow sufficient clearance between the moving and stationary blades, and yet reduce the leakage of steam to a minimum.

Ques. 784.—Is there not danger of out leakage of steam, and in leakage of air, where the shaft passes out of the high and low-pressure ends of the cylinder?

Ans.—There is; but this is provided for by glands that are made practically frictionless by water packing, without metallic contact.

Ques. 785.—How is the power of the "Parsons" type of steam-turbine transmitted to the electric generator, or other machine to be run?

Ans.—The shaft is extended at the low-pressure end, and coupled to the shaft of the generator by means of a flexible coupling.

Ques. 786.—What provision is made in this type of steam-turbine for speed regulation?

Ans.—The speed of the "Parsons" turbine is regulated by a very sensitive governor driven from the turbine shaft by means of cut gears working in an oil bath. The governor operates a balanced throttle-valve, and may be adjusted for speed while the turbine is in motion if necessary for the synchronizing of alternators, and dividing the load.

Ques. 787.—Suppose there should be an accidental derangement of the governing mechanism, what provision is made for preventing dangerous over speed?

Ans.—A separate safety governor is provided, driven directly by the turbine shaft, without the intervention of gearing, and so adjusted that if the speed of the turbine should reach a predetermined point above that for which the main governor is set, the safety governor will come into action, and trip a valve, thus shutting off the steam, and stopping the turbine.

Ques. 788.—Is the arrangement of "balance-pistons" described in answer to question 780 carried out in all sizes of steam-turbines of the "Parsons" type?

Ans.—No. In the larger sizes of the Allis Chalmers steam-turbine, the largest one of the three pistons at the high-pressure end is replaced by a smaller balance-piston located at the low-pressure end of the turbine, and working inside a supplementary cylinder.

This piston presents the same effective area for the steam to act upon, as did the larger piston, because the working area of the latter in its original location consisted only of the annular area included between its periphery, and the periphery of the next smaller piston.

Ques. 789.—How is the pressure of the steam brought to bear upon this equalizing piston in its new position?

Ans.—By means of passages through the body of the rotor, connecting the third stage of the cylinder with the supplementary cylinder in which the piston revolves.

Ques. 790.—How are the blades or paddles fitted to, and held in the rotor, and cylinder of the Allis Chalmers steam-turbine?

Ans.—Each blade is individually formed by special machine tools, so that its root or foot is of an angular dove-tail shape, and at its tip there is a projection.

Foundation rings are provided for each row of blades.

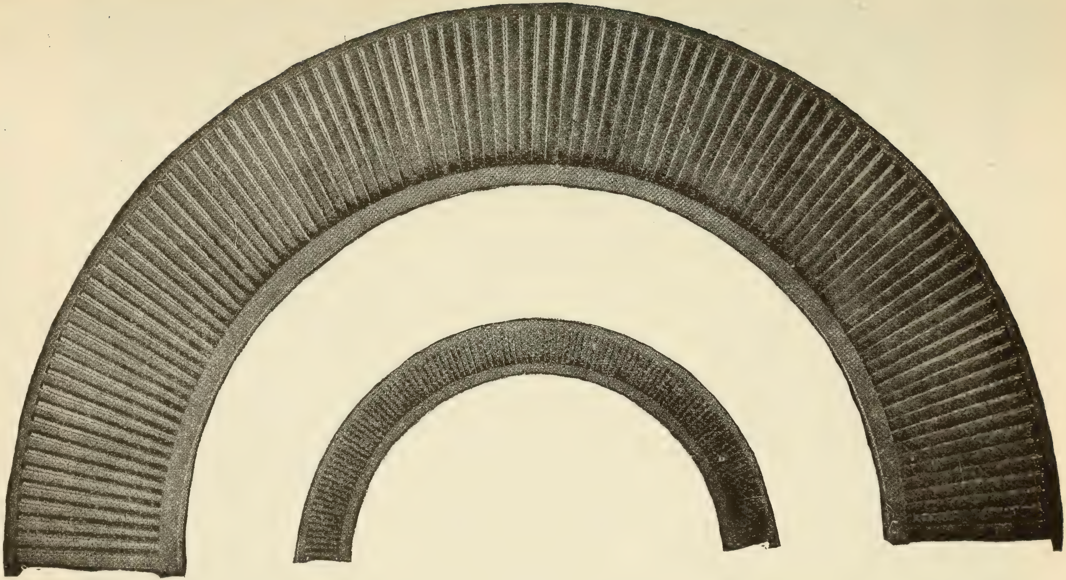


FIG. 210.

Half ring of blades inserted in the foundation ring before being placed upon the rotor, showing substantial construction.

These rings have slots of dove-tail shape cut into them to receive the roots of the blades. These slots are accurately spaced, and inclined so as to give the required pitch and angle to the blades. The foundation rings themselves are dove-tail in cross section, and are inserted in dove-tail grooves cut in the turbine cylinder, and rotor respectively. These rings are firmly held in place by key pieces that are driven into place, and upset into undercut grooves, thus locking the whole structure firmly together.

Ques. 791.—How are the tips or outer ends of the blades protected?

Ans.—By a shroud ring for each row, in which holes are punched to receive the projections on the tips of the blades.

These holes are spaced by special machinery to match the slots in the foundation ring.

Ques. 792.—Describe the construction of the shroud rings.

Ans.—They are channel shaped in cross section, and are made thin, so that in case of accidental contact with an opposing surface no dangerous heating will occur, neither will the rubbing be so liable to rip out the blades, as it is when they are unprotected by a shroud ring.

Ques. 793.—Mention another advantage in connection with the use of a shroud ring.

Ans.—The blades in each row are stiffened, and held together as a unit by its use, thus permitting smaller clearances, and reducing the leakage loss to a minimum. The channel shape of the shroud ring also forms an effective baffle to the steam leakage.

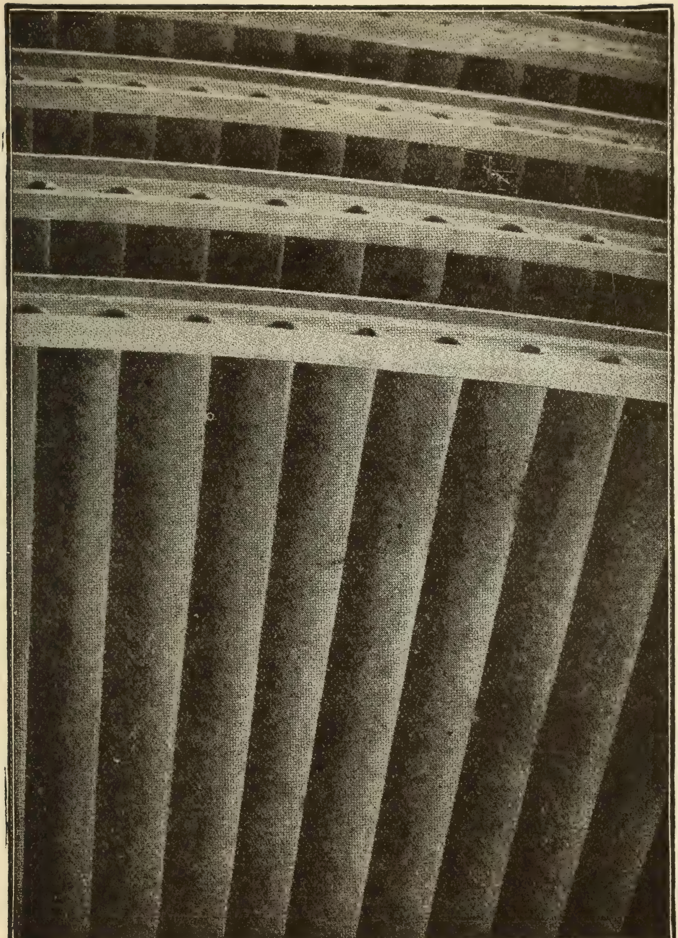


Fig. 211.

Fig. 211 illustrates blades as fitted in the rotor of Allis Chalmers steam turbine. The shroud ring protecting the tips of the blades is also shown.

Ques. 794.—What type of bearings are the Allis Chalmers steam-turbines fitted with?

Ans.—Self-adjusting ball and socket bearings especially designed for high speed, shims being provided for proper alignment.

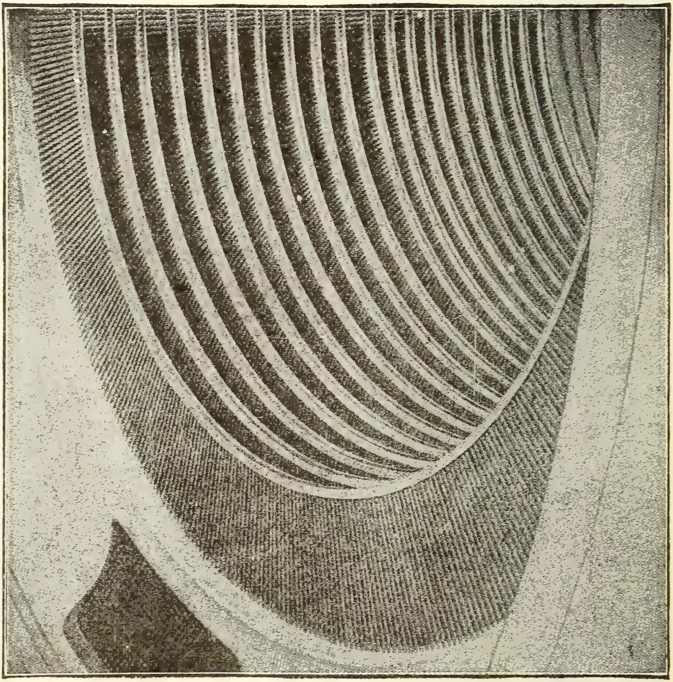


Fig. 212.

Fig. 212 shows a number of rows of stationary blades fitted in the cylinder of an Allis Chalmers steam turbine.

In the smaller sizes the bearing shells are made of special bronze, and in the larger sizes white metal is used for bearing surface.

Ques. 795.—How are these bearings lubricated?

Ans.—The oil is supplied freely to the middle of each bearing, and allowed to flow out at the ends, where it is caught, passed through a cooler, and pumped back to the bearings, to be used again and again.

Ques. 796.—Does the fact that the oil is supplied to the bearings in large quantities necessarily imply a heavy expenditure for oil?

Ans.—It does not; for the reason that the bearings practically float on oil films, thus preventing that "wearing out" of the oil which occurs when it is supplied in diminutive doses.

Ques. 797.—Can superheated steam be used to advantage in steam-turbines?

Ans.—It can; in fact the steam-turbine has solved the problem of superheated steam, owing to the absence of all rubbing parts exposed to the steam. This permits the use of steam of high temperature thus making it possible to realize the advantages of economical operation.

Ques. 798.—Is there not danger of distortion of the turbine cylinder being caused by the very high temperatures to which it is exposed by the use of superheated steam?

Ans.—There have been numerous instances in the past of unequal expansion of the top, and bottom of the cylinder thereby causing the rotating blades to come in contact with the cylinder walls, and be ripped out, but this difficulty has in a great measure been overcome by certain designers of steam-turbines, who have made a special study of the laws of expansion and contraction of metals, and have thus been enabled to make such a distribution of the metal, as to cause an equal expansion of all parts of the cylinder.

Ques. 799.—What effect does the accidental carrying over of water with the steam, have upon the steam-turbine?

Ans.—The sudden presence of a quantity of water with the steam, caused by foaming or priming of the boilers, would cause no more serious results than the slowing down of the turbine during the time necessary to permit the water to be discharged from the exhaust end.

Ques. 800.—What may be said in general of the steam-turbine?

Ans.—It has passed through the experimental stage, and has come to the front, as an efficient power producer, having a bright future before it.

DE LAVAL STEAM TURBINE.

CLASS C.

Ques. 801.—In what respect does the Class C De Laval Turbine differ mainly from the regulation type of De Laval Turbine referred to on pages 304 to 314?

Ans.—In the construction of the buckets, and guide vanes; also in the accessibility of the parts.

Ques. 802.—Describe the construction of the buckets in this type of steam Turbine.

Ans.—The buckets are made of nickel-bronze and are secured to the rim of the wheel by bulb shanks. They may also be replaced individually without disturbing other buckets.

Ques. 803.—Describe the construction of the guide vanes in the Class C Turbine.

Ans.—The guide vanes are of nickel-bronze, and are attached to steel retaining rings in the same manner as are the rotating buckets.

Ques. 804.—What can be said in favor of this method of attaching guide vanes, and buckets?

Ans.—It is superior to the common method of *casting* these important parts of the turbine in with a portion of the casing, or the rim of the wheel.

Ques. 805.—Give a reason for this.

Ans.—If guide vanes, or buckets that are cast in, should become corroded, and need replacing, it is necessary to replace a portion of the casing, or the wheel rim, in order to bring the turbine back to its original efficiency.

Ques. 806.—What amount of work is necessary in order to replace one, or more of these parts in the Class C De Laval Steam Turbine?

Ans.—See answer to question 802.

Ques. 807.—How are changes in boiler pressure, or in vacuum, provided for in the Class C Turbine?

Ans.—By simply replacing the nozzles by others designed for the new ratio of expansion.

Ques. 808.—Is this possible in turbines in which the nozzles are a permanent part of the main turbine structure?

Ans.—It is not.

Ques. 809.—How is the speed of the Class C De Laval Turbine controlled?

Ans.—Two governors are provided, one of which is called the emergency governor.

Ques. 810.—In what way may a turbine governor be rendered useless, and still retain all its parts unbroken?

Ans.—By the valves becoming clogged with scale, waste or other foreign matter.

Ques. 811.—What special provision does this type of steam turbine possess for the prevention of accidents in case the emergency governor should fail?

Ans.—The wheel itself is designed to withstand the highest speed, and in addition to this precaution, the entire wheel is encircled by a steel ring which would effectually prevent the penetration of detached parts.

Ques. 812.—How may the rotating parts of the De Laval Class C Turbine be removed entirely from the casing when repairs are necessary?

Ans.—By lifting the casing cover, and loosening and removing the bearing caps of the shaft.

Ques. 813.—Why is it possible to maintain indefinitely a high steam economy with this type of steam turbine?

Ans.—This is due to the fact that provision is made for the easy and quick replacement of those parts subject to wear.

Ques. 814.—Is the Type C De Laval Steam Turbine built in the larger sizes?

Ans.—It is not, at present.

Ques. 815.—Mention some of the principal uses for which this turbine is adapted.

Ans.—It is especially adapted to the driving of cen-

trifugal pumps, blowers, exciters, and small dynamos.

Ques. 816.—Describe the various conditions of operation for which the Class C Steam Turbine is built.

Ans.—It may be operated high pressure condensing, or high pressure non-condensing. It may also be operated with a certain degree of back pressure. Again, it may be operated as a low pressure condensing turbine, or it may be operated on mixed flow service.

EXTRACTS FROM UNITED STATES GOVERNMENT RULES FOR THE EXAMINATION OF APPLICANTS FOR ENGINEERS' LICENSE.

Ques. 817.—Give some of the principal regulations relative to Marine Engineers.

Ans.—Before an original license is issued to any person to act as engineer, he must personally appear before some local board, or a supervising inspector for examination; but upon the renewal of such license, when the distance from any local board, or supervising inspector is such as to put the person holding the same to great inconvenience, and expense to appear in person, he may upon taking the oath of office before any person authorized to administer oaths, and forwarding the same, together with the license to be renewed, to the local board, or supervising inspector of the district in which he resides, or is employed, have the same renewed by the said inspectors, if no valid reason to the contrary be known to them, and they shall attach such oath to the stub end of the license, which is to be retained on file in their office. And inspectors are directed, when licenses are completed, to draw a broad pen and ink red mark through unused spaces in the body thereof, so as to prevent as far as possible, illegal interpolation after issue.

Ques. 818.—Give in brief the classification of engineers on the lakes, and seaboard.

Ans.—The classification of engineers on the lakes, and seaboard shall be as follows:

Chief Engineer.

First Assistant Engineer.

Second Assistant Engineer.

Third Assistant Engineer.

Ques. 819.—What limitations are placed upon chief engineers, and assistant engineers relative to their sphere of action?

Ans.—Inspectors may designate upon the certificate of any chief, or assistant engineer the tonnage of the vessel on which he may act."

Ques. 820.—What additional restrictions are placed upon assistant engineers?

Ans.—First, second, and third assistant engineers may act as such on any steamer of the grade of which they hold a license, or as such assistant engineer on any steamer of a lower grade than those to which they hold a license.

Ques. 821.—On what grades of steamers may assistant engineers act as chief engineers?

Ans.—Assistant engineers may act as chief engineers on high pressure steamers of one hundred tons burden and under, of the class and tonnage, or particular steamer for which the inspectors, after a thorough examination, may find them qualified. In all cases where an assistant engineer is permitted to act as first (chief) engineer, the inspector shall state on the face of his certificate of license, the class and tonnage of steamers, or the particular steamer on which he may so act.

Ques. 822.—What is the duty of an engineer when he assumes charge of the boilers and machinery of a steamer?

Ans.—His duty is to forthwith thoroughly examine the same, and if he finds any part thereof in bad condition, caused by neglect or inattention on the part of his predecessor, he shall immediately report the facts to the local inspectors of the district, who shall thereupon investigate the matter, and if the former engineer has been culpably derelict of duty, they shall suspend or revoke his license.

Ques. 823.—What are some of the important requirements regarding service that will entitle a person to receive an original license as engineer or assistant engineer?

Ans.—He must have served at least three years in the engineers' department of a steam vessel; provided that any person who has served as a regular machinist in a marine engine works for a period of not less than three years; and any person who has served for a period of not less than three years as a locomotive engineer, stationary engineer, regular machinist in a locomotive, or stationary engine works, and any person who has graduated as a mechanical engineer from a duly recognized school of technology, may be licensed as engineer on steam vessels, after having had not less than one year's experience in the engine department of a steam vessel.

Ques. 824.—What are the requirements regarding education?

Ans.—No original license shall be granted any engineer, or assistant engineer, who cannot read and write, and does not understand the plain rules of arithmetic.

Ques. 825.—What are the requirements regarding the age of an applicant?

Ans.—He must be not less than twenty-one, nor more than thirty years of age in order to receive an appointment as second assistant engineer.

Ques. 826.—What is the penalty for making a false statement before a board of examination, or of producing a false certificate as to age, time of service or character?

Ans.—Any person found guilty of such action will be dropped immediately.

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MECHANICAL DRAWING
AND
MACHINE DESIGN

DRAFTING TOOLS.

Compasses. These, as well as all other instruments, should be chosen with great care on account of their variety in shape and quality. Drafting instruments are as a rule made of German silver and steel. The steel should be of the best grade and carefully tempered. The material used in the manufacture of some instruments is of so poor a quality that it neither holds its shape nor wears well. It is better therefore when buying, to select instruments of high grade, and which are made of the best German silver and a good quality of steel, as the joints are always carefully fitted and

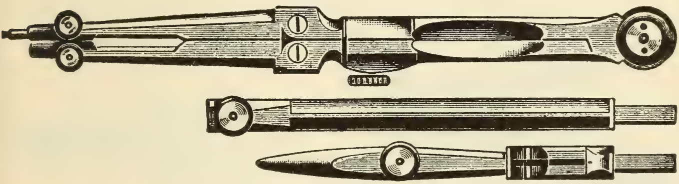

Fig. 1—Compass Set.

they will withstand the constant usage of many years. A compass set of convenient form is shown in Fig. 1. It has three removable parts: the pencil-point, the pen-point, and the lengthening-bar. There is a hinged joint in each leg of the compass and the socket for the removable legs is provided with a clamping screw. The shanks of the removable legs should be a nice fit in the socket and require scarcely any effort to remove.

They should, however, stay in the socket without being held by the clamping screw. The lengthening bar is used to extend the pen or pencil-legs when drawing large circles.

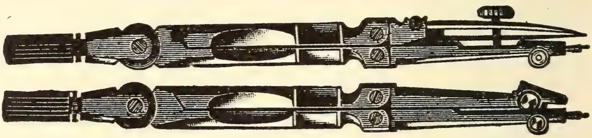

Fig. 2—Pen and Pencil Compasses.

A pen and pencil compass set of smaller size, without detachable legs are shown in Fig. 2, these instruments will be found useful in many cases as a medium between the large compasses and the spring-bow set.

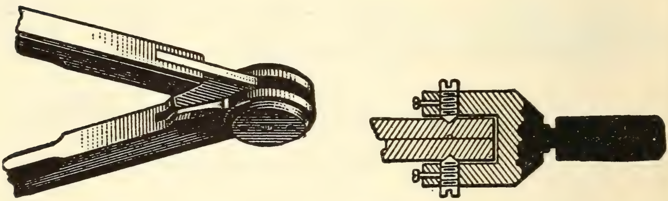

Fig. 3—Compass Joints.

The most important part of a pair of compasses is the head, which forms the hinged joint. There are two forms of joints: the **tongue-joint**, as shown in the left-hand view in Fig. 3, in which the head of one shank has a tongue, generally made of steel, which moves between two lugs on the other shank, and the **pivot joint**, as shown in the right-hand view in Fig. 3, in which each shank is reduced to half its thickness at the head. These shanks are surrounded by a clamp or yoke, which carries two cone-pointed set-screws, one in each side, the points of these screws working in countersinks in the yoke. The yoke is provided with a milled or knurled handle to manipulate the compass. The head joint of the compass should move freely and evenly throughout its entire movement, and not stiff at one point and loose at another. It should also be tight enough in the joint to hold its adjustment when once set. Figure 4 shows the method of holding a compass, and the correct position of the fingers before and after describing a circle. The non-removable leg of the compass should carry a needle-point, that may

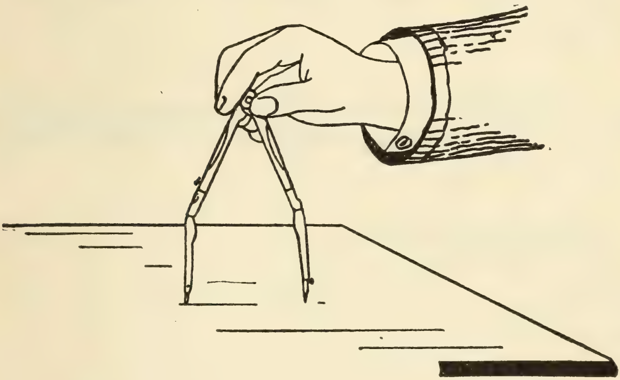

Fig. 4—Correct Manner of Holding a Compass.

be easily replaced if lost or damaged, and it should have a shoulder to prevent the point from sinking into the paper beyond a certain depth. The needle-point should also be capable of being adjusted in or out, and fastened securely at any desired point, thus making the leg of the compass a little longer or shorter as may be desired.

The socket for the lead in the pencil-point should hold the lead firmly without the necessity of wedging it in the socket by means of paper or small pieces of wood.

When first adjusting the compass for use, place the pen-point in the instrument and securely clamp it in place, firmly against the shoulder of the socket, then adjust the needle-point so that its point is even with that of the pen. When once properly adjusted the needle-point should not be changed. The needle-point is usually made with a cone-point at one end and a fine shouldered-point at the other. The cone-point should never be used, as it makes too large a hole in the drawing paper.

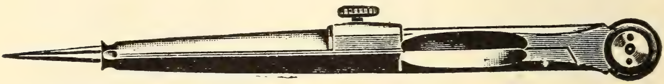

Fig. 5—Hair Spring Dividers.

Hair Spring Dividers. Dividers such as are shown in Fig. 5 are used for laying off equal distances and for transferring measurements from one part of a drawing to another, or from one drawing to another. They consist of steel points set in German silver shanks which are hinged together. The joints of the dividers should work smoothly, the legs come close together, and the steel points should be sharp and of the same length. One of the legs of the dividers has a spring controlled by an adjustable thumb-nut. By means of this device, from which the instrument gets its name, the adjustable leg may be moved a trifle after the rough or approximate adjustment of the dividers has been made.

Spring-bow Instruments. The spring-bow dividers, pencil and pen, as shown in Fig. 6, are for the purpose of describing small circles and laying off distances of very small dimensions and are very convenient for these purposes. Any form of spring-bow instruments with interchangeable or removable legs will be found very unsatisfactory. The legs should be made of one piece of steel, to which the handle is attached. Any

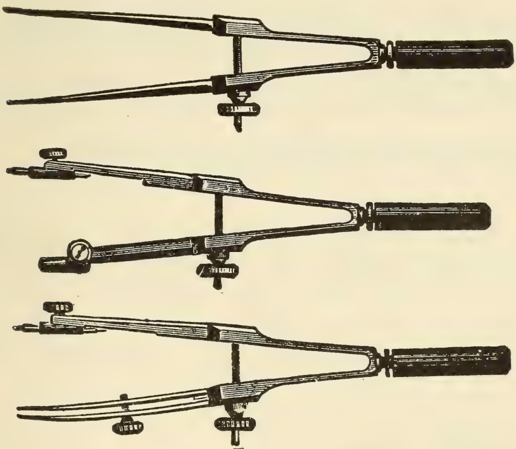

Fig. 6—Spring-bow Instruments.

instrument in which the legs are separate pieces fastened to the shank are undesirable, because the parts are liable to become loose. The spring-bow dividers are used like the hair-spring dividers, for the spacing of distances, they have the advantage of being fixed in any position so that there is no liability of a change of measurement by the handling of the instrument. When spacing distances the divider is rotated alternately right and left, with the forefinger on top of the handle.

Ruling Pens. Ruling pens are of two different kinds, one kind with a hinge joint to allow the blades to be opened for cleaning and the other kind without a joint and made from a solid piece of steel. Two sizes of ruling pens with hinged joints are shown in Fig. 7. The joint in this style of pen should be very carefully

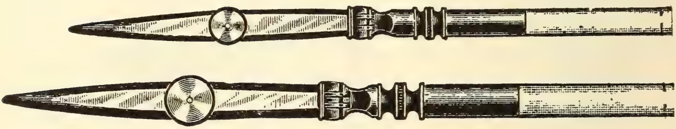

Fig. 7—Ruling Pens with Hinged Blade.

made, otherwise the hinged blade will very soon become loose and render the pen useless. The best kind of pen for general use is the kind shown in Fig. 8, in which the upper blade springs open when the adjusting screw is removed from the lower blade. A pen

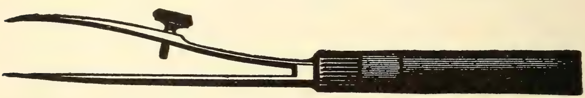

Fig. 8—Ruling Pen with Spring Blade.

such as the one just described is to be preferred to one with a joint, no matter how well made it may be. Ruling pens with broad nibs and flat handles, as shown in Fig. 9, are preferred by many draftsmen, they hold a large quantity of ink and make a very uniform line.

The position in which a ruling pen should be held when drawing lines perpendicular to the T-square is shown in Fig. 10. The drawing board should be placed

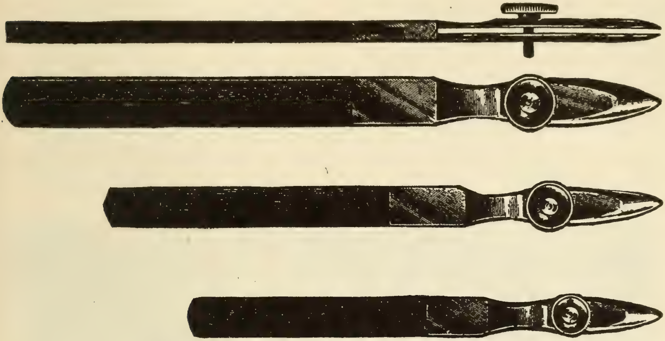

Fig. 9—Ruling Pens with Wide Blades.

so as to permit the light to come from the upper left-hand corner, this position of the T-square and triangle

Fig. 10—Correct Manner of Holding a Ruling Pen.

will avoid any possibility of the shadows of the T-square blade or triangle being cast on the lines to be drawn.

Sharpening a Ruling Pen. The blades of the pen should be curved at the points, and elliptical in shape. To sharpen the pen, screw the blades together and then move the pen back and forth upon a fine oil-stone, holding it in the position it should have when in use, but moving it so that the points are ground to the same length, and to an elliptical form. When this form has been secured, draw a folded piece of the finest emery paper two or three times between the blades, which are

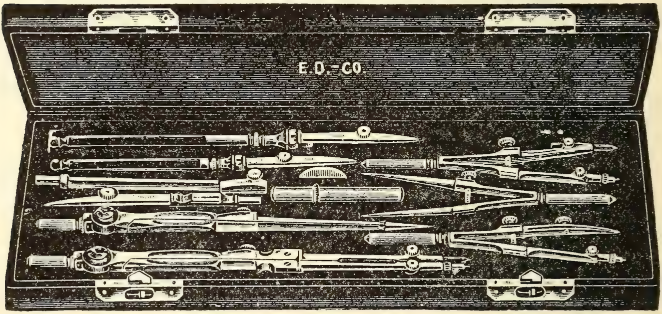

Fig. 11—Complete Set of Instruments in Case.

pressed together by the screw. This will remove any roughness from the inner surfaces of the blades, these surfaces should not be ground upon the oil-stone.

When the blades are ground to the proper shape, they must be placed flat upon the stone and ground as thin as possible without giving them a cutting edge. To do this, the pen should be moved back and forth and slightly revolved at the same time. Both blades must be made of equal thickness. If either blade is ground too thin, it will cut the paper as would a knife, and the process must be repeated from the beginning. In order to see the condition of the blades, they should be slightly separated while being brought to the proper thickness.

Drafting Instruments. A leather-covered case with a complete set of instruments in a velvet lined tray is shown in Fig. 11. This outfit is sufficient to fulfill the requirements of any ordinary draftsman in the way of instruments.

T-Square. The length of a T-square is always measured by the length of the blade outside of the head. The T-square should always be as long as the drawing board, and if possible a little longer. For the general run of work the head of the T-square should be of a single and fixed piece, that is fastened permanently to the blade. The head should have its upper inside

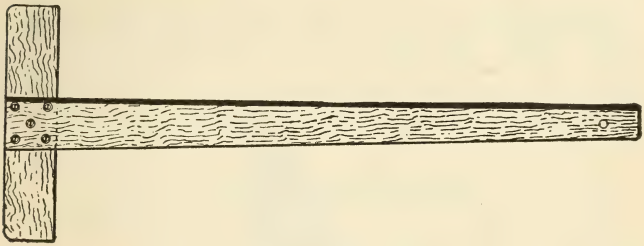

Fig. 12—Slanting Blade T-Square.

corner rabbeted, so that the guiding edge of the head may be trued up when occasion demands it. A very convenient form of T-square is shown in Fig. 12, which has a slanting blade, the working edge of which is lined with ebony.

More elaborate forms of T-squares are sometimes used, in which the head is double and one side swivels in order to draw parallel lines other than horizontal. The adjustable or swivel head is clamped in any desired position by means of a thumb-screw.

Fig. 13—60 and 45 Degree Triangles.

Triangles or Set-Squares. Triangles are made of wood, hard rubber or transparent celluloid. The principal forms of triangles are shown in Figs. 13 and 14,

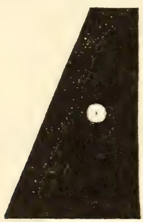

Fig. 14—15 Degree Triangle.

which are 60°, 45° and 15° respectively. The two triangles generally used by draftsmen are the 60° and 45°. The former has angles of 30°, 60° and 90°. The latter two 45° and a 90° angle.

Testing Triangles. Place the triangle on the T-square with the vertical edge at the right, draw a fine line in contact with this edge, then reverse the triangle and move the vertical edge towards the line. If the vertical edge of the triangle and the line coincide the

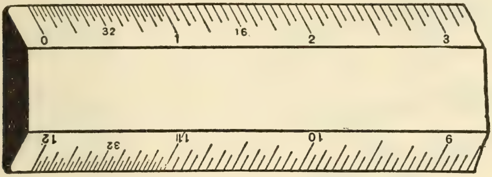

Fig. 15—Flat Beveled-edge Scale.

angle is 90°. If they do not coincide, and the vertex of the angle formed by the line and the vertical edge of the triangle is at the top, the angle is greater than 90° by half the angle indicated. If the vertex of the angle is below, the angle is less than 90° by half the amount indicated.

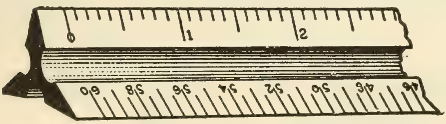

Fig. 16—Triangular Scale.

Scales. The best and most convenient form of scale for general use is that shown in Fig. 15. Another form of scale which is very commonly used is shown in Fig. 16. The ordinary length of a scale is 12 inches, not counting the small portion at each end, which is undivided, and whose use is to protect the end graduations from injury. A scale should be used for dimensioning drawings only, and not used as a ruler or straight-edge. The measurements should be taken directly from the scale by laying it on the drawing, and not by transferring the distances from the scale to the drawing by means of a pair of dividers.

Fig. 17—French Curves.

Curves. For inking in lines which are neither straight lines nor arcs of circles, it is necessary to use curves. They are made in a great variety of forms as illustrated in Fig. 17, but the form similar to that illustrated in Fig. 18 will be found the most useful. They are made of wood, hard rubber and celluloid. Many curved lines can be inked in by means of a compass, but when the radius is too great, a curve should be used.

Paper. The paper must be tough and should have a surface which is not easily roughened by erasing lines drawn upon it. This is important when drawings are to be inked. For all mechanical work, the paper should be hard and strong.

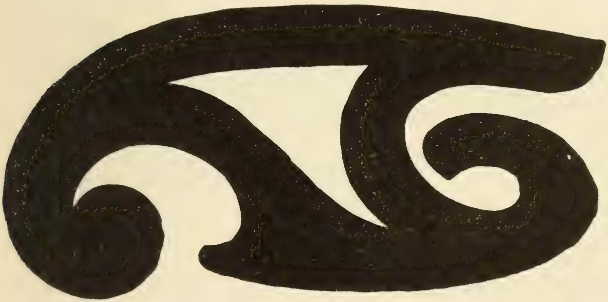

Fig. 18—Useful Form of Curve.

For pencil drawings a paper which is not smoothly calendered is best, because the pencil marks more readily upon an unpolished paper, and because its surface will not show erasures as quickly as that of a smooth paper. For sketching, several kinds of paper, which are good enough for the work, may be obtained both in sheets, in block form, and also made up in blank books.

Whatman's paper is the best for drawings which are to be inked. There are two grades, hot and cold pressed, suitable for this use, the cold-pressed having the rougher surface. If the paper is not to be stretched, the cold-pressed is preferable, as its surface shows erasures less than that of the hot-pressed. The side from which the water-marked name is read is the right side, but there is little difference between the two sides of hot and cold pressed papers. Stretching the paper is unnecessary except when colors are to be applied by the brush, or when the most perfect inked drawing is desired.

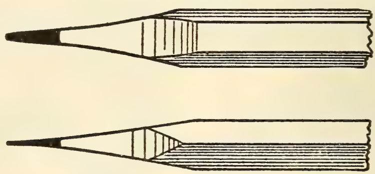

Fig. 19—Correct Manner of Sharpening a Pencil.

Pencils. Lead pencils for drafting use are made of different degrees of hardness and each kind of pencil has its grade indicated by letters stamped on it at one end. The grade of pencil mostly used by draftsmen is 4 H, a 6 H, pencil is too hard and unless used with great care will indent the paper so that the pencil marks cannot be erased. A 4 H pencil requires greater care and more frequent sharpening, but the draftsman will in this manner acquire a lighter touch, which is of much value. Drafting pencils should always be sharpened to a chisel or wedge-shaped point, as shown in Fig. 19, the finishing of the point should always be completed with a fine file or a sand paper pencil sharpener, but never with a knife. In drawing the pencil should be held vertical, or nearly so, the arm free from the body, and the flat side of the chisel-point lightly touching the edge of the blade of the T-square. Always draw from left to right, or from the bottom to the top of the board.

Pencil Sharpeners. Pencil sharpeners or pointers are of many different kinds, from a piece of fine sand paper or a file to quite complicated machines. For ordinary use a sand paper block from which the sheets

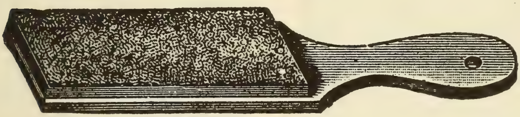

Fig. 20—Sandpaper Pencil Sharpener.

can be removed as soon as worn out, will be found the most convenient, as shown in Fig. 20. In sharpening a drafting pencil remove the wood from the end by means of a sharp knife, exposing about one-fourth to three-eighths of an inch of the lead. The end of the lead should then be sharpened to a chisel or wedge-shaped point on the sand paper block.

Pencil Erasers. A pencil eraser or rubber should be of soft, fine-grained rubber, free from sand or grit and having no tendency to glaze or smear the surface of the drawing paper. A pencil eraser of the kind shown in Fig. 21 will be found very satisfactory for general use.

Ink Erasers. Inked lines should always be removed from the drawing by means of a sand-rubber, which is known as an ink eraser, but never by scratching the surface of the paper with a knife. As all drawing inks dry rapidly, and should not penetrate the surface of the paper, the object in erasing is to remove the ink from the surface of the paper without injury to it. An ink eraser, such as shown in Fig. 22, will leave the surface of the drawing in good condition to again receive ink.

Fig. 21—Pencil Rubber or Eraser.

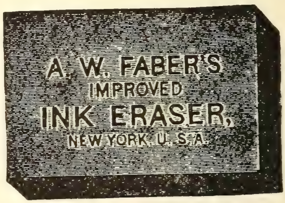

Fig. 22—Ink Rubber or Eraser.

Eraser Guard. An eraser guard or shield, which is used to protect other lines when removing an inked line from the surface of the drawing paper, consists of a thin sheet of flexible metal, usually brass, provided with slots and holes of various shapes and sizes. The shield or guard permits erasures to be made of limited size without damage to the rest of the drawing.

Drawing Ink. Black drawing ink, preferably, some make of waterproof ink, is to be had in liquid form, as shown in Fig. 24. The liquid ink is preferable to the Indian or Chinese stick inks, as shown in Fig. 25, which take considerable time to prepare, besides necessitating fresh mixing each time the ink is used.

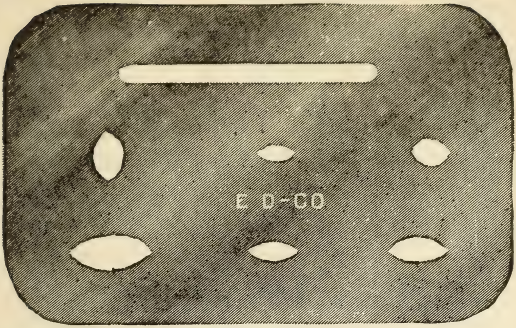

Fig. 23—Erasing Guard or Shield.

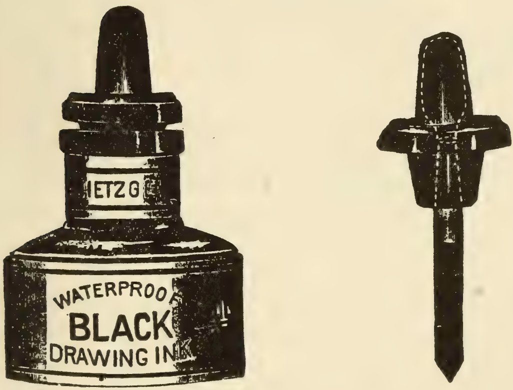

Fig. 24—Waterproof Black Drawing Ink.

Fig. 25—Chinese Stick Black Drawing Ink.

Protractor. A protractor is a circular scale and is divided into degrees and fractions of a degree. Protractors are made both circular and semi-circular in shape, the latter being the ordinary and most commonly used form, as shown in Fig. 26. Protractors are made of paper, horn, brass, German silver and steel. Protractors usually have their edges bevelled so as to bring the divisions on the scale close to the drawing paper. A semi-circular protractor is to be

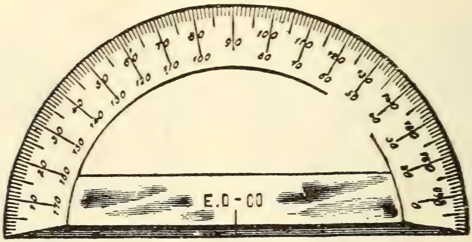

Fig. 26—German Silver Protractor.

preferred for all ordinary work. A semi-circular protractor has a straight edge upon which the center of the circle is marked, so that the protractor may be readily applied to the point at which it is desired to read or lay off an angle.

Drawing Boards. A drawing board for ordinary use should be about 20 by 27 inches in size. The material should be of first quality clear soft pine, free from pitch and thoroughly kiln dried. The board should be made of five or six strips about 4 by 27 inches, well glued together and held from warping by two cleats on the back, as shown in Fig. 27.

The working edge of the drawing board should be tested from time to time, as any unevenness in this edge will impair the accuracy of the drawing. Some draftsmen use the lower edge of the board when drawing long lines parallel to the working edge. This necessitates making this edge true, and the angle between this and the working edge exactly 90°

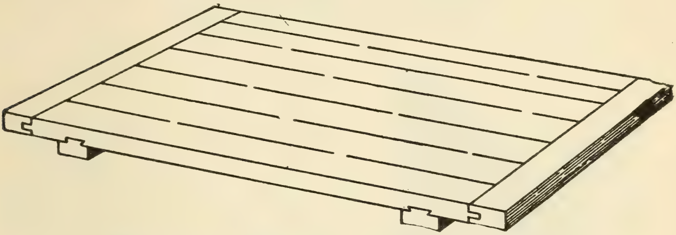

Fig. 27—Drawing Board with Cleats on Back.

Thumb-Tacks. Thumb-tacks are made of German silver or brass disks with pointed steel pins in their centers. The heads or disks should have very thin edges in order that the T-square may readily slide over them.

Lettering Triangle. A triangle or set-square for laying out lettering is shown in Fig. 28. The use of this triangle is plainly indicated by its name.

Section Liners. A section liner is a device for drawing a series of parallel lines equi-distant from each other. One form of section liner is shown in Fig. 29. Its operation is as follows: Place the instrument in the position shown in the drawing, and rule a line along its vertical edge. Hold the straight-edge firmly in place, and slide the triangle along it until the other side of the tapered edge of the tongue comes in contact with the other stud and holds it in this position, then allow the straight-edge to be drawn forward by the spring. Then draw a second line which will evidently be parallel to the first. The distance between the lines is regulated by moving the tongue in or out between the studs, as far as desired.

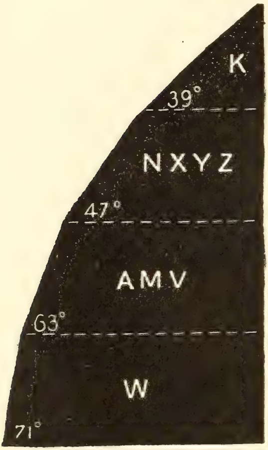

Fig. 28—Lettering Triangle.

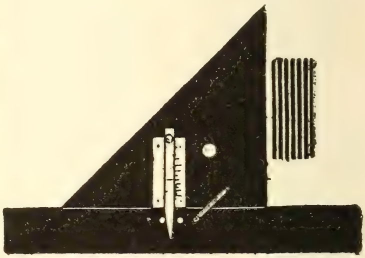

Fig. 29—Section Liner with Vertical Adjustment.

Another form of section liner is shown in Fig. 30, having a horizontal instead of a vertical adjustment to regulate the width of the spacing.

Beam Compasses. A beam compass is not, as a rule, included in a draftsman's outfit, but every well equipped drafting room should have one. A beam compass is shown in Fig. 31, with removable legs and pen, pencil and needle-points. The right-hand leg in the

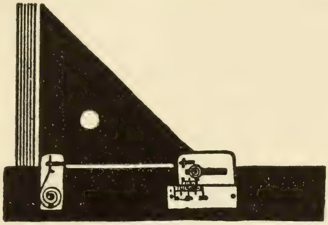

Fig. 30—Section Liner with Horizontal Adjustment.

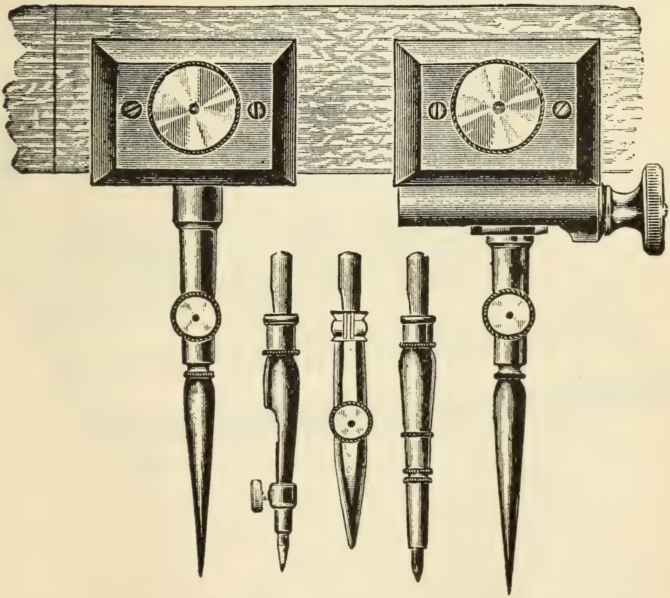

Fig. 31—Beam Compass with Pen, Pencil and Needle-Points.

illustration has a horizontal adjustment of about one-half an inch, operated by the milled thumb-nut shown.

Water Colors. These may be obtained in the form of a thick paste in small porcelain pans, or in thin paste or semi-liquid form in collapsible tubes. The colors in tubes are liable to get hard, in which case they cannot be expelled from the tubes by pressure. The caps to the tubes also get stuck in place by the colors and are often removed with much difficulty. For the draftsman's purposes the moist colors in pans will be found the most satisfactory.

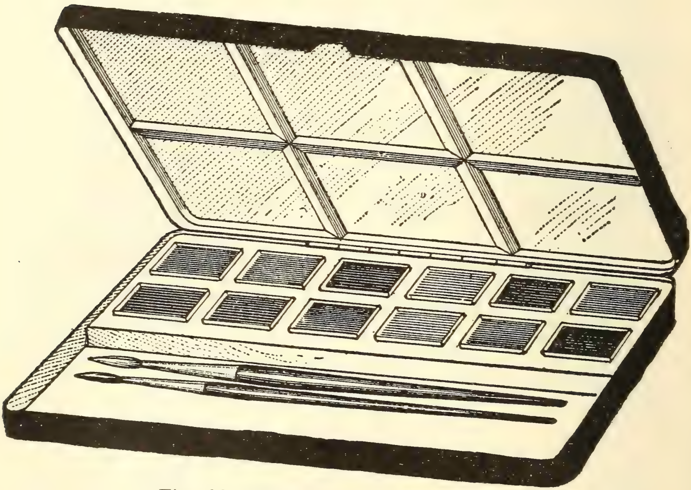

Fig. 32—Moist Water Colors in Case.

A box of moist water colors is illustrated in Fig. 32. The colors should be kept in a box of this kind, which can also be used as a palette. The box keeps all dust and dirt from the colors and prevents them from drying out rapidly.

Water Color Brushes. These are made from black or red sable and camel's hair. Black sable brushes are too expensive for the draftsman's ordinary use.

The best grade of camel's hair brushes such as are shown in Fig. 33, will be found quite satisfactory for ordinary use.

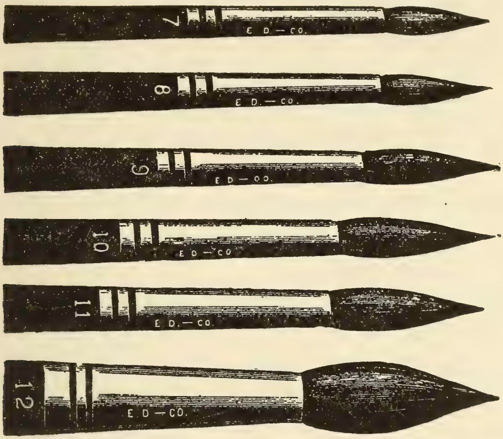

Fig. 33—Water Color Brushes.

To ascertain whether a brush is of good quality or not, dip it in water until thoroughly wet, and then remove the water from it by a quick motion. The brush if of good quality should assume a convex shape, come to a fine point and also preserve its elasticity.

GEOMETRICAL DEFINITIONS OF PLANE FIGURES.

A line is the boundary or limit of a surface.

A line has only one dimension, that of length.

A point is considered as the extremity or limit of a line. The place where two lines intersect is also a point. A point has position but no dimensions.

In practical work a point is represented by a fine dot.

Lines may be either straight, broken or curved.

A straight line is one which has the same direction throughout its length.

A straight line is also called a **right line.**

A straight line is usually called a line simply, and when the word line occurs it is to be understood as meaning straight line unless otherwise specified. A straight line is the shortest distance between two points. If any other path between the points were chosen, the line would become curved or broken. Therefore two points determine the position of the straight line joining them.

A broken line is one which changes direction at one or more points.

A curved line is one which changes direction constantly throughout its length. The word curve is used to denote a curved line.

Lines may be represented as full, dotted, dashed, or dot-and-dashed.

A full line is one which is continuous throughout its length.

A dotted line is one which is composed of alternate dots and spaces.

A dash line is one which is composed of alternate dashes and spaces.

A dot-and-dash line is one which is composed of dots, spaces and dashes. These may be arranged in several ways according to the character of the line, that is, the meaning it is to convey.

Surfaces may be either plane or curved. A plane surface is usually called a plane.

A plane is such a surface that if a straight line be applied to it in any direction, the line and the surface will touch each other throughout their length.

A curved surface is one no part of which is a plane.

Any combination of points, lines, surfaces or solids is termed a **figure**.

A plane figure is one which has all of its points in the same plane.

Plane geometry treats of figures whose points all lie in the same plane.

Lines may be so situated as to be parallel or inclined to each other.

Parallel lines are those which have the same or opposite directions. Parallel lines are everywhere equally distant. Parallel lines will not meet however far produced.

Inclined lines are those other than parallel. Inclined lines will always meet if produced far enough. Their mutual inclination forms an angle.

The **extremities of a surface** are lines.

A **plane rectilineal angle** is the inclination of two straight lines to one another in a plane which meet together, but are not in the same straight line as in Fig. 34.

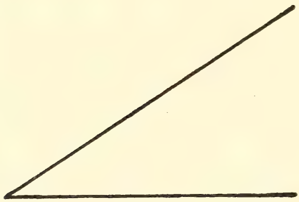

Fig. 34.

Fig. 35.

When a straight line, standing on another straight line, makes the adjacent angles equal to one another, each of the angles is called a **right angle** and the straight line which stands on the other is called a **perpendicular** to it as in Fig 35.

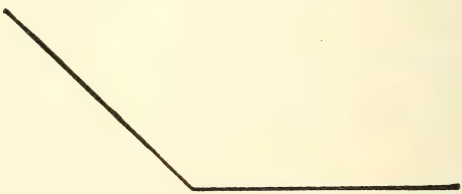

Fig. 36.

An **obtuse angle** is that which is greater than a right angle as in Fig. 36.

An **acute angle** is that which is less than a right angle as in Fig. 34.

A term or boundary is the extremity of anything.

An **equilateral triangle** is that which has three equal sides as in Fig. 37.

An **isosceles triangle** is that which has two sides equal as in Fig. 38.

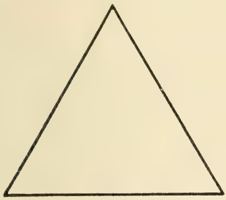

Fig. 37.

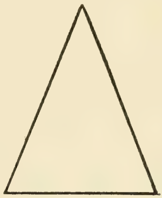

Fig. 38.

A **scalene triangle** is that which has three unequal sides as in Fig. 39.

A **right angled triangle** is that which has a right angle as in Fig. 40.

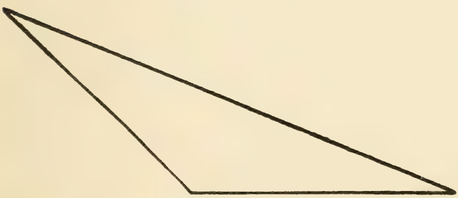

Fig. 39.

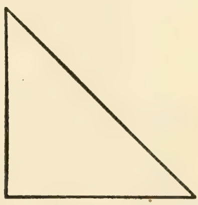

Fig. 40.

An **obtuse-angled triangle** is that which has an obtuse angle as in Fig. 39.

The **hypothenuse** in a right-angled triangle is the side opposite the right angle as in Fig. 40.

A **square** is that which has all its sides equal and all its angles right-angled as in Fig. 41.

A **rectangle** is that which has all its angles right angles, but only its opposite sides equal as in Fig. 42.

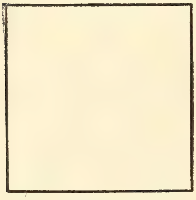

Fig. 41.

Fig. 42.

A **rhombus** is that which has all its sides equal, but its angles are not right angles as in Fig. 43.

A **quadrilateral** figure which has its opposite sides parallel is called a parallelogram as in Figs. 41, 42 and 43.

A line joining two opposite angles of a quadrilateral is called a **diagonal.**

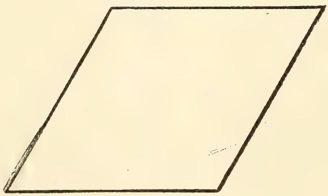

Fig. 43.

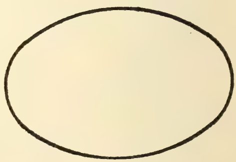

Fig. 44.

An **ellipse** is a plane figure bounded by one continuous curve described about two points, so that the sum of the distances from every point in the curve to the two foci may be always the same—Fig. 44.

PROPERTIES OF THE CIRCLE.

A **circle** contains a greater area than any other plane figure bounded by the same length of circumference or outline.

A **circle** is a plane figure contained by one line and is such that all straight lines drawn from a point within the figure to the circumference are equal, and this point is called the center of the circle.

A **diameter** of a circle is a straight line drawn through the center and terminated both ways by the circumference, as AC in Fig. 45.

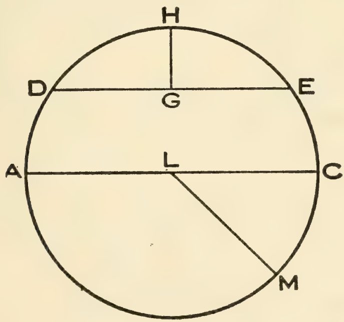

Fig. 45.

A **radius** is a straight line drawn from the center to the circumference, as LH in Fig. 45.

A **semicircle** is the figure contained by a diameter and that part of the circumference cut off by a diameter as AHC in Fig. 45.

A **segment** of a circle is the figure contained by a straight line and the circumference which it cuts off, as DHE in Fig. 45.

A **sector** of a circle is the figure contained by two straight lines drawn from the center and the circumference between them, as LMC in Fig. 45.

A **chord** is a straight line, shorter than the diameter, lying within the circle, and terminated at both ends by the circumference as DE in Fig. 45.

An **arc** of a circle is any part of the circumference as DHE in Fig. 45.

The **versed sine** is a perpendicular joining the middle of the chord and circumference, as GH in Fig. 45.

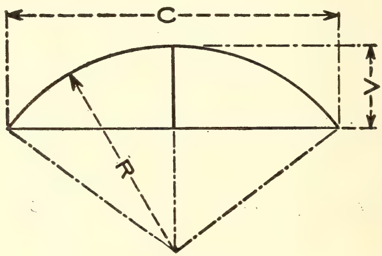

Fig. 46.

Circumference. Multiply the diameter by 3.1416, the product is the circumference.

Diameter. Multiply the circumference by .31831, the product is the diameter, or multiply the square root of the area by 1.12837, the product is the diameter.

Area. Multiply the square of the diameter by .7854, the product is the area.

Side of the square. Multiply the diameter by .8862, the product is the side of a square of equal area.

Diameter of circle. Multiply the side of a square by 1.128, the product is the diameter of a circle of equal area.

To find the versed sine, chord of an arc or the radius when any two of the three factors are given.—Fig. 46.

$$R = \frac{C^2 + 4V^2}{8V} \qquad C = 2\sqrt{V(2R - V)}$$

$$V = R - \sqrt{\frac{4R^2 - C^2}{4}}$$

To find the length of any line perpendicular to the chord of an arc, when the distance of the line from the center of the chord, the radius of the arc and the length of the versed sine are given—Fig. 47.

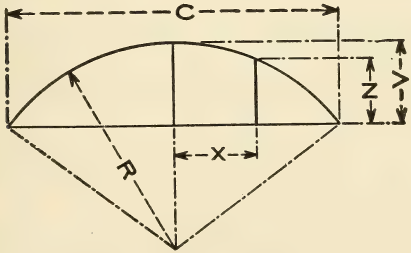

Fig. 47.

$$N = \sqrt{(R^2 - X^2)} - (R - H \qquad R = \frac{C^2 + 4V^2}{8V}$$

$$C = 2\sqrt{V(2R - V)} \qquad V = R - \sqrt{\frac{4R^2 - C^2}{4}}$$

To find the diameter of a circle when the chord and versed sine of the arc are given.

$$AC = \frac{DG^2 + GH^2}{GH}$$

To find the length of any arc of a circle, when the chord of the whole arc and the chord of half the arc are given—Fig. 48.

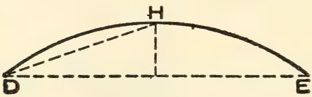

Fig. 48.

$$\text{Arc } DHE = \frac{8DH - DE}{3}$$

A **Tangent** is a straight line which touches the circumference but does not intersect it. The point where the tangent touches the circle is called the **Point of Tangency.**

Two **Circumferences** are tangent to each other when they are tangent to a straight line at the same point.

A **Secant** is a straight line which intersects the circumference in two points.

A Polygon is **inscribed** in a circle when all of its sides are chords of the circle.

A Polygon is **circumscribed** about a circle when all of its sides are tangent to the circle, and a circle is circumscribed about a polygon when the circumference passes through all the vertices of the polygon.

DEFINITION OF POLYGONS.

A **polygon,** if its sides are equal, is called a regular polygon, if unequal, an irregular polygon.

A **pentagon** is a five-sided figure.

A **hexagon** is a six-sided figure—Fig. 49.

A **heptagon** is a seven-sided figure.

An **octagon** is an eight-sided figure.

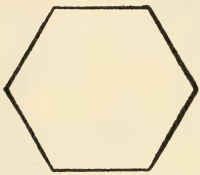

Fig. 49—Hexagon.

A **nonagon** is a nine-sided figure.

A **decagon** is a ten-sided figure.

A **unadecagon** is an eleven-sided figure.

A **duodecagon** is a twelve-sided figure.

GEOMETRICAL DEFINITION OF SOLIDS.

A **solid** has length, breadth and thickness. The boundaries of a solid are surfaces.

A **solid angle** is that which is made by two or more plane angles, which are not in the same plane, meeting at one point.

A **cube** is a solid figure contained by six equal squares—Fig. 50.

A **prism** is a solid figure contained by plane figures of which two that are opposite are equal, similar, and parallel to one another, the other sides are parallelograms—Fig. 51.

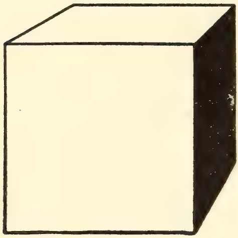

Fig. 50—Cube.

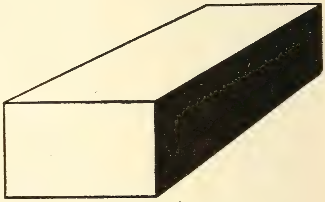

Fig. 51—Prism.

A **pyramid** is a solid figure contained by planes, one of which is the base, and the remainder are triangles, whose vertices meet a point about the base, called the vertex or apex of the pyramid—Fig 52

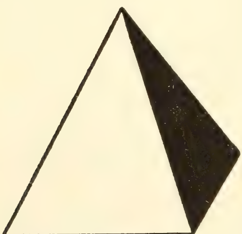

Fig. 52—Pyramid.

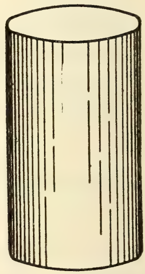

Fig. 53—Cylinder.

A **cylinder** is a solid figure described by the revolution of a rectangular or parallelogram about one of its sides—Fig. 53.

The **axis** of a cylinder is the fixed straight line about which the parallelogram revolves.

The **ends** of a cylinder are the circles described by the two revolving sides of the parallelogram.

A **sphere** is a solid figure described by the revolution of a semicircle about its diameter, which remains fixed—Fig. 54.

The **axis** of a sphere is the fixed straight line about which the semicircle revolves.

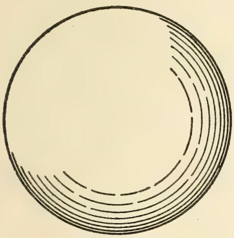

Fig. 54—Sphere.

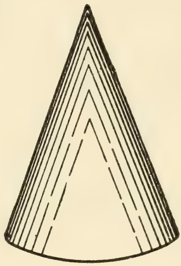

Fig. 55—Cone.

The **center** of a sphere is the same as that of the semicircle.

The **diameter** of a sphere is any straight line which passes through the center and is terminated both ways by the surface of the sphere.

A **cone** is a solid figure described by the revolution of a right-angled triangle about one of its sides containing the right angle, which side remains fixed—Fig. 55.

The **axis** of a cone is the circle described by that side of the triangle containing the right angle which revolves.

The **base** of the cone is the circle described by that side of the triangle containing the right angle which revolves.

If a cone be cut obliquely so as to preserve the base entirely, the section is an **ellipse.**

When a cone is cut by a plane parallel to one of sloping sides, the section is a **parabola, if cut at right angles to its base, an hyperbola.**

MECHANICAL DRAWING.

While many draftsmen are familiar with all of the problems given in this section of the work, it is not to be expected that all draftsmen or students are thoroughly conversant with all of them, and it is intended that this section of the work shall be used not only as reference data but for practical examples of elementary mechanical drawing. If the different problems given in this section are drawn with great accuracy, the technical skill acquired in drawing and proper handling of the different instruments will be found to be of great value. It will not be necessary to ink in these simple geometrical problems, as it is better to acquire precision or accuracy in pencil work before going further. These problems are believed to be an essential part of a work on mechanical drawing. To understand geometry certain qualities of mind are absolutely necessary, and many persons find it impossible to grasp even the simple problems of this study. The draftsman or student who is without practical knowledge of geometry is very poorly equipped for his duties.

GEOMETRICAL PROBLEMS.

THE CONSTRUCTION OF ANGLES.

To bisect a given angle. Let DAC be the given angle. With center A and any radius AE describe an arc cutting AC and AD at E and G. With the same radius and centers E and G, describe arcs intersecting at H, and join AH. The angle DAC is bisected—Fig. 56.

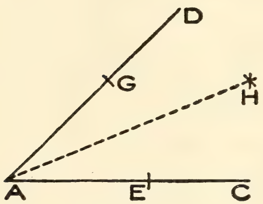

Fig. 56.

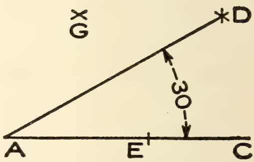

Fig. 57.

To construct an angle of 30°. With radius AE and with center A and E, describes arcs intersecting at G. With the same radius and with centers E and G, describe arcs intersecting at D, and join AD. The angle DAC contains 30°—Fig. 57.

To construct an angle of 60°. With radius AE, and with centers A and E, describe arcs intersecting at G, draw AD through G. The angle DAG contains 60°—Fig. 58.

To construct an angle of 45°. With radius AE and centers A and E, describe arcs intersecting at F, draw EG through F, and make FG equal to FE. Join GR, and with center R and radius AE make AH equal to

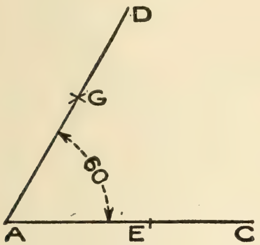

Fig. 58.

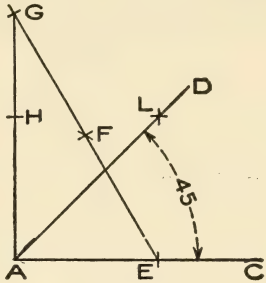

Fig. 59.

AE, with the same radius and with centers E and F describe arcs intersecting at L, draw AD through L. The angle DAC is 45°—Fig. 59.

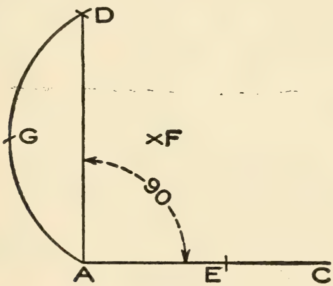

Fig. 60.

To construct an angle of 90°. With radius AE and centers A and E, describe arcs intersecting at F, with the same radius and center F describe the arc AGD, with radius AE, lay off AG and GD and join DA. The angle DAG is 90°—Fig 60.

To bisect a straight line—Fig 61. Let BC be the straight line to be bisected. With any convenient radius greater than AB or AC describe arcs cutting each other at D and E. A line drawn through D and E will bisect or divide the line BC into two equal parts.

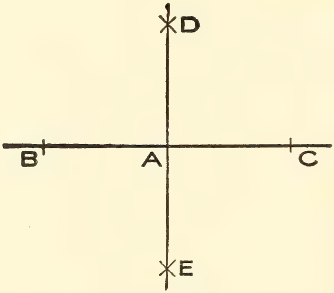

Fig. 61.

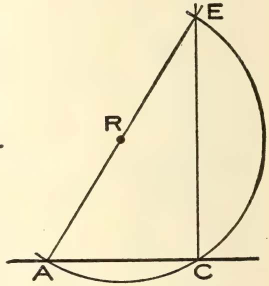

Fig. 62.

To erect a perpendicular line at or near the end of a straight line—Fig. 62. With any convenient radius and at any distance from the line AC, describe an arc of a circle as ACE, cutting the line at A and C.

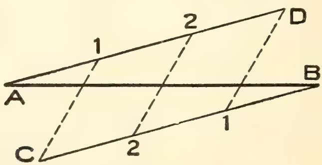

Fig. 63.

Through the center R of the circle draw the line ARE, cutting the arc at point E. A line drawn from C to E will be the required perpendicular.

To divide a straight line into any number of equal parts—Fig. 63. Let AB be the straight line to be divided into a certain number of equal parts: From the points A and B, draw two parallel lines AD and BC, at any convenient angle with the line AB. Upon AD and BC set off one less than the number of equal parts required, as A-1, 1-2, 2-D, etc. Join C-1, 2-2, 1-D, the line AB will then be divided into the required number of equal parts.

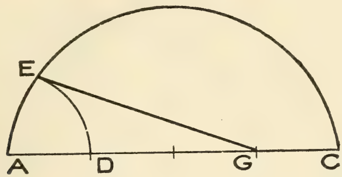

Fig. 64.

To find the length of an arc of a circle—Fig. 64. Divide the chord AC of the arc into four equal parts as shown. With the radius AD equal to one-fourth of the

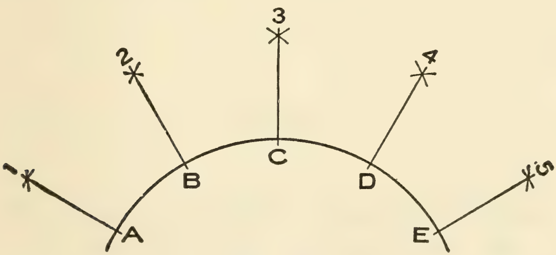

Fig. 65.

chord of the arc and with A as the center describe the arc DE. Draw the line EG and twice its length will be the length of the arc AEC.

To draw radial lines from the circumference of a circle when the center is inaccessible—Fig. 65. Divide the circumference into any desired number of parts as AB, BC, CD, DE. Then with a radius greater than the length of one part, describe arcs cutting each other as A-2, C-2, B-3, D-3, etc., also B-1, D-5. Describe the end arcs A-1, E-5 with a radius equal to B-2. Lines joining A-1, B-2, C-3, D-4 and E-5 will all be radial.

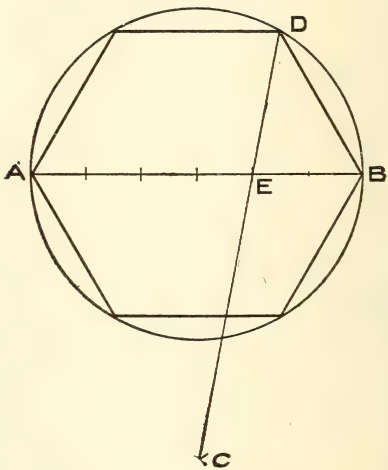

Fig. 66.

To inscribe any regular polygon in a circle—Fig. 66. Divide the diameter AB of the circle into as many equal parts as the polygon is to have sides. With the points A and B as centers and radius AB, describe arcs cutting each other at C. Draw the line CE through the second point of division of the diameter of AB, intersecting the circumference of the circle D. A line drawn from B to D is one of the sides of the polygon.

To cut a beam of the strongest shape from a circular section—Fig 67. Divide any diameter CB of the circle into three equal parts as CF, FE and EB. At E and F erect perpendiculars EA and FD on opposite sides of the diameter CB. Join AB, BD, DC and CF. The rectangle ABCD will be the required shape of the beam.

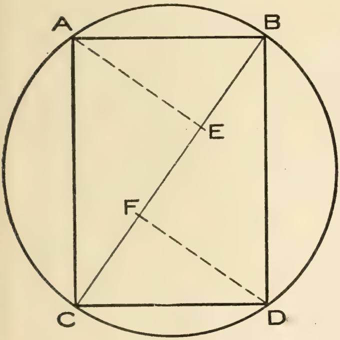

Fig. 67.

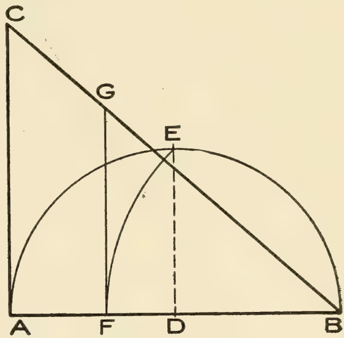

Fig. 68.

To divide any triangle into two parts of equal area—Fig. 68. Let ABC be the given triangle: Bisect one of its sides AB at D and describe the semicircle AEB. At D erect the perpendicular DE and with center B and radius BE describe the arc EF which intersects the line AB at F. At F draw the line AG parallel at AC, this divides the triangle into two parts of equal area.

To inscribe a circle of the greatest possible diameter in a given triangle—Fig. 69. Bisect the angles A and B, and draw the lines, AD, BD which intersect each other at D. From D draw the line CD perpendicular to AB. Then CB will be the radius of the required circle CEF.

To construct a square equal in area to a given circle —Fig. 70. Let ACBD be the given circle: Draw the diameters AB and CD at right angles to each other,

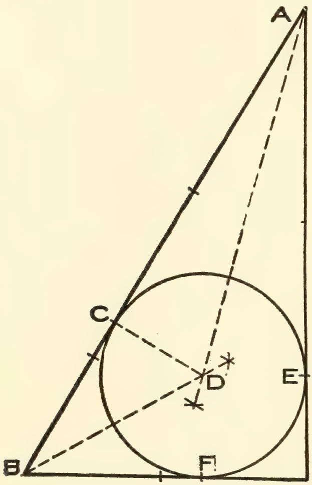

Fig. 69.

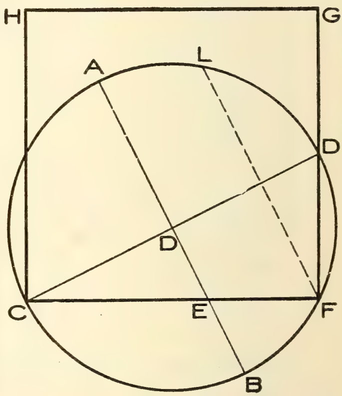

Fig. 70.

then bisect the half diameter or radius DB at E and draw the line FL, parallel to BA. At the points C and F erect the perpendiculars CH and FG, equal in length to CF. Join HG, then CFGH is the required square. The dotted line FL is equal to one-fourth the circle ACBD.

To construct a rectangle of the greatest possible area in a given triangle—Fig. 71. Let ABC be the given triangle: Bisect the sides AB and BC at G and D. Draw the line GD and from the points G and D, draw the lines GF and DE perpendicular to GD, then EFGD is the required rectangle.

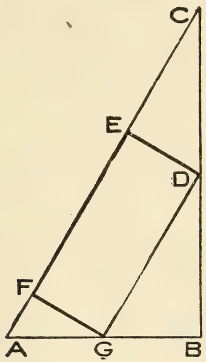

Fig. 71.

To construct a rectangle equal in area to a given triangle—Fig. 72. Let ABC be the given triangle: Bisect the base AB of the triangle at D and erect the

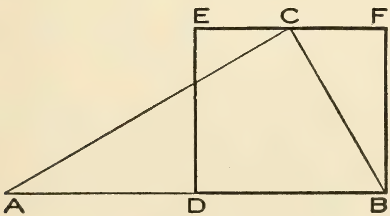

Fig. 72.

perpendiculars DE and BF at D and B. Through C draw the line ECF intersecting the perpendiculars DE and B at E and F. Then BDEF is the required rectangle.

To construct a triangle equal in area to a given parallelogram—Fig. 73. Let ABCD be the given parallelogram: Produce the line AB at B and make BE equal to AB. Join the points A and C and ACE will be the triangle required.

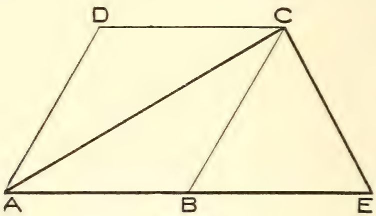

Fig. 73.

To inscribe a square within a given circle—Fig. 74. Let ADBC be the given circle: Draw the diameters AB and CD at right angles to each other. Join AD, DB and CA, then ACBD is the inscribed square.

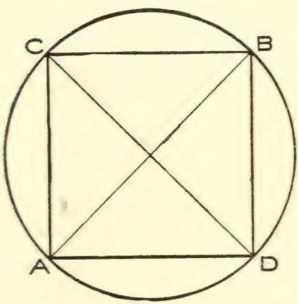

Fig. 74.

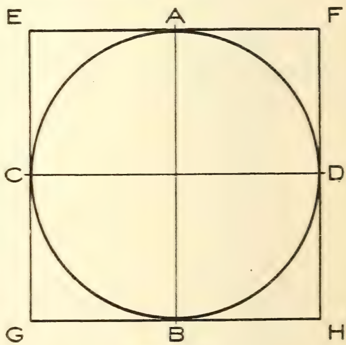

Fig. 75.

To describe a square without a given circle—Fig. 75. Draw the diameters AB and CD at right angles to each other. Through A and B draw the lines EF and GH, parallel to CD, also draw the lines EG and FH through the points C and D and parallel to AB, this completes the required square EFGH.

To construct an octagon in a given square—Fig. 76. Let ABCD be the given square: Draw the diagonal lines AC and BD, which intersect each other at the point O. With a radius equal to AO or OC, describe the arcs EF, GH, IK and LM. Connect the points EK, LG, FI and HM, then GFIHMKEL is the required octagon.

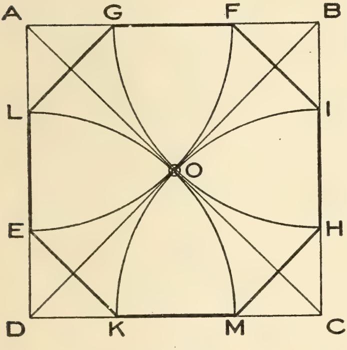

Fig. 76.

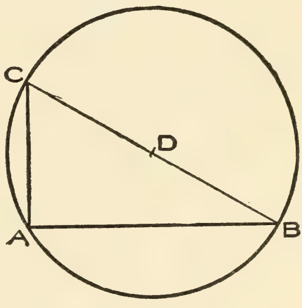

Fig. 77.

To construct a circle equal in area to two given circles—Fig. 77. Let AB and AC equal the diameters of the given circles: Erect AC at A and at right angles to AB. Connect B and C, then bisect the line BC at D and describe the circle ACB which is the circle required and is equal in area to the two given circles.

To describe an octagon about a given circle—Fig. 78. Let ACBD be the given circle: Draw the diameters AB and CD at right angles to each other. With any convenient radius and centers A, C, B and D describe arcs intersecting each other at E, H, F and G. Join EF and GH which form two additional diameters. At the points AB and CD draw the lines KL, PR, MN and ST, parallel with the diameters CD and AB respectively. At the points of intersection of the circumference of the circle by the lines EF and GH, draw the lines KP, RM, NT and SL parallel with the lines EF and HG respectively, then PRMNTSLK is the required octagon.

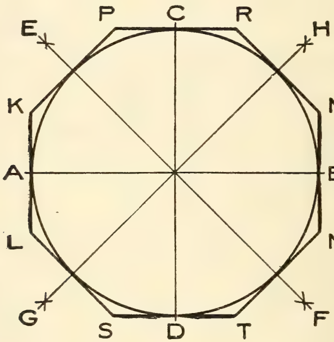

Fig. 78.

To draw a straight line equal in length to a given portion of the circumference of a circle—Fig. 79. Let ACBD be the given circle: Draw the diameters AB and CD at right angles with each other. Divide the radius RB into four equal parts. Produce the diameter AB and B and make BE equal to three of the four parts of RB. At A draw the line AF parallel to CD and then draw the line ECF which is to one-fourth of the circumference of the circle ACBD. If lines be drawn from E through points in the circumference of the circle as 1 and 2, meeting the line AF and G and H, then C-1, 1-2 and 2-A will equal FG, GH and HA respectively.

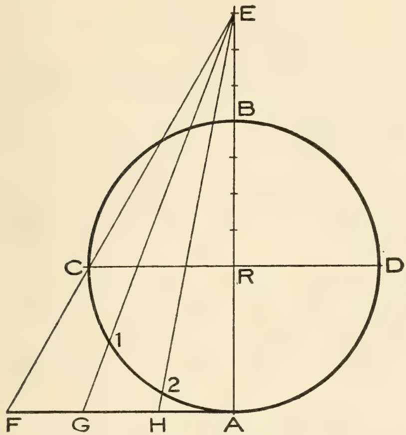

Fig. 79.

To construct a square equal in area to two given squares—Fig. 80. Let AC and AD be the length of the sides of the given squares: Make AD perpendicular to AC and connect DC, then DC is one of the sides of the square DCEG which is equal to the two given squares.

To inscribe a hexagon in a given circle—Fig. 81. Draw a diameter of the circle as AB: With centers A and B and radius AC or BG, describe arcs cutting the circumference of the circle at D, E, F and G. Join EF, FB, BG, GD, DA and AE, this gives the required hexagon.

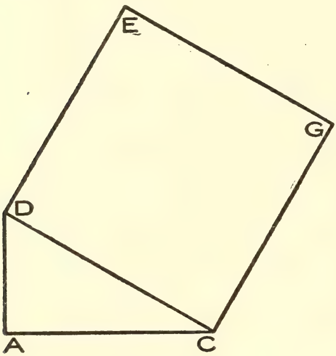

Fig. 80.

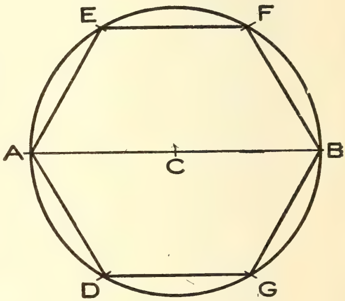

Fig. 81.

To describe a cycloid, the diameter of the generating circle being given—Fig 82. Let BD be the generating circle: Draw the line ABC equal in length to the circumference of the generating circle. Divide the circumference of the generating circle into 12 parts as shown. Draw lines from the points of division 1, 2, 3, etc., of the circumference of the generating circle par-

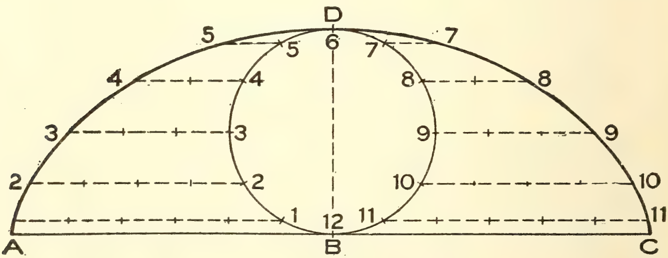

Fig. 82.

allel to the line ABC and on both sides of the circle. Lay off one division of the generating circle on the lines 5 and 7, two divisions on the lines 4 and 8, three divisions on the lines 3 and 9, four divisions on the lines 2 and 10, and five divisions on the lines 1 and 11. A line traced through the points thus obtained will be the cycloid curve required.

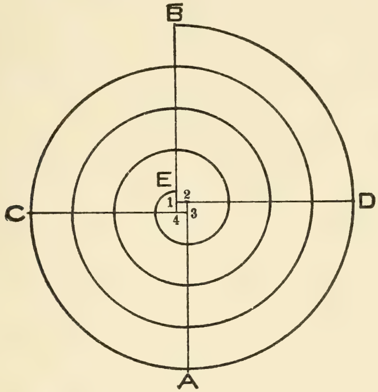

Fig. 83.

To develop a spiral with uniform spacing—Fig. 83. Divide the line BE into as many equal parts as there are required turns in the spiral. Then subdivide one of these spaces into four equal parts. Produce the line BE to 4, making the extension E-4 equal to two of the subdivisions. At 1 draw the line 1-D, lay off 1-2 equal to one of the subdivisions. At 2 draw 2-A perpendicular to 1-D and at 3 in 2-A draw 3-C, etc. With center 1 and radius 1-B describe the arc BD with center 2 and radius 2-D describe the arc DA, with center 3 and radius 3-A, etc., until the spiral is completed. If carefully laid out the spiral should terminate at E as shown in the drawing.

MACHINE DRAWING

The draftsman should not as a rule be content with simply reproducing the views shown in the different examples given, to the dimensions marked on them, but should lay out other views and cross sections. The great importance of the value of being able to make intelligible free hand sketches of machine details cannot be overestimated, the draftsman should practice this art, not only from the illustrations given herewith, but from actual machine details. Fully dimensioned free hand sketches of actual machines or their details, form excellent examples for drawing practice. All such sketches should be made in a book kept for the purpose, always putting in the dimensions where possible. The description of the various applications of the mechanical powers hereinbefore given is more for reference than for the purpose of teaching these principles. As machine drawing is simply the application of the principles of geometry to the representation of machines, if the draftsman or student is not already familiar with the study of geometry, he should make himself acquainted with the problems given in this work, before going further.

U. S. Standard Hexagonal Bolt-head and Nut. Two types of head and nut are illustrated, the rounded or spherical, and the chamfered or conical, as shown in Fig. 84. Three dimensions are fixed by this standard: First, the distance across the flats or short diameter, commonly indicated by H, and equal to one and one-half times the diameter of the bolt plus one-eighth of an inch; second, the thickness of the head, which is equal to one-half its short diameter; third, the thickness of the nut, which is equal to the diameter of the bolt.

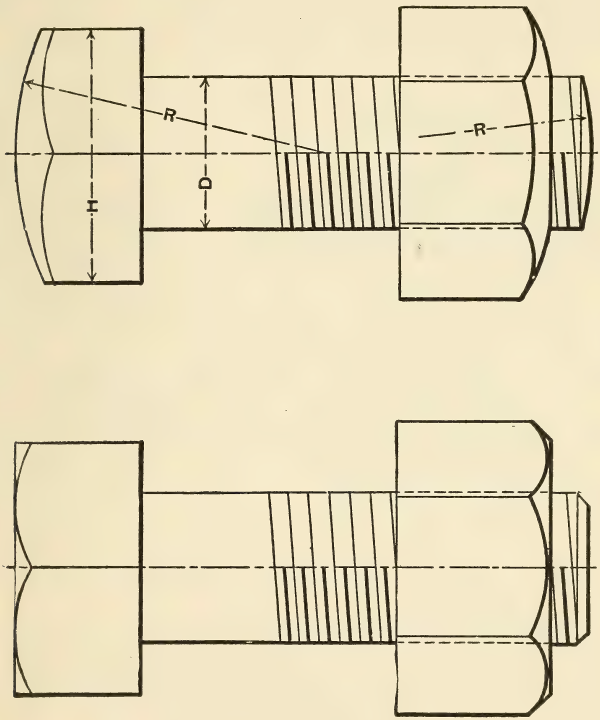

Fig. 84. Hexagonal-head Bolt and Nut.

Example 1: Hexagonal head bolt and nut. Draw the views of the bolts and nuts as shown in Fig. 84, for bolts 4 inches long under head and 1 inch diameter. Scale—Full size.

Cast iron flange coupling. In the kind of coupling shown in Fig. 85 a cast iron center or boss provided with a flange is secured to the end of each shaft by a sunk key driven from the face of the flange. These flanges are then connected by bolts and nuts.

To ensure the shaft being in line the end of one projects into the flange of the other.

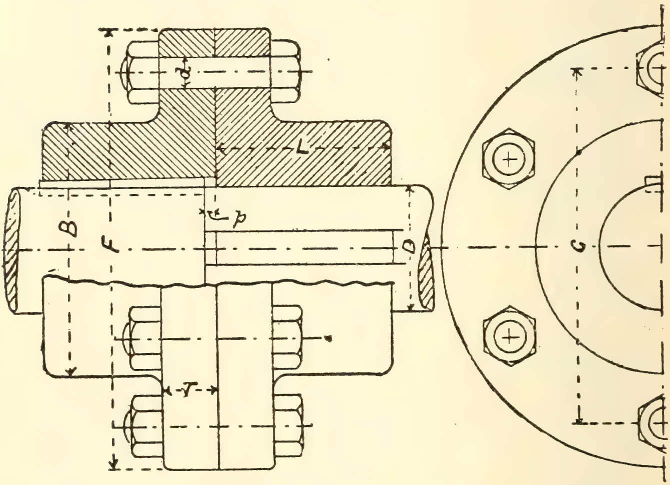

Fig. 85. Cast-iron Flange Coupling.

In order that the face of each flange may be exactly perpendicular to the axis of the shaft they should be faced in the lathe, after being keyed on to the shaft.

If the coupling is in an exposed position, where the nuts and bolt-heads would be liable to catch the clothes of workmen or an idle driving band which might come in the way, the flanges should be made thicker, and be provided with recesses for the nuts and bolt-heads.

DIMENSIONS OF CAST-IRON FLANGE COUPLINGS.

Diameter of shaft D	Diameter of flange F	Thickness of flange T	Diameter of boss B	Depth at boss L	Number of bolts	Diameter of bolts d	Diameter of bolt circle C
1½	7¼	⅞	3½	2⅝	3	⅝	5½
2	8⅞	$1\frac{1}{16}$	4⅝	$3\frac{3}{16}$	4	¾	6¾
2½	10⅝	1¼	$5\frac{5}{16}$	3¾	4	⅞	8⅛
3	12⅜	$1\frac{7}{16}$	6¼	$4\frac{5}{16}$	4	1	9½
3½	13⅛	1⅝	7⅛	4⅞	4	1	$10\frac{5}{16}$
4	14	1¾	8	$5\frac{7}{16}$	6	1	11¼
4½	15⅝	2	8⅞	6	6	1⅛	12½
5	17⅜	2⅛	$9\frac{13}{16}$	6⅝	6	1¼	$13\frac{13}{16}$
5½	18¼	$2\frac{5}{16}$	10¾	7¼	6	1¼	14¾
6	19⅞	2½	11⅝	7¾	6	1⅜	16

The projection of the shaft **p** varies from ¼ inch in the small shafts to ½ inch in the large ones.

Example 2. Cast-iron Flange Coupling. Draw the views shown in Fig. 85 of a cast-iron flange coupling, for a shaft 5 inches in diameter, to the dimensions given in the above table. Scale—3 inches to 1 foot.

Proportions of Rivet Heads. The diameter of the snap head is about 1.7 times the diameter of the rivet, and its height about .6 of the diameter of the rivet. The conical head has a diameter twice and a height three-quarters of the rivet diameter. The greatest diameter of the oval head is about 1.6, and its height .7 of the rivet diameter. The greatest diameter of the countersunk head may be one and a half, and its depth a half of the diameter of the rivet.

Example 3. Single-riveted butt Joints. In Fig. 86 are shown two forms of single riveted butt joints.

TABLE SHOWING THE PROPORTIONS OF SINGLE RIVETED LAP JOINTS FOR VARIOUS THICKNESSES OF PLATES.

Thickness of plates.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$
Diam. of rivets	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{1}{16}$	$1\frac{1}{8}$
Pitch of rivets	$1\frac{7}{16}$	$1\frac{11}{16}$	2	$2\frac{1}{16}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$

Distance from center of rivets to edge of plate = $1\frac{1}{2}$ times diameter of rivets.

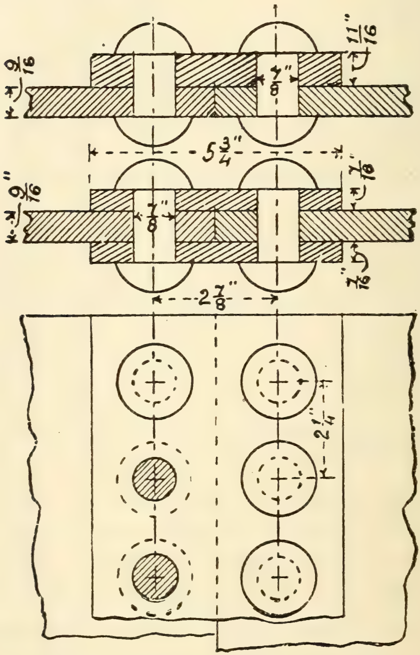

Fig. 86. Single Riveted Butt Joints.

One of the sectional views shows a butt joint with one splice plate, the other sectional view shows a joint with two splice plates. The plan view shows both arrangements. Draw all these views full size.

Example 4. Corner of Wrought-iron Tank. This exercise is to illustrate the connection of plates which are at right angles to one another by means of angle irons. Fig. 87 is a plan and elevation of the corner of a wrought-iron tank. The sides of the tank are riveted to a vertical angle iron, the cross section of

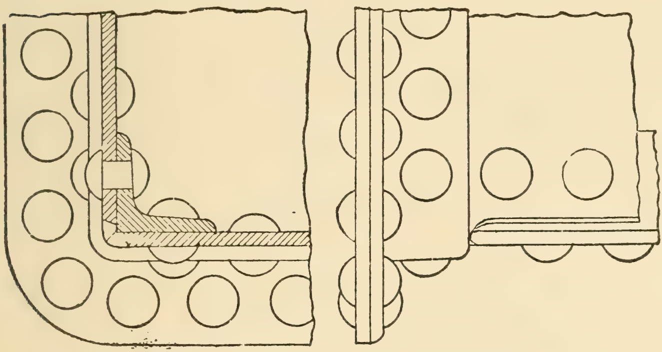

Fig. 87. Corner of Wrought-iron Tank.

which is clearly shown in the plan. Another angle iron of the same dimensions is used in the same way to connect the sides with the bottom. The sides do not come quite up to the corner of the vertical angle iron, excepting at the bottom where the horizontal angle iron comes in. At this point the vertical plates meet one another, and the edge formed is rounded over to fit the interior of the bend of the horizontal angle iron so as to make the joint tight. Draw this example half size.

The dimensions are as follows: angle irons $2\frac{1}{2}$ inches $\times 2\frac{1}{2}$ inches $\times \frac{3}{8}$ inch, plates $\frac{3}{8}$ inch thick, rivets $\frac{3}{4}$ inch diameter and 2 inches pitch.

Example 5. Gusset Stay. In order that the flat ends of a steam boiler may not be bulged out by the

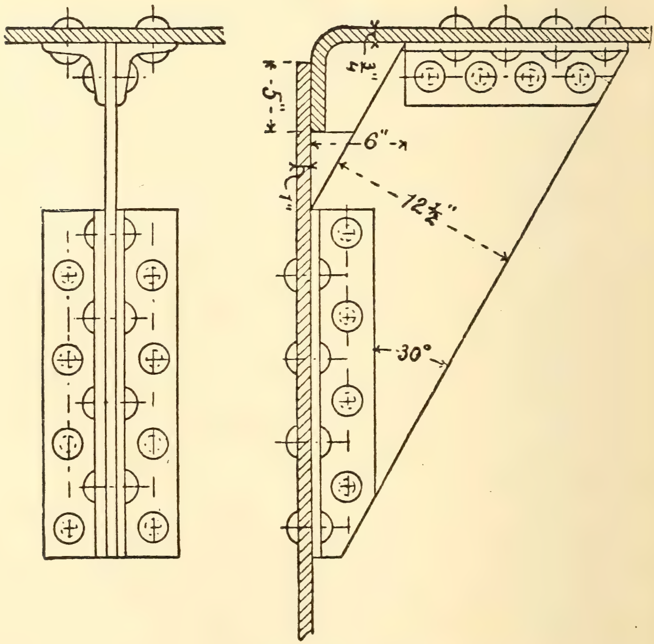

Fig. 88. Gusset Stays.

pressure of the steam they are strengthened by means of stays. One form of boiler stay, called a gusset stay, is shown in Fig. 88. This stay consists of a strip of wrought-iron plate which passes in a diagonal direction from the flat end of the boiler to the cylindrical shell. One end of this plate is placed between and riveted to two angle irons which are riveted to the shell of the boiler. A similar arrangement connects the other end of the stay plate to the flat end of the boiler. In this example the stay or gusset plate is ¾ of an inch thick, the angle irons are 4 inches broad and ½ inch thick. The rivets are 1 inch in diameter. The same figure also illustrates the most

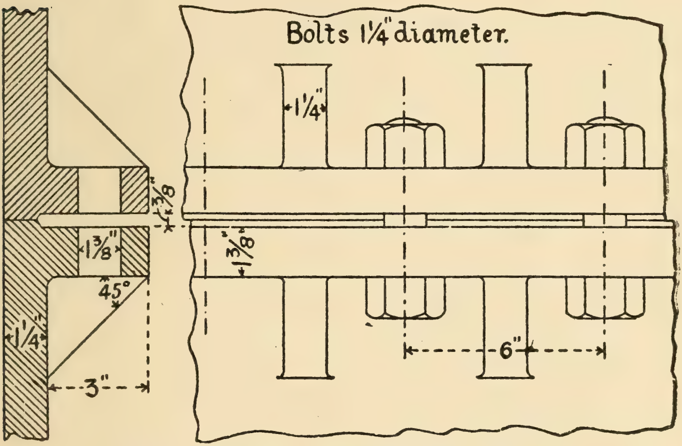

Fig. 89. Flanged Joint for Cast-iron Plates.

common method of connecting the ends of a boiler to the shell. The end plates are flanged or bent over at right angles and riveted to the shell as shown. The radius of the inside curve at the angle of the flange is 1¼ inches. Draw this example to a scale of 3 inches to 1 foot.

Example 6. Flanged Joint for Cast-iron Plates. Draw the views shown in Fig. 89. Draw also a plan. The bolts and nuts must be shown in each view. The

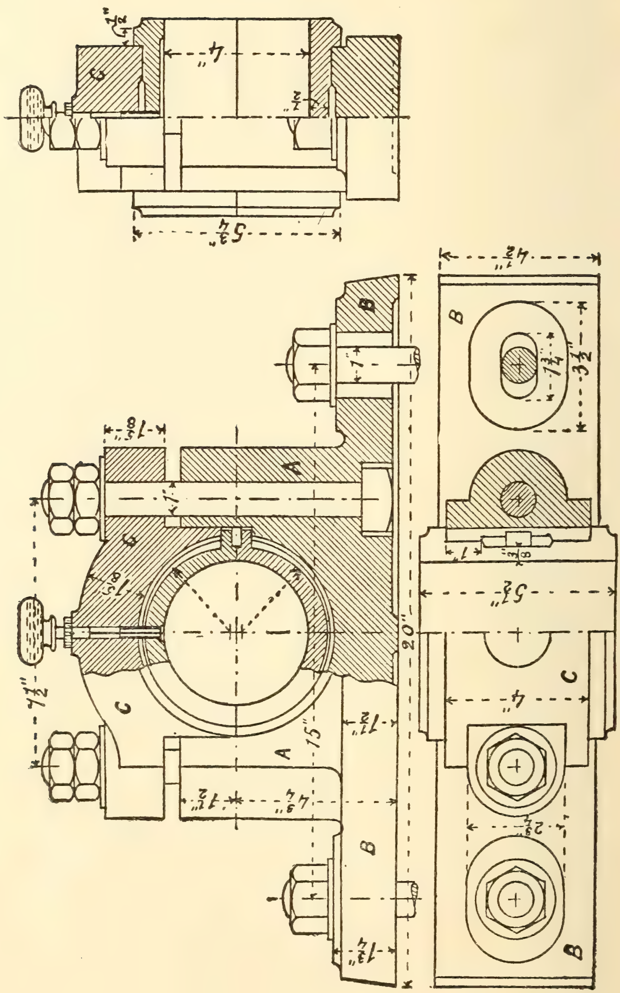

Fig. 90. Pillow Block with Brass Bushing.

holes for the bolts are square, and the bolts have square necks. Draw this example half full size.

Pillow Block. One form of pillow block is shown in Fig. 90. A is the block proper, B the sole-plate through which pass the holding down bolts. C is the cap. Between the block and the cap is the brass bushing which is in halves.

In the block illustrated the journal is lubricated by a needle lubricator; this consists of an inverted glass bottle fitted with a wood stopper, through a hole in which passes a piece of wire, which has one end in the oil within the bottle and the other resting on the journal of the shaft. The wire or needle does not fill the hole in the stopper, but if the needle is kept from vibrating the oil does not escape owing to capillary attraction. When, however, the shaft rotates, the needle begins to vibrate, and the oil runs down slowly on to the journal; oil is therefore only used when the shaft is running.

Example 7. Pillow Block for a Four-inch Shaft. Draw the views shown of this block in Fig. 90. Scale 6 inches to 1 foot.

Proportions of Pillow Blocks. The following rules may be used for proportioning pillow blocks for shafts up to 8 inches diameter. It should be remembered that the proportions used by different makers vary considerably, but the following rules represent average practice:

Diameter of journal	$=d$
Length of journal	$=l$
Height to center	$=1.05d+.5$
Length of base	$=3.6d+5$

Width of base	$=.8l$
" block	$=.7l$
Thickness of base	$=.3d+.3$
" cap	$=.3d+.4$
Diameter of bolts	$=.25d+.25$
Distance between centers of cap bolts	$=1.6d+1.5$
" " " base bolts	$=2.7d+4.2$
Thickness of step at bottom . .	$=t=09d+.15$
" " sides . .	$=\frac{3}{4}t$

The length of the journal varies very much in different cases, and depends upon the speed of the shaft, the load which it carries, the workmanship of the journal and bearing, and the method of lubrication. For ordinary shafting one rule is to make l=d+1. Some makers use the rule l=1.5d, others make l=2d.

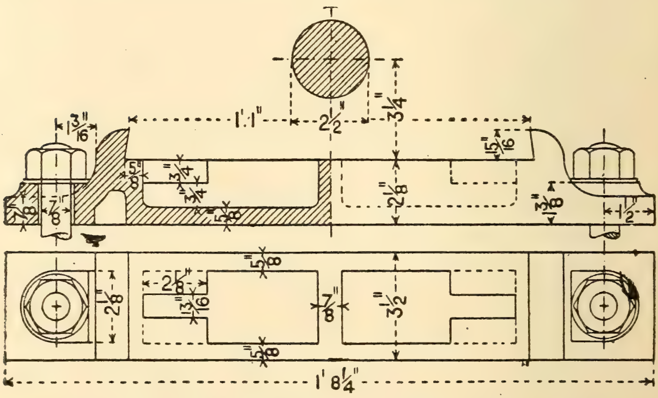

Fig. 91. Sole Plate for a Pillow Block.

Example 8. Sole Plate for a Pillow Block. Draw the views for a sole plate for a pillow block as shown in Fig. 91. Draw also an end elevation. Scale—Half size.

Example 9. Bracket for Pillow Block. Draw the side and end elevations shown in Fig. 92, and from the side elevation project a plan. Scale—Half size.

Example 10. Wall Bracket and Bearing. Draw the side and end elevation partly in section as shown in Fig. 93, and project a complete plan below. Scale—Half size.

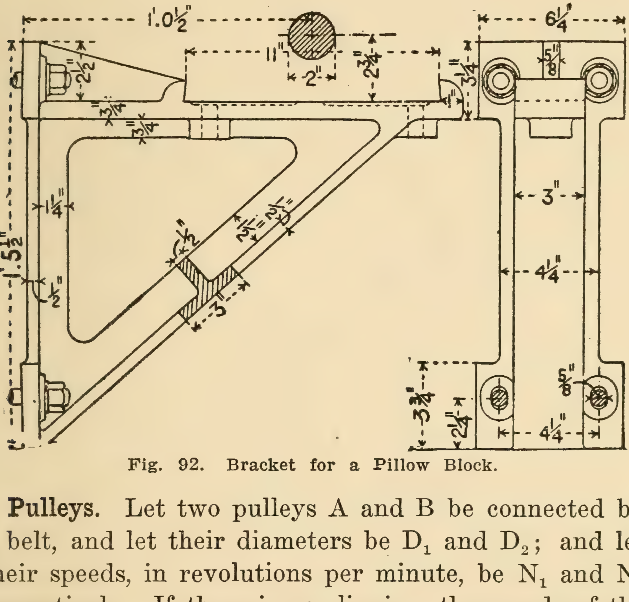

Fig. 92. Bracket for a Pillow Block.

Pulleys. Let two pulleys A and B be connected by a belt, and let their diameters be D_1 and D_2; and let their speeds, in revolutions per minute, be N_1 and N_2 respectively. If there is no slipping, the speeds of the rims of the pulleys will be the same as that of the belt, and will therefore be equal. Now the speed of the rim of A is evidently$=D_1\times 3.1416\times N_1$, while the speed of the rim of B is$=D_2\times 3.1416\times N_2$. Hence $D_1\times 3.1416\times N_1=D_1\times 3.1416\times N_2$, and therefore

$$\frac{N_1}{N_2}=\frac{D_2}{D_1}$$

Pulleys for Flat Belts. In cross section the rim of a pulley for carrying a flat belt is generally curved as shown in Fig. 94, but very often the cross section is straight. The curved cross section of the rim tends to keep the belt from coming off as long as the pulley is rotating. Sometimes the rim of the pulley is provided with flanges which keep the belt from falling off.

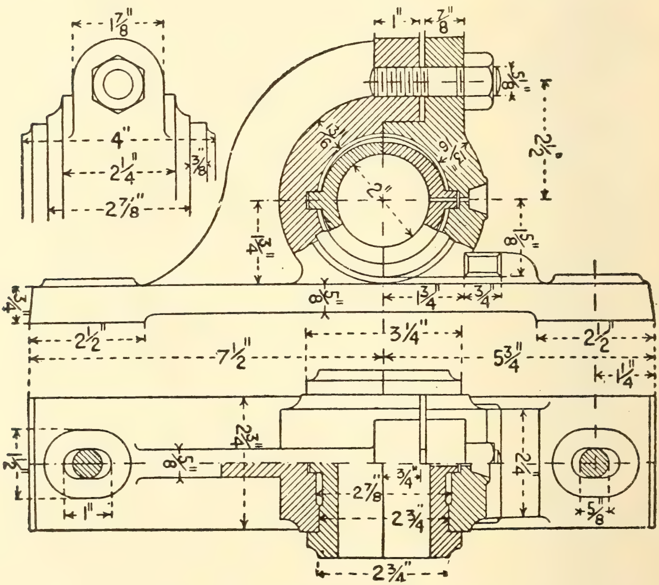

Fig. 93. Wall-bracket and Bearing.

Pulleys are generally made entirely of cast iron, but a great many pulleys are now made in which the center or hub only is of cast iron, the arms being wrought iron cast into the hub, while the rim is of sheet iron.

The arms of pulleys when made of wrought iron are invariably straight, but when made of cast iron they are very often curved. In Fig. 94, which shows an arrangement of two cast-iron pulleys, the arms are straight. Through unequal cooling, and therefore unequal contraction of a cast-iron pulley in the mould, the arms are generally in a state of tension or com-

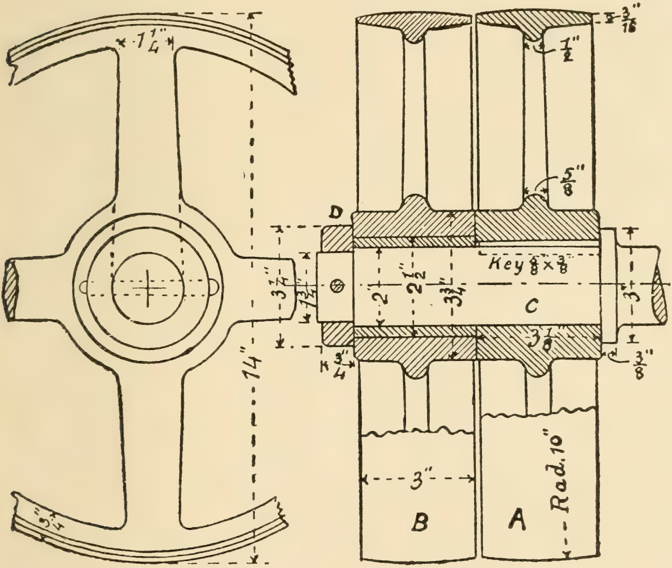

Fig. 94. Tight and Loose Pulleys.

pression, and if the arms are straight they are very unyielding, so that the result of this initial stress is often the breaking of an arm, or of the rim where it joins an arm. With the curved arm, however, its shape permits it to yield, and thus cause a diminution of the stress due to unequal contraction.

The cross section of the arms of cast-iron pulleys is generally elliptical.

Example 11. Tight and Loose Pulleys. Fig. 94 shows an arrangement of tight and loose pulleys. A is the fast pulley, secured to the shaft C by a sunk key, B is the loose pulley, which turns freely upon the shaft. The loose pulley is prevented from coming off by a collar D, which is secured to the shaft by a tapered pin as shown. The nave or boss of the loose pulley is here fitted with a brass bushing, which may be removed when it becomes too much worn. Draw the elevations shown, completing the left-hand one. Scale 6 inches to 1 foot.

By the above arrangement of pulleys a machine may be stopped or set in motion at pleasure. When the driving belt is on the loose pulley the machine is at rest, and when it is on the tight pulley the machine is in motion. The driving belt is shifted from the one pulley to the other by pressing on that side of the belt which is advancing towards the pulleys.

Gear Wheels. Let two smooth rollers be placed in contact with their axes parallel, and let one of them rotate about its axis, then if there is no slipping the other roller will rotate in the opposite direction with the same surface velocity, and if D_1, D_2 be the diameters of the rollers, and N_1, N_2 their speeds in revolutions per minute. it follows as in belt gearing that

$$\frac{N_1}{N_2}=\frac{D_2}{D_1}$$

If there be considerable resistance to the motion of the follower slipping may take place, and it may stop. To prevent this the rollers may be provided with teeth, then they become spur wheels, and if the teeth be so shaped that the ratio of the speeds of the toothed rollers at any instant is the same as that of the smooth rollers, the surfaces of the latter are called the pitch surfaces of the former.

Pitch Circle. A section of the pitch surface of a toothed wheel by a plane perpendicular to its axis is a circle, and is called a pitch circle. We may also say that the pitch circle is the edge of the pitch surface. The pitch circle is generally traced on the side of a toothed wheel, and is rather nearer the points of the teeth than the roots.

Pitch of Teeth. The distance from the center of one tooth to the center of the next, or from the front of one to the front of the next, measured at the pitch circle, is called the pitch of the teeth. If D be the diameter of the pitch circle of a wheel, n the number of teeth, and p the pitch of the teeth, then $D \times 3.1416 = n \times p$.

By the diameter of a wheel is meant the diameter of its pitch circle.

Form and Proportions of Teeth. The ordinary form of wheel teeth is shown in Fig. 95. The curves of the teeth should be cycloidal curves, although they are generally drawn in as arcs of circles. It does not fall within the scope of this work to discuss the correct forms of gear teeth.

Example 12. Spur Gear. Fig. 95 shows the elevation and sectional plan of a portion of a cast-iron spur gear. The diameter of the pitch circle is $23\frac{7}{8}$ inches, and the pitch of the teeth is $1\frac{1}{2}$ inches, so that there will be 50 teeth in the gear. The gear has six arms. Draw a complete elevation of the gear and a half sectional plan, also a half-plan without any section. Draw also a cross section of one arm. Scale 3 inches to 1 foot.

Mortise Gears. When two gears meshing together run at a high speed the teeth of one are made of wood. These teeth, or cogs, as they are generally called, have tenons formed on them, which fit into mortises in the rim of the gear. This gear with the wooden teeth is called a mortise gear.

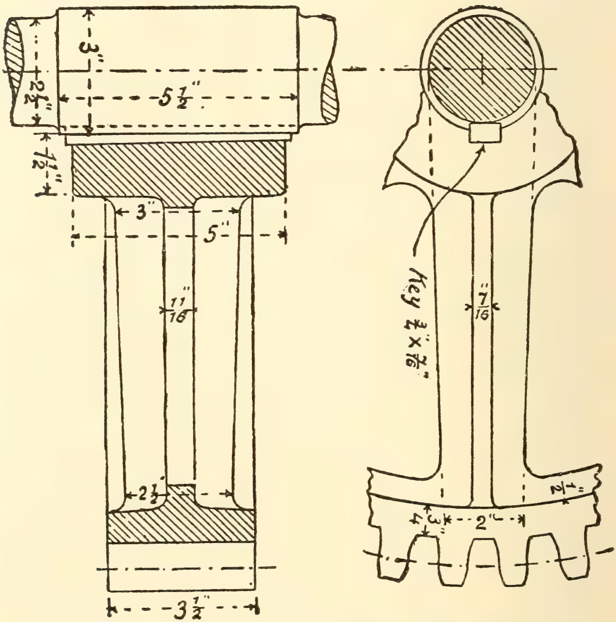

Fig. 95. Portion of a Cast-iron Spur Gear.

Coupling Rods. A rod used to transmit the motion of one crank to another is called a coupling rod. A familiar example of the use of coupling rods will be found in the locomotive. Coupling rods are made of wrought iron or steel, and are generally of rectangular section. The ends are now generally made solid and lined with solid brass bushes, without any adjustment for wear. This form of coupling rod end is found to answer very well in locomotive practice, where the

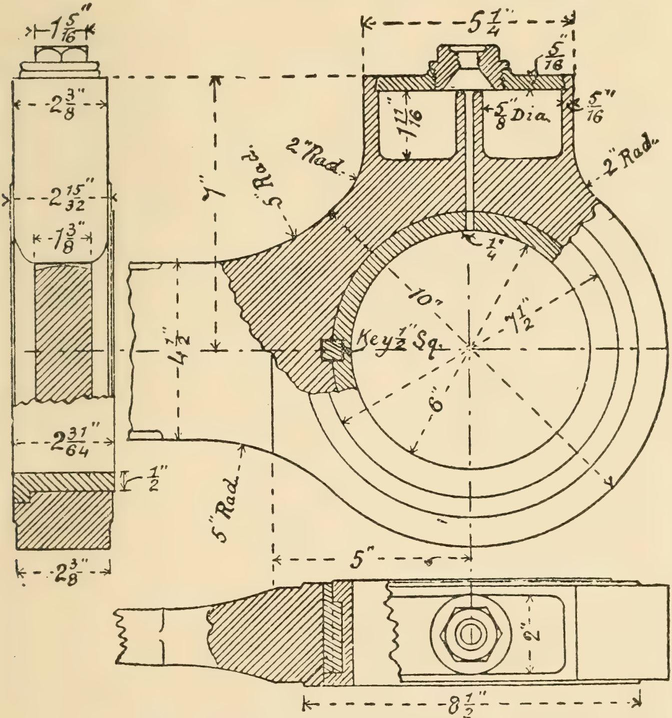

Fig. 96. Locomotive Coupling-rod End.

workmanship and arrangements for lubrication are excellent. When the brass bush becomes worn it is replaced by a new one.

Fig. 96 shows an example of a locomotive coupling rod end for an outside cylinder engine. In this case it is desirable to have the crank-pin bearings for the coupling rods as short as possible, for a connecting rod and coupling rod in this kind of engine work side by side on the same crank-pin, which, being overhung, should be as short as convenient for the sake of strength. The requisite bearing surface is obtained by having a pin of large diameter. The brass bush is prevented from rotating by means of the square key shown. The oil-box is cut out of the solid, and has a wrought-iron cover slightly dovetailed at the edges. This cover fits into a check round the top inner edge of the box, which is originally parallel, but is made to close on the dovetailed edges of the cover by riveting. A hole in the center of this cover, which gives access to the oil-box, is fitted with a screwed-brass plug. The brass plug has a screwed hole in the center, through which oil may be introduced to the box. Dust is kept out of the oil-box by screwing into the hole in the brass plug a common cork. The oil is carried slowly but regularly from the oil-box over to the bearing by a piece of cotton wick.

Example 13. Coupling Rod End. Draw first the side elevation and plan, each partly in section as shown in Fig. 96. Then instead of the view to the left, which is an end elevation partly in section, draw a complete end elevation looking to the right, and also a complete vertical cross section through the center of the bearing. Scale 6 inches to 1 foot.

Stuffing-boxes. In Fig. 97 is shown a gland and stuffing-box for the piston rod of a vertical engine. A B is the piston rod, C D a portion of the cylinder cover, and E F the stuffing-box. Fitting into the bottom of the stuffing-box is a brass bush H. The space

K around the rod A B is filled with packing, of which there is a variety of kinds, the simplest being greased hempen rope. The packing is compressed by screwing

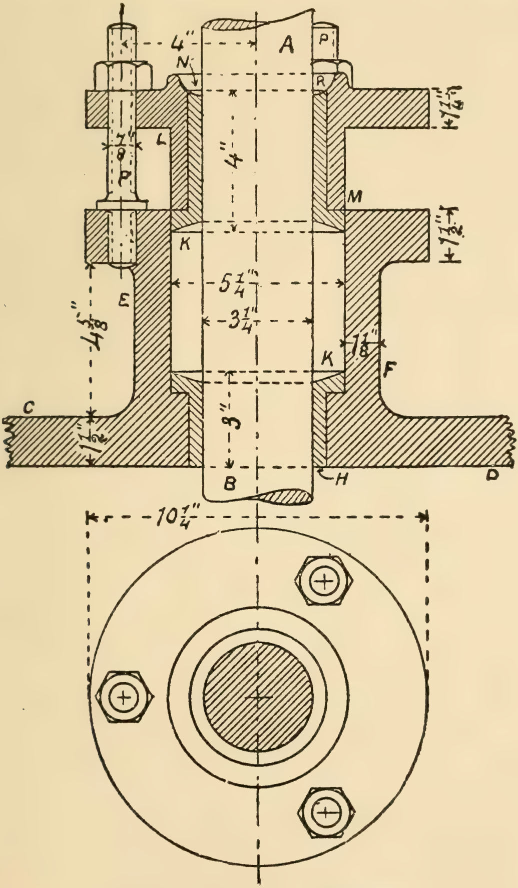

Fig. 97. Gland and Stuffing-box.

down the cast-iron gland L M, which is lined with a brass bush N. In this case the gland is screwed down

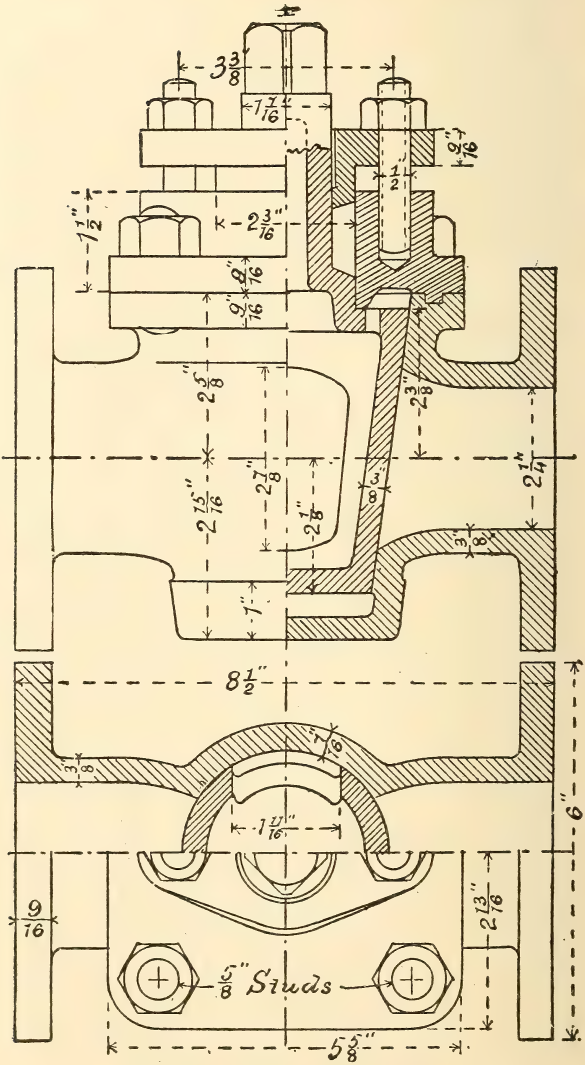

Fig. 98. Water or Steam Cock.

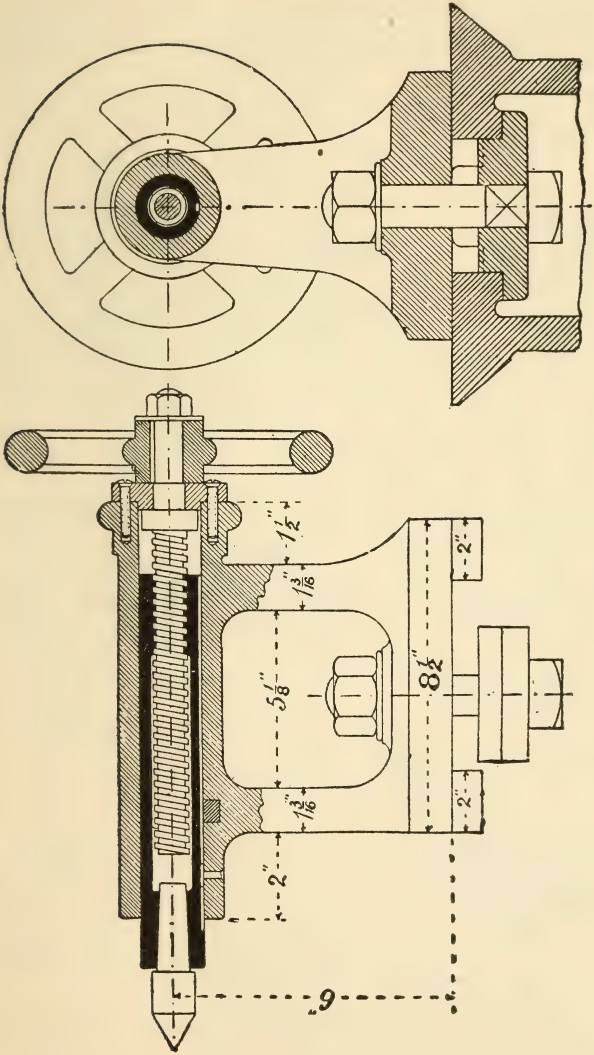

Fig. 99. Tailstock for 12-inch Lathe.

by means of three stud-bolts P, which are screwed into a flange cast on the stuffing-box. Surrounding

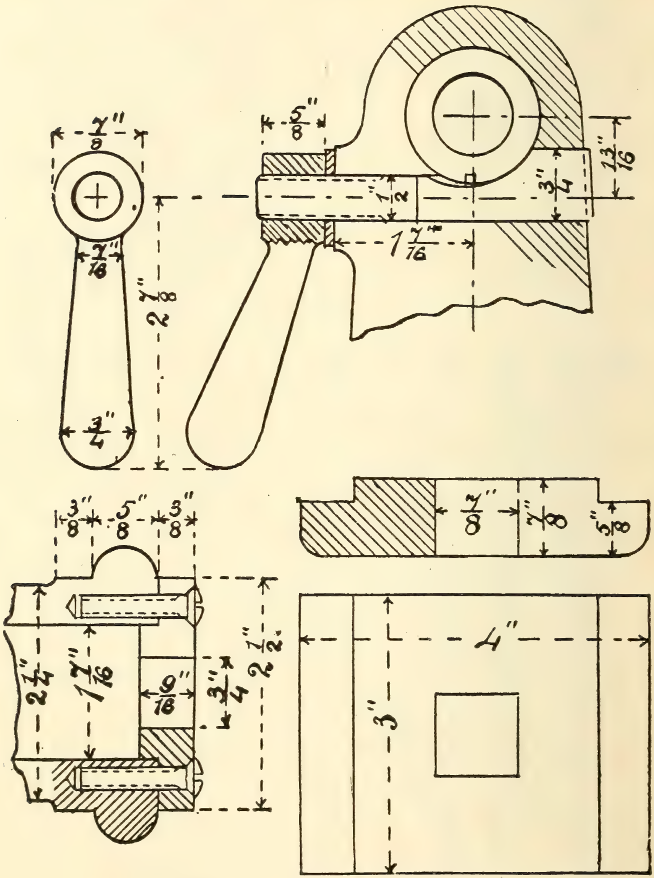

Fig. 100. Details of Tailstock.

the rod on the top of the gland there is a recess R for holding the lubricant.

The object of the gland and stuffing-box is to allow the piston rod to move backwards and forwards freely without any leakage of steam.

Example 14. Gland and Stuffing-box for a Vertical Rod. Draw the views shown in Fig. 97 to the dimensions given. Scale 6 inches to 1 foot.

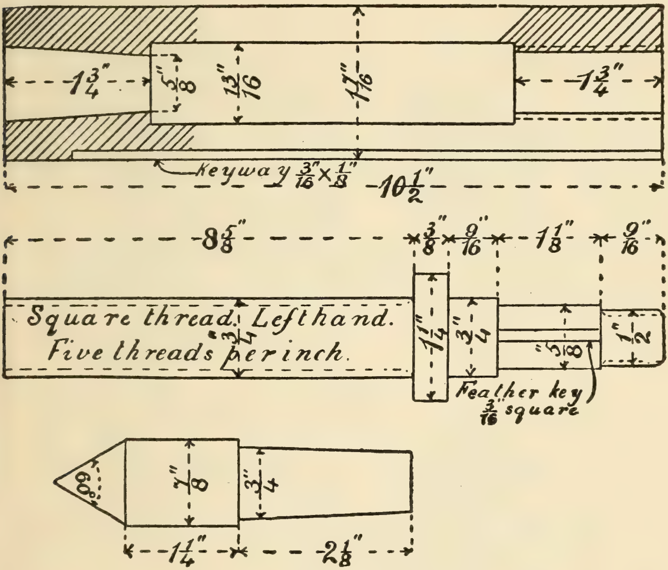

Fig. 101. Details of Tailstock.

Water or Steam Cock. Fig. 98 shows a cock of considerable size, which may be used for water or steam under high pressure. The plug in this example is hollow, and is prevented from coming out by a cover which is secured to the casing by four stud bolts. An annular ridge of rectangular section projecting from the under side of the cover, and fitting into a corresponding recess on the top of the casing, serves

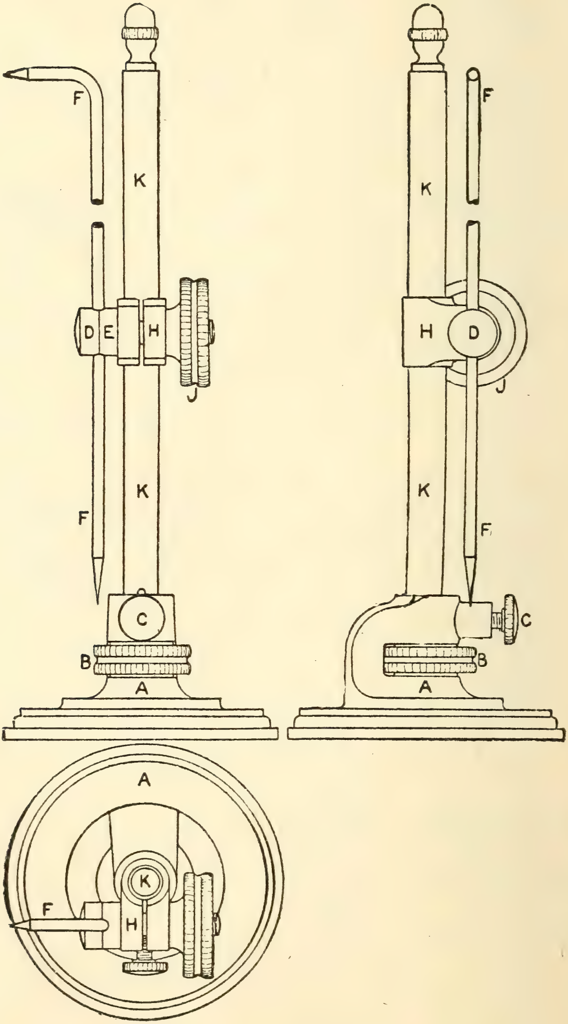

Fig. 102. Surface Gauge.

to ensure that the cover and plug are concentric, and prevents leakage. Leakage at the neck of the plug is prevented by a gland and stuffing-box. The top end of the plug is made square to receive a handle for turning it. The size of a cock is taken from the bore of the pipe in which it is placed, thus Fig. 98 shows a 2½-inch cock.

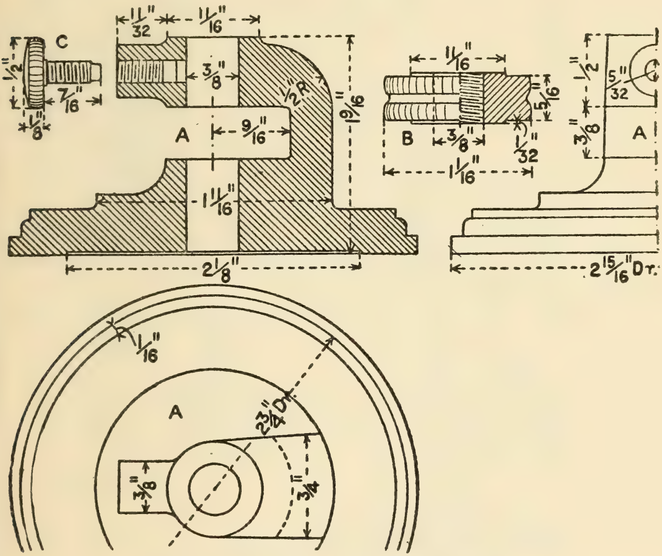

Fig. 103. Details of Surface Gauge.

Example 15. 2 1-2-inch Steam or Water Cock. First draw the views of this cock shown in Fig. 98, then draw a half end elevation and half cross section through the center of the plug. Scale 6 inches to 1 foot.

Instead of drawing the parts of the pipe on the two sides of the plug in the same straight line as in Fig. 98, one may be shown proceeding from the bottom of the casing, so that the fluid will have to pass through the bottom of the plug and through one side. This is a common arrangement.

All the parts of the valve and casing in this example are made of brass.

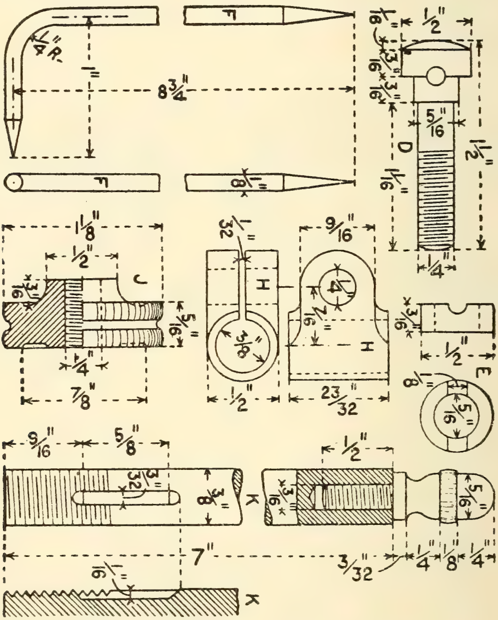

Fig. 104. Details of Surface Gauge.

Example 16. Tailstock for 12-inch Lathe. Two views of this tailstock are shown in Fig. 99. On one of these views a few of the principal dimensions are marked. The details, fully dimensioned, are shown separately in Figs. 100 and 101.

Explain clearly how the center is moved backwards and forwards, and also how the spindle containing it is locked when it is not required to move.

Draw, half-size, the views shown in Fig. 99, and from the left-hand view project a plan. Draw also

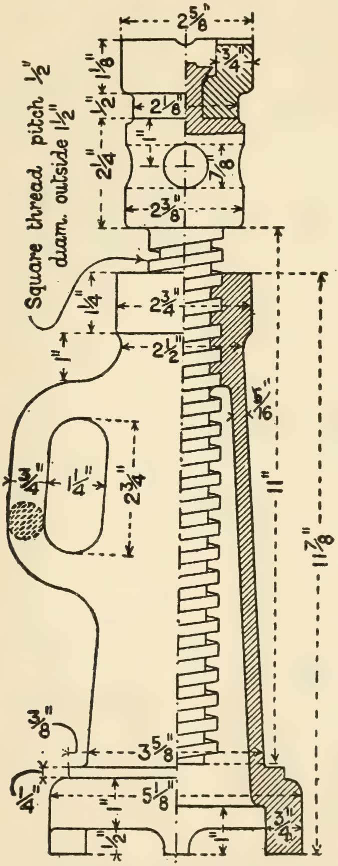

Fig. 105. Jack Screw.

the detail of the locking arrangement shown in Fig. 100.

Example 17. Surface Gauge. First draw, full size, all the details separately, as shown in Figs. 103 and 104, then draw, full size, the plan and two elevations of the tool complete, as shown in Fig. 102.

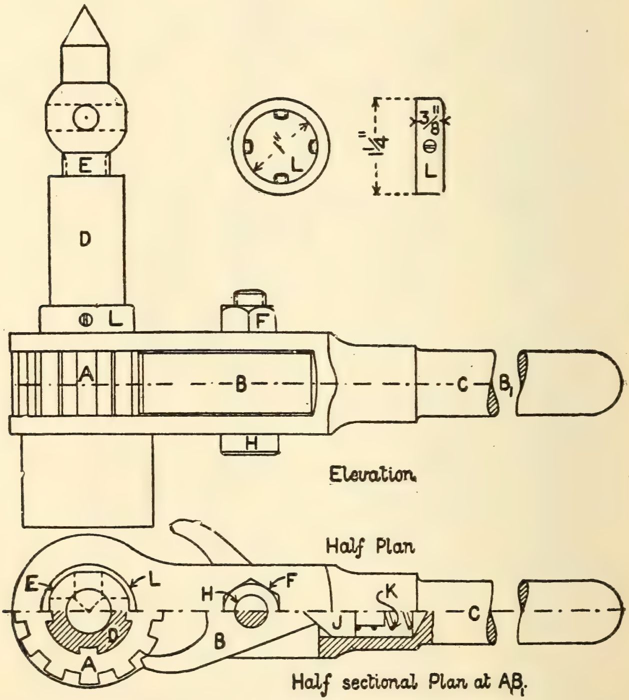

Fig. 106. Reversible Ratchet-drill.

F is the scriber which may be clamped at any part of the straight portion, between D and E. The scriber may also be placed at any angle to the horizontal, and the point at which it is clamped may be placed at any height from the base A within the limits of the upright K. D and E are carried by the clamp H, which embraces the upright K. By turning the milled

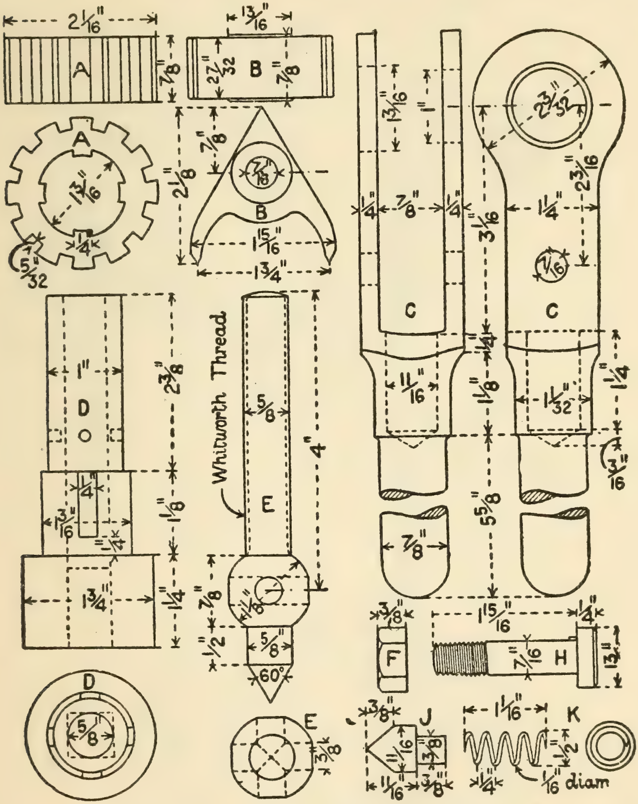

Fig. 107. Details of Ratchet-drill.

nut J the scriber is fixed in position in relation to K. A fine vertical adjustment is obtained by rotating the milled nut B. After all adjustments have been made, K is locked in position by the set-screw C.

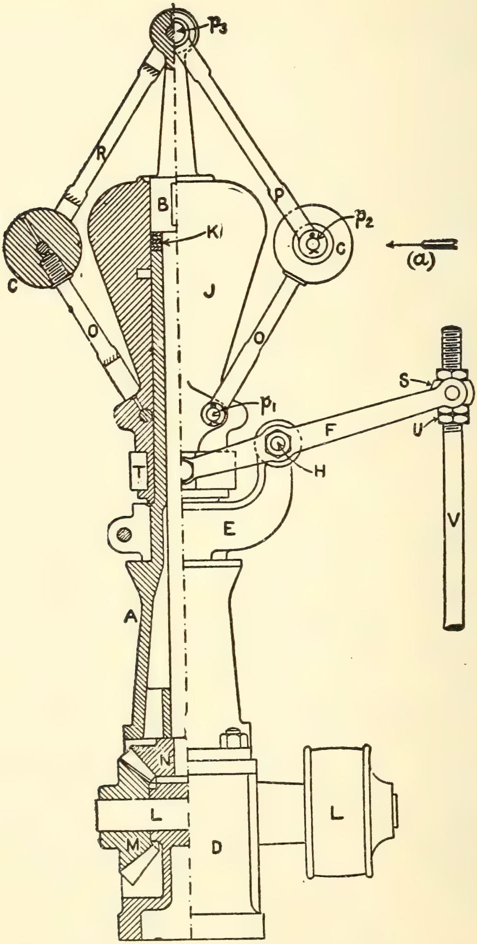

Fig. 108. Steam Engine Governor.

Example 18. Jack Screw. From the half elevation and half section shown in Fig. 105 make working drawings of the separate parts of the jack-screw, then draw the views shown below of the complete machine. Scale 6 inches to 1 foot.

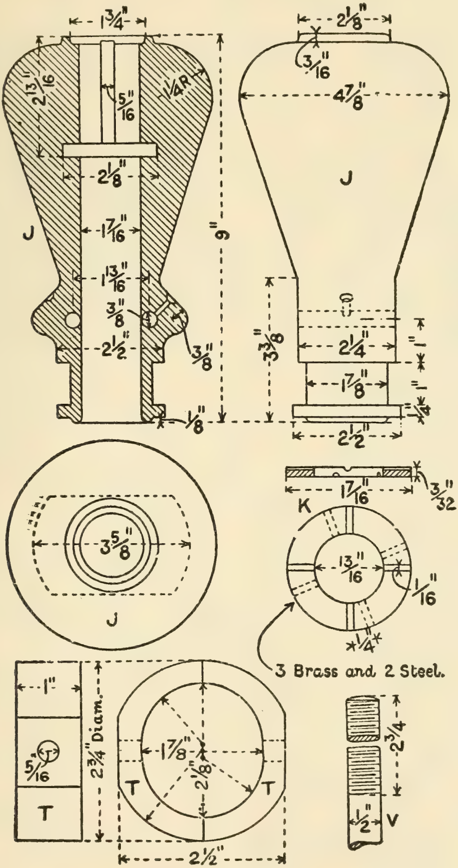

Fig. 109. Details of Governor.

Example 19. Reversible Ratchet-drill. Draw, full size, the views shown in Fig. 106 of a reversible ratchet-brace. Draw also the details separately, as shown in Fig. 107. All the dimensions are to be obtained from the detailed drawings.

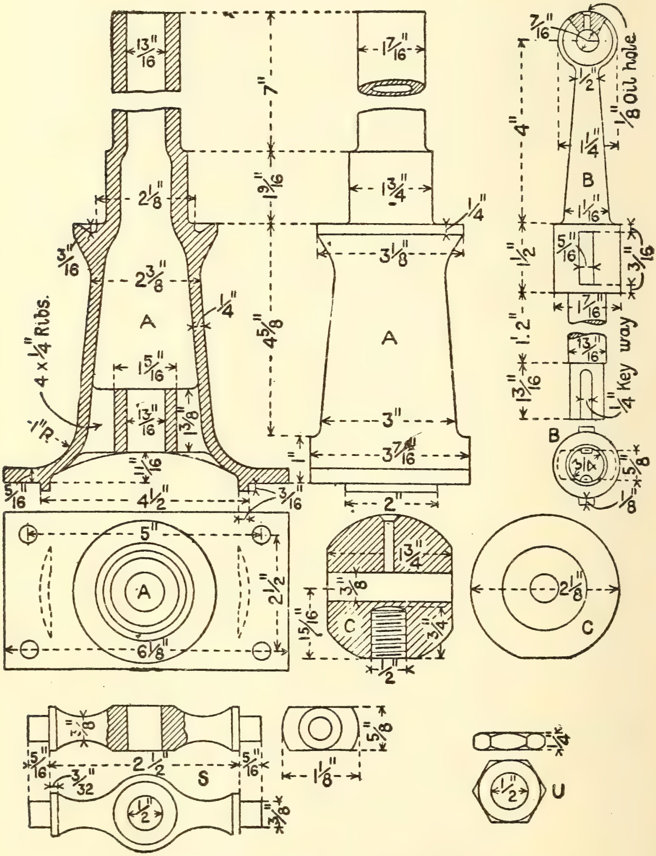

Fig. 110. Details of Governor.

Example 20. Steam Engine Governor. Draw the half elevation and half section of the governor com-

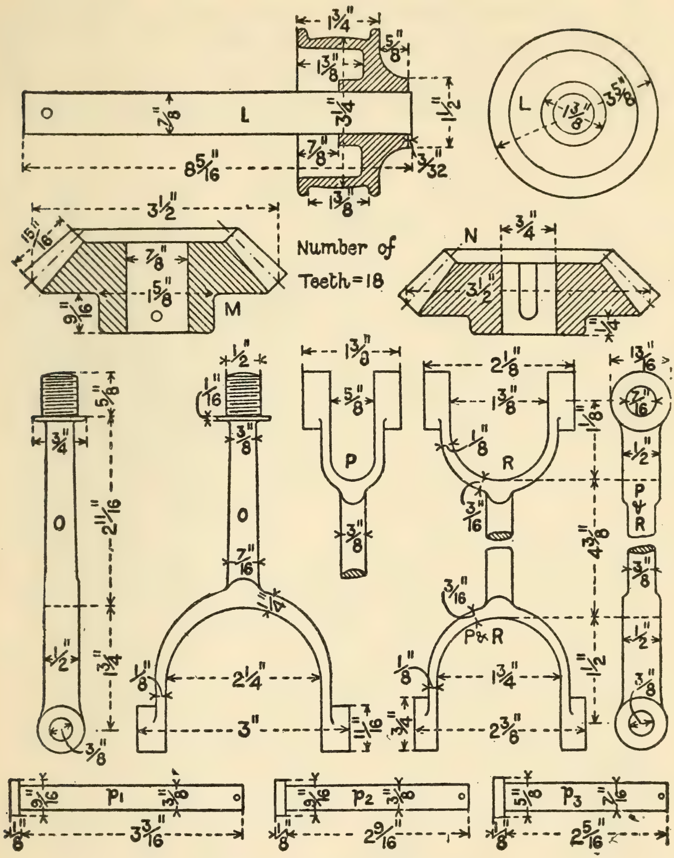

Fig. 111. Details of Governor.

plete, as shown in Fig. 108. Draw also a plan and an elevation looking in the direction of the arrow (a). Scale 6 inches to a foot. All the dimensions are to be taken from the illustrations of the details shown in Figs. 109, 110, 111 and 112.

The governor illustrated is used on an engine having a cylinder 8 inches in diameter, with a piston stroke of 16 inches. The crank-shaft runs at about 110 revolutions per minute, and the governor-spindle

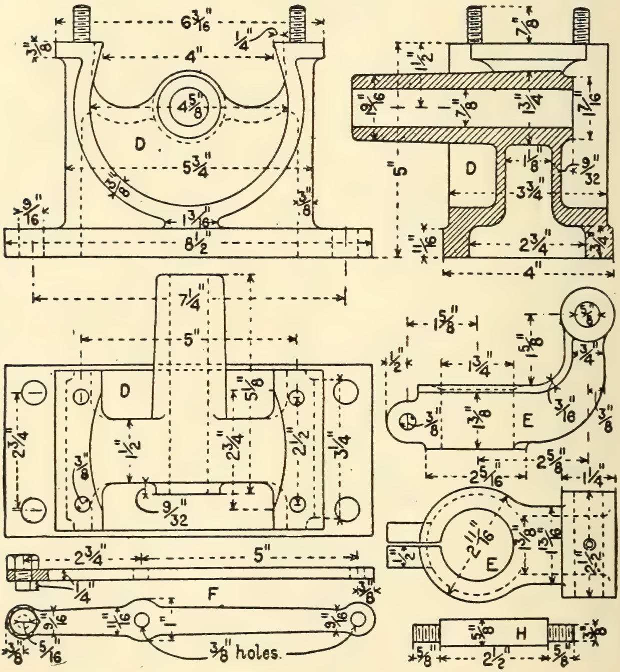

Fig. 112. Details of Governor.

is driven at three times the speed of the crank-shaft. The governor controls the expansion valve. This type of governor is known as the "Porter" governor, from the name of the inventor.

MECHANICAL DRAWING AND MACHINE DESIGN.

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