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MACHINE SHOP MECHANICS

THE WHY OF THINGS IN THE SHOP

BY

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PREFACE

This may perhaps be called the "Why of Things in the Machine Shop."

There are many happenings in our everyday work, such as friction, oil flying out from a bearing, etc., which cannot be understood or explained without a little knowledge of the natural laws which govern the whole universe.

These laws, which are fixed and unchanging, affect everything we do and it is only by understanding these laws that we can run our shops and build successful machines.

Such common examples as the effect of heat on making fits and on measurments and the use of screws and levers for utilizing power are more or less familiar to all; and it is with the hope of making the foundation principles of mechanics perfectly clear that this third book of the series has been written.

THE AUTHOR.

CONTENTS

CHAPTER PAGE

I LEVERS 1

II THE SCREW AND WEDGE 19

III INCLINED PLANES. 28

IV GRAVITY 31

V FRICTION. 42

VI HEAT 46

VII INERTIA 56

VIII BELTS AND PULLEYS. 60

IX BLOCK AND TACKLE. 75

X GEARING. 85

XI CENTRIFUGAL FORCE 107

XII HYDRAULICS 113

XIII STEAM PRESSURE 123

XIV THE FORCE OF A BLOW 126

XV STRENGTH OF MATERIALS 131

XVI SHAFTING 145

XVII ACTION AND REACTION 147

XVIII BEAMS 156

XIX MEASURING MOMENTS 161

XX FORCE DIAGRAMS 164

INDEX. 173

MACHINE SHOP MECHANICS

MACHINE SHOP MECHANICS

CHAPTER I

LEVERS

The principles of mechanics can be boiled down to two, the lever and the wedge, instead of the six that were formerly used. For the "wheel and axle" is nothing but a lever and the "inclined plane" is simply a stationary wedge of large size.

So we can confine ourselves to the lever and wedge as the two principles to think about.

The first and probably the most important principle or element in mechanics or of machines, is the lever. It is used more than any other as it enters into practically every machine in some form or other. Although we are more familiar with the simple forms such as the crowbar or steelyard, the common blacksmith tongs and cutting pliers, all revolving parts such as the pulleys or gears, are simply other forms of levers with a continous rim.

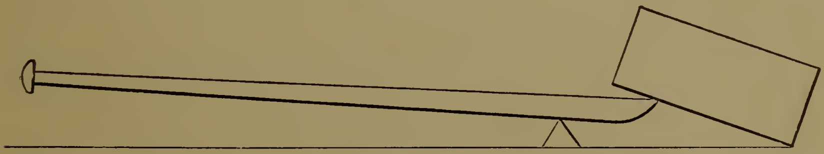

FIG. 1.

Figs. 1, 2 and 3 show three common forms in which levers are used while Figs. 4, 5 and 6 show three other applications which are not so often considered as levers. The shaded levers, drawn across the pulley arms and

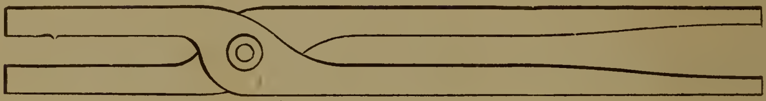
FIG. 2.

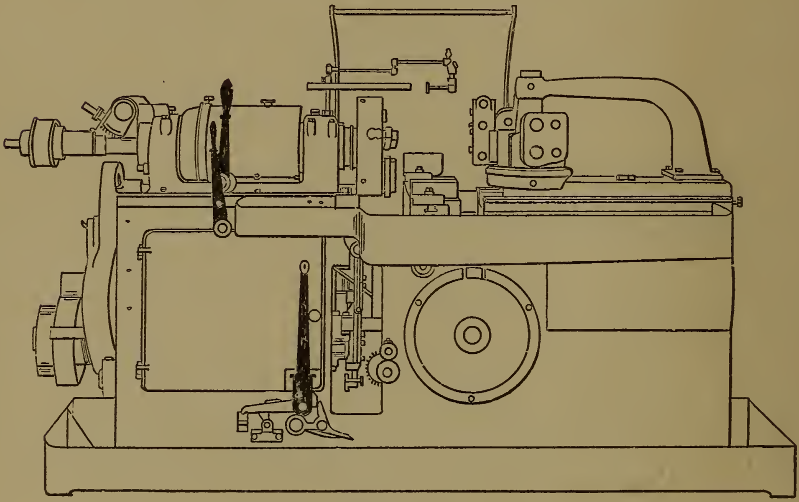
FIG. 3.

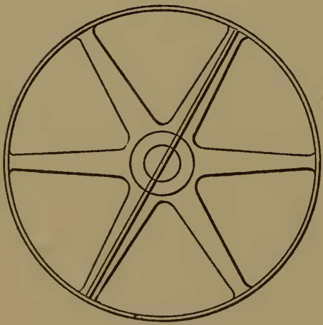
FIG. 4.

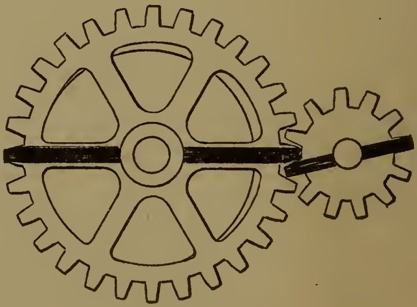
FIG. 5.

across the gears, show how the lever principle acts here as in the other cases.

The elliptical gear (Fig. 6) is equivalent to a series of levers of different lengths, so that first the driver and then the driven have the longer arm. This varies the speed of the driven as well as the power required to drive it.

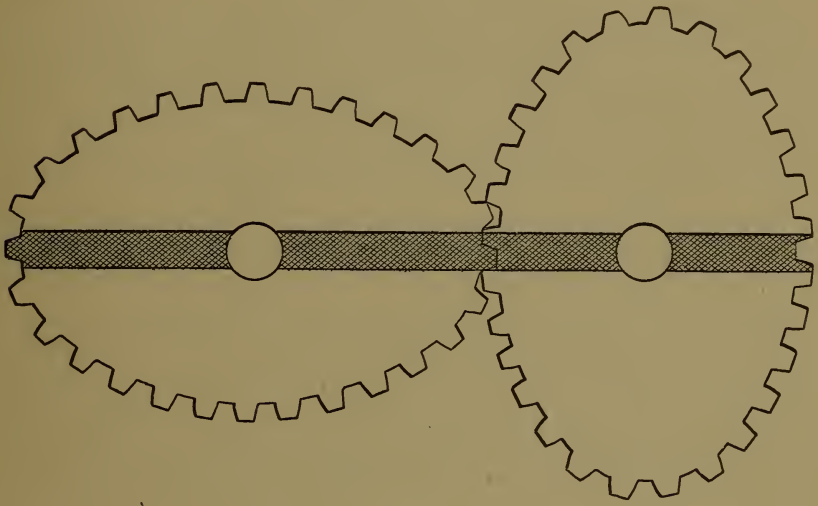

FIG. 6.

The Three Kinds of Levers

Levers are divided into three classes known as the first, second, and third class. Figs. 7, 8 and 9 show the difference between them, which is important.

The difference is in the location of the pivot or fulcrum and the way in which the power is applied. In all diagrams *F*=fulcrum or pivot, *L*=the load or work to be done, and *P*=power applied.

In the *first* class the fulcrum is between the power and load. The power and load move in opposite directions.

In the *second* class the load is between the fulcrum and the power. The power and the load move in the same direction.

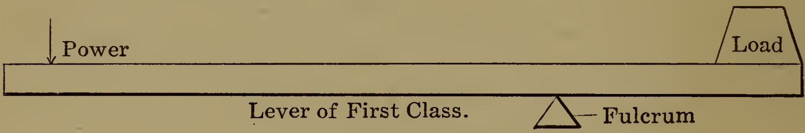
Power
Load
Lever of First Class.
Fulcrum

FIG. 7.

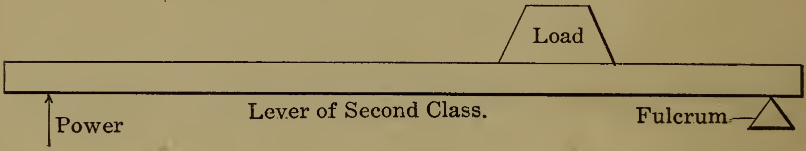
Load
Power
Lever of Second Class.
Fulcrum

FIG. 8.

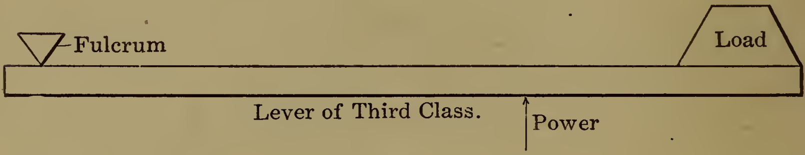
Fulcrum
Load
Lever of Third Class.
Power

FIG. 9.

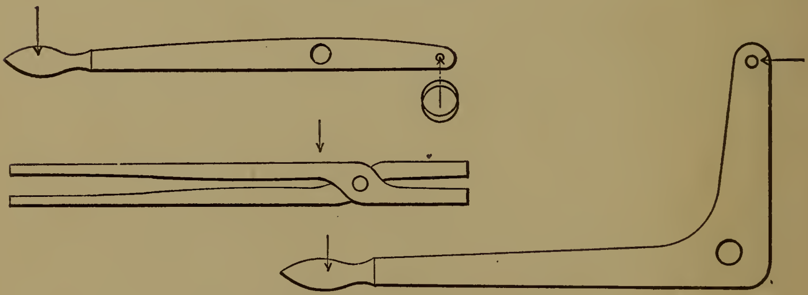

FIG. 10.—Levers of the First Class.

In the *third* class the power is between the fulcrum and load. The power and the load move in the same direction.

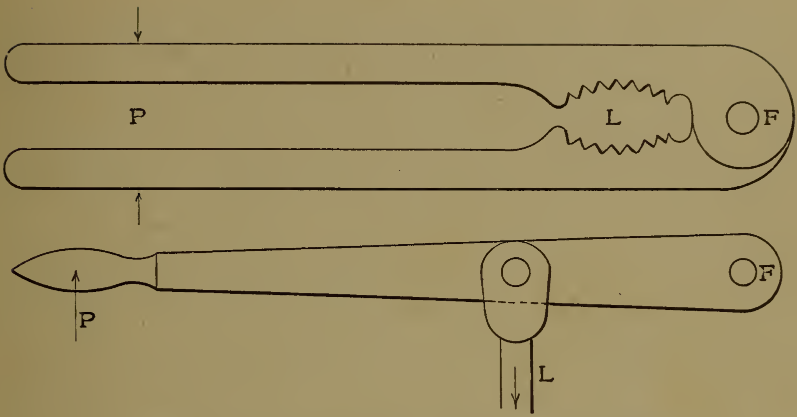

FIG. 11.—Two Levers of the Second Class.

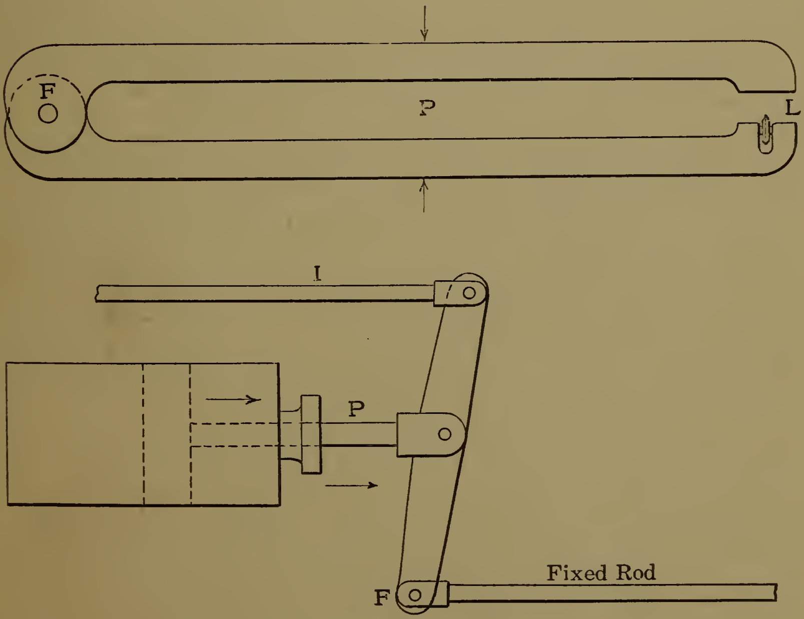
F
P
L
L
P
Fixed Rod
F

FIG. 12.—Levers of the Third Class.

In Fig. 10 are those examples of levers of the *first* class. The bent or bell-cranked lever makes no difference in the class, as the fulcrum is between the load and the power.

In Fig. 11 the nut cracker and the lever with the fulcrum at the end show two examples of levers of the *second* class.

In Fig. 12 is the *third* class with the power applied between the fulcrum and the load. The upper illustration is a water gage glass cutter which is familiar to all engineers. The load is the glass cutter on the tube at the end, the power being applied by squeezing the two arms together at P by the hand. The lower is an air brake connection between the air cylinder and the lever.

Work and Leverage

Having learned the kinds of levers and their uses, the question of leverage, or the advantages of using the different kinds, is in order.

And this is so closely allied with the question of "work" that we will consider both together as we go along.

Work is the overcoming of resistance in any way. Energy is the power of doing work.

Practically everything we do is work in the broad sense. The work done in a college boat race or a foot-ball game would drive more machinery than you might think. And the crew or team with the most energy does the most work, and wins.

Running or walking up stairs is work and requires energy; so does driving a nail into a piece of wood. The nail overcomes the resistance of the wood, and the hammer has motion which drives it.

Work done always shows itself in some way, or has possibilities of giving back part of the work expended. If you hammer a piece of cold metal, it may do no useful work; but the metal becomes warm as a result of the work put into it. If the hammering is done fast enough, it may even heat it to a visible red or hotter.

This is due to the moving or rubbing of the small particles of metal called molecules and atoms on each other, as they are hammered, and the metal changes shape ever so slightly. If you raise a brick from the floor to the shelf, you have put work into overcoming the resistance of gravity; but it will not give back anything until it falls to the floor again. Then it may drive a nail, break a board, or smash a man's foot, depending on what it strikes.

Measuring the Work Done

Work is measured by foot pounds as a unit just as we measure floors in square feet. A foot pound is 1 pound raised 1 foot; but it makes quite a difference whether you do it in a minute or once a day, so the unit of work is 1 pound raised 1 foot in 1 minute.

If you carry a 20-pound pulley 20 feet up a ladder in 1 minute and weigh 150 pounds yourself, you have done $20+150\times 20$ or 3400 foot pounds of work. As a horse-power is 33,000 foot pounds, you have done a little over 1/10 of a horse-power.

By remembering that work in all cases equals the amount of force in pounds multiplied by the distance through which it moves in a given time, you will never fall a victim of "power" multiplying machines or perpetual-motion devices.

Taking the crowbar as the simplest example, as in Fig. 13, we can see just how this works out in actual practice. Here we have a 5-foot crowbar resting over a block 1 foot from the end under the piece to be raised. The piece weighs 500 pounds. What power must you apply to the other end to raise the block?

The part of the crowbar which rests on the block of wood or the block itself is called the fulcrum. It does not matter which, as it is the distance from the two ends that counts. The power arm we call *P*, the weight arm *W*, and the fulcrum *F*. The weight arm is 1 foot long and the weight 500 pounds, but to avoid confusion with foot pounds we generally use inch pounds for such problems as this and say the weight arm is 12×500=6000 inch pounds.

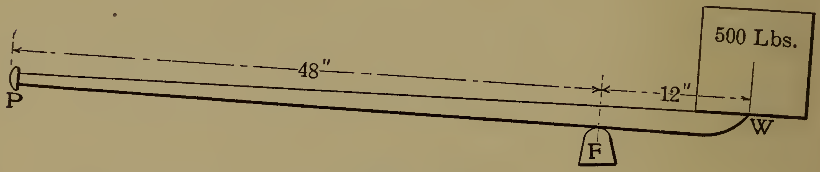

FIG. 13.

Now the power end where we apply our muscle is 4 feet or 48 inches long; so it is plain that to balance the weight arm we must apply as much power as, when multiplied by 48, will equal 6000. In other words, we must have 6000 inch pounds on the power arm of the crowbar to balance the weight arm; so we divide 6000 by 48 and get 125 pounds.

As this will only balance the piece, we must apply a little more than 125 pounds to raise the piece from the floor.

We could have found this in another way, and after you have had a little practice you will probably do it in your head. The power arm in this case is four times the length of the weight arm, so we can see at once that one-quarter the load on the weight arm will balance it if applied to the other end. But we will see this plainer a little later.

The Relation Between Distance Moved and the Weight

We also find out another interesting thing in this connection if we watch closely, and that is that the piece will only be raised one-quarter the distance we move the end of the crowbar to which we apply the power. If we move the end of the bar 24 inches, the piece will be raised 6 inches; so we can see that the movement of the weight and the power bear a direct relation to the length of the two arms *PF* and *FW*. This is what measures the work done.

If we move the crowbar 2 feet at the power end and it only moves a foot at the weight end, the work done will be 125×2 or one-half of 500=250 foot pounds in either case, providing it is done in just 1 minute. This shows us that the distance the power and the weight move varies just in proportion to the length of the two arms of the levers. This is a good thing to store away where you won't forget it. Perhaps it will be easier if we put it in a separate sentence like this.

Power × distance it moves = weight × distance it moves, and

Length of power arm × power applied = length of weight arm × weight.

Take a pair of pliers and see what pressure you can apply, as in Fig. 14. The handles are 10 inches long from the rivet, but the hand will cover say 4 inches; so we call the power applied at the center of the hand, or 8 inches from the rivet, which is the fulcrum. The jaws are $1\frac{1}{2}$ inches long and we want to find out what pressure can be applied by say a 10-pound pressure of the hand.

Here the power arm *PF* is 8 inches and the weight arm *FW* is $1\frac{1}{2}$ inches. We can say; multiply *PF* by 10 and get 80 inch pounds, and divide this by $1\frac{1}{2}$ getting $53\frac{1}{3}$ pounds pressure between the jaws; or we can say *PF* equals $\frac{16}{2}$ inches and *FW* equals $\frac{3}{2}$ inches and 16 divided by 3 equals $5\frac{1}{3}$, so that the pressure will be $5\frac{1}{3}$ times the power applied.

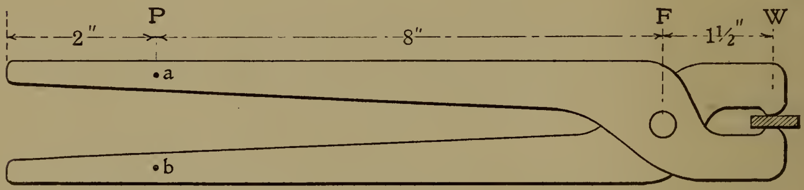

FIG. 14.

You can also measure the movement of the jaws and you will find that they will move just an inch when a point 8 inches (as *ab*) from the rivet has moved $5\frac{1}{3}$ inches. This is a lever or a pair of levers.

You can try a little experiment that may impress this more firmly on your mind than a page of printed matter. Take a very light 6-inch rule and 6 pennies or 6 nuts or anything that weighs alike. Put a penny on each end of the rule, as in Fig. 15, and it will balance evenly over a sharp edge, such as a triangular scale. Move the 6-inch scale 1 inch to the left. You have 4 inches on the left and 2 inches on the right. Now the penny on the left will almost balance two on the right. Move it another inch and you have 5 inches on the left and 1 inch on the right. In this position one penny at the left would balance five at the right, because the length of the power arm is five times as long as the weight arm if the weight of the rule didn't interfere. The lighter the rule and the heavier the weights the less this will affect the result.

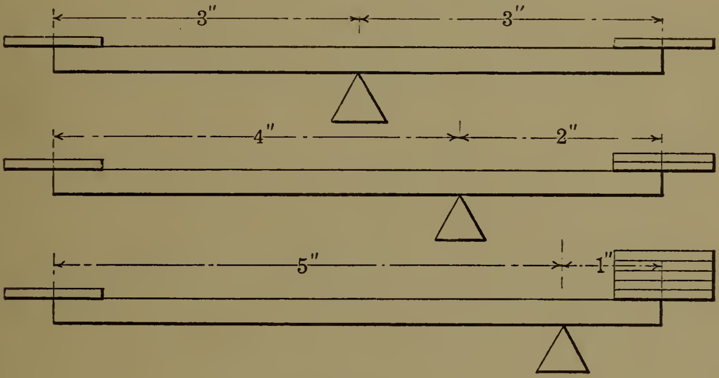

FIG. 15.

Weighing Castings

Suppose you have a lot of castings to weigh and no scales handy. Get a beam, say 100 inches long, and a known weight, such as 10 pounds; fasten this at *a*, Fig. 16. Hook the casting on the beam at *b* and move the beam along the hanger or fulcrum until it balances. Measure each arm of the beam and you can guess very closely to the weight of the piece.

If it balances when the beam is half on each side, it weighs the same as the known weight *w*; but suppose it balances when the weight *w* is 87 inches from the hanger, as at *X*, then the power arm is 87×10=870. Divide this by the weight arm, 13 inches, and we find the casting weighs $66\frac{9}{13}$—pretty close to 67 pounds. You will want a heavier weight than 10 pounds for convenience, although you can weigh pretty heavy castings with this, for if the casting balances the weight at only 5 inches from the hanger or fulcrum, you have the power arm $95 \times 10 = 950$; dividing this by 5 inches shows the weight of the casting to be 190 pounds. This isn't an ideal method of weighing castings, but it will show many points about levers that are interesting.

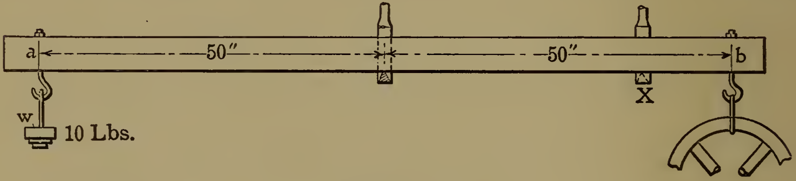

FIG. 16.

If in the first case we put a crowbar under the end of a piece and lift, we are not lifting the whole weight. The floor is supporting one-half and the crowbar the other, so we are only lifting one-half of it.

Shifting a Load

In the same way when you go fishing and happen to have good luck, you can sometimes make the other fellow carry more than half the load by shifting the basket toward his end of the stick, unless he also knows the game.

Call *A* yourself and *B* the other fellow. If the basket of fish is in the center you are each carrying half the load. If you can push it next to his hand at his end of the pole he is carrying it all—if he is easy—while you only carry half the pole. Then it is clear that at any point between the center of the pole and his hand he is carrying more than his share, and the position determines how much.

Calling the pole 6 feet long and the basket weighing 18 pounds, as shown by Fig. 17, you each carry the same. But move the basket to *D*, 4 feet from you and 2 feet from him. In this case his hand is the fulcrum for your lift (and your hand is for his lift); as the weight is between the fulcrum and the power, the lever is different from the crowbar type. That was a lever of the first class, while this is of the second class. But the same facts hold in each case. Your power arm *AD* is twice as long as his, *BD;* consequently he is carrying twice as much of the load as you are, or two-thirds to your one-third, 12 pounds to your 6.

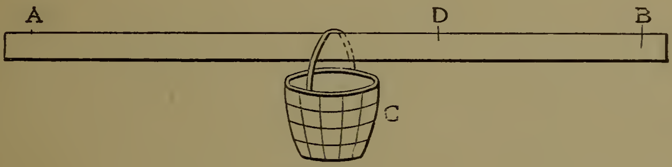

FIG. 17.

Pushing it along another foot when he isn't looking would make it 5 to 1, which would make him carry 15 pounds to your 3 and then he would probably wake up.

Third Class Levers

Fig. 18 shows a lever of the third class. In this class of lever the power arm *PF* is always less than the weight arm *WF*; consequently the power applied must always be more than the weight moved.

In this case, if the weight W is 10 pounds and the distance $WF=6$ feet, we have $10 \times 6=60$ for weight arm; divide this by the power arm $FP=4$ feet, which gives 15 pounds at P to resist the downward pull of 10 pounds at W.

Levers bent at right angles, as in Fig. 19, are called bell cranks; they act in the same way as when used in the old-fashioned house bells to transmit the power around a corner. The lever arms are measured in a straight line from the fulcrum to the points at which power is applied or taken off. In this figure all three levers have the power arms PF twice as long as the weight arms FW, so that 1 pound pull at P would balance 2 pounds' resistance at W. As there are three levers with these same proportions, there are three multiplications; so that 1 pound pull at P_1 will balance 6 pounds at W_4.

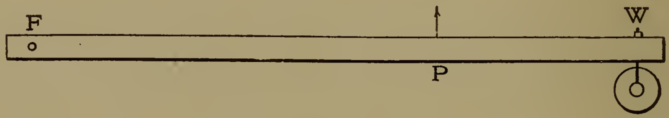

FIG. 18.

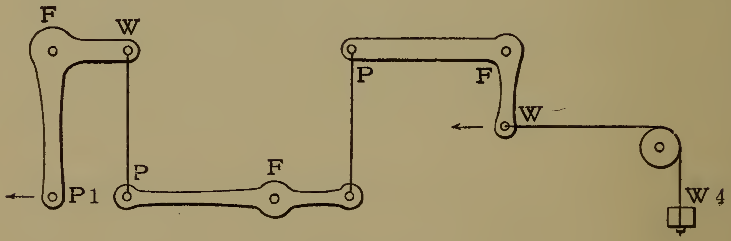

FIG. 19.

But don't think we have gained any power, for the 1 pound will have to move 6 times as far as it moves W_4.

Compound Levers

When we combine levers in this way, it is called compounding; it is quite a job to figure them all out, but it isn't necessary when you have the levers before you to measure.

Take the case of the wire cutters in Fig. 20, and we have a good example of compounding levers and toggle joints. But if we measure the opening of the jaws *J* and of the handle *H* and divide *H* by *J*, we have the leverage without bothering to measure up separate power arms and work arms. If *H* moves 3 inches while *J* moves $\frac{1}{8}$ inch, we divide 3 inches by $\frac{1}{8}$ and get 24, showing the leverage to be 24 to 1.

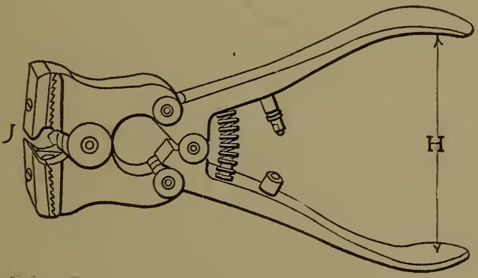

FIG. 20.

We sometimes see crooked levers on grindstones, especially those carried around the streets by the scissors-sharpening fraternity, and the reason is something of a mystery. No matter how crooked a lever is, the real effective lever is only the distance from the center of the axle to the center of the crank pin. In Fig. 21 is a horrible example, and the real crank length is only *X*.

These may be sold to the grinders the same way a "power increaser" was sold to a lot of sugar cane men in Louisiana years ago. A slick talker showed how to lengthen the lever arm of their horse-power sweeps by doubling back toward the center, giving a longer lever and less travel for the horse, as shown in Fig. 22. It is said a great many were sold and the seller decamped before they woke up to the fact that the effective power arm was only from *H* to *A*.

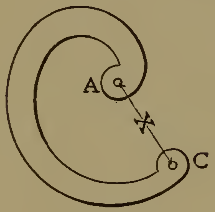

FIG. 21.

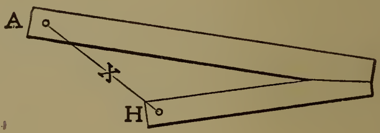

FIG. 22.

If the question of levers ever bothers you about power arms and lever arms, just get a lever or use your rule, and lay it out in the same proportion as the lever you are puzzled over. Then move it about its fulcrum and measure the distance traveled by the weight and by the power.

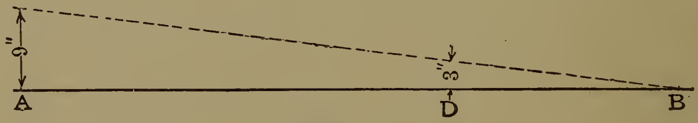

FIG. 23.

That tells the story every time, whether it is first-, second-, or third-class levers.

Take the fishing basket in Fig. 17 and draw a line as in Fig. 23. Consider *B* as the fulcrum and lift the end *A* 9 inches. Measure the movement of the basket at *D* and it will be 3 inches, showing that *A* has a 3 to 1 advantage over *B*.

Consider *A* as the fulcrum, as in Fig. 22, and lift *B* 9 inches. Then the basket has been raised 6 inches, or an advantage of 1½ to 1, instead of 3 to 1, as the other fellow has. So it is plain that the man at *A* is carrying only half as much as *B*. Shift the basket to the center and it will be clear that each has the same leverage, so that each will be carrying the same load.

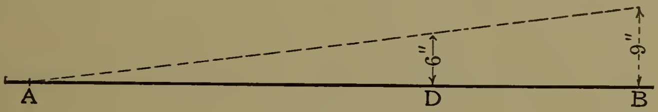

FIG. 24.

No matter what kind of a lever you are using, first-, second-, or third-class, measure the movement of the power and the load and there will be no doubt as to what is happening. Take as an example the third-class lever shown in Fig. 18 and draw it out as in Fig. 25. Here the load or weight moves 9 inches, while the power moves only 6 inches. So it must be plain that it will take a power greater than the load to balance or lift it. If the weight is 10 pounds, multiply 9×10 and get 90; then divide this by 6, and 15 pounds is the power that must be applied at P to balance the weight *W*.

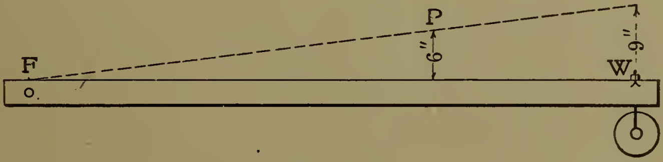

FIG. 25.

A spring-balance scale can be used to advantage in testing this question by getting a bar and a weight, then shift the fulcrum, the weight, and use the scale in applying the power.

EXAMPLES

1. With a 6-foot lever of the first class and the fulcrum 18 inches from the load of 150 pounds, how much power will be necessary to balance it? *Ans.* 50 pounds.

2. Suppose the load and the power are reversed, what power will be necessary? *Ans.* 450 pounds.

3. What force does a nut cracker of the second class exert on a nut when a pressure of 15 pounds is applied 6 inches from the rivet, the center of the nut being 1½ inches from the rivet? *Ans.* 60 pounds.

4. Taking the same nut cracker with a force of 20 pounds pressing the handles together at the same point (6 inches), what spring in place of the nut will be necessary to balance this? *Ans.* an 80-pound spring.

5. With a lever which gives a leverage of 4 to 1; that is, has a power arm four times as long as the weight arm, how far will the load move when the power arm moves 18 inches? *Ans.* 4½ inches.

6. Do you do more work in carrying a 10-pound weight up a ladder or up an incline? *Ans.* This depends on the time taken to do the work. If they are done in the same time, the work is the same. The incline is easier because it allows you to take more time to the work.

7. How can you easily find the leverage ratio with any series of compound levers? *Ans.* By measuring the distance the power arm moves and dividing this by the distance the load or weight arm moves.

CHAPTER II

THE SCREW AND WEDGE

The screw thread is one of the most common of machine shop principles and yet is not thoroughly understood by many who have never taken the time to look into the matter. In reality it is simply a wedge or inclined plane, wrapped around a rod or cylinder, the lead being simply the height of the upper end of the incline above the lower end. In Fig. 26 two inclines are shown, the upper, *A*, being made to represent $\frac{1}{4}$ inch lead and the lower *B*, $\frac{1}{2}$-inch lead.

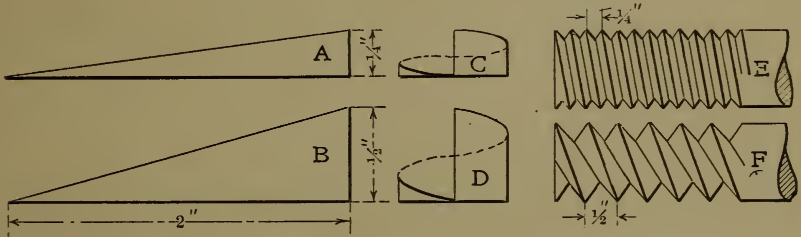

FIG. 26.

When these are wrapped around a rod they appear as shown at the right and simply represent a single thread, one being twice as sharp in lead as the other. This, it will be noticed, makes the angle of the lower one twice as sharp as the upper. The same thing would occur if the same lead was had on a smaller rod, so that we see how the angle of the thread depends not only on the lead but on diameter of the screw itself. From this it will be clear that a 10-pitch thread may appear very fast, that is to have a very sharp angle, on a $\frac{1}{2}$-inch screw and very slow, or with a very slight angle, on a 4-inch screw. Yet the advance movement of each will be exactly the same. At *E* and *F* is shown the difference in the angle between a $\frac{1}{4}$- and $\frac{1}{2}$-inch lead on a screw of the same diameter.

The increase in angle due to the lead is also shown even more clearly in Fig. 27, being particularly noticeable at the bottom of the threads, as where the thread is cut clear to the center, the point of thread tool moves in a line with the center of the piece and practically planes a straight line while the sides are cutting as the stock revolves. Needless to say it is almost impossible to cut a thread like this owing to the tool binding at certain points due to the change of angles. This is why the grinding of thread tools is a very particular job when sharp pitches are to be cut, and a good table of thread angles should always be consulted when this is to be done.

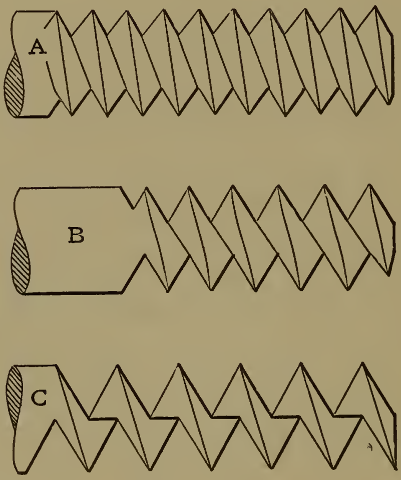

FIG. 27.

Power of Screws

In calculating the power exerted by a screw always bear in mind that the friction is an unknown quantity and that it increases as the strain is put on the screw. Although calculated at 50 per cent., it runs much higher than this in many cases and cuts down the actual power more than we may think.

The question of applying power with a screw, as in a screw jack or a vise or a lathe dog, is always interesting and sometimes surprising, especially when we accidentally twist the end of a bolt or screw off when using a wrench several sizes too large. In order to see why this happens, or what pressure we must put on a screw jack to raise a given weight, a little simple figuring is necessary, but it is very simple after we understand what we are trying to find and what factors enter into it.

It is simply another case of the lever to the extent of depending on the power applied, the distance through which it moves and the distance moved through by the piece being raised or squeezed as the case may be. This means that we must know the lead of the thread, and the distance through which the power moves, which is the circumference of a circle with a diameter twice the distance from the hand to the center of the screw. The diameter of the screw has nothing to do with it although it sometimes seems as though it ought to.

Suppose a jack (Fig. 28) has a screw with $\frac{1}{4}$-inch lead and the lever is long enough (a little over 18 inches) so that the hand applying the power moves a distance of 10 feet or 120 inches to each turn of the screw. This means that while the hand moves 120 inches the screw only advances

¼ inch so that for every inch the screw moves the hand travels 4 × 120 or 480 inches, making the leverage 480 to 1. Or a force of 10 pounds on the handle would exert a pressure of 4,800 inch pounds, not allowing for any friction.

Pressure screws are nearly always made with square threads so that the thrust will be against a square or flat side instead of an angle as in a V-thread. This makes it a case of plain surface friction instead of a wedging action into the bargain as with a thread having angular sides. The friction varies very largely, depending on conditions, but may probably be taken at 50 per cent. and be safe for most cases. This would make an effective pressure of 2400 inch pounds for each 10 pounds applied at the handle.

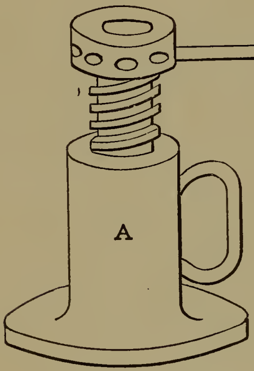

FIG. 28.

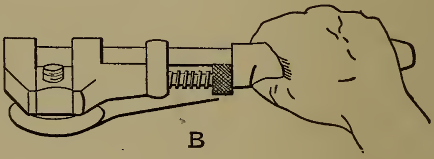

FIG. 29

Why Bolts Break

Taking the case of a ½-inch bolt and we find from the bolt tables that the area at the bottom of the thread is about ⅛ of a square inch, 0.126 to be exact. Assuming that the bolt is made of steel that has a tensile or pulling strength of 60,000 pounds, this will break at about 7500 pounds. As the thread is 13 to the inch it will take 13 turns to make an inch movement or we can multiply any power we apply by 13 and get the same results.

Suppose we grip a nut with a wrench, as in Fig. 29, which will allow us to apply power at about 12 inches from the center. This gives a movement of about 75 inches in swinging a full circle and if we apply only 20 pounds pressure we have $20 \times 75 = 1500$ inch-pounds to only move the nut $\frac{1}{13}$ of an inch, so we multiply this by 13 and get 19,500 inch pounds or more than double the breaking strength of the bolt. Even allowing that 50 per cent. of this is lost in friction, there is still enough to break the bolt and shows why bolts often break when we least expect them, because we do not realize the pressure we exert with a nut on the bolt itself.

This is just the same as forcing a wedge under a nut on a bolt, when the same pressure and movement of the wedge will produce the same movement of the nut. The action is identical, as this is simply the case of a wedge wrapped around a rod.

We must remember that whenever we tighten a vise or exert pressure in any way, after the slack is all taken up any further movement means that something has to give. It may be the stretching of the screw, the slipping of a collar, if there is one, or the compression of the vise jaws or nut or the work held between them. In any case something gives and care must be taken that this stress does not exceed the elastic limit of the material.

The Wedge

When we consider the wedge it makes no difference whether the work moves on the wedge or the wedge moves under the work, the action and results are the same. But it does matter in what direction the power is applied, whether parallel to the base or to the incline as in Fig. 30. In the first case, *A*, the rise of the incline takes place while it moves the length of the base and in the second case, *B*, the same rise requires the length of the incline. This means that a little less pull will be required to raise the weight in the second case, simply because it moves through a longer distance while it is being raised.

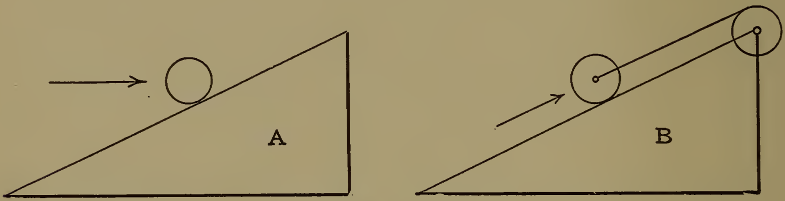

FIG. 30

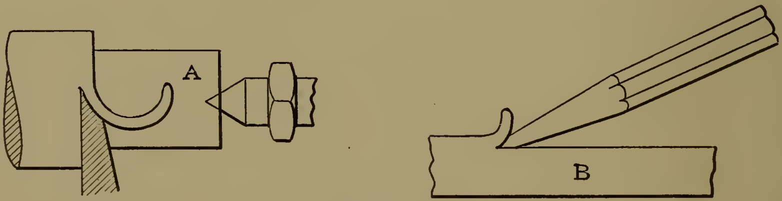

FIG. 31.

The action of a lathe tool is also that of a wedge in cutting metal or wood, as in *A*, Fig. 31. Here the cutting-edge wedges between the body of the metal and the chip and forces it away from the rest of the metal. Another similar example is the cold chisel, as in *B*. In each of these cases it is easily seen that the sharper the angle the easier the chip is cut, but if too thin the tool will not stand and so we make a compromise to secure a tool that will stand up and still cut with the least resistance possible.

Fig. 32 shows a wedge applied to a press, *A* being the wedge, *B* the ram, *C* the guide, *D* the die and *E* the material under compression. When the wedge is moved 4 inches under *B*, the ram is moved ½ inch, giving a leverage or gain of 8 to 1. The same thing is shown in Fig. 33, where a cam, *F*, is shown acting on the roller *G*, which forces the ram through the guide *H*, compressing the material *J* between the ram and the die I. The cam is simply a circular wedge and works continuously instead of having to be moved back and forth as with the other.

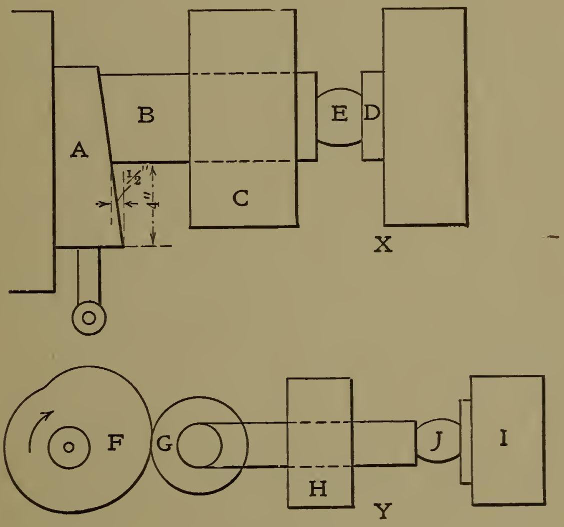

FIG. 32.

The Toggle

While Fig. 33 is a combination of levers known as a toggle, it is first cousin to the wedge and may be just mentioned here. Starting with the toggle pin at 1, move it down to 2 and note that the pin in the slide also moves to 2. Moving it to 3 and 4 moves the pin slide a smaller amount each time so that while the power arm moves the same distance each time, the slide moves a smaller amount, increasing the leverage and giving something of a wedging action.

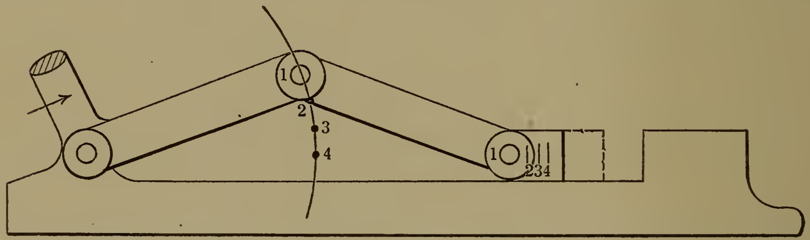

FIG. 33.

EXAMPLES

1. How can you prove that a screw thread is a wedge? *Ans.* By wrapping a triangular piece of paper around a lead pencil, as in Fig. 26.

2. What pressure can you exert with a screw jack having $\frac{1}{2}$ inch pitch screw, a lever 2 feet long and a pressure of 50 pounds, allowing 50 per cent. for friction? *Ans.* 7500 pounds.

3. What strain will a monkey wrench put on a $\frac{3}{4}$-inch bolt if the distance from the center of the bolt to the center of the hand is 10 inches and the pull is 15 pounds? *Ans.* A $\frac{3}{4}$-inch bolt has 10 threads, so the pull × the

path of the power in one turn = 15 × 62.8 = 942.5 and 942.5 × 10 = 9425. This is a heavy strain on the bolt, even after allowing for friction of the thread.

4. What pressure will be exerted by the wedge action press shown in Fig. 32? *Ans.* Neglecting friction, the pressure is that due to the pressure on the wedge × the distance the wedge moves ÷ the distance the dies move in pressing the work.

5. What is the effect of the cam action shown in Fig. 32? *Ans.* The same as the wedge, the circumference of the cam being taken as the movement of the wedge.

CHAPTER III

INCLINED PLANES

The inclined plane is simply another form of the wedge which is also the element in the screw and the cam. It is used so much in machine work, particularly in design, that it is well to know a little about it. The way in which the power acts affects the work done and Fig. 34 shows four ways which are in common use. In actual machines the inclines themselves are just as likely to move as the roller or other load, but that does not affect the problem in the least. When the power is applied parallel to the incline we multiply the power by the length of the incline and divide by the height to find what load it will sustain.

In *A*, Fig. 34, the incline is 30 feet long and has a rise of 15 feet, so that every pound of weight will support 2 pounds on the incline. If the incline was 30 feet and the height 20 feet, every pound of weight would support 1½ pounds of load and when it got to be 30 feet incline to 30 feet rise, or vertical, the weight and load must be equal.

When the power acts parallel with the base as at *B*, Fig. 34, the power multiplied by the length of the base equals the load times the height of the plane. This assumes that the power is kept parallel to the base and does not change as the load is moved up the incline. In this case, as in the other, the power moves twice the distance the load is lifted, so that the power ratio is still 2 to 1.

In this case, increasing the height to 30 feet would make it equal the base and the load would move the same distance as the power, so that the power ratio would be 1 to 1 or 10 pounds in each case.

In *C* and *D* are two cases where the power is not parallel to either incline or base and in which no rule can be given.

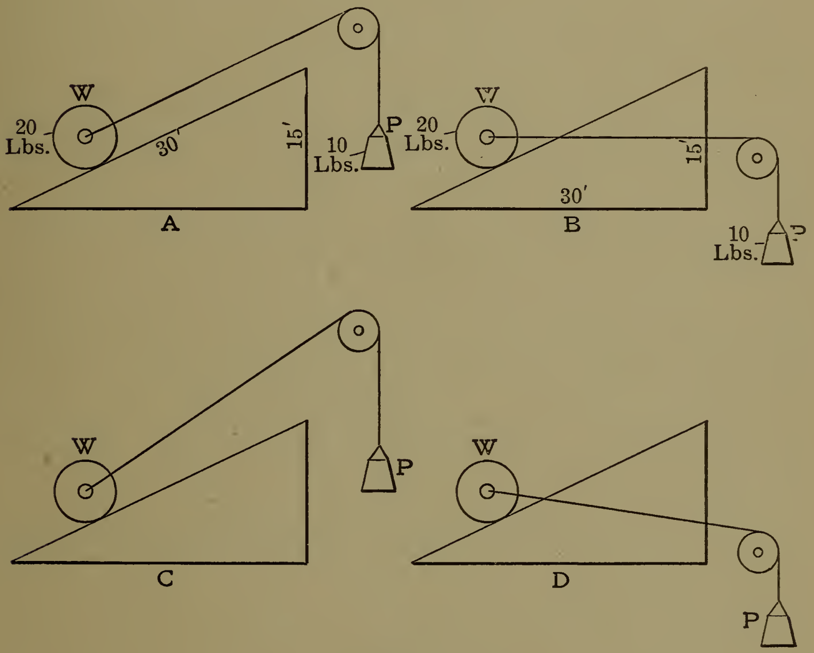

FIG. 34.

In *C* the power tends to lift the load away from the plane and would act as though the incline was at the same angle as the power. While in *D* the pull is against the plane and again changes the ratio of power to load.

In all cases except the first two, the exact angle must be laid out as shown in Chapter XIX.

EXAMPLES

1. An incline runway is 8 feet on the ground, 10 feet on incline, and has a rise of 6 feet. What pull, acting in the direction of the incline, will be required for a weight of 100 pounds, neglecting friction? *Ans.* The pull can act through 10 feet in lifting the weight 6 feet. Load times height = 100 × 6 = 600. Dividing by 10 = 60 pounds.

2. Take the same incline and have the pull parallel to the base. What pull will be required? *Ans.* 75 pounds.

3. An incline is 20 feet long on the incline and has a rise of 5 feet. What pull will hold a barrel weighing 400 pounds if the rope is parallel to the incline? *Ans.* 100 pounds.

4. With the plane having a 20-foot base, rise of 6 feet, pull parallel to the base and same load, allowing for 20 percent. friction; find the pull. *Ans.* 144 pounds.

5. With a plane 40 feet long, 8 feet rise, pull parallel to incline, what will a pull of 100 pounds sustain? *Ans.* 500 pounds.

6. With a load of 600 pounds, a pull of 150 pounds parallel to the base 20 feet long, what can be the maxium height of the plane? *Ans.* 5 feet.

7. With a pull of 100 pounds parallel to the incline, a rise of 6 feet and load of 300 pounds, what must the length of the incline be? *Ans.* 18 feet.

CHAPTER IV

GRAVITY

Most of us know that gravity is the force, or attraction of the earth, that makes us fall when the ladder breaks under us or causes an apple to drop from the tree to the ground, but few of us realize its importance in our every-day work. Without it we should have no stability in buildings or machines because it is this attraction, this pulling of things toward the earth, that gives them what we call weight.

When we say that this machine weighs more than that hammer we mean that the kind and amount of material it contains is attracted more strongly than the other. We say that lead is heavier than water for the same reason, and prove it by weighing a cubic inch of each or dropping a piece of lead into water and see that it sinks—but more of that later.

This weight or attraction holds us to the ground, prevents a light gust of wind from blowing us over and helps in many ways, although when it comes to lifting a heavy casting it would be much easier if we could lessen the attraction. This attraction of the earth, or gravitation, is what makes a rifle ball eventually fall to the ground even when shot from the muzzle at a velocity of 3000 feet per second. The earth is constantly pulling at it and it finally lands when this attraction is greater than the force which is driving it forward. It also retards and slows down the speed of a stone being thrown into the air and accelerates or hastens its fall after it starts to come down.

This phase of the attraction is very interesting and useful in some lines of mechanical work, such as drop hammers.

The weight of a falling body makes no difference as to its velocity unless its bulk is very large for the weight or its shape is such that the air retards its fall.

In a vacuum tube with all air removed a feather and a bullet will both fall with the same velocity, but in the air the feather will float down much more slowly.

If a stone is dropped from any point it immediately begins to gain speed or accelerate and the farther it falls the faster it travels. Starting at rest, or zero, it gains speed till at the end of the first second it will have fallen 16 feet,* and as it started from rest, is traveling at the rate of 32 feet per second.

It keeps on increasing the farther it falls, adding 32 feet every second to the velocity. This means that the velocity at the end of any second will be 32 times the number of seconds, and if it falls 10 seconds it will be traveling at the rate of 320 feet per second, which is nearly 4 miles a minute.

This increase in velocity means that it falls through a greater distance each second, so that if it falls 10 seconds, it is not exactly clear how far it has fallen.

Speed and Distance of Falling Bodies

The diagram in Fig. 35 shows a very easy way of remembering this, or of always being able to tell the distance fallen without figures, as it is simply a series of triangles, one row for each second of fall. Each triangle represents a fall of 16 feet so that to find the distance fallen through in any second, just count the number of triangles in that row. Or if the total fall is wanted, add all the triangles down to the point where it lands.

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*This is more correctly 16.08 feet, but 16 feet answers very well for ordinary calculations.

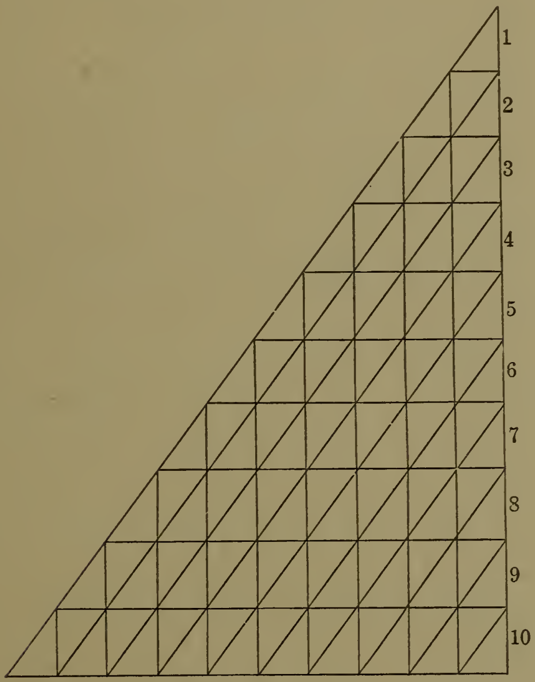


FIG. 35.

This shows that at the end of the third second it has fallen through nine triangles, and as each triangle equals 16 feet it has fallen 144 feet. This also shows that at the end of this third second it is falling at the rate of 3×32, or 96 feet per second. At the end of the fifth second it is falling at the rate of 5×32, or 160 feet per second, and has fallen through a space of 25 triangles or 25×16, or 400 feet.

There is also an easy way to figure these things if the triangles seem clumsy and in any case it is well to know both ways. This can be put in the form of rules as follows:

Having:	To find:	Rule:
1. Time in seconds.	Velocity at end of any second.	Multiply time in seconds by 32.16.
2. Time in seconds.	Space fallen through in any second.	Subtract 1 from twice the time in seconds and multiply by 16.08
3. Time in seconds.	Total space fallen through.	Square the time in seconds and multiply by 16.08.

Rules for Gravity Calculation

To try these let us find the velocity at the end of the fifth second. This gives 5×32.16=160.8. To find space fallen through during the fourth second: Multiply the 4 by 2=8. Subtract 1 leaving 7, and multiply by 16.08. This gives 16.08×7=112.56 feet.

The total space fallen through at the end of the fifth second is found by multiplying 5×5=25, and multiplying by 16.08=25×16.08, or 402 feet.

To apply this to shop work we shall have to make some other rules by transposing or shifting these as follows:

Having:	To find:	Rule:
4. Distance fallen through in feet.	Time required to fall a given distance.	Divide the distance by 16.08 and take the square root.
5. Distance fallen through in feet.	Velocity at end of fall in feet.	Find time required as above, then use Rule No. 1.

Rules for Gravity Calculations

Perhaps you have noticed that a small piece of wood strikes a pretty hard blow after it falls from a high place, while from a short distance you would hardly notice it. This is because of the velocity it gains during the fall and a 1-ounce weight falling a long distance can do a lot of damage. These rules help us find the velocity and from this we can easily find the blow that will be struck. Suppose a pound weight falls 144 feet, what will be its velocity? By rule 5 we see that it is first necessary to find the time by dividing 144 by 16, which gives 9, and taking square root of 9 = 3. The weight will then fall in 3 seconds and the velocity will be according to rule 1: 3 × 32 = 96 feet per second. Change this to minutes by multiplying by 60 and we have 5760 feet per minute.

In the same way, if a pound weight is thrown upward with a velocity of 5760 feet per minute, it will rise to a height of 144 feet in 3 seconds, stop and begin falling until it reaches the ground in 3 seconds, and again has a velocity of 96 feet a second, or 5760 feet per minute.

When a body rolls down an incline it is drawn down by gravity just the same as though it fell straight, but the velocity depends on the incline. If the height of the incline is one-half the length of the incline, the velocity will be one-half that of a body which drops freely. If the height be one-third the length of the incline the velocity will be one-third and so on, remembering that the velocity will be that due to the height of the plane and not to the length of the incline.

Specific Gravity

Although this does not often come into shop use it is well to know that it simply means the weight of any substance, as compared with an equal bulk of pure water. As a cubic foot of water weighs 62.355 pounds, and as a cubic foot of cast iron weighs 450 pounds, we say its specific gravity is 7.21. We often speak of things being as heavy as lead and yet lead is only 11.38 times as heavy as water, while gold is 19.258 and platinum 21.5 times as heavy. In other words the specific gravity of lead, gold and platinum is 11.38, 19.258 and 21.5, respectively.

Most woods are lighter than water, although a few are heavy enough to sink even without being water-logged, or the pores soaked full of water. These are box, ebony, lignum vitæ and live oak, although they vary a little and you may find a piece which will not sink in water. Oils are also usually lighter than water, but not in all cases, and most liquids are also lighter.

Weight of Bodies in Water

An interesting thing about specific gravity is the difference between the weight of bodies in air and in water. This is said to have been discovered by Archimedes, one of the old Greek philosophers who noticed the difference between the exertion required to lift his arm in the water and after it left the water and was wholly in the air. The discovery is said to have elated him so much that he left the bath and ran down the street to his laboratory, quite forgetting to put on any clothes.

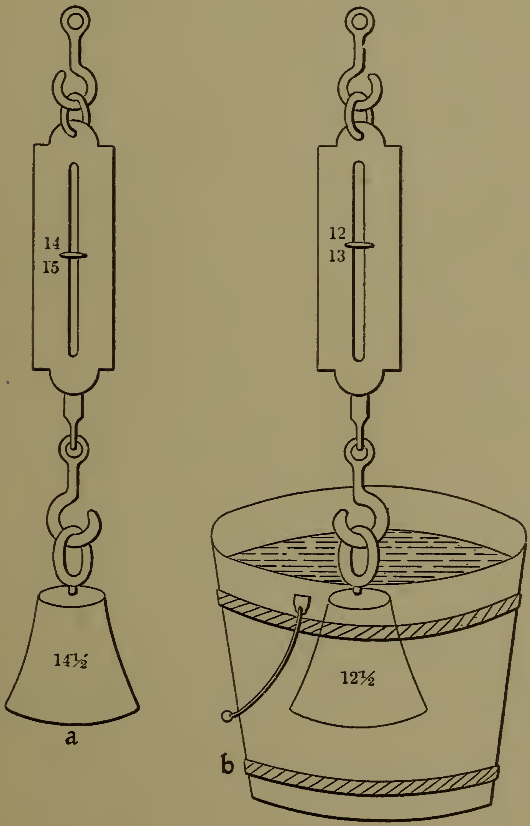


FIG. 36.

It is interesting to try this either in a bath tub or by weighing a piece of iron, as in Fig. 36, first in air as at *a*, and then in a pail of water, as at *b*, and noting the difference.

If we take a piece of iron which weighs 14½ pounds in air and then weigh it in water we will find that it weighs about 12½ pounds in the water as nearly as we can weigh with the scales shown. This means that the water which is displaced by the iron weighs 2 pounds and shows that the specific gravity of the iron is 7.21, or is 7.21 times the weight of water having the same bulk.

Knowing that the specific gravity of any body equals its weight in air divided by the difference between this and its weight in water, we can put this in the form of rules which may be easy to understand or remember.

Having:	To find:	Rule:
Weight in air and weight in water.	Specific gravity.	Subtract the weight in water from the weight in air, and divide weight in air by this.
Weight in air and specific gravity.	Weight in water.	Divide weight in air by specific gravity and subtract this from weight in air.
Weight in water and specific gravity.	Weight in air.	Divide 1 by the specific gravity, subtract this from 1. Divide the weight of body in water by this decimal.

Rules for Specific Gravity

The last rule you will seldom need, but it is not difficult even if it sounds a little confusing.

A practical application of the lessening of weight by water can be seen in some pumping engines where the plungers are so designed that they displace a volume of water equal to the weight of the pistons themselves, so that they practically float and greatly reduce the friction between the plunger and the cylinder.

An iron steamship floats because the amount of water displaced by the part of the vessel that is under water weighs more than the submerged part and just equals the weight of the whole vessel. A solid cubic foot of iron will sink at once, but the same cubic foot, weighing 450 pounds, may be cast into a hollow globe or dish and will then displace 450 pounds of water instead of 62½ pounds when it was solid. The amount it will sink depends on the number of square feet of surface that it presents to the water. The cubic foot of iron can be so arranged that it will just sink or just float. Or it will remain at any depth by making it have a volume of 7.21 cubic feet, because it takes 7.21 cubic feet of water to weigh as much as 1 cubic foot of cast iron.

The following table from the American Machinists' Handbook, showing the specific gravity of metals as well as some of their other properties, will be found useful as a reference:

PROPERTIES OF METALS.

Metal	Melting point	Wt. per cu. in.	Wt. per cu. ft.	Tensile stength	Specific gravity	Chemical symbol
Aluminum	1157	.0924	159.63	20,000	2.56	Al.
Antimony	1130	.2424	418.86	....	6.71	Sb.
Bismuth	505	.354	611.76	....	9.83	Bi.
Brass, cast	1692	.3029	523.2	24,000	8.393	
Bronze	1692	.319	550.	36,000	8.83	
Chromium	3500	.2457	429.49	....	6.8	Cr.
Cobalt	2732	.307	530.6	....	8.5	Co.
Copper	1929	.322	566.	36,000	8.9	Cu.
Gold	1965	.6979	1206.05	20,000	19.32	Au.
Iridium	3992	.8099	1400.	....	22.42	Ir.
Iron, cast	2700	.26	450.	16,500	7.21	Fe.
Iron, wrought	2920	.278	480.13	50,000	7.7	Fe.
Lead	618	.41	710.	3,000	11.37	Pb.
Manganese	3452	.289	499.4	....	8.	Mn.
Mercury	−39	.4909	848.35	....	13.59	Hg.
Nickel	2700	.3179	549.34	....	8.8	Ni.
Platinum	3227	.7769	1342.13	....	21.5	Pt.
Silver	1733	.3805	657.33	40,000	10.53	Ag.
Steel—cast	2450	.28	481.2	50,000	7.81	
Steel—rolled	2600	.2833	489.6	65,000	7.854	
Tin	445	.2634	455.08	4,600	7.29	Sn.
Tungsten	3600	.69	1192.31	....	19.10	W.
Vanadium	3230	.1987	343.34	....	5.50	V.
Zinc	779	.245	430.	7,500	6.86	Zn.

EXAMPLES.

1. What is the velocity of a falling body at the end of the first second? *Ans.* 32.16 feet per second.

2. How far does it fall during the first second? *Ans.* 16.08 feet.

3. Is the increase in velocity regular? *Ans.* Yes, add 32.16 feet for each second it falls.

4. If a body falls 5 seconds, what is its velocity when it strikes the ground? *Ans.* 160.8 feet per second.

5. How far will a stone fall in 7 seconds? *Ans.* 787.92 feet.

6. If a piece of wood drops 160 feet, how fast is it traveling when it strikes? *Ans.* About 100 feet per second.

7. Does the weight of a body affect its velocity in falling? *Ans.* Not unless the shape of the body offers more resistance to the air, as in a feather.

8. What does specific gravity mean as applied to cast iron? *Ans.* Specific gravity is the relation between the weight of a body and the same volume of water. A cubic foot of cast iron weighs 450 pounds and a cubic foot of water weighs 62.355. Cast iron is 7.21 times heavier, so the specific gravity of cast iron is 7.21.

9. Does gravity affect a body at high velocity, such as a bullet fired from a gun? *Ans.* Yes, a bullet fired from a gun and one dropped from the same height as the gun barrel will both reach the ground at the same time.

10. How does a vacuum affect the action of gravity? *Ans.* Only by removing all air resistance so that a feather will fall as quickly as a bullet.

CHAPTER V

FRICTION

Friction may be called the resistance to motion which is produced by any bearing surfaces.

If we slide a brick on a rough board it takes considerable force to do it. If we substitute a smooth iron block and a smooth iron plate for the brick and board, we find it slides much more easily. If we lubricate the plate with oil or graphite, we find that it moves very much easier than before. So the friction depends on the condition of the surfaces as well as the weight of the object moved.

In the moving parts of machinery we find friction a decided nuisance, yet in other cases it is used to good advantage. If we could do away with friction in bearings we could save an enormous amount of power every year. But if we had no friction for braking surfaces we would be badly off indeed. If it were not the friction between our shoes and the sidewalk we would be as though we were always walking on ice, which would be inconvenient and dangerous.

These different conditions of surfaces in contact show us that the amount of friction depends on the materials in contact as well as the weight of the moving parts.

We would not expect two rough files to rub together very easily as the teeth catch in each other. This increases with the pressure tending to force them together.

But if we take two dead smooth files, they rub together very well, the teeth are so much finer and shallower.

If we rub the teeth of the coarse files full of graphite, we find that they run together fairly well, while the dead smooth treated in the same way, run almost as well as plain pieces of steel.

All Bearing Surfaces are Rough

Now all surfaces which bear together are more or less like the files. They have small teeth in the way of small projections and hollows which fit into each other when they are run together. These are so small on a surface that they are invisible except with a powerful magnifying glass, but they are there just the same. The fewer there are, the easier the bearing runs.

The lubricant used fills these hollows and keeps the metal surfaces apart with a film of oil or whatever is used. A light oil will work into a finer bearing than heavy oil, but will not keep the surfaces apart so well if the load is heavy. But we must not forget that some heavy oils are positively sticky and hinder rather than help easy running.

Measuring Friction

In order to have some way of determining and comparing the friction of different surfaces, engineers use what is known as the "coefficient of friction." This simply means the force required to move a body as compared with its weight.

If a weight of 10 pounds be placed on a table as in Fig. 37. and a cord attached which runs over a pulley to a weight *W*, we have a means of weighing the power required to move it.

Suppose a 3-pound weight will just move it dry and a 1½-pound weight after the plate has been lubricated. Then the "coefficient of friction" was $\frac{3}{10}$ dry, and $\frac{1\frac{1}{2}}{10}$ lubricated.

These would be written as 0.3 and 0.15 and is 30 and 15 per cent. of the weight of the body moved.

The friction of journals varies widely with the materials used. Cast iron on cast iron and on bronze averages about .07 for intermittent work to .04 for steady work. These are for lubricated bearings.

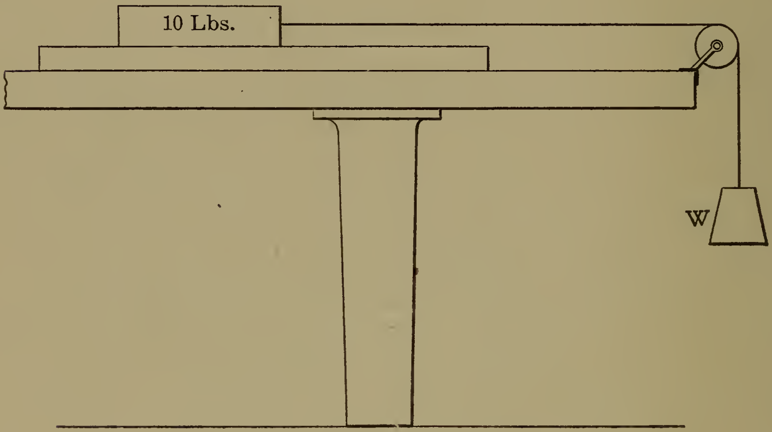


FIG. 37.

Journal friction is a sliding friction the same as a cross head sliding in its guides. The only difference is that it is continuous.

Rolling friction is where a wheel rolls over the ground or a ball bearing rolls around in its ball races. Rolling friction is less than sliding friction.

Another way of considering friction is by what is called the "angle of repose." Taking the same weight as before we put it on the same plate and tip one end of the plate up until the weight slides down the plate as in Fig. 38. The greatest angle to which the plate can be tipped without the weight sliding is the "angle of repose."

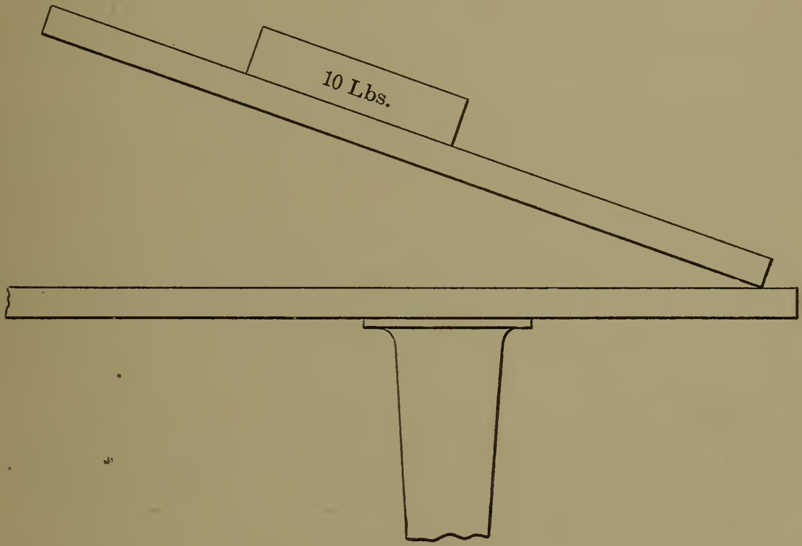


FIG. 38.

This is especially useful with such material as sand or coal. In that case it is piled up until it will not hold itself at any greater angle. This shows the greatest angle that it can be piled or loaded with safety—that is, without rolling or sliding off the pile or load.

CHAPTER VI

HEAT

None of the natural laws affect us more, in the shop or out of it, than the laws governing heat. Although we use the terms heat and cold, they are really to distinguish different degrees of heat, for heat and cold are simply comparative terms.

As an example, note how warm a drink of ice water seems when you are eating ice cream. Or take three dishes, as in Fig. 39, and put ice water in No. 1, luke-warm water in No. 2, and hot water in No 3. Put your left hand in No. 1 and your right hand in No. 2, then change the left to No. 2 and the right to No. 3. Dish No. 2 was the warm water in the first case, but is now the cold water. Or, place one hand in No. 1 and the other in No. 3, then put both in No. 2; it will feel warm to the left hand and cool to the right hand, showing that they are all comparative.

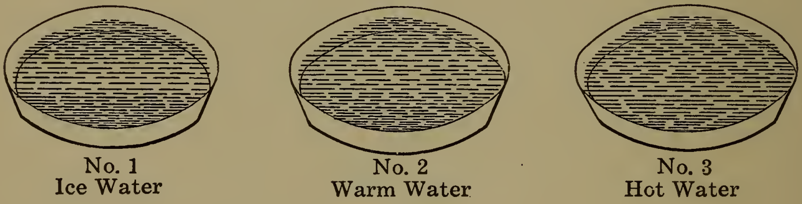


FIG. 39.

Even the ice water is hot as compared with liquid air;

so we are safe in saying that instead of being hot and cold, they are all different degrees of heat.

As an everyday example, take the men in a shop and you will find some who are warm at 65 degrees and others cold at 70 degrees.

When Fahrenheit made his thermometer he made a freezing mixture, the coldest he knew of, and called that zero, which gave us the very illogical and unsatisfactory thermometer scale we use to-day. The Centigrade thermometer is much more sensible in every way, the freezing point being zero and the boiling point 100 degrees above freezing.

It is assumed that absolute zero—the absence of all heat, or the coldest possible—is 461 degrees below the zero of the Fahrenheit scale, but this is not a fixed value and we have little to do with it in any case.

Heat is developed in many ways: by burning the gases in coal or wood, or gas which has been made from any substance whatever; by friction; by hammering, rolling, compressing or bending metal; by bodies falling through space, and in many other ways.

How Heat is Generated in the Shop

Leaving aside the burning method, take a bearing that is running too fast, is too heavily loaded, or is run without oil, and we know that heat develops all too quickly. This is caused by the rubbing of the two surfaces which disturbs the molecules or minute particles of the metal. The same thing is done by bending a piece of metal or by hammering it, by letting a drop press fall on it, or by dropping it through a long distance.

You can readily try this in many ways, as by bending a piece of wire back and forth till it breaks, hammering the same piece of wire, or any small piece of metal. Any change of shape in metal develops heat, as you can see in any drawing or rolling operation. Both the cutting tool and the work develop heat, partly from friction and partly from the effect of tearing the metal apart.

Heat and Energy

Heat and energy are so closely related that it is difficult to separate them. When brakes are applied to stop a car the brake shoes and the wheels develop heat; the quicker the stop the more rapidly it is developed.

When a cannon ball strikes a target of armor plate it develops a terrific heat, due to the energy of the flying shot being absorbed in a few inches and a few seconds.

A weight of 1 pound falling through a distance of 778 feet into a pound of water will raise the temperature of the water 1 degree. This is called the mechanical equivalent of heat.

Heat expands everything we have to do with in the shop, whether liquid, gases, or solids. Water is expanded as it heats until, when it becomes steam at atmospheric pressure, it occupies over 1600 times as much space as when it was water. The mercury in a thermometer tube is expanded by heat and climbs up, step by step, registering the heat by the scale marks at the side. Metals expand in the same way and more than we are apt to think.

How Heat Affects Machinists

There are many examples of the effect of heat that play an important part in shop work, especially where fine measuring is to be done. Take a half-inch ball and put it between the points of a micrometer as shown in Fig. 40, using just enough pressure on the screw to hold it. Hold the micrometer in the hand as shown and the ball will drop out of the points as the heat of the hand expands the frame.

This is why many measuring gages have a wooden or rubber handle. This does not convey the heat at all readily from the hand to the steel and prevents distortion due to this heat.

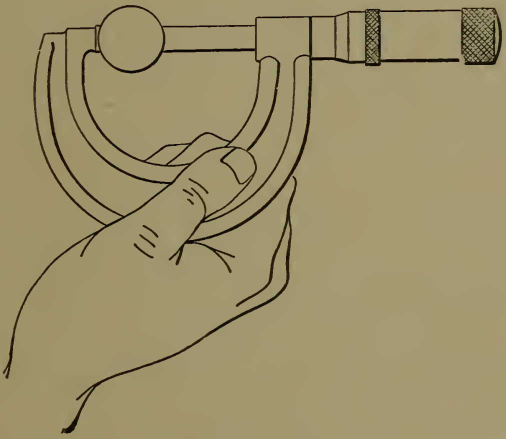


FIG. 40.

A shop superintendent gave some of his foremen a lesson in measuring in a similar way. He had them each measure a certain piece with the same micrometer and each got a different reading; then after talking with them a little while he measured the same piece and made it even more than the first man.

The first man held it some time in making his measurement, and as each foreman took it, the micrometer kept on expanding a little. Then it was laid aside to cool off before the superintendent himself measured it. This made the differences in the measurements taken.

How Heat Fooled the Foreman

In a shop building gas engines and heated by stoves, there came very near being a tremendous row all on account of the expansion of metals. The cylinder-boring machine was near one of the stoves and one cold morning the man who turned the pistons over in the corner came over to try one in the cylinder that was waiting for it. His measurements were right and it went in with a nice running fit just as it should, so he left it there and went back to turn up the next one.

The foreman had never liked this particular piston man any too well and when he came around an hour or so later he tried the piston to the cylinder and it wouldn't even enter. This was a good excuse to call down the piston man and a boy brought him over to show him that the piston was altogether too large.

Knowing that it had gone in before he was naturally indignant and started to put it in, when to his surprise it would not enter.

Then the superintendent came along and hearing the story, told them what the trouble was.

The cylinder was warm, being by the stove. The piston was cold, having been turned in the cold corner of the shop. On being brought over to the cylinder it fitted nicely, but on being left there by the stove it gradually warmed up to the temperature of the cylinder and expanded until it was larger than the cylinder bore.

These go to show that to have things fit they must be measured at the same temperature and that a few degrees of heat may make much more difference than we are apt to think.

Heat of Grinding

We know how the point of a drill or other tool heats up in grinding on a dry wheel and how the temper runs if the tools are of carbon steel. The rubbing of the wheel heats the metal in spite of the constant cutting that is being done by the many sharp parts of the wheel.

In grinding round work in a grinder, the effect of heat can be noticed in many ways. If the piece to be ground has sprung in hardening so that more is to be ground from one side than the other, it is often very noticeable. The high side strikes the wheel first and as more must be ground from this side, it heats up more than the other. This heats the high side of the work most, making it expand more than the other and forcing the center of the bar toward the grinding wheel, which grinds off still more and heats it still further. This is why we sometimes find that after such a piece cools down, it is out of true and the side which was thrown out in hardening, is now the "low" side, that is, the indicator or wheel will touch the other side first.

This is also noticed in grinding flat work. Here the heat is all on one side, which expands and rises up against the wheel so that more is ground off in the center than at the ends. When the work cools it will often be found low in the center.

Heat of Friction

Heat is developed by the friction of two pieces together, or by the friction of the particles (or molecules as they are called) of which the material is made. In hammering a piece of steel, the particles are forced together or forced to vibrate and this causes the heat. The same thing occurs when we bend a piece of metal or stretch or compress a spring, and, if continued for some time, the heat produced can be plainly felt by the hand.

Machines often run smoothly for the first half hour and then stick and bind because they have warmed up and expanded, forcing out the oil or lubricant and finally becoming so tight that they seize or "freeze," as it is often called in the shop.

Allowing for Expansion

This is why it is not often safe to run bearings as tight as they might be if they remained cool and where judgment comes is as to how much shall be allowed. A little "shake" when the bearing is cold may be too tight after it warms up.

Lathe heads, or other machines with bearings at each end of a long spindle, sometimes give trouble from expansion lengthwise. In such cases it is usual to take the end thrust all at one point near the spindle nose, leaving the spindle free to move through one bearing, taking all end thrust in the other.

In the same way the tail center of cylindrical grinding machines is usually held against the work by a spring. This allows the center to move back as the work expands and avoids either binding on the centers or springing the work, if it is very slender. And it is simply another example of the way in which expansion must be allowed for in the shop.

Steam pipes, for heating or otherwise, make another good example. They go out of shape when heated up and also expand lengthwise considerably. In one instance the foreman put a wedge between the end of the steam-heating pipes and the wall to stop the movement of the pipes. But instead of stopping the expansion it pushed out the brick wall and caused a nice little bill for repairs.

All metals expand at a different rate as shown in the accompanying table. While these amounts seem small, when they are multiplied by the number of inches and by the number of degrees the metal is heated up, it is much larger than might be imagined.

EXPANSION PER INCH OF METALS BY HEAT.

Metal	Expansion for 1 deg. Fahr.
Aluminum, cast	0.00001234
Brass, cast	0.00000957
Brass, rolled	0.00001052
Copper	0.00000887
Gold	0.00000786
Iron, wrought	0.00000648
Iron, cast	0.00000556
Lead	0.00001571
Nickel	0.00000695
Platinum	0.00000479
Silver	0.00001079
Steel, cast	0.00000636
Steel, tempered	0.00000689
Tin	0.00001163
Zinc	0.00001407

Fahrenheit and Centigrade

It is convenient to know the relation between the two ways of measuring and the degrees of heat, and the following table from the American Machinists' Handbook gives the comparison in handy form.

FAHRENHEIT AND CENTIGRADE THERMOMETER SCALES.

F	C	F	C	F	C	F	C	F	C
−40	−40.	70	21.1	185	85.	950	510.	2100	1149.
−35	−37.2	75	23.9	190	87.8	1000	537.8	2150	1176.5
−30	−34.4	80	26.7	195	90.6	1050	565.5	2200	1204.
−25	−31.7	85	29.4	200	93.3	1100	593.	2250	1232.
−20	−28.9	90	32.2	205	96.1	1150	621.	2300	1260.
−15	−26.1	95	35.	210	98.9	1200	648.5	2350	1287.5
−10	−23.3	100	37.8	212	100.	1250	676.5	2400	1315.5
− 5	−20.6	105	40.6	215	101.7	1300	704.	2450	1343.
0	−17.8	110	43.3	225	107.2	1350	732.	2500	1371.
+ 5	−15.	115	46.1	250	121.2	1400	760.	2550	1399.
10	−12.2	120	48.9	300	148.9	1450	788.	2600	1426.5
15	− 9.4	125	51.7	350	176.7	1500	816.	2650	1455.
20	− 6.7	130	54.4	400	204.4	1550	844.	2700	1483.
25	− 3.9	135	57.2	450	232.2	1600	872.	2750	1510.
30	− 1.1	140	60.	500	260.	1650	899.	2800	1537.5
32	0	145	62.8	550	287.8	1700	926.	2850	1565.
35	+ 1.7	150	65.6	600	315.6	1750	954.	2900	1593.
40	4.4	155	68.3	650	343.3	1800	982.	2950	1621.
45	7.2	160	71.1	700	371.1	1850	1010.	3000	1648.5
50	10.	165	73.9	750	398.9	1900	1038.	3050	1676.
55	12.8	170	76.7	800	426.7	1950	1065.5	3100	1705.
60	15.6	175	79.4	850	454.4	2000	1093.	3150	1732.
65	18.3	180	82.2	900	482.2	2050	1121.	3200	1760.

This can be easily calculated without the table by remembering the following facts:

The Centigrade scale starts at 32 of the Fahrenheit scale and advances 100 degrees while the Fahrenheit scale is going 180 degrees, from 32 to 212. This makes the Centigrade scale $\frac{100}{180}$ or $\frac{5}{9}$ of the Fahrenheit scale between these points.

But the 32 degrees has to be accounted for, so we say: To convert Fahrenheit to Centigrade, subtract 32 from Fahrenheit, divide remainder by 9 and multiply by 5. Example: Convert 212 Fahrenheit to Centigrade. $212-32=180$; $180\div 9=20$; $20\times 5=100$. *Ans.* 212 Fahrenheit $=100$ Centigrade.

To convert Centigrade to Fahrenheit, divide by 5, multiply by 9 and add 32. Example: 200 Centigrade to Fahrenheit. $200\div 5=40$; $40\times 9=360+32=392$ degrees Fahrenheit.

EXAMPLES

1. What is the difference between the Fahrenheit and Centigrade thermometer scales?

2. What are the freezing and boiling points of each? *Ans.* Fahrenheit freezing point 32 degrees, boiling 212 degrees. Centigrade freezing is 0, boiling 100 degrees.

3. How much will a steel rod which is just 1 inch long at zero measure at 200 degrees Fahrenheit. *Ans.* Taking the expansion from the table as 0.00000689, multiply this by 200 and get 1.001378 inch or over 0.001 inch increase.

4. What are the effects of grinding work that is not round? *Ans.* As it grinds more from one side it also heats that side more and is apt to spring out.

5. How do we know that all kinds of work develop heat? *Ans.* Because it does not matter what we do to a piece of metal, bend it, hammer it or cut it, it becomes warmer than it was originally.

CHAPTER VII

INERTIA

Inertia is one of the forces that we have to contend with and may be called the tendency of anything to keep on in whatever it is doing. Or to say it differently, the tendency of anything in motion to keep moving and of any stationary body to remain at rest.

When a stone is lying on the ground, it will remain there until some outside force sets it in motion. This may be the toe of a boy's new shoe, a rush of water from a hose, a cloud burst or any other force, but some outside force is necessary.

When a bullet leaves a gun it would go on indefinitely if it were not for the resistance of the air and the constant pulling of the force of gravity. These will eventually stop it even if it does not strike any object in the meantime. Or a line shaft in motion would continue in motion if it were not for the friction of the bearings and the resistance of the air against the pulley arms, rims, etc.

When you try to jump a rapidly moving car the shock comes from the sudden changing from rest to motion. This can be lessened by running in the direction the car is moving before attempting to jump aboard, simply because the inertia is partially overcome before the jump is made. If you are running at the same rate of speed as the car, you can step aboard without shock of any kind. In the same way if two trains are running side by side at the same speed, you can step from one to the other as easily as though both were standing still. This is true whether they are running 6 miles or 60 miles per hour, so long as they are running at the same speed.

In the same way if one train is moving at 10 miles an hour and another at 15 miles, the shock of jumping from one to the other will be the same as though you jumped on or off a train moving at the difference in speed, or 5 miles an hour.

In jumping from a moving car the body tends to move at the same rate as the car. When the feet strike the ground they stop while the body tends to keep on in the direction of the car. If you keep both feet fixed you are very apt to be thrown to the ground, so you take a step or two and gradually overcome the inertia of motion or momentum. This is why you fall more readily if you step off a car backward.

Inertia and momentum are sometimes used to express the same thing. Inertia may be said to represent the tendency to remain at rest and momentum the tendency to keep in motion.

Inertia in the Shop

Inertia comes into play in the shop in several ways. A wrench laid on a planer table will be moved at the reversal point because it partakes of the motion of the table and, when the table reverses, the wrench keeps on in the same way until its motion is checked by friction.

In the same way a lathe or boring mill tends to run after the power is shut off and brakes are often used to save time. It sometimes happens that when the brake is applied suddenly the inertia or momentum of the revolving chuck loosens it and often unscrews it completely from the spindle.

When one or more bodies are placed on anything that can move, it partakes of it the motion of the moving piece. If we stop the moving piece suddenly, the loose piece keeps on. In the same way we can walk either forward or backward on a moving train so long as the motion is uniform. But if the train slows down suddenly, you notice it at once.

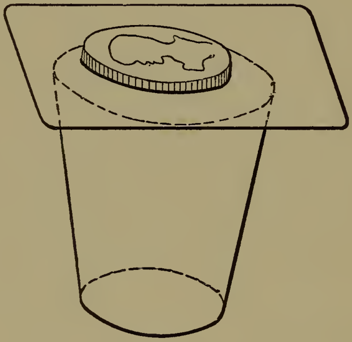


FIG. 41.

In the same way you can throw and catch a ball in a box car and have no difficulty as the ball partakes of the motion of the car. This could be done on a flat car and the ball thrown up in the open air except for the effect of the wind and air resistance. You can easily try this by tossing a ball in air while walking or running.

An opposite effect is seen in Fig. 41 where a card is placed over a glass and a coin or other small object on the card. By striking the card a sharp blow, as by snapping the finger, the card will be driven out and the coin fall in the glass. The quick movement of the card did not give the coin time to overcome its inertia before the card was out of the way.

In the same way it is often possible to drive a very small punch through a piece of hard metal by a quick blow when it would be impossible to force it through by a slow, steady pressure. In the first place it does not have time to bend before it is through while in the latter the strain finds time to bend and break it. There are many operations which are done easily at high speed that could not be done at all at slow speed.

EXAMPLES

1. Think over a number of shop examples in which inertia plays an important part.

2. What makes it harder to start up a long line of shafting or a machine than to keep it in motion? *Ans.* Inertia or the tendency to remain as it was, at rest.

3. Why are we thrown forward when a train stops suddenly? *Ans.* From the inertia. We have acquired the motion of the train and tend to keep on in the same direction.

4. Why do planer belts squeak at reversal? *Ans.* They are running rapidly and when shifted from a loose pulley to one running in the opposite direction, the inertia of both belt and pulley maintains the motion in opposite directions and the belt squeaks.

5. Explain why a wrench laid on a planer table is moved along the table at reversal.

CHAPTER VIII

BELTING

As belting is the most common method of transmitting power, it is an important part of practical shop mechanics to understand the principles involved.

The power of a belt depends on the speed and the effective tension. The effective tension is the difference between the two sides of the belt which may be known as the "driving" and "following" sides or the "tight" and the "slack" side. This tension in turn depends on the width of the belt and the strain it will stand. The driving power also depends on the surface friction and the angle of wrap.

In good practice a single belt is counted on to stand a stress of 60 pounds per inch of width without undue stretch and with a fair length of life. For double belts this figure is 105 pounds, and 150 pounds for triple belts.

For best results the pulley should not be too small, as it imposes to severe bending strains on the belt which injures it and at the same time prevents as good contact between belt and pulley.

Thin belts are best on small pulleys and a good rule is to never have a pulley whose diameter in feet is less than the belt thickness in inches. That is, a belt $\frac{1}{4}$ inch thick should not be used on a pulley less than $\frac{1}{4}$ of a foot, or 3 inches, in diameter or a belt $\frac{1}{2}$ inch thick on less than a 6-inch pulley. A very small pulley, say $1\frac{1}{2}$ inches or $\frac{1}{8}$ of a foot, would require a belt $\frac{1}{8}$ inch thick. The crowning of a pulley also affects the contact and bending of the belts.

Creep of Belt and Tension

The creep of a belt depends on the load and the elasticity of the belt and should not exceed 1 per cent. in good practice. As the creep depends on the difference in tension between the two sides, it is necessary to keep the effective tension or the difference between the two sides of belt down, to prevent excessive creep.

The best practice seems to be to limit the difference in tension to 40 pounds per inch of width for single belts, to 70 pounds for double, and to 100 pounds for triple belts per inch of width. The ratio of tension which has been found best, varies with the diameter of the pulleys and can be stated as 2 for small pulleys, 2½ for pulleys of medium size, and 3 for large pulleys A large pulley gives a better contact than a small one and a thin belt wraps around easier and better than a thick one. For this reason many prefer a wide single belt, or even two single belts, to a narrow thick belt.

The ratio of tensions means the difference between the two sides of the belt. On small pulleys the tight side should not be over double the slack side while on large pulleys it can be increased to three times the slack side.

Tables I and II have been prepared by Prof. W. W. Bird and will be found very useful. The factor in Table I is to be used where the belt wraps half way round the pulley or 180 degrees, which is usually assumed in common practice, but where more accurate figuring is necessary the factor should be taken from Table II.

Horse-power of Belts

These tables are very conservative as they require from 830 to 1100 feet of belt speed per inch of width for single belts while many rules only call for 600 feet. This varies with the arc of contact, which depends on the size of the pulleys and the slackness of the belt, as can be seen in Fig. 42. The arc of contact must always be taken from the small pulley, as this is what governs the power transmitted.

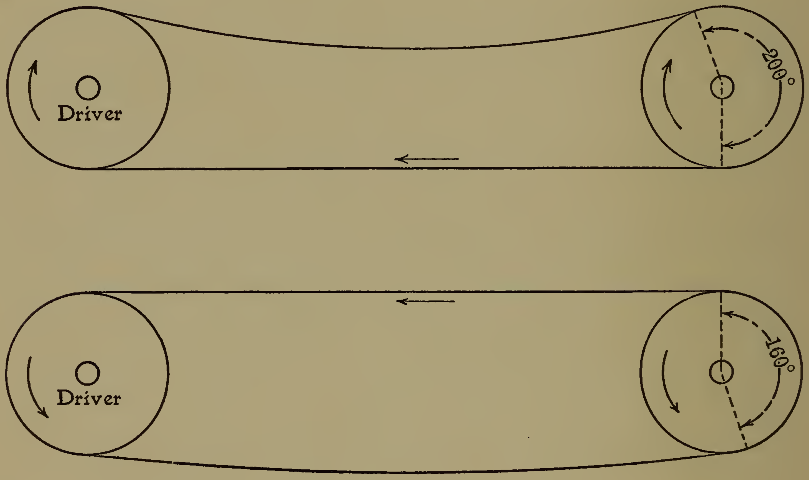


FIG. 42.

This is why a tightener is often used near the small pulley, as in Fig. 43, to increase the arc of contact.

To find the horse-power, multiply the velocity in feet per minute by the width in inches and divide by the factor in Table I, according to the arc of contact. For rough estimating it will be safe enough to take 900 feet as the factor.

Put in the formula style we can say: Horse-power =

$$\frac{\text{velocity in feet per minute} \times \text{width of belt}}{\text{factor}}$$

or $$H.P = \frac{V \times W}{F} \text{ or } \frac{V \times W}{900} \text{ for single belt.}$$

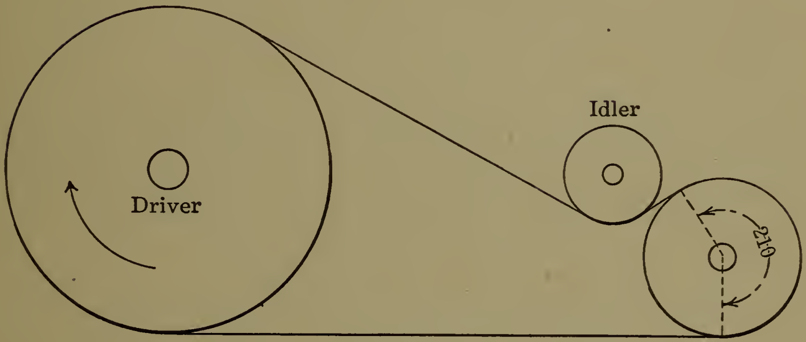


FIG. 43.

For canvas belt it is safe to count a 4-ply belt as equal to a single leather belt.

To find the belt speed in feet per minute, divide the diameter of pulley in inches by 12 and multiply by 3.1416 and by the turns per minute.

How fast will a belt run over a 48-inch pulley making 400 revolutions per minute?

Divide 48 by 12=4. 4×3.1416=12.5664 which we call 12.5 feet. Multiplying this by the number of revolutions we have 12.5×400=5000.0 feet per minute. This is faster than it is usually advisable to run a belt as centrifugal action tends to reduce the pulley contact. Many consider 4500 feet per minute as the fastest speed advisable, although there are cases where 5000 and even 5500 feet per minute

TABLE I

Diameter of pulley	Under 8″	8″-36″	Over 3 feet	Under 14″	14″-60″	Over 5 feet	Under 21″	21″-84″	Over 7 feet
Thickness of belt	Single	Single	Single	Double	Double	Double	Triple	Triple	Triple
Factor	1100	920	830	630	520	470	440	370	330
Difference of tensions	30	36	40	52.5	63	70	75	90	100
Per cent. of creep	.74	.89	.99	.74	.89	.99	.74	.89	.99
Ratio of tensions	2.00	2.50	3.00	2.00	2.50	3.00	2.00	2.50	3.00
Tension on tight side	60	60	60	105	105	105	150	150	150

TABLE II

Pulleys	220°	210°	200°	190°	180°	170°	160°	150°	140°	130°	120°	
Under 8″	980	1010	1040	1070	1100	1140	1180	1220	1270	1330	1400	Single
8″-36″	810	830	860	890	920	950	990	1040	1100	1170	1240	
Over 36″	730	750	770	800	830	860	890	930	980	1030	1100	
Under 14″	560	570	590	610	630	650	670	700	730	760	800	Double
14″-60″	460	470	480	500	520	540	570	600	630	660	700	
Over 60″	420	430	440	450	470	490	510	530	560	590	630	
Under 21″	390	400	410	420	440	460	480	500	520	540	560	Triple
21″-84″	320	330	340	350	370	390	410	430	450	470	490	
Over 84″	290	300	310	320	330	340	360	380	400	420	440	

are in use. After 4000 feet is reached, however, the gain due to speed is not nearly as great as below that point.

If this belt is 6 inches wide it will transmit

$$\frac{5000 \times 6}{900} = 33.3 \text{ horse-power.}$$

Suppose we have to transmit 40 horse-power at a belt speed of 4000 feet per minute, how wide must the belt be?

We transpose our rule to read

$$\text{Width} = \frac{\text{H.P.} \times \text{F}}{\text{V}} \text{ or } \frac{40 \times \text{F}}{4000}.$$

If we decide to use a 24-inch pulley and a single belt we find that F=920 for 180 degrees of contact, so we have

$$\frac{40 \times 920}{4000} = 9.2 \text{ or } 9\tfrac{1}{4} \text{ inches}$$

wide. This is a little wide for a single belt, so we try a double belt and find that F = 520 which gives

$$\frac{40 \times 520}{4000} = 5.2$$

as the width necessary.

Suppose once more that we have to transmit 40 horse-power with a 5-inch double belt with 180 degrees of contact. We again transform the rule to read

$$\text{V} = \frac{\text{H.P.} \times \text{F}}{\text{W}} = \frac{40 \times 520}{5} = 4160 \text{ feet}$$

per minute.

This gives the three rules as follows:

$$\text{H.P.} = \frac{\text{Velocity} \times \text{Width}}{\text{Factor}} \qquad (1)$$

$$\text{Width} = \frac{\text{H.P.} \times \text{Factor}}{\text{Velocity}} \qquad (2)$$

$$\text{Velocity} = \frac{\text{H.P.} \times \text{Factor}}{\text{Width}} \qquad (3)$$

At high speeds centrifugal force (see Chapter XI), adds to the belt tension and decreases the driving power. Up to 2000 feet per minute the effect is very small, but above that it becomes more and more of an item.

Long or Short Belts

When belts are run horizontally or at a moderate angle a long center distance is a good thing (within reason) as, if the belt runs properly, there will be considerable sag on the top side which increases the arc of contact.

With vertical belts, however, the longer they are the heavier they are and the more they stretch from their own weight, so that a long vertical belt has to be laced very tight to make it drive on the lower pulley at all.

Open and Crossed Belts

Open and crossed belts are very common in the shop, to secure a forward and a reverse motion. In each case the shafts should be parallel and the pulleys in line as shown in Fig. 44. By taking care to have a smooth joint next to pulley and twisting the belts so the inside or pulley side comes together at the crossing point, no trouble is experienced.

One of the crossed belt problems is in cutting holes in floors or partitions for the belts to run through. Owing to the twist in the belt it is necessary for the holes to be at an angle, but the angle depends on the size of the pulleys, their distance apart, and the location of the partition or floor between the pulleys.

With the partition at the crossing point it is only necessary to cut a single hole at 45 degrees, as at *A*, Fig 44, but when the cut is near one pulley or the other, two holes become necessary, as shown at *B*, *B*. In this case the angle must be laid out by making a diagram of the pulleys, belt and floor, but a little experience will enable us to guess very close to the right place and angle. There is no simple rule which will cover it.

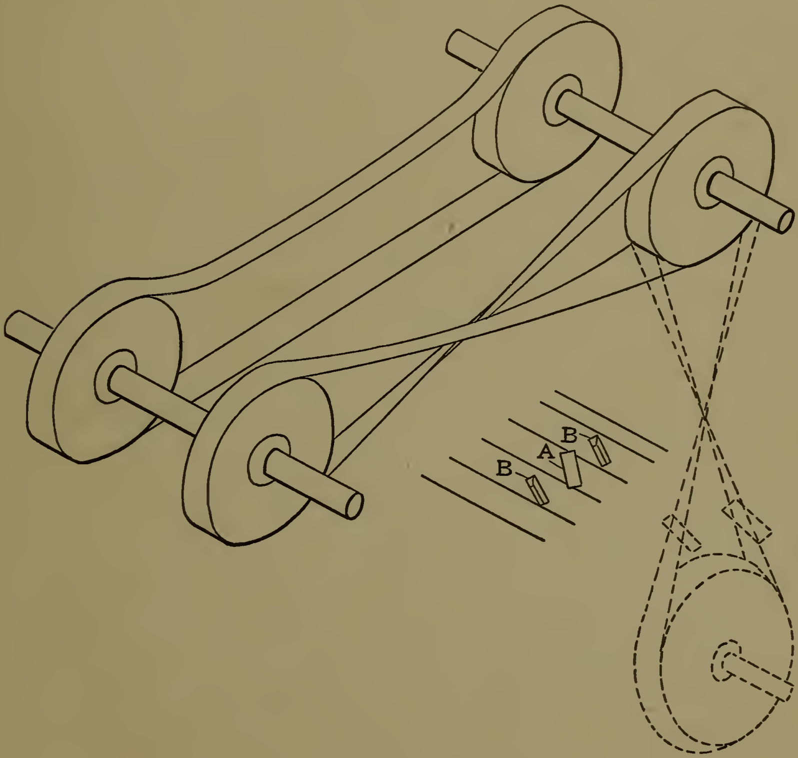


FIG. 44.

Quarter Turn Drives

It often becomes necessary to belt shafts which are not parallel but at right angle or nearly so, such as cross shafts in a shop or factory. Shafts can be connected at any angle by the use of guide pulleys but right-angle turns can be made without them.

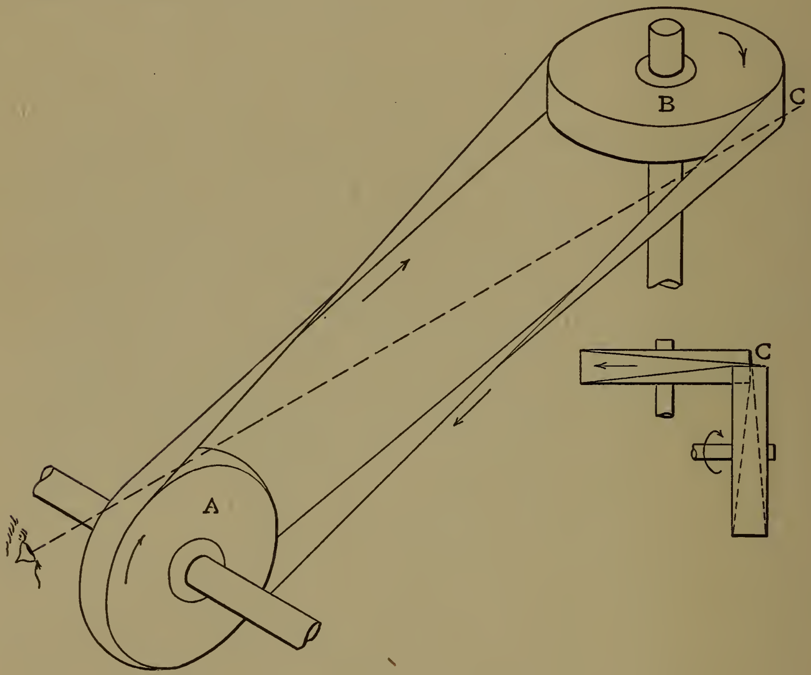


FIG. 45.

There is a rule for locating pulleys for such work which is easily learned but is not generally known, and unless they are located in their right positions the belt will not stay on the pulleys without guides.

The rule is: The belt must always run on to a pulley in line with that pulley but it can be drawn sideways on leaving the pulley.

Taking Fig. 45, we see that the sighting is done from the top of pulley *A* to the center of the driving side of *B*. This is shown in the small sketch also.

A belt will run sideways at quite an angle on leaving a pulley but it must lead on to the pulley perfectly straight unless guides are used.

In Fig. 45 it will be seen that the belt is pulled to the left on leaving *A* and that it is pulled down on leaving *B*, but the top of *A* is in line with the center at *C*, and the driving edge of *B* is in line with the center of *A*.

Reverse the direction of motion and the belt immediately runs off because the rule has been broken. In this case the driving side of pulley will not be in line with the center of the other pulley, so that the belt will not lead on properly.

To run this quarter turn drive in the opposite direction it is necessary to lower pulley *B* on its shaft an amount equal to the diameter of *A* and to move *A* to the left a distance equal to the diameter of *B* as shown in Fig. 45.

Although the belt can be made to run at quite an angle after it leaves the pulley, it is not good practice and this should be kept as small as possible. This means long center distances between shafts when they can be had.

Guiding a Quarter Turn Belt

This is a modification of the plain quarter turn drive (Fig. 46), and the idler or guide pulley should be on the slack or return side of the belt as shown. This prevents the binder pulley bearings from getting much of the load or pull, which would be very heavy if on the other side.

This can be laid out on paper but requires considerable figuring with angles. In most cases this can be laid out direct. Locate the two pulleys so that the straight side of belt will run true as shown before. If the belt is vertical, this can be done by dropping a plumb line from the center of the face of upper pulley so that it touches the face of the lower pulley. Or they can be sighted in any case.

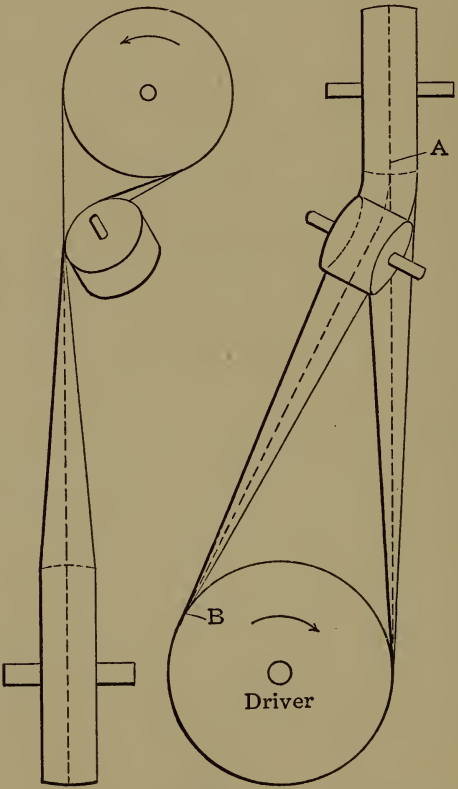


FIG. 46.

Then a line drawn from the center of pulley face as *A*, to the outside of other pulley as *B*, gives the line of the slack side of the belt and the guide pulley can be set correctly after a few trials.

The use of double guide pulleys is shown in Fig. 47.

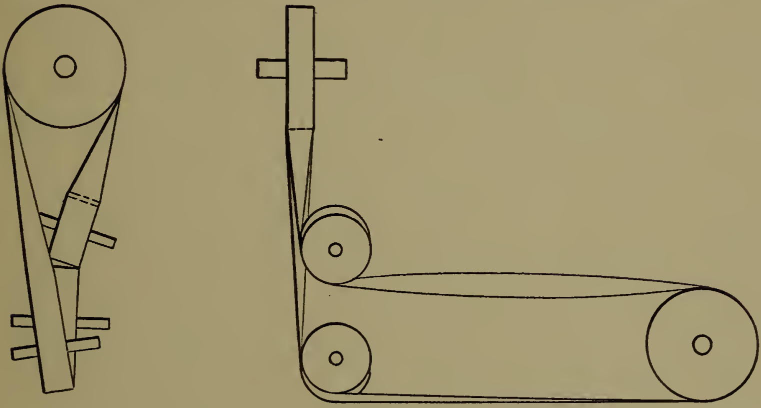


FIG. 47

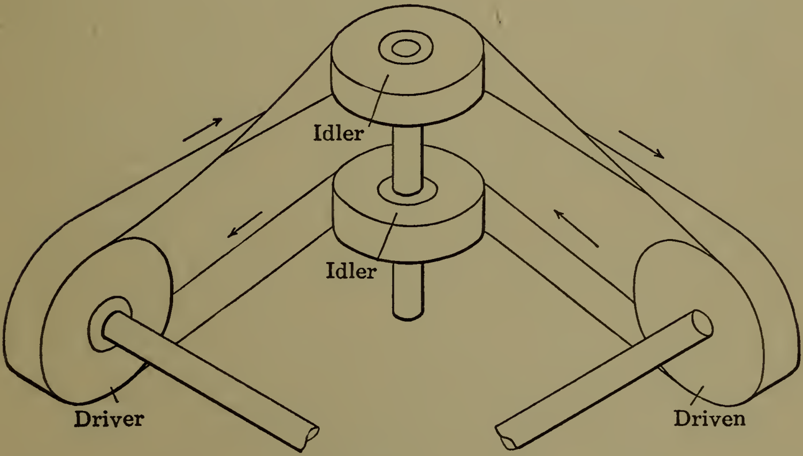


FIG. 48.

Muley Belt Drive

Another very common form of belt drive is shown in Fig. 48, which is known as a "muley" belt. This has two idler pulleys on a vertical shaft. This shaft is usually fastened to the ceiling and braced at the bottom to hold it against the belt pull.

Both of the horizontal shafts should be at the same height or on the same level and the pulleys should be of the same size. The distance between the horizontal shafts and muley shaft should not be more than will let the belt twist easily. This can usually be taken as about 12 times the width of the belt.

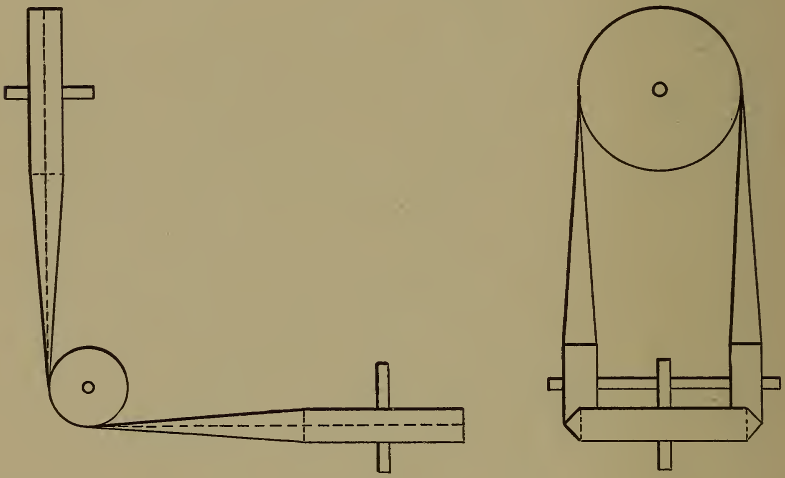


FIG. 49.

The laying out is done as shown in Fig. 49.

These do not need to be at right angle and in fact can be used to connect two parallel shafts which are too close together to be belted directly. This can be readily seen by imagining the driving and driven shafts in Fig. 49 to be swung together until they are parallel.

EXAMPLES

1. What does the driving power of a belt depend on?

2. What is the effective tension of a belt?

3. Why does a wide belt drive more than a narrow belt at the same speed? *Ans.* Because its total tension is greater.

4. What is the smallest size of pulley that should be used with a belt $\frac{1}{4}$ inch thick and why? *Ans.* 3 inches.

5. What is the creep of a belt, and what is a safe allowance?

6. What should be the limit of effective tension on a double belt 6 inches wide? *Ans.* 420 pounds.

7. What speed of a 1-inch single belt will transmit one horse-power? *Ans.* From 700 to 950 feet per minute.

8. Should the belt wrap well around the pulley for best results and why?

9. What horse-power can we count on for a single belt 3 inches wide, running 3000 feet per minute? *Ans.* 10 horse-power.

10. How wide must a double belt be to transmit 40 horse-power at a speed of 4000 feet per minute on a 24-inch pulley with 180 degrees arc of contact. *Ans.* $5\frac{1}{4}$ inches.

11. What velocity will be necessary to transmit 20 horse-power with a 5-inch single belt on a 40-inch pulley with a contact of 190 degrees? *Ans.* 3200 feet per minute.

12. Why are long belts good for horizontal driving and bad for vertical belts?

13. What is the rule about locating pulleys for quarter turn drives.

14. Why cannot a quarter turn drive without guide pulleys be run backward?

15. What is the highest advisable speed to run belts, and why? *Ans.* About 5000 feet because centrifugal force tends to stretch the belt and impair contact with the pulley. It also adds to the belt strain.

CHAPTER IX

WORK DONE BY BELTS AND BLOCK AND TACKLE

With the cone-driven lathe, every mechanic has noted that although the speed of the lathe might be even less with the belt on the large cone and the back gears out than with the back gears in and the belt on the small step, it will not pull nearly as heavy a cut. Of course, they are not all designed this way, but some are and the difference in the cut they will pull is very noticeable. In the first case the belt is running very slowly and it slips, while in the other it is running at a much higher speed and pulls more.

This shows us that the speed of a belt has everything to do with the power it can transmit and if we look at a planer and then a lathe we see a great difference in belt practice. In the planer we run a narrow belt at very high speed and in the lathe we too often run a wide and heavy belt at a much slower speed.

The power of a belt depends on its speed, its width, and on the tension to which it is strained. A high-speed belt does not have to be strained as tight as a slow-speed belt and is easier on bearings on that account. With the same tension a 1-inch belt running at 1000 feet a minute will do as much work as a 2-inch belt at 500 feet in a minute and, generally speaking, high-speed belts are the best to use.

It is well to remember that a narrow belt costs less than a wide one, and if it will do the same work by running it faster it is economy to do so. It is also easier on the bearings, as while the tension is the same per inch of belt width, there is less total pull on the bearing.

Friction and Spur Gearing

In any kind of gearing, speed counts the same as in belting when it comes to transmitting power. Two friction pulleys running together at a high speed will transmit a lot of power while at slow speed they will slip at a very light load.

Spur gearing is the same and small light gears at high speed may transmit as much power as larger and heavier gears at slow speed. The greatest objection is the noise at very high speed.

Here, as with belts, the width of the teeth or the surfaces in contact affect the power that can be transmitted, but the speed also cuts an important figure. The speed also affects the wear of the teeth very much, especially where the action is a sliding rather than a rolling motion.

Horse-power

The term horse-power is a little indefinite at times, but is easily understood if we get a few facts firmly fixed in our minds.

A horse-power is equivalent to 33,000 *pounds raised* 1 *foot high in* 1 *minute.*

The minute is the unit of time and we can do a horse-power of work by raising 3300 pounds 10 feet, or 330 pounds 100 feet or 33 pounds 1000 feet in a minute. Or we can raise 10 pounds 3300 feet, 100 pounds 330 feet or 1000 pounds 33 feet a minute. Any combination of pounds and feet that will make 33,000 when multiplied together, makes 1 horse-power if it is done in 1 minute.

A simple and easy way of measuring this is shown in Fig. 50, which is only good for small powers, but other devices on the same principle are used for heavier powers.

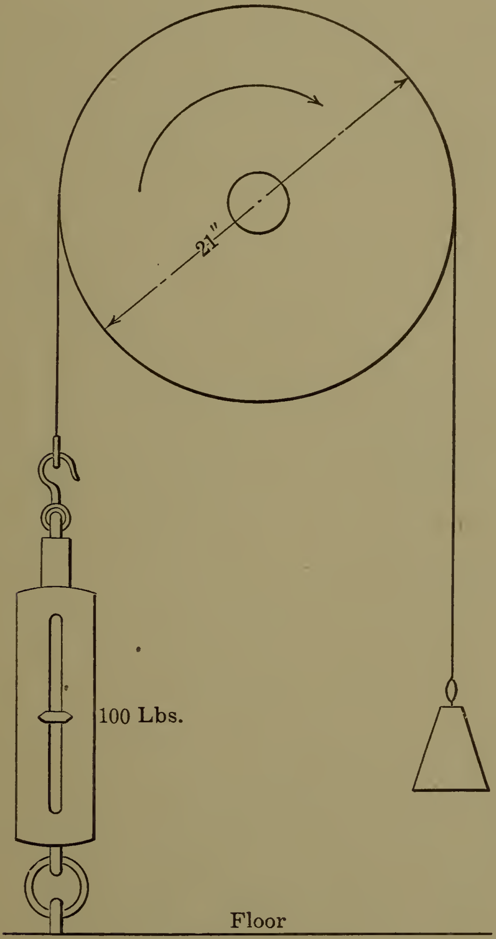


FIG. 50.

The belt going over the pulley is counterweighted to keep it tight and the pulley runs as shown by the arrow. Suppose there is a motor connected to the shaft running at

200 revolutions per minute and that the scale shows a pull of 100 pounds. The pulley diameter is 21 inches, so that the circumference is 66 inches or 5½ feet. The surface speed is then 1100 feet per minute. Multiplying this by the pull, we have 110,000 foot pounds per minute. Dividing by 33,000 gives 3⅓ horse-power.

For larger powers the device shown in Fig. 51, and known as the Prony brake, is used in various forms, the load being weighed on the scales shown. The calculations are similar to the others as we find the speed at which the point which rests on the scale would travel if it revolved around the shaft and multiply this by the load it puts on the scale. This divided by 33,000 gives the horse-power.

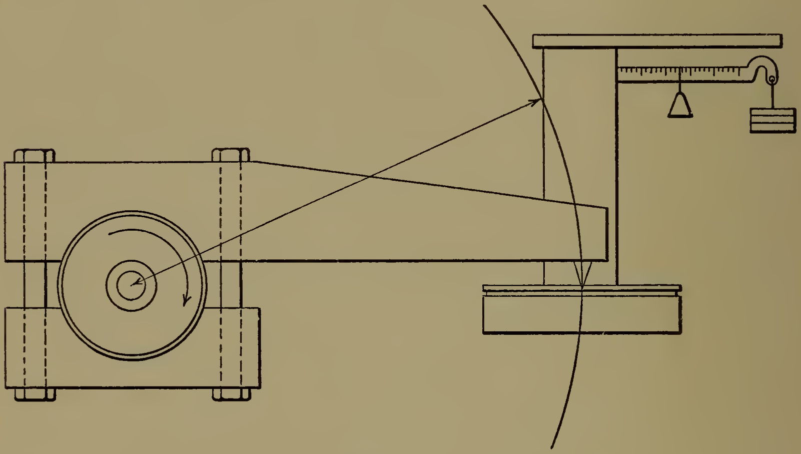


FIG. 51.

The difficulty with all such devices is to keep the brake blocks from overheating from the friction, and on some special machines of this kind, called dynamometers, the friction surfaces are kept flooded with water.

Leverage Again

The power of belts or gears and the measuring of this power all comes back to the question of leverage. With the belt, the radius of the pulleys from the center of the shaft to the rim is the lever arm and the longer this is the less belt tension will be needed to do a given amount of work if the belt speed is the same. The belt on the small pulley also loses power from bending and slipping.

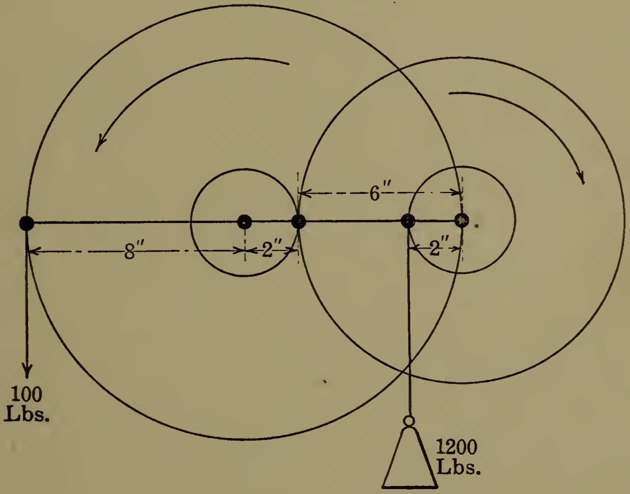


FIG. 52.

In the case of gears we are apt to get a little mixed as we usually see a small pinion drive a large gear and know that, while the lever arm of the pinion is shorter than of the driven gear, there is a gain in power to use the common term. But we overlook the fact that the power or lever arm turning the pinion is much longer and that this is a compound lever at work as seen in Fig. 52.

Forgetting all about gears and just considering the heavy lines Fig. 52 as levers, we can figure out the power or ratio of gearing very quickly. With the length of leverage shown, the power or pulley arm is 8 inches and the load or pinion arm 2 inches, so that every pound applied at the pulley rim means 4 pounds at the pinion or the rim of the driven gear. This driven gear has a 6-inch lever arm and carries a roll or drum 4 inches in diameter or with a 2-inch lever arm, so that the ratio here is 3 to 1. As 4 pounds is delivered to the 6-inch arm, then the power at the drum will be 3×4, or 12 pounds for every pound applied to the first pulley.

It is well to remember, however, that this is not all gain and that we cannot really gain power anyhow. What we really do is to transform speed into power and when we say we gain 12 to 1 we simply mean that we have reduced the speed to $\frac{1}{12}$ and can handle a load of 12 times the initial pull, less the loss by friction. So, calling the initial pull 100 pounds and the rim speed 2400 feet a minute, we know that 1200 pounds can be lifted at a speed of 200 feet a minute or a total of $100 \times 2400 = 240{,}000$ foot pounds or 7.27 horse-power, not allowing for loss in the friction of bearings, in gearing and in belts and rope.

The question of power is the same in any case of belts, pulleys or gearing and all depends on the lever arms employed. This can be followed out very nicely by taking a geared head lathe and tracing the movement of various gears.

In any case of levers, pulleys or gears it is always well to bear in mind that we can find the ratio or so-called gain or loss in power by comparing the first and last movements. If the power is 10 times as fast as the load, no matter how many levers, gears or pulleys and belts are used in between, the load can be 10 times the power applied, less the loss by friction. Or if the power applied only moves 10 feet a minute and the load 50 feet, then the power must be five times as much as the load, in addition to the loss by friction in all cases.

Pulley Blocks and Tackle

Along this same line is the well-known hoist or pulley and snatch block. Yet it is a little puzzling at times owing to the number of pulleys employed and the various turns made by the ropes.

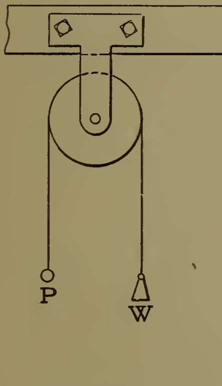


FIG. 53.

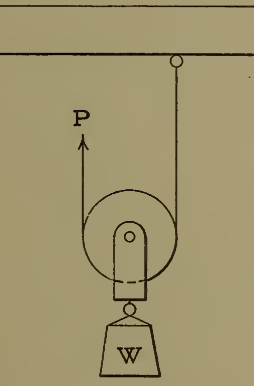


FIG. 54.

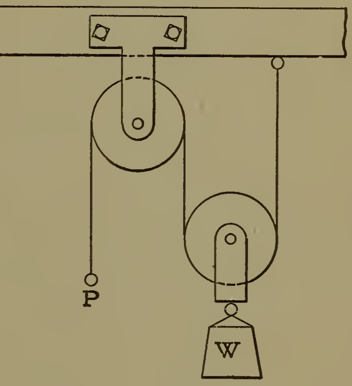


FIG. 55.

Fig. 53 shows a single pulley fixed to the ceiling and it will be perfectly clear that when the power end of the rope is pulled down one foot the weight rises an equal amount, so that no gain is made by this arrangement. It is, however, often much more convenient at times as it is usually easier to pull down than up. This shows that a fixed pulley simply alters the direction of the rope or application of power, but does not affect the power in the least.

In Fig. 54 the rope is fastened to the ceiling and a pulley on the weight allows it to be raised by pulling up on the rope at *P*. Here the pulley is movable and we can readily see that the rope at *P* must be pulled up 2 feet to raise the weight 1 foot. This shows that each movable pulley increases the weight that can be raised by the same power and also the distance the rope must move as compared with the load.

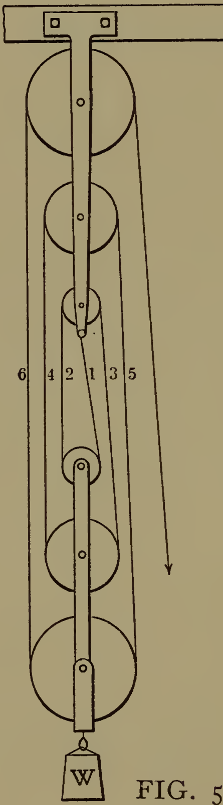


FIG. 56.

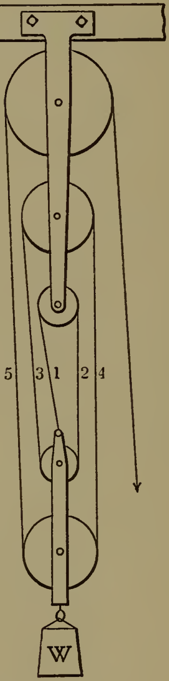


FIG. 57.

Going a little further we have in Fig. 55 the combination of a fixed and a movable pulley. With this we can see that the movable pulley enables a pull of 10 pounds at *P* to raise a 20-pound weight and that the fixed pulley simply changes the direction of the pull but leaves the weight raised the same as through but one pulley was used.

A still more complicated combination is shown in Fig. 56, in which there are 3 fixed and 3 movable pulleys. In this combination the weight that can be supported is as many times the power as there are parts of the rope supporting the movable pulleys. Counting these we find 6 ropes supporting the movable block, so that 10 pounds at *P* will support a weight of 60 pounds under the block.

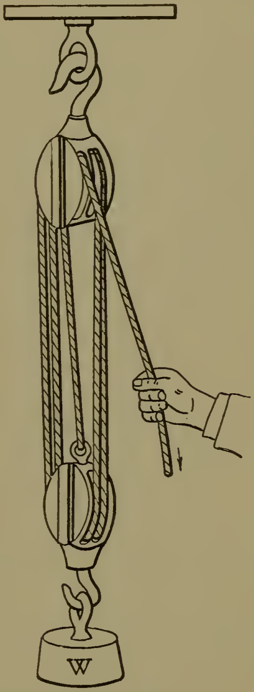


FIG. 58.

This shows that it makes a difference whether the dead end of the rope is fastened to the fixed pulley as in Fig. 56 or to the movable pulley as in Fig. 57. In the latter case it has only 2 movable pulleys and but 5 supporting ropes, so that there is only a 5 to 1 ratio instead of a 6 to 1, and but 5 pulleys are used instead of 6.

This may be summed up as follows:

When the fixed end of the rope is fastened to the *fixed* block, the number of parts of the rope supporting the load equals *twice* the number of *movable* pulleys.

When the fixed end of the rope is fastened to the *movable* block, the number of parts of the rope supporting the load equals *twice* the number of movable blocks, *plus one.*

The weight that can be supported is as many times the power applied as there are parts of the rope supporting the movable pulleys.

In practical use the pulleys are not separated as shown but are built together in one block as in Fig. 58. The same principles hold in either case and it is well to know what you can lift or pull with a given set of tackle and power to apply, as this is especially useful in setting up new machinery.

It must also be remembered that there is considerable loss in power from the small bends of the ropes around the pulleys so that a given power will *hold* a load considerably greater than the figures would show while, on the other hand, to lift a given weight will require more than the calculated power. With these facts in mind the operation of the blocks will be clear to anyone who needs to use them.

EXAMPLES

1. Why does a planer usually do more work with a narrow belt than a lathe? *Ans.* It runs faster.

2. What is a safe figure for the horse-power of a 1-inch single belt with a good contact on pulley? *Ans.* 800 feet per minute should give 1 horse-power.

3. If a Prony brake shows 100 pounds on the scales with a 5-foot arm and an engine speed of 100 r. p. m., what is the horse-power? *Ans.* 9.51 horse-power.

4. What should the same Prony brake show to indicate 20 horse-power at 150 r. p. m. *Ans.* 140 pounds.

5. What will a 50-pound pull on a tackle like Fig. 56 support, not allowing for friction? *Ans.* 300 pounds.

CHAPTER X

GEARING OF DIFFERENT KINDS

Although gears have been shown to be simply a form of the lever or a series of levers, there are a number of gearing problems which come up in the shop and in machine design that are often a little puzzling.

The plain spur and bevel gear are both in the same class so far as being levers are concerned, but they are often combined in different ways that make them more difficult problems than that shown in Fig. 52.

Differential Pulleys and Gears

The use of differential pulleys and gearing is not clearly understood and as it plays an important part in machine construction and design, it should be studied until its principles are clear.

Perhaps the easiest way to see just what this means is to take the old "Chinese windlass" (Fig. 59) which simply means that different diameters are used for the ropes. If we wrap one end of the rope around the small diameter *A* and the other around the large diameter *C*, we are ready to start to work.

Turning the drum in the direction of the arrow we wind up on *C* and unwind from *A*. Now as *C* is the larger we wind up faster than we unwind, so that the load, supposed to be suspended from the pulley *B*, is lifted at a rate due to one-half the difference between the diameters of the pulleys. If *A* is 12 inches and *C* 24 inches in circumference, the rope will wind on *C* 12 inches more than it unwinds, from *A*, and as this is divided by the upward movement of *B*, the load is raised 6 inches.

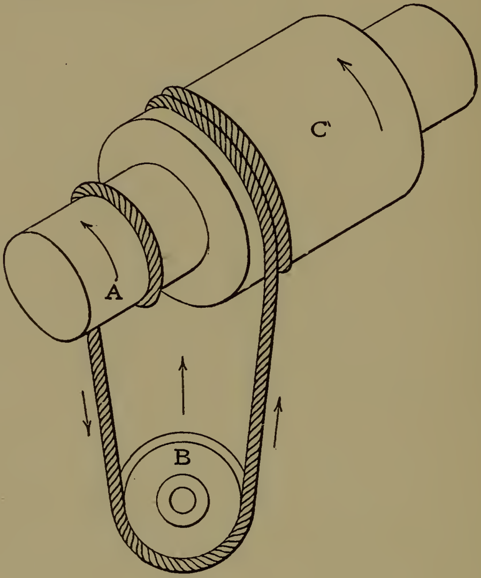


FIG. 59.

The advantage of such an arrangement is that we can use a drum approximately 4 and 8 inches, which will support a heavy load, while we get the results of a 2-inch drum which would not only be weak but cause a sharp bend in the rope.

In Fig. 60 is another form of differential arrangement that has no special application but shows how two pulleys of different diameters, with straps attached to blocks, will move one block, *D* faster than *C* and gradually draw away from it.

An application of this principle is seen in cotton combing machines, where one set of combs is drawn faster than the other so that the cotton is combed with both moving just as though one comb was stationary.

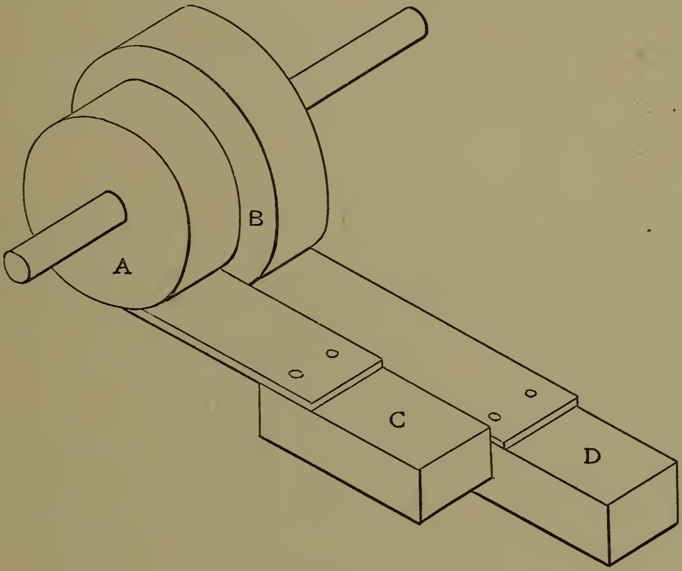


FIG. 60.

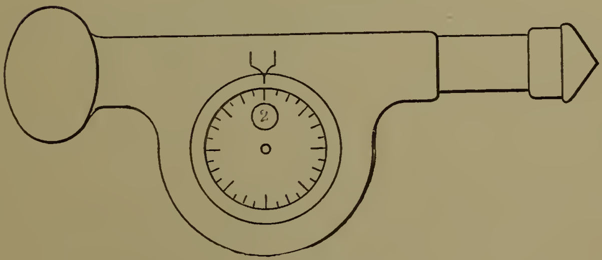


FIG. 61.

One of the most common forms of differential gearing is the speed indicator shown in Fig. 61. This consists of two thin worm wheels, one with 99 and the other 100 teeth, as shown in diagram, Fig. 62; both of these run on the same worm and are so nearly the same diameter that the difference is hardly noticeable.

The dial with 100 teeth is usually graduated for every 5 teeth and when it makes one revolution it is clear that the worm has made 100 revolutions. As the other disk has but 99 teeth it is clear that when the worm has made 100 revolutions this will turn one tooth more than one revolution. By having a hole in the larger disk, and having the 99-tooth disk graduated in line with this hole, we get the "hundred" graduations. That is, after the 100-tooth

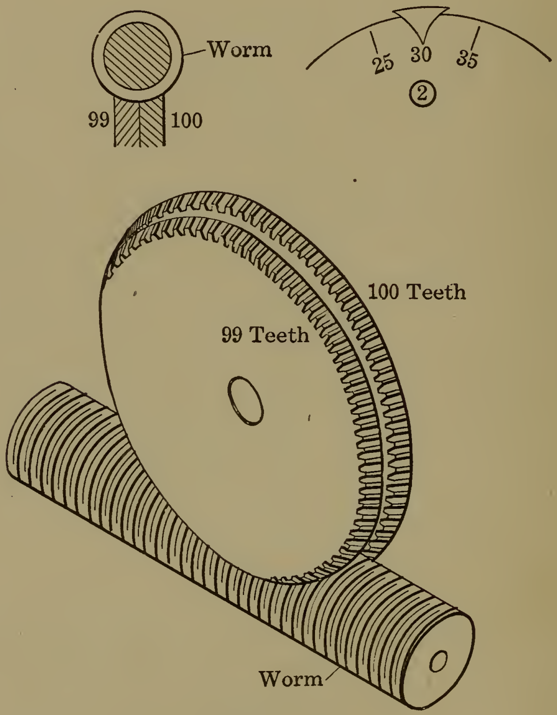


FIG. 62.

disk has made one revolution it will show 1 through the hole, showing 100 revolutions have been counted and when it has made one more revolution the large disk will have gained another tooth on the smaller, showing number 2 through the hole.

Any other ratio can be used until we get such a large difference in diameter that they will not run well together.

Differential Threads

Differential threads are very interesting although they are not used very largely except in special cases. Fig. 63 shows a crude application but one which shows the principle. The block *A* is fixed and the end of the screw having a thread with a lead of $\frac{1}{4}$ inch goes in this block. The movable jaw *B* has a thread having a lead of $\frac{3}{16}$ inch.

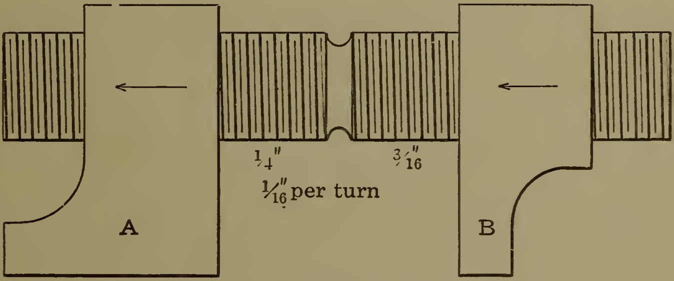


FIG. 63.

If both threads were alike it is very clear that turning the screw would simply run it through both blocks just as though they were both a single nut. But, as they are different, let us see what happens.

One turn of the screw carries it *into* the block *A* $\frac{1}{4}$ inch and *out of* block *B* $\frac{3}{16}$ inch, which moves *B* toward *A*, the difference between these two amounts or $\frac{1}{16}$ inch, just as though a thread with $\frac{1}{16}$ inch lead had been used.

It may seem foolish to use two threads when one will do unless we stop to think there may be cases where a 16 thread would be very fine and would not have strength enough for heavy pressure. By combining two coarse threads in this way we can get any small movement we wish, with the strength of a coarse thread to resist pressure. Fig. 64 shows another example of this. This is a form of screw press which in practice would be made with two screws geared together but which is shown with one screw for simplicity.

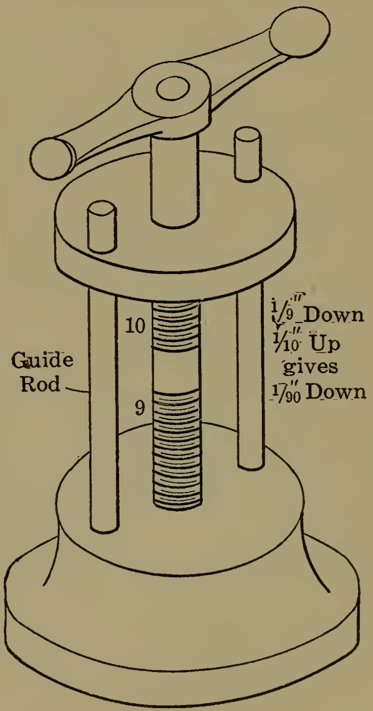


FIG. 64.

The lower half of the screw, which threads into the base, has a thread 9 to the inch while the upper half has a 10 thread.

Turning the screw to the right, screws it down *into* the base and at the same time screws it *out of* the upper plate, the difference between the two movements being the downward movement of the plate.

One turn gives the screw and plate $\frac{1}{9}$ inch downward movement and $\frac{1}{10}$ inch upward movement or $\frac{10}{90}$ down and $\frac{9}{90}$ up, leaving a net downward movement of $\frac{1}{90}$ of an inch which would give considerable pressure. That is, if a force of 10 pounds be used on the end of the lever and the distance this travels be 100 inches, we have 1000 inch pounds moving the plate only $\frac{1}{90}$ of an inch. This would give a pressure of $90 \times 1000 = 90{,}000$ pounds, less what was lost in friction which would be one-half at least; probably very much more.

The result is the same as with a single screw of 90 threads to the inch, which would be impractical in every way.

This arrangement of threads, in connection with a large dial graduated into say 100 parts, would give divisions of $\frac{1}{9000}$ of an inch, which is pretty fine. Various combinations of thread can also be made to secure almost any desired result.

A right and a left hand thread would add to, instead of decreasing the movement and are not used for this purpose.

This can be readily seen by again considering Fig. 63 and assuming that the thread in *B* was a left handed. Then, instead of screwing *out of B*, it would screw *into* it and add the $\frac{1}{4}$ and $\frac{3}{16}$ inch, making a $\frac{7}{16}$ inch movement of *B* instead of $\frac{1}{16}$ inch as with both right hand threads.

Differential Levers

In Fig. 65 is an example which is unusual and would probably be used but seldom. The lever fulcrums at *F* and has two rods or bars, *A* and *B*, which are connected to the lever at different points. The lower one rests on a board and the upper one on that, a mark being made in the mid position shown.

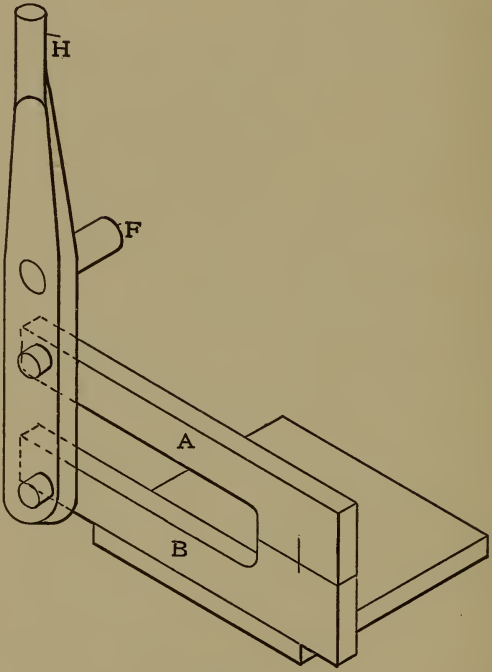


FIG. 65.

Now while it would seem that both bars would move together, it is evident that the lower bar *B* will move farther (and consequently faster) than *A* because it is connected further from the fulcrum. When the handle *H* is moved, the lower bar *B* will move away from *A* no matter in which direction it is moved. An application of such a device might be the combing of flax or cotton if the adjoining surfaces of *A* and *B* were provided with teeth and kept the right distance apart.

Another Differential Gear

Another form of differential gear is shown in Fig. 66, which is a form sometimes known as "planetary" or "sun and planet" gearing. In this the gear *A* is fixed on a stationary shaft, the pulley *F* is driven by a belt but runs loose on the shaft *G*, the shaft being driven by the gear *B*, which is keyed to it, through the gears *C* and *D*.

As the gear *A* is stationary, the gear *C*, which with *D* is keyed to the shaft *E* (this shaft running loose in the pulley), must run around it as the pulley is driven by its belt.

This makes the gear *C* roll around *A* and as *C* and *D* are keyed together, *D* would simply roll around *B* if *A* and *B* had the same number of teeth and *C* and *D* were also alike.

But as *C* has 18 teeth and *A* only 15 teeth, one revolution of the pulley makes *C* turn only $\frac{15}{18}$ of a revolution and as *D* turns with it, we see that *D* must also make $\frac{15}{18}$ of a revolution to one of the pulley. As *D* contains 17 teeth, it will turn $\frac{15}{18}$ of 17 or $\frac{255}{18}$ which equals $14\frac{3}{18}$ or $14\frac{1}{6}$ teeth.

The gear *D* must then carry the gear *B* $14\frac{1}{6}$ teeth. This is $1\frac{5}{6}$ teeth less than the teeth of gear *B*, or $\frac{11}{6}$ teeth. Now if we assume that the gear *B* was fixed, it is clear that *D* would move $\frac{16}{17}$ of a turn to one revolution of the pulley or 1 tooth of motion is equal to $\frac{1}{16}$ of a revolution. So for $\frac{11}{6}$ teeth the motion would be $\frac{11}{6} \times \frac{1}{16} = \frac{11}{96}$ revolutions of the gear *B* to one of the pulley.

This is not half as hard as it sounds as can be readily seen by considering it as a plain case of a train of gears, counting the drivers and driven gears in the usual way. In this case gears *A* and *D* are the driving gears with 15 and 17 teeth respectively, while the driven gears, *C* and *A* have 18 and 16 teeth. So we say:

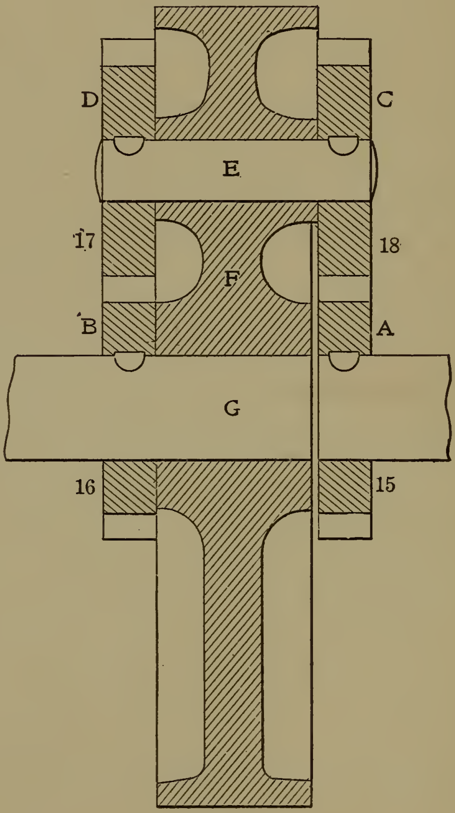


FIG. 66.

$$\frac{\text{Drivers } 15 \times 17 = 225}{\text{Driven } 18 \times 16 = 288} = \frac{85}{96}$$

That is, the motion of gear *B* is $\frac{96}{96} - \frac{85}{96}$ or $\frac{11}{96}$ revolution *less* than *A* if *A* were running. If *A* were running, *B* would run $\frac{11}{96}$ revolution in the *opposite* direction but as *A* is fixed, it runs in the same direction, but that it runs only $\frac{11}{96}$ as fast as the pulley.

If these gears were reversed so that the ratio was more than 1, the gear *B* would move in the opposite direction to the pulley.

Sun and Planet Gears

Fig. 67 shows a gear train that is worth studying a little as modifications of this form are used in automobile and other power transmissions.

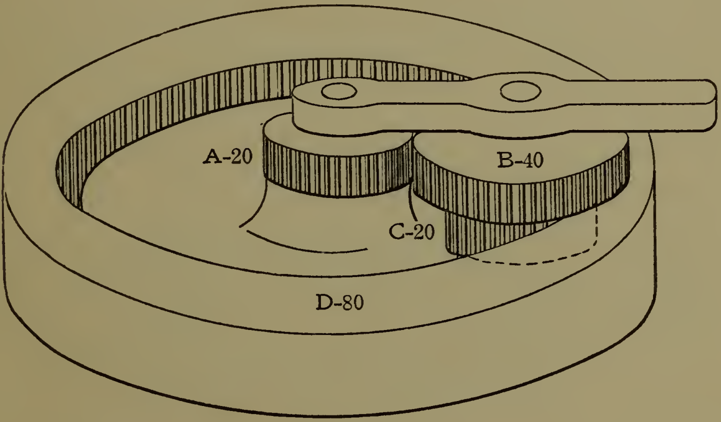


FIG. 67.

The three gears *A*, *B* and *C* have 20, 40 and 20 teeth respectively while *D* is an internal gear with 80 teeth. Gear *A* is fixed to a stud which runs up through the center of gear *D* and on which it turns.

If we move the handle *H* through one revolution, all the gears move around the central gear *A* as follows:

As gear *A* has 20 teeth, it only moves gear *B* 20 teeth or half a revolution. Gear *C* being fast to *B* also moves one half a turn or 10 teeth in this case as *C* has 20 teeth. The half turn of *C* can only move *D* 10 teeth or $\frac{1}{8}$ of a revolution, so that we have a speed reduction of 8 to 1.

Now reverse the case and imagine the gear *D* to be fixed and the gear *A* free to turn. One turn of the handle *H* will revolve gear *C* 4 times and as *B* is fast to it, this must also move 4 revolutions. As *B* has 40 teeth, and 4 times 40=160, gear A will also move 160 teeth or 8 revolutions.

Automobile Differential Gears

These are of two general types, one having bevel and the other spur gears. Each has its advocates, the superiority being largely a matter of detail in mechanical construction.

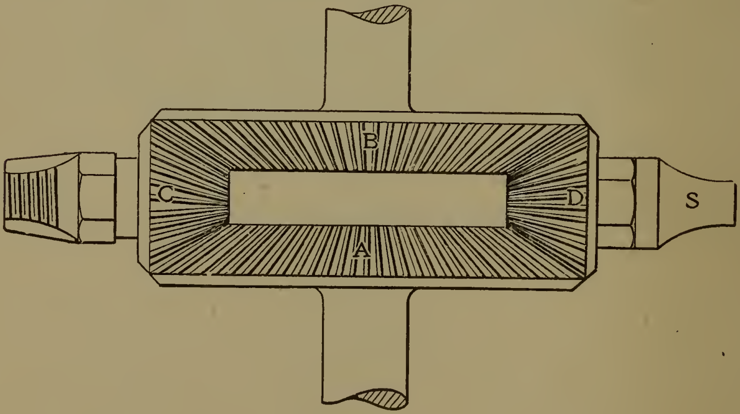


FIG. 68.

The bevel-gear type is the older and is shown in Fig. 68. This is made up of two bevel gears *A* and *B* with bevel pinions *C* and *D* meshing with them. There are usually three pinions, though sometimes more are used. Two will show how it works as well as more.

These pinions are carried in a ring or frame which is driven from the engine, either by chain or gear. As the pinions are in mesh with both *A* and *B* and as the pinions are not revolved, but simply driven by the outside ring, they act as a lock between the gears *A* and *B* and turn them both in the same direction as *long as they are both driving the same load.*

Now if we cut out the engine and jack the rear of the car up so the wheels clear the ground and turn the wheel connected to *A*, one of two things can happen. Either *B* will run the *other way* (and this usually happens) or both *A* and *B* will run together, carrying the bevel pinions *C* and *D* and the ring that holds them along with it. If the parts connected to the carrying ring and gear *S* have more resistance than the axle and parts connected to *B*, then the pinions will be held in their original position and simply revolve on their stud, turning *B* in the opposite direction. But if *B* turns the hardest then it will stand still and the driving gear be turned in the same direction as *A* only more slowly.

In actual work the driving wheel *S* turns both *A* and *B* together until a curve is reached, when the outside wheel must travel faster than the inside, while if both were solid on one axle either one or the other would have to slide the whole difference in the distance or it would be divided between the two. This allows each wheel to travel its proper distance without sliding and both be driving all the time. In doing this, the gears *A* and *B* move in opposite directions an amount depending on the sharpness of the curve.

When one wheel drops into a rut or sand hole and the other is comparatively free in loose soil, it is very apt to spin the wheel in the free wheel and in the opposite direction. This is a disadvantage and on heavy trucks there is usually an arrangement that allows *A* and *B* to be locked together, cutting out the differential entirely, so that both wheels must turn together until they are out of the hole.

This differential is also used on some gear hobbing machines and is often called a "jack-in-the-box."

The Spur Gear Differential

This has been developed considerably during the last few years and while it performs the same duties it does so in a different way.

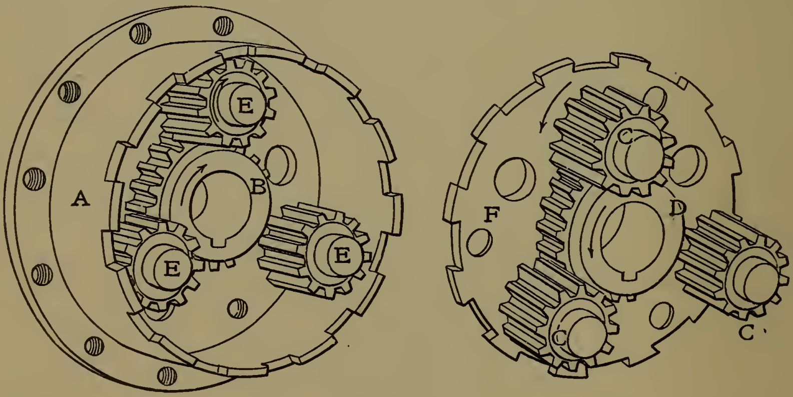


FIG. 69.

Fig. 69 shows a differential gear box of this kind and the operation is as follows:

While the action is the same as with the bevel-gear differential the construction is different as can be seen in Fig. 69. The driving gear fastens to the case *A* which carries 3 studs and pinions *E*, *E*, *E*. The gear *B* is keyed to the half axle on that side. The other side of the body *F* carries 3 similar studs and pinions *C*, *C*, *C*, while gear *D* is keyed to the other half axle.

Pinions *E*, *E*, *E*, mesh with gear *D* and pinions *C*, *C*, *C* with gear *B*, and the pinions also mesh together in pairs. In this way there is a solid lock between the gears and pinions when the body is turned by the driving gear and the resistance is uniform on each side. But if one side meets with a resistance or starts to slip as in turning a corner, the gears move with either as in the bevel-gear differential.

To see just how this works, suppose we turn the gear *B* as shown by the arrow. This turns pinion *C* in the direction of its arrow and pinion *E* in turn revolves the same as *B*, driving gear *D* in the opposite direction as shown by the arrow.

It looks complicated but a little care will trace out any gear train. This may be easily done by remembering that every other gear turns in the same direction and that if the gears in mesh are an *even* number such as 2, 4, 6, 8, etc., the last gear always turns *opposite* to the first while if the number of gears is *odd*, the last gears the *same* way as the first.

Another Differential Combination

This is another bevel gear combination (Fig. 70) which has peculiar properties and is sometimes used in machine construction for various purposes, such as tapping devices.

Suppose these gears to be in a case and so held that the middle gear *B* and the shaft *C* cannot turn around the shaft S. Then if gears *A* and *D* run loose on the shaft, gears *A* and *D* will run in opposite directions, the motion being reversed by the gear *B*.

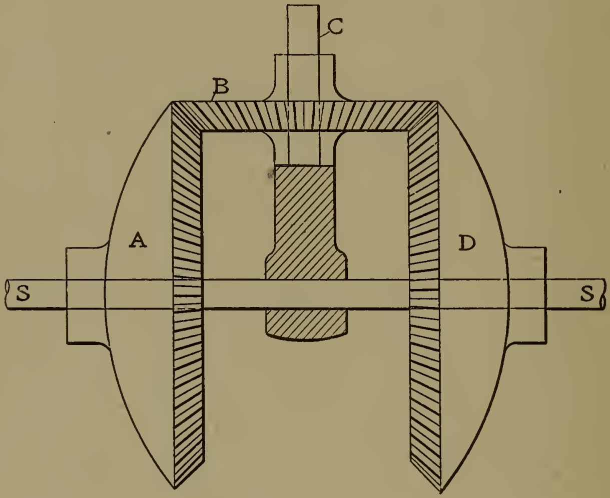


FIG. 70.

Now if we hold *D* fast and turn gear *B* around the shaft, we will see that gear *A* will be turned twice for every revolution of *B*. In a tapping device, the tap will be driven in by the direct, slow speed and then reversed and the tap backed out at double the speed by turning the center gear.

Triplex Hoisting Block

The Yale and Towne triplex hoist is another practical example in this line. This is shown in two views, Fig. 71 being general, with parts being cut away to show the internal mechanism; Fig. 72 shows the gearing.

The pinion *A* is on the end of the central shaft which is turned by the chain running over the hand wheel. This meshes in the gears *B B* which also have small pinions on

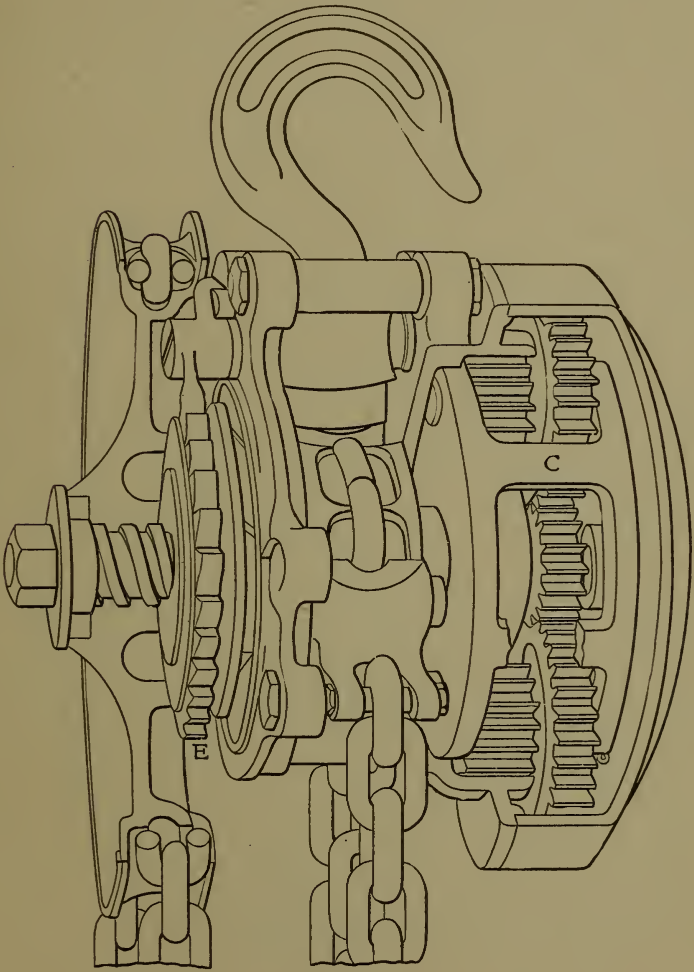


FIG. 71.

the back side. These pinions mesh in the internal gear *D* which is solid with the case of the hoist. The gears *B B* and their pinions are carried in the cage *C* which is fastened to the sheave or drum which carries the load or hoisting chain.

When the hand chain is pulled it turns the pinion *A* and this drives the gears *B*. With *A* turning in the direction of the arrow, the gears *B B* will be driven as shown and their pinions, meshing in the stationary internal gear *D*, will carry the frame *C* and the hoisting drum at a greatly reduced speed.

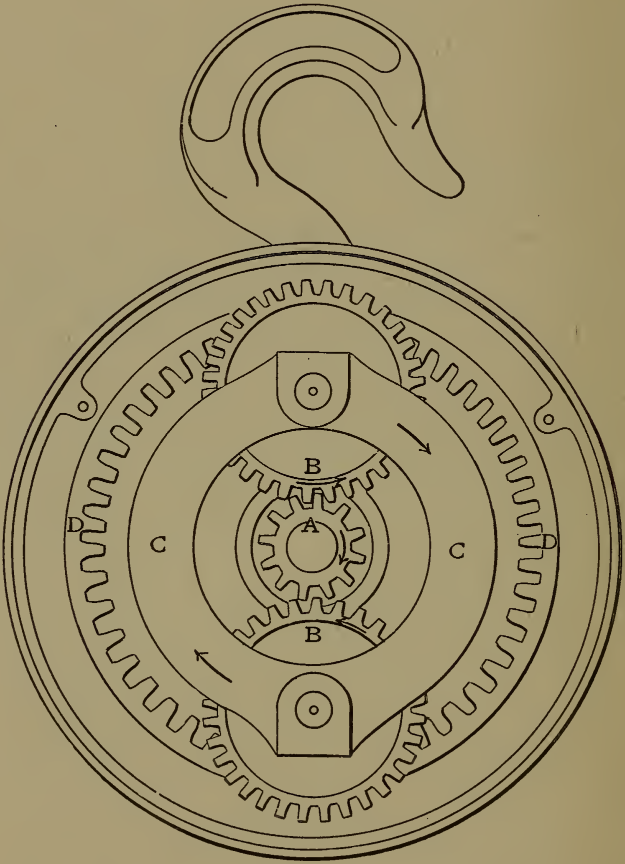


FIG. 72.

If *A* has 12 teeth and *B* 24 teeth, one turn of *A* will give *B* one-half turn. If the pinions on *B* also have 12 teeth they will move but one-half of this or 6 teeth in the gear *D*. If *D* has 48 teeth it will take 8 revolutions of *A* to turn the frame *C* and the hoisting drum once, so that the gearing would be 8 to 1 and 1 pound pull on the gear *A* would lift 8 pounds on the load chain, omitting friction.

As a matter of fact it is more than an 8 to 1 gain as the hand chain wheel is larger than the load chain drum so that the advantage is increased. Friction, however, plays an important part under heavy load and must always be considered.

The load is held by the friction disk *E* with the ratchet teeth on the outside. In hoisting, the hand wheel runs toward us and the thread in the hub and on the shaft forces it against the friction disk, turning it under the pawl at the top.

When the hand chain is released the friction disk *E* is wedged tight between the wheel and the load drum and the pawl prevents the disk turning backward.

To lower the load the hand chain is pulled backward, which loosens the hand wheel from the friction disk and allows the load drum to turn backward. Holding the hand chain again tightens the wheel against the disk and stops the load. So that it is necessary to run the hand chain backward to lower which prevents accidental lowering at all times.

Differential Indexing

Another very common form of differential gearing is used on the dividing head of milling machines in differential indexing. The index plate is geared to the spindle through bevel and spur gearing so as to give the desired movement of the spindle.

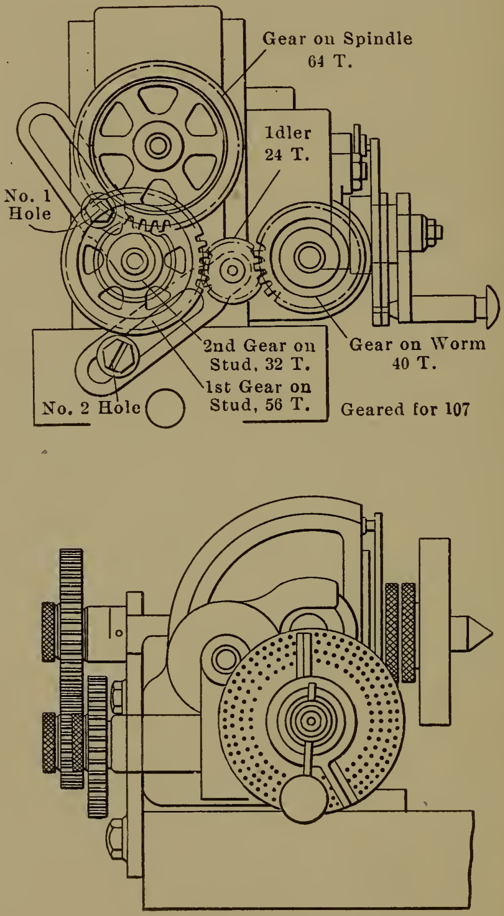

Gear on Spindle 64 T.
Idler 24 T.
No. 1 Hole
2nd Gear on Stud, 32 T.
1st Gear on Stud, 56 T.
Gear on Worm 40 T.
No. 2 Hole
Geared for 107

FIG. 73.

Suppose we want 107 divisions:

As usually geared the index crank makes 40 turns to 1 revolution of the spindle. If we use a plate with 20 holes and move 8 holes each time, it will take 100 moves to rotate the worm 40 turns or give 1 turn of the spindle. This is because $100 \times 8 = 800$ holes and as there are 20 holes in the circle, $800 \div 20 = 40$ turns.

If we make 107 moves, with the index plate fixed, we would move it more than 1 revolution, because $107 \times \frac{8}{20}$ or $\frac{107 \times 8}{20} = \frac{107 \times 2}{5} = 42.8$ revolutions of the worm. This is 2.8 revolutions too much and the index plate must be geared so as to move *back* 2.8 revolutions, while the spindle is moving forward 1 revolution.

Using a 2 to 1 compound gear or a 32-tooth gear on the stud and a 64-tooth gear on the spindle we have this ratio $\frac{2.8}{1} = \frac{2.8}{2} \times 2$, $\frac{2.8}{2} \times \frac{20}{20} = \frac{56}{40}$ and $\frac{2}{1} \times \frac{32}{32} = \frac{64}{32}$; so that $\frac{2.8}{1} = \frac{56}{40} \times \frac{64}{32}$, with the 40-tooth gear on the worm, gearing, through an idler into the 56-toothed gear on the stud. Solid with this is the 32-toothed gear which drives the 64 on the spindle. The idler makes the index plate turn in the opposite direction to the crank.

This can well be seen in Fig. 73.

EXAMPLES

1. What is the object of using differential gearing levers or threads?

2. Study how differential gearing is applied to indexing a dividing head.

3. How does the speed indicator work?

4. What is the objection to differential screws for power purposes? *Ans.* Excessive friction.

5. Study the "sun and planet" or planetary gearing and understand how it works. What is it used for? *Ans.* Some automobile transmissions, machine drives, etc.

6. How do the differential driving gears of the automobile work and why are they used?

7. Figure out different combinations of gearing for hoisting blocks to handle 1, 2 and 5 ton loads, omitting friction.

CHAPTER XI

Centrifugal Force

Centrifugal (accent on the second syllable) force, like gravity, is always with us and a little understanding of it will explain many things that happen every day in the shop and elsewhere.

Put a few drops of oil on the face plate near the center and start the lathe or boring mill at a fairly high speed as in Fig. 74. The oil immediately spreads out in all directions, usually in narrow streams, but in straight lines or radially from the center. Put a ball on the table and it immediately rolls out until it reaches the edge. Then it flies at a tangent or in a straight line at right angles to the radial line by which it came from the centre. The same is true with anything you put on the table.

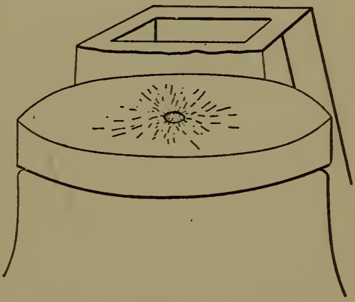


FIG. 74.

Every revolving body has a tendency to fly away from the point about which it revolves or from its center of revolution, the tendency increasing rapidly as the speed is increased.

An interesting example is the old one of swinging a pail of water around your head, as in Fig. 75, or swinging in a vertical path so as to bring the pail upside down when at the top of the swing. If this is turned too slowly the force of gravity overcomes the centrifugal force and the water falls when in the overhead position, but it does not need to be swung very fast to keep the water pressing against the bottom of the pail in its endeavor to get out through the bottom.

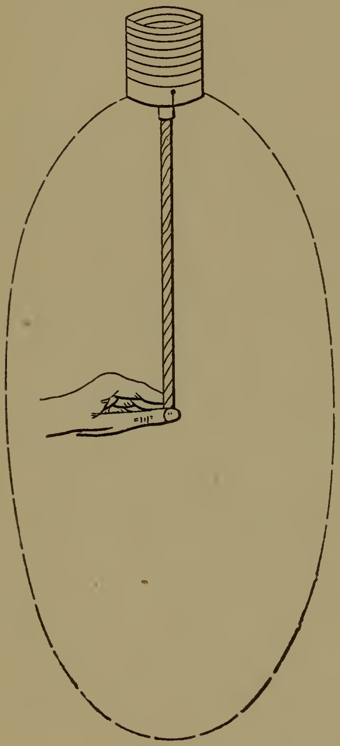


FIG. 75.

In a small wheel or where a large wheel is run at slow speed, centrifugal force gives us very little trouble, but at high speeds grinding wheels and flywheels sometimes burst and throw pieces a long distance, often with disastrous effect.

Interesting examples of the practical uses we make of centrifugal force can be seen in the fly ball or other governor for steam engines and other motors. Here an increase in speed throws the governor balls or weights out from the center and in so doing closes a valve which reduces the steam pressure. This checks the speed, the balls drop, and the valve opens again, thus keeping the engine at a pretty constant speed.

Centrifugal force is also used in separating oil from chips and from waste, as well as water from cloth and yarns, and milk from cream.

In the case of liquids, as in the cream separator, the heaviest liquid, the milk in this case, is thrown off. With chips or waste, the material is confined in a perforated pan and the oil is thrown to the outside by the centrifugal force.

The reason an unbalanced pulley or other revolving piece gives trouble is that the heavy side has a greater tendency to fly away from the center than the rest of it.

Measuring the Force

The centrifugal force developed in any body depends on three things: The weight, the distance of the revolving weight from the center of rotation (or the center of the shaft on which is turns), and the number of revolutions per minute. It increases directly as the weight and the distance from the center, but increases as the *square* of revolutions.

That is a weight of 200 pounds has twice the centrifugal force of 100 pounds at the same radius and speed. Or the same weight at the same speed has twice the centrifugal force if the radius is doubled. But the same weight and same radius have *four* times the centrifugal force at *double* the speed.

For if we double the speed we say $2 \times 2 = 4$, and know the centrifugal force is four times as great. Or if the speed is $2\frac{1}{2}$ times as great the centrifugal force will be $2\frac{1}{2} \times 2\frac{1}{2} = 6\frac{1}{4}$ as great and so on.

In considering calculations on centrifugal force we usually consider the weight as being in the center of the rim, in a flywheel, or near the rim in a grinding wheel, or in the knives in a cutting head for a buzz planer.

Taking a flywheel as a good example, let us consider a wheel having a rim which figures out to weigh 1000 pounds. The wheel is 50 inches outside diameter, the rim 2 inches thick and it runs 100 revolutions per minute.

The rule is centrifugal force equals 0.00034 times the weight in pounds, times the radius or distance from center of shaft and the center of rim in *feet*, times the *square* of the number of revolutions per minute.

Or as a simple formula:

$$\text{Centrifugal force} = 0.00034 W \times R \times N^2.$$

Where

W = Weight in pounds.

R = Radius in feet.

N = Revolutions per minute.

With the 50-inch wheel, a rim 2 inches thick would make the center of the rim 48 inches or 4 feet across, and half of this is 2 feet for R. Then $N^2 = 100 \times 100$ or 10,000, so the centrifugal force is $0.00034 \times 1000 \times 2 \times 10{,}000 = 6800$ pounds.

If we double either the weight or the distance, we double the centrifugal force, but if we double the speed to 200 revolutions per minute we multiply $200 \times 200 = 40000$ and get $0.00034 \times 1000 \times 2 \times 40{,}000 = 27{,}200$ pounds or 4 times as much as before.

If we ran the flywheel 300 revolutions the force would be 9 times the first case or 61,200 pounds. Or if we reduced the speed to 50 turns it is only $\frac{1}{4}$ or 1700 pounds.

When a wheel bursts it is because the centrifugal force was more than the strength of the metal to withstand it. If the rim was 12 inches wide, the cross section would be $2 \times 12 = 24$ square inches, so that a strain of 27,200 pounds is only a little over 10,000 pounds per square inch and good cast iron will stand 25,000 to 30,000 before breaking, but it is not good practice to run under a strain of more than $\frac{1}{5}$ of this.

When belts are run at very high speed the centrifugal force tends to throw them away from the pulleys and reduces the contact. This reduces the belt pull and with it the power transmitted. For this reason it is not advisable to run belts or ropes much over 5000 feet a minute.

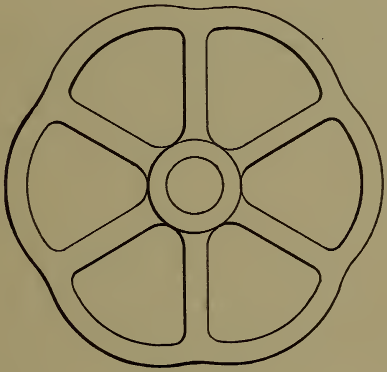


FIG. 76.

On thin-rimmed flywheels or pulleys running at high speed the tendency is for the rim to be thrown out between the spokes, as shown in Fig. 76, exaggerated to show the idea. When this occurs so as to bend the rim sufficiently, it breaks between the spokes. In a sectional wheel, the joint is usually the weak spot.

EXAMPLES

1. Why does oil fly out on a face plate, and why is it thrown off from gears and pulleys?
2. How and why do cream separators work?

3. How does centrifugal force act on governor ball of an engine?

4. On what 3 things does the amount of force developed depend?

5. What is the centrifugal force developed by a 10-pound governor ball held 12 inches from the shaft and running 100 revolutions per minute?

Ans. 34 pounds.

6. Increase the weight to 20 pounds and the speed to 150. *Ans.* 153 pounds.

7. Double the speed. *Ans.* 612 pounds.

8. What shop accidents are commonly due to centrifugal force?

CHAPTER XII

HYDRAULICS

It is sometimes a little confusing to understand how the pressure exerted on a liquid, as water or oil, or a fluid like steam or gas, extends in every direction and to see the difference between pressure per square inch and total pressure. It seems to be the modern tendency to use the terms "liquid" and "fluid" interchangeably, which is not always as clear as the older method of using "liquid" to mean substances like water, oil, alcohol, etc., while "fluid" was confined to gaseous substances as steam, gas and vapors of all kinds. And, when any distinction is necessary, the older method will be used to avoid confusion.

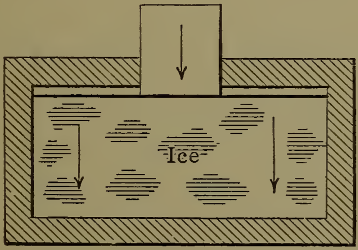


FIG. 77.

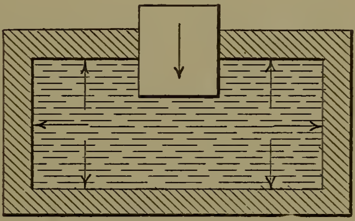


FIG. 78.

If we have a tank in which the water has frozen into a solid block, and exert pressure through an opening in the top, as in Fig. 77, the pressure would all be down and there would be no tendency to bulge the sides of the tank. If now we melt the lower half of the ice cake and again exert a pressure, we can readily see that the water will attempt to escape in all directions, as shown by the arrows in Fig. 78. It will even try to flow up around the ice above, and will succeed unless it fits more closely than any piece of ice would. This is simply because the particles of the water are free to move in any direction, while the ice is a solid.

Melting all the ice and exerting pressure with the same plunger the same condition now exists all over the tank and unless the plunger is carefully packed where it enters the tank the water will flow up around it as it is forced down into the tank. If the tank is of thin material it can be seen to bulge on all sides as well as the top and bottom, giving good evidence of the pressure in all directions. If the material of which the tank was made was ductile enough to be able to assume a new shape as the pressure was applied it would become a ball or sphere with all parts equally distant from the center, and any further pressure would not change its shape until it burst from the material being unable to withstand the strain. It is also well to note that the strain in such a case is a tensile or pulling strain, the same as in a tie rod for a jib crane.

Having seen how the pressure extends or is exerted in all directions it becomes easier to understand the way in which the pressure exerted is applied to each square of surface which it touches. Referring to our tank of solid ice once more, let us suppose the plunger weighs 10 pounds. If this rests on the ice and presses it downward, the total pressure on the bottom of the tank will be the weight of the ice plus the weight of the plunger. But when the ice is melted and the pressure is distributed in all directions, the case is different. If the plunger has an area of 1 square inch, which means a diameter $1\frac{1}{8}$ inches, then the weight of the plunger gives a pressure of 10 *pounds per square inch, all over the inside surface of the tank.*

Calling the tank a 10-inch cube, we have 6 surfaces each 10×10 or 100 square inches, 600 square inches in all, each square inch subjected to a pressure of 10 pounds.

Taking a pump cylinder 10 inches in diameter and assuming it must pump against a pressure of 10 pounds per square inch, we must find the area or total number of square inches of the piston. This is $10\times10\times0.7854=78.54$ square inches and as there is a pressure of 10 pounds on each square inch, the total resistance is 785.4 pounds. This is the same whether there is water pressure of 10 pounds running the pump as a motor or whether steam or other power is pumping water against a pressure of 10 pounds per square inch.

A very common application of hydraulic power is the hydraulic jack or "whisky" jack, as it used to be called on account of using whisky as the liquid to prevent freezing. This makes a good example of how the pressure acts on each square inch of surface.

The power is applied to the pump lever, Fig. 79, which operates a small plunger or piston, say 1 inch in area, and the leverage makes it easy to apply 100 pounds pressure to the plunger. This forces the liquid through the check valves, up between the head and the outside casing which raises the load.

The pressure exerted on the plunger, 100 pounds to the square inch, is transferred to every square inch of the lifting area, and if this is 10 square inches, the total lifting pres-

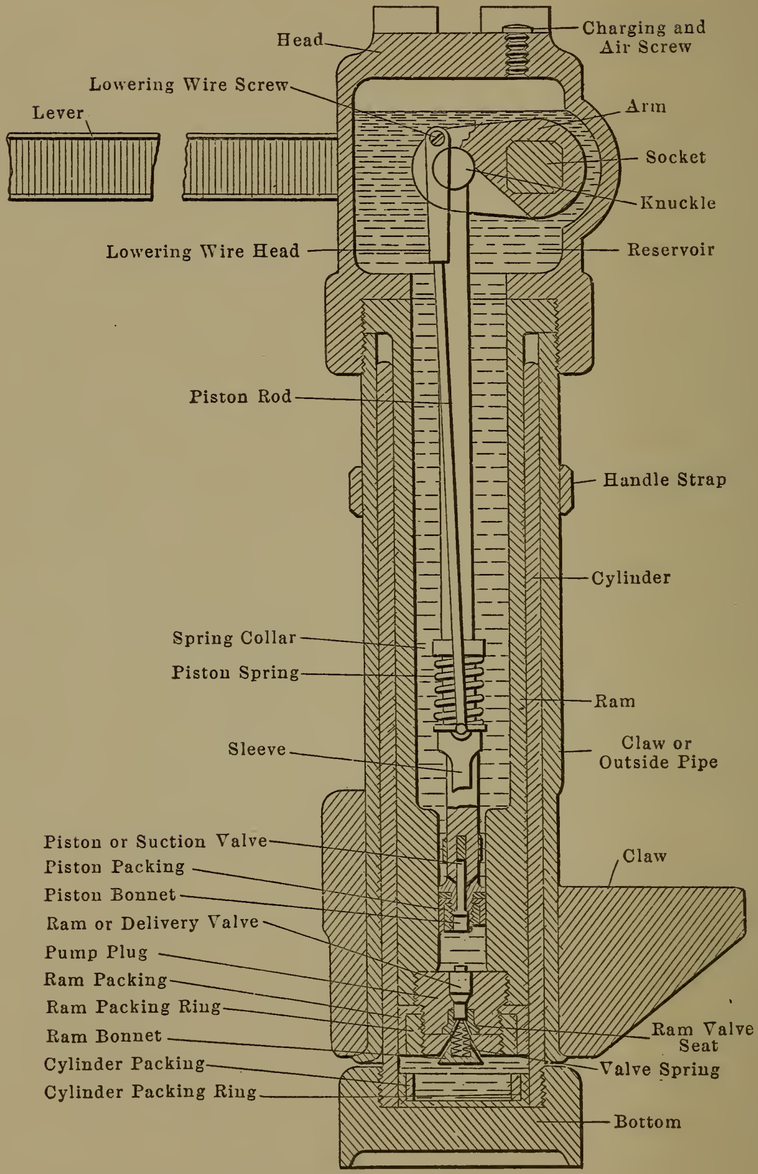

Head
Charging and Air Screw
Lowering Wire Screw
Lever
Arm
Socket
Knuckle
Lowering Wire Head
Reservoir
Piston Rod
Handle Strap
Cylinder
Spring Collar
Piston Spring
Ram
Sleeve
Claw or Outside Pipe
Piston or Suction Valve
Claw
Piston Packing
Piston Bonnet
Ram or Delivery Valve
Pump Plug
Ram Packing
Ram Packing Ring
Ram Valve Seat
Ram Bonnet
Cylinder Packing
Valve Spring
Cylinder Packing Ring
Bottom

FIG. 79.

sure will be 1000 pounds. Increasing this to 20 square inches doubles the total load that can be lifted and so on as far as necessary. We must remember, however, that every time we enlarge the lifting area, it makes so much more space to be filled and the lifting will be slower as it takes more strokes to fill the lifting head. With a head of 10-inch area the pumping plunger must move 10 times as fast as the load, while with a 20-inch head this will be doubled. This does not allow for any liquid slipping back through the valves, which is usually the case.

This shows that by making the pumping plunger very small, say $\frac{1}{4}$ of a square inch in area, we can easily get an enormous pressure on the lifting ram, as, if we can exert 100 pounds with a plunger 1 inch in area, the same pressure and the same leverage will give 400 pounds on each square inch of the lifting head. But in every case we must bear in mind that what we gain in pressure we lose in speed. The work done always equals the force applied multiplied by the distance through which it moves, less the loss by friction.

There is no getting away from that law. We must pay for what we get in some way and the only way in which one device excels another is in applying the power with less loss. No mechanism ever gives back all you put into it.

We can reverse the jack proposition in the riveter or similar machine. Here we have water at a given pressure, say 100 pounds per square inch, applied to a ram with an area of 20 square inches, and we get a pressure of 2000 pounds on the rivet. The pressure per square inch depends on the diameter of the rivet, a rivet with a $\frac{1}{2}$-inch area receiving a pressure of 4000 pounds per square inch.

If instead of a riveting die the small end of the piston head be a plunger extending into a tank full of water, it will exert a pressure per square inch on every part of the tank, equal to difference in area between the large and small plungers. With a 10-inch area on the receiving head, and ½-inch area on the plunger going into the tank, there will be 20 pounds pressure per square inch on every part of the tank for every pound of pressure per square inch on the receiving piston.

It must also be remembered that the plunger acts on the water in a full tank or cylinder, entirely by the amount it displaces and that it need not fit the cylinder closely. All that is necessary is that it be confined so that it can only escape in the desired direction.

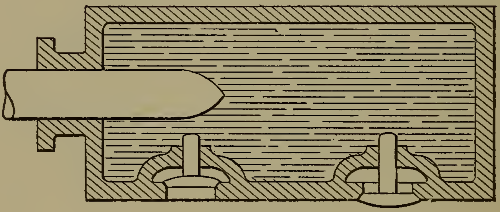


FIG. 80.

In each case the water that will be pumped will be equal to the volume of as much of the plunger as enters the water. Fig. 80 shows in a crude way a pump which works very successfully. The end of the plunger is pointed to make it enter the water more easily, and at each stroke it displaces a body of water equal to the space occupied by the plunger as it moves into the water. When the plunger is withdrawn, more water rushes in and is promptly pushed out at the next stroke. The surrounding water may be said to act as a cylinder in this case. This form of pump was designed by the late Charles T. Porter for handling the hot water of his condensers in compound engines.

Pressure Due to "Head" or Height

When we speak of water having a good "head" we mean pressure due to a given height from which the water flows. This is why we put water tanks on the roofs of buildings or on towers. The height gives a good head or pressure, which is 0.434 of a pound on each square inch of area for every foot of height. This is equivalent to 1 pound for approximately 27 inches of height and is simply because 12 cubic inches of water weighs 0.434 of a pound. That is, the water which can be held in a tube 1 inch square and 12 inches long, will weigh 0.434 of a pound.

The main point to remember is that the *pressure per square inch is entirely independent of the size of the pipe.* This may be hard to understand as it seems as though a large column of water should exert more pressure than a small one, but this is not the case, the pressure is due to height and to nothing else.

If we have 2 pipes, one only ½ inch in diameter and the other 12 inches in diameter, both filled with water and both 100 feet high, a gage at the bottom of each pipe would show the same pressure, 100×.434 or 43.4 pounds per square inch in each case. This also shows that the pressure tending to burst the pipe is greater near the bottom and that the pipe should be made stronger as it nears the base.

It is natural to suppose that a large body of water, as in Fig. 81, would exert more pressure on the keg at the bottom than if only a small pipe was run up as in Fig. 82, but such is not the case as the pressure is identical in both instances.

The pressure is due to the height and is exerted on each square inch of the keg and is the same in both.

Another somewhat similar case and one that is equally puzzling, is the pressure of water against a dam. This depends entirely on the height or depth of the water and not at all on the amount of water behind the dam. A dam 50 feet high and 100 feet long has to be just as strong to hold back the water in a reservoir 10 feet long as though it was 10 miles long. The water next to the dam is all that acts against it and this depends solely on its height; the rest of the water is supported by the sides and bottom of the reservoir.

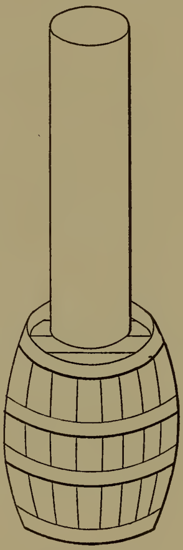


FIG. 81.

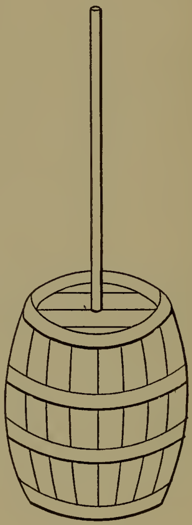


FIG. 82.

This information is very handy in all work with pumps, the raising of water to tanks and other work where liquids are handled.

Hydraulic Pressure in the Shop

A very practical example of the fact that liquid or hydraulic presssure acts in all directions is found in the case of the so-called "bulging die" used in press or drawing work for sheet metal. Such parts as the tops for salt and pepper shakers or similar work where it is difficult to force the metal into the dies by purely mechanical means.

An idea of such a case can be had in Fig. 83, where the piece to be "bulged" is shown at *E E*, after having been drawn perfectly straight in a regular drawing die. The piece is then placed in the cavity of the die, the die being made in two parts, C D, so as to be parted to remove the piece after bulging. The plunger *A* forces the oil or water used down into the shell, and as it is supported at every point except the rounded cavity *F F*, it can only act at this point. The liquid acts in all directions and forces the lower end of the shell out into the cavity.

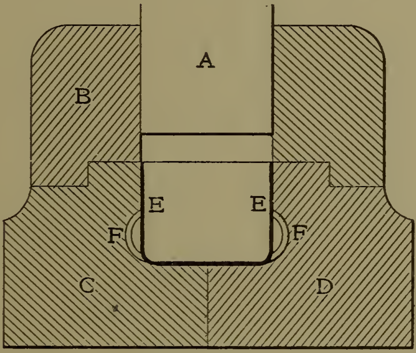


FIG. 83.

If this was a perfectly plain surface it might be rolled out with a tool inside the shell, but this would be impossible in a fancy design as is often used. If the pressure is heavy enough for the thickness of the metal, it will be forced into every crevice of the die.

In some places rubber is used in place of water or oil, as it acts in the same way and is easier to use in some cases.

EXAMPLES

1. Why does liquid or hydraulic pressure act in all directions? *Ans.* Because the particles are free to move in all directions when any pressure is put on any part of the liquid.

2. What pressure will be given by a storage tank 200 feet in the air? *Ans.* 86.8 pounds per square inch.

3. With a hydraulic jack having a pump plunger with ½ square inch area and a ram with 15 square inches area, what pressure can be got with a 20-pound pull and a lever of 10 to 1? *Ans.* 6000 pounds not allowing for friction.

4. Will a pump work without the piston fitting the cylinder? *Ans.* Yes, if the piston can displace or reduce the volume of water as it moves.

5. What is this pump called. *Ans.* A displacement pump.

6. Will a large or a small pipe give the most "head."? *Ans.* No difference when water is standing. With water in motion the small pipe gives a little the most friction.

CHAPTER XIII

STEAM PRESSURE

Steam pressure also acts in all directions as with hydraulics.

One of the common errors that crops up from time to time is the idea that we can gain power in a steam, air or hydraulic cylinder by making the piston head conical or rounded instead of flat. In Fig. 84 we have three pistons in the same sized cylinder. Piston *A* is the regular type and presents a flat surface of 100 square inches while *B* is a sharp cone and *C* is rounded. Both *B* and *C* have a larger surface presented to the steam pressure but they will not exert an ounce more pressure on that account. All the pressure is exerted at right angles to the surface presented so that the arrows show how some of this acts against itself.

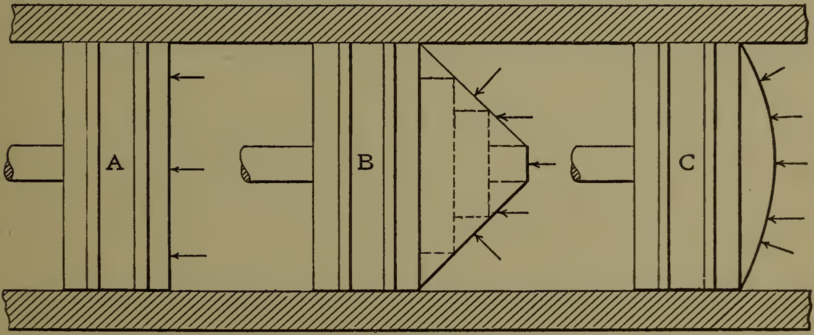


FIG. 84.

To make this perfectly clear, suppose we turn the conical surface of piston *B* into the steps shown by the dotted lines. Then we can see that all pressure not exerted in a forward or pushing direction will act at right angles to it, and will not push the piston at all. The various surfaces in the forward direction are no greater than in the plain piston *A*, so that it should be perfectly plain that there is no gain in the power exerted by having the piston in any shape but flat. It is only the unbalanced portions that can get the pressure in any case.

Balanced Pressure and Reducing Valves

A good example of balanced pressures is shown in Fig. 85 which is a form of reducing valve first brought into practical use in connection with compound locomotives. Let it be supposed that one cylinder is 4 times the area of the other, although this is all out of proportion for acutal use. To make them each do equal work we must have an equal

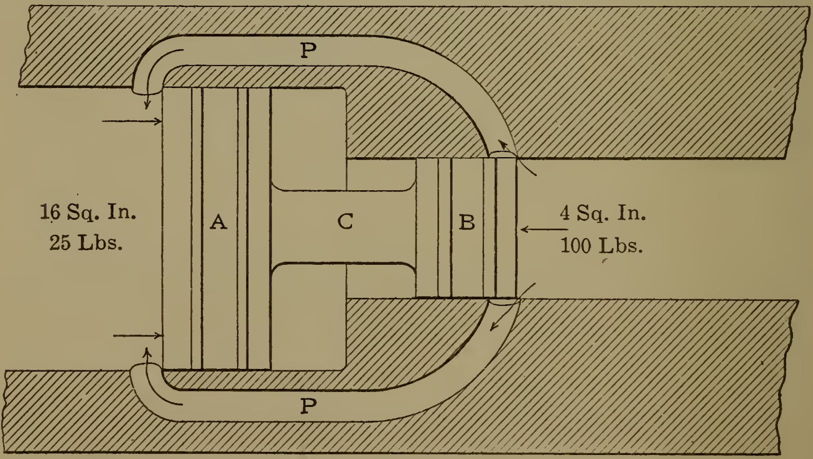


FIG. 85.

total pressure in both cylinders which means that the pressure per square inch in the small cylinder must be 4 times as great as in the large cylinder.

Calling the small cylinder 4 square inches and the steam pressure 100 pounds, we have a total pressure of 400 pounds. Then as the large cylinder is 4 times as large it must be 16 square inches. To get the same total pressure it is very clear that the pressure per square inch must be $\frac{1}{4}$ as great as in the small cylinder or 25 pounds and we prove this by multiplying 16 by 25 and getting 400 pounds as before.

With the live steam pressing against the small end of the differential or double ended piston, there is a total pressure of 400 pounds forcing it toward the left and the ports *P P* will be opened and steam will go to the back side of the large piston and as it accumulates here it tends to force *A* toward the right. When the accumulated pressure equals 25 pounds per square inch or 400 pounds total, the pistons are balanced and steam will flow around just fast enough to maintain this difference in pressure.

If more steam is used from the large end, the pressure falls, the steam from the other end forces the port open wider and more steam flows into the large cylinder until the pressure again balances. If the steam in the large cylinder rises, it forces the piston to the right and shuts off the flow into the large cylinder until such time as the pressure in this cylinder drops below the 25 pounds per square inch.

This same working holds good whether it is steam, compressed air, or liquids of any kind and is a very useful principle in many cases.

CHAPTER XIV

THE FORCE OF A BLOW

This is a question that comes up periodically in the shop and one that is not easy to answer because the whole question is so apt to be misunderstood.

It must be carefully borne in mind that when any body is raised through any distance, the act of raising is work done on that body against the action of gravity. This work is equal to the weight multiplied by the distance through which it is moved.

When this body is allowed to fall again, the work stored up in it by its being lifted is transformed into energy of motion. When it strikes any object, the act of stopping the body forces it to give up its energy of motion, which results in changing the shape or breaking, either the falling body or the object it strikes, or both. This means that heat is produced in any case.

The work done on a body in lifting it depends on the weight and the distance it is lifted. So, when it is allowed to fall, the work done when it stops falling or strikes any object is the weight multiplied by the distance through which it falls.

But the force of the blow depends on the deformation or the distance one piece goes into the other. It might perhaps be called the distance the weight moves after it strikes the object.

The work done by the blow must be equal the work stored in the falling body. So, if we divide this work by the penetration, or the distance the weight moves, we get the "force of the blow." This shows us that the force of the blow depends on the object it strikes.

Taking a drop hammer, as in Fig. 86, as a convenient illustration and consider the weight of the head to be 2000 pounds with a fall 5 feet. We will neglect friction to make it more simple, so that this gives 10,000 foot pounds as the energy stored up in the hammer head when it is raised to a height of 5 feet. This was received from the driving belt and will be given out when it falls on the anvil or any object placed on it.

When it falls, this is transformed into velocity and when it strikes the work on the anvil, this velocity is changed back into work which equals the weight or force multiplied by the distance through which it falls.

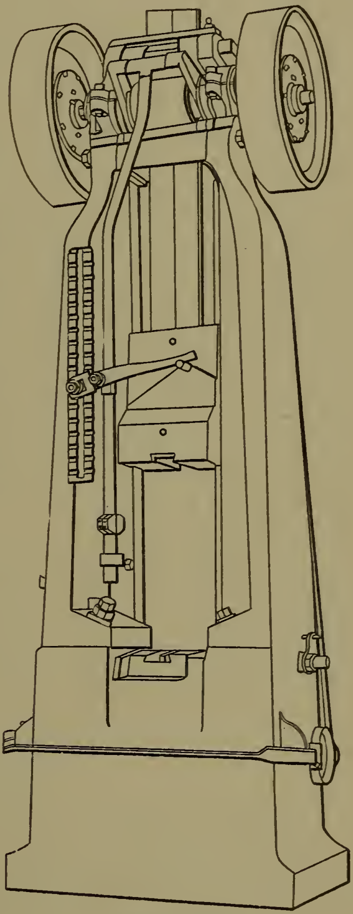


FIG. 86.

Let us suppose it strikes a piece of lead and flattens it 1 inch; that is, the hammer head moves 1 inch after it strikes the object. This is $\frac{1}{12}$ of a foot, for we must have everything in feet, so the distance moved through after striking is $\frac{1}{12}$ foot.

As the total work available in the hammer head was 10,000 foot pounds and this is given up in a distance of $\frac{1}{12}$ of a foot, the force of the blow in this particular case is 10,000 divided by $\frac{1}{12}$ (not $\frac{1}{12}$ of 10,000 as this would be 10,000 divided by 12 instead of $\frac{1}{12}$) which is equal to $12 \times 10,000 = 120,000$ pounds.

Take another case where the hammer strikes a punch and drives it a foot before coming to rest. The force of the blow in this case will only be 10,000 pounds because it is distributed over a greater distance.

If, on the other hand, the hammer head falls on a piece of steel that is only compressed $\frac{1}{4}$ inch or $\frac{1}{48}$ of a foot, we will find the force of the blow much greater than before, for instead of 120,000 pounds we have 480,000 pounds in this case.

This can be seen from the fact that a blow which would fracture a piece of hardened steel, because it could not compress it, would hardly injure a piece of india rubber, which gives readily to a blow.

Driving a Nail

Taking another example of a nail being driven by a common hammer, as in Fig. 87. If the wood is so hard that the nail hardly moves under the blow, the head of the nail is very apt to split or break or the nail to bend. But if the wood is soft the same blow drives it in without doing any damage whatever.

Figuring out a case we have: Weight of hammer 3 pounds, distance through which it moves 3 feet, $3 \times 3 = 9$ foot pounds of energy. The nail is driven in $\frac{1}{4}$ or $\frac{1}{48}$ of a foot. Dividing 9 by $\frac{1}{48} = 9 \times 48 = 432$ foot pounds, the force of the blow.

The question is often asked, "What becomes of the work which is delivered by the falling weight?"

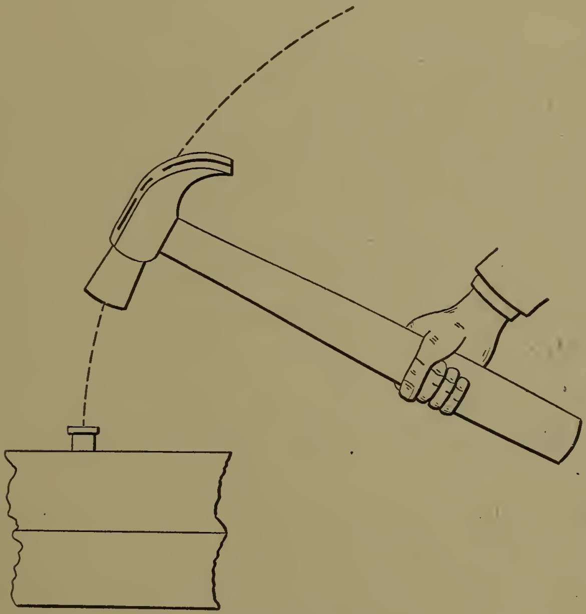


FIG. 87.

It is used up in changing the shape and in heating the piece which is struck by it. Part of it goes into the rebound of the parts, vibrations in the earth, etc., the last being excellent proof of the statements made concerning the force of the blow of a hammer.

Taking a steam hammer and it is very noticeable that when the piece being forged is hot and soft there is almost no vibrations to the earth but when it becomes cooler and harder the force of the blow is so much greater that the earth vibrations are much more noticeable and extend to a greater distance.

Steam and air hammers are always rated by the weight of the falling parts, regardless of the steam or air pressure used in forcing them down to the work.

EXAMPLES

1. What energy is stored in a hammer which is lifted ready to strike a blow? *Ans.* The weight of the hammer multiplied by the distance raised.

2. What happens when the hammer falls? *Ans.* The energy must be given up and does work.

3. What work is done when it strikes? *Ans.* The work equals the weight of the hammer multiplied by the distance through which it falls.

4. What is the force of the blow? *Ans.* The stored energy divided by the distance the hammer moves after striking.

5. What is the unit of distance to be used in energy or work problems? *Ans.* Always the foot.

6. What does the force of the blow depend upon? *Ans.* The material struck or the distance the hammer moves after striking, the weight of the hammer and the distance it moves.

7. What is the force of a blow from a blacksmith's sledge weighing 8 pounds falling 3 feet and compressing a piece of steel $\frac{1}{10}$ of an inch? *Ans.* 2880 pounds.

8. How are steam or air hammers rated? *Ans.* By the weight of the falling parts.

CHAPTER XV

STRENGTH OF MATERIALS

Every mechanic is interested in a general way in the material he handles and becomes more or less familiar with it. But it is very easy to think of a steel bar as being too stiff to bend or of cast iron as too brittle to be bent out of shape even a small amount without breaking.

Deflection

In reality neither of these are true. Take a steel bar 1 inch square and say 4 feet long, support the ends on any convenient points and if you sight along the top you can see that there is a sag in the center. This is called "deflection" to distinguish it from other ways in which any material will yield. The shorter the bar or the larger it is the less the deflection will be. But when we see that the 4-foot bar, 1 inch square, will sag so as to be seen, we can readily believe that a much larger bar will have a little deflection and that even the largest bar will not be entirely free from the same fault.

This is true no matter what the material, and it affects every building and every machine in the country. The floor beams sag of their own weight and of course deflect more when a load is on them. The overhead crane, the line shaft, the lathe bed and spindle, the crank pin of the engine, the huge coast defense gun, or the barrel of the sportsman's rifle, none are free from some deflection of this kind, depending on the size, the strength of the material, and the way it is supported.

Everything of this kind is known as a beam and the method of supporting has much to do with the deflection and the load any beam will stand. If we lay a piece across a central support it will deflect equally on each side. If we support it at each end it will sag the same amount as each end dropped in the first case, but if we support it at one end only, the other end will sag or deflect 4 times as much as the other cases. This shows the advantage of supporting a lathe spindle or anything else as near the place where the strains come as possible.

Deflection of a Grinder Table

It is almost safe to say that no bed or table of any machine is, or can be, stiff enough to avoid all deflection when overhung.

In a shop where grinders are made, and which have a very stiff table, there was a workman with the combative temperament of one who is looking for trouble. His work was scraping them in and he was a good hand at it too. One day he had just finished scraping in the bed when the whistle blew for 6 o'clock, so he pushed it on the bench and started for home.

Next morning he tried the table on the bed and found that the bearing had changed. Instead of showing a nice bearing from end to end it now bore hardest on the ends and he was sure some one had tampered with it. But it was found that he had left it on the bench with one end hanging off and that the table had acquired a slight bend or deflection during the night.

In another case a test was made with a finished machine by putting the table in the center of its travel and clamping a piece of work with flat ends (not centered) between the centers as lightly as possible, just enough to prevent its dropping out. Then the table was started toward the end of the travel and the piece dropped out long before it got there. This shows the deflection of the table when it overhangs the base and shows why it is almost impossible to grind to an absolutely uniform diameter on long work.

Tension

When we see a rod hanging from the roof and supporting a heavy weight we know the strain is tending to keep the rod straight just as it would keep a chain or a piece of rope straight if it were used in the same way. This is called tension and from this comes the expression we often see used, of the "tensile strength" of a piece of steel. This means the strength to resist its being pulled apart by a direct straight pull and is very high in some of the new alloy steels.

The strength of a bar of any kind is always calculated for 1 square inch of area no matter what the real size may be. Thus if we are testing a steel rod $\frac{1}{2}$ inch square, we know it is only $\frac{1}{4}$ of a square inch, so if it breaks at 20,000 pounds we multiply this by 4 and say that the tensile strength is $20{,}000 \times 4 = 80{,}000$ pounds per square inch.

Testing of all kinds, to be accurate, is done in a testing machine which indicates and usually registers the strain when the piece broke. If we have only a small testing machine and a large bar to test, we cut a small piece from the large bar, machine it so that we know its size and area, then test that and find the strength of the whole bar or the strength per square inch by multiplying.

You will find many examples of material in tension as well as in deflection; in fact all material has strains in deflection, tension, compression, torsion or shear, we shall see later. Take a jib crane as in Fig. 88 and see that the tie or tension rod *T* is in a straight pull or tension while the arm is a beam supported at each end. It is made narrow but deep because this shape makes the strongest beam with the smallest amount of material. This is the reason that floor joists or beams are made in this way. The limit of width or narrowness is the buckling or twisting of the beam under strain. They must be wide enough to bear well at the ends and not twist or buckle when the load comes on.

The brace *B* is in compression and the post *P* resists a strain that is mostly bending.

Compression

When a load is applied so that it tends to crush or push the particles together, it is said to be in *compression* because it is being compressed. Steel seems to be so hard that it cannot be compressed but in reality it can be compressed almost as easily as cast iron. Steel is much stronger in every other way, however, and it is well to remember this exception.

When a column holds up a floor or any other weight as a floor support, the leg of a bench or lathe, it is in compression and the tendency of the load is to force the particles together and crush the piece. In wood, this causes splintering; in cast iron or other brittle substances like stone, it cracks

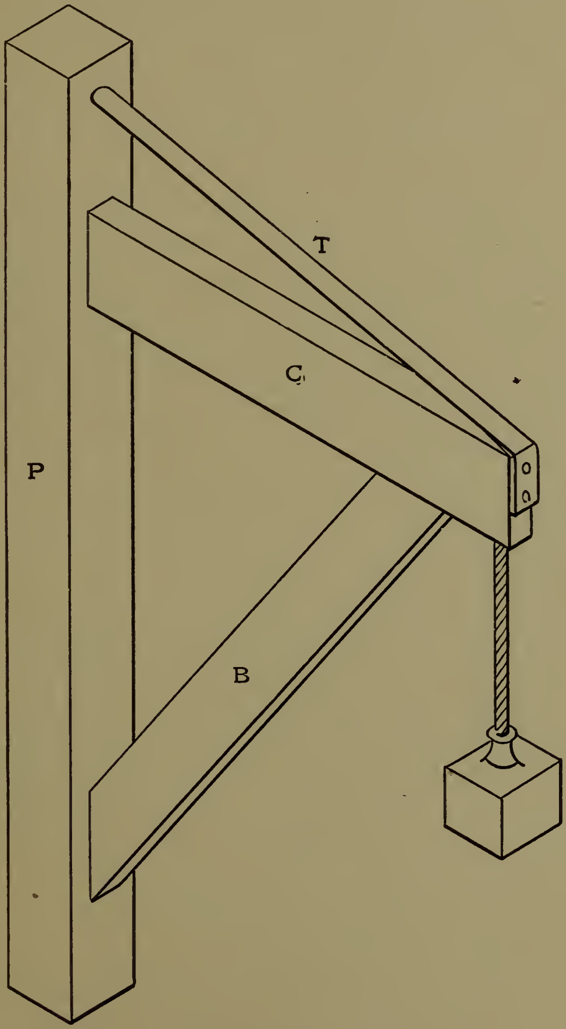


FIG. 88.

and crumbles; in tough metals like steel it bulges, changes the shape and perhaps buckles but does not usually break. Brackets or braces where the load comes against the ends are in compression as in *B* in Fig. 88.

Torsion or Twisting

There is another kind of strain which is very common, that of twisting or torsion. It exists in every machine having rotating parts and in some which do not. Every revolving shaft is subject to torsional strains if it is doing any work, and even the friction of the bearing sets up a slight twisting tendency which is so small as to be unmeasurable in most cases.

To fully appreciate this, take a bar of soft metal, such as lead, and make it do some work such as a line shaft would do in driving machinery of any kind. It will twist with a very little pressure because it has a low resistance to torsion but it shows the action on all pieces which have to resist a twisting motion.

Familiar examples of this can be found in lathe, drill or other spindles, in lead screws and feed rods, in vise or adjusting screws of any kind, in taps, cap screws, wood screws, drills, reamers, milling cutter arbors, etc., etc. When we use too much power in screwing in a bolt, we break it by twisting it in two.

In most machinery a very slight twisting is not important as it does not affect the work until it becomes enough to strain the material beyond the elastic limit, so that it will not spring back or return to its original position. But in very fine measuring machinery or where fine indexing is to be done, the shaft must be made so large and stiff that no appreciable torsion occurs.

Suppose Fig. 89 to be an indexing shaft and it should twist as shown by the line along the shaft owing to the strain imposed by the pulleys or gears being acted on in the direction of the arrows. It is clear that the indexing would lag the amount of the twist and in the case of a lead screw of a very accurate machine, this twisting would seriously affect the lead of the screw. While the amount of twist shown is exaggerated, there are strains at work in every power shaft to do this to a greater or less degree.

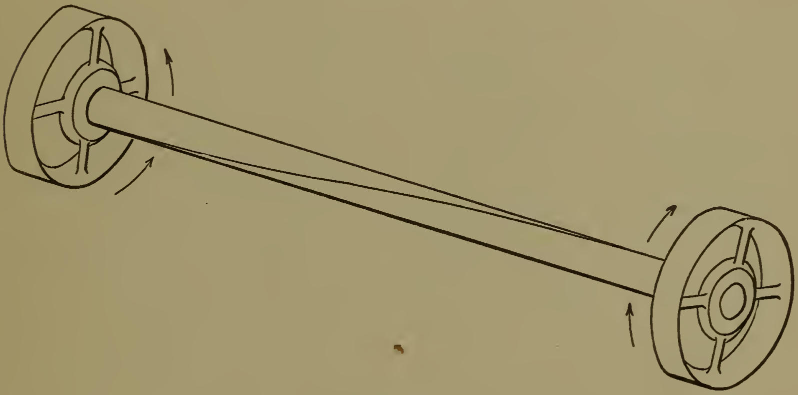


FIG. 89.

Shearing Strain

There is still another kind of strain to which material is subjected, known as shearing, because the piece is in some way between other pieces pulling in an opposite direction and tending to shear the metal as though it was cut in pair of shears. Fig. 90 shows a number of such cases.

At *A* is a weight or tie rod held on a pin between two plates. The strain tends to shear or cut the pin at each side as shown by the dotted lines. This is true whether the pin is tight or loose in either or in all three of the pieces. This is called a double shear because it can shear at 2 points and will stand twice as much as a single shear.

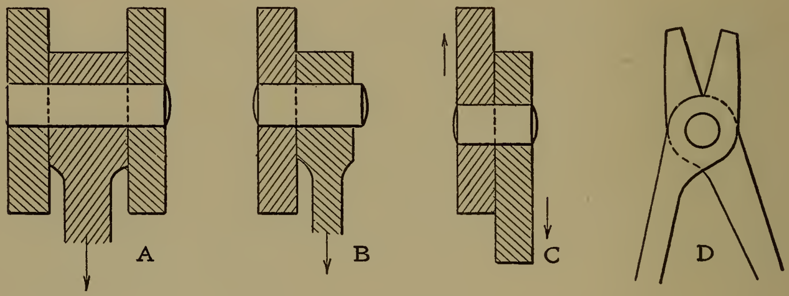


FIG. 90.

At *B* is a pin in single shear, the pin being fastened in either member. *C* shows another single shear between riveted plates as in a boiler, the pin being riveted into both plates, and *D* is a common pair of tongs. In all these cases there is apt to be bending strain as well from the rivet shearing.

The Vise and the Monkey Wrench

A common bench vise as in Fig. 91 must resist almost all the different kinds of strains. The screw is in tension and also under a torsional strain, due to the friction of the threads, when being used to tighten a piece firmly in the jaws. The handle has its bending strain from the power applied to the screw. The jaws have a very heavy bending strain tending to bend them back or force them open.

With the jaws opened the sliding bar on the front jaw has a heavy bending strain which sometimes breaks the bar. The pin which locks the swiveling base is subjected to shearing strains and the metal in the jaw faces in under compression as well as the thrust bearing for the screw, so we have all kinds of strains represented.

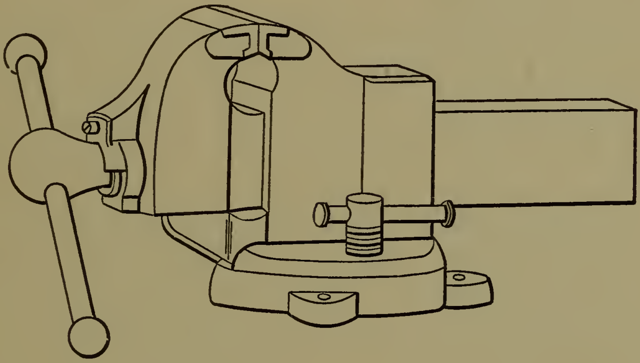


FIG. 91.

In a very similar way the monkey wrench has about the full variety of strains, even when not used as a hammer or struck with a sledge to move a rusty nut.

Breaking or Ultimate Strength

The point at which any material breaks is called its ultimate strength. This is figured in pounds to the square inch the same as in all other calculations of this kind, regardless of the size of pieces being tested. To find the breaking strength of an inch bolt, we figure the area at the bottom of the thread and find this to be .551 square inch. If the bolt is made of steel that breaks at 60,000 pounds per square inch, this should break at about 33,000 pounds.

But in practice we do not now consider the breaking strain, as it does not matter so much what strain will break the bolt as how much it will stand before it begins to stretch or yield to the load.

Elastic Limit or Yield Point

The point where a piece of any material starts to stretch is called its "elastic limit," which means that this is the limit to the strain that it will stand without stretching or taking a permanent set. Up to this point the metal will always return to its original length and shape just as a rubber band will resume its normal length unless we stretch it so far as to destroy the life or elasticity of the rubber.

In making bolts or other parts of machinery we do not want them to stretch or "set," so that we are more interested in knowing how much they will stand before reaching the yield point or elastic limit than we are in their breaking strength.

With this in view, steel makers have been giving their attention to get mixtures that will have a high elastic limit and paying very little attention to the breaking point. Some of the steels using a small amount of vanadium have shown remarkably good results in this direction.

A peculiarity of the stretching of metal in this way is the fact that it raises the elastic limit or increases its strength.

If a piece of steel is strained enough to stretch it slightly, it is stronger than before and another test at a later time will show a higher elastic limit than before.

We usually think of cast iron as brittle, yet it has considerable elasticity at times as can be seen in Fig. 92.

Cuts *A* and *B* show the same piece in two positions, the difference in length being $1\frac{3}{8}$ inches in a piece which is normally $6\frac{3}{8}$ inches long. In *C* and *D* there is $4\frac{1}{4}$ inches difference between the outer holes in the two pieces.

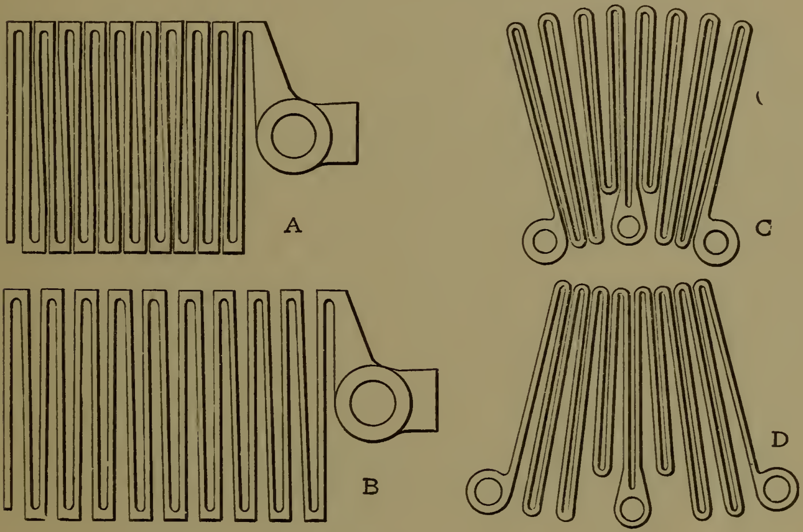


FIG. 92.

Elongation

After a bolt or other piece of metal starts to stretch, it lengthens more or less before it finally breaks. The amount of this increase in length is called "elongation." This has very little effect in using the metal but it tells an important story to the engineer who is testing the material.

When the elongation is slight, it means that the piece breaks very quickly after it starts to yield, as in cast iron. That is, it gives almost no warning before breaking should the breaking point be accidentally reached, even for a moment.

But a metal that has considerable elongation, such as most steels, stretches enough to give ample time to remove the load before rupture occurs.

Reduction of Area

When a piece of metal starts to stretch it is very clear that the area will be reduced, as the same volume of metal must be smaller in diameter if it is made longer. This can be readily proved with a rubber band, with a stick of gum, or a small bar of lead.

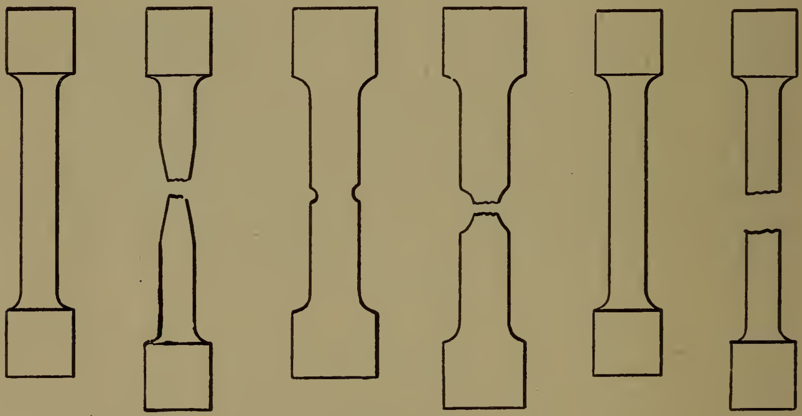


FIG 93.

The elongation and the reduction of area are very closely related, as the more a piece stretches the smaller must the diameter become and the greater the reduction in area.

The illustrations in Fig. 93 show how specimens look both before and after testing, while Fig. 94 shows a machine for making tests of this kind. The test pieces are put into the clamp *C*, and the two jaws forced apart by the screws *S*, while the scale beam is kept balanced by the weight *W*, which measures the pull on the piece just as a scale beam shows the load on a platform scale.

Table showing different stresses in pounds per square inch at which metals will work safely with a steady load:

	Tension.	Compression.	Bending.	Shear.	Torsion.
Cast iron........	4200	12000	6–8000	4000	4–6000
Wro't iron, bar..	1500	15000	15000	12000	7500
Mild steel......	13–17000	13–17000	13–17000	10–13000	8–12000
Tool steel......	17–21000	17–21000	17–21000	13–17000	12–16000
Steel castings...	8–12000	12–16000	10–14000	7–12000	7–12000
Phosphor Bronze	10000			7000	4200

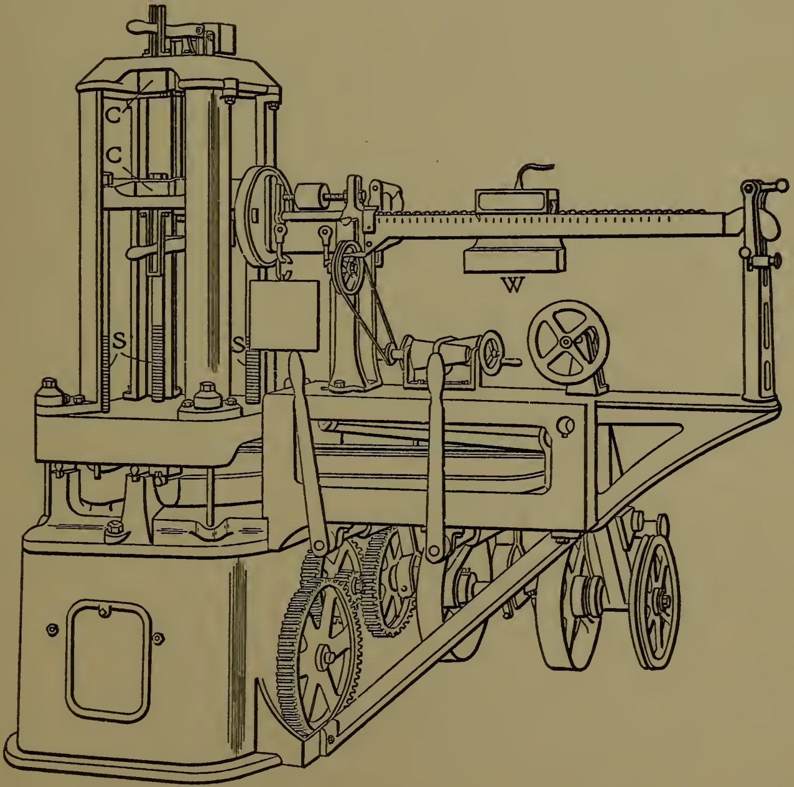


FIG. 94.

EXAMPLES

1. What are the 5 kinds of strains to which materials are subjected? *Ans.* Bending, Tension, compression, torsion and shearing.

2. How do these affect the work in a shop? *Ans.* By causing strains in machines or parts of machines such as planer or grinder tables. Read about two actual cases of this.

3. What is meant by tensile strength? By elastic limit? By yield point? By permanent set? By elongation and reduction of area?

4. Is strength and stiffness the same property? *Ans.* No. A certain shaped bar, such as an I beam, may be very much stiffer than a round bar which has a greater tensile strength.

5. How can torsion be made least objectionable in a shaft? *Ans.* When twisting is not permissible, or must be equalized, it is a good plan to use a stiff shaft and drive it in the center so the twisting will be equal at each end.

CHAPTER XVI

STRENGTH OF SHAFTING

One of the most common problems in shop mechanics is the strength of shafting for various purposes. These are usually divided into three classes according to the work they are to do.

First, are *head* or *jack* shafts which mean the first or distributing shaft in a power plant, when one is used. In the average shop the engine drives the lower line shaft which combines the work of a jack shaft. These are subjected to the most strain, both from twisting and from bending by the pull of the belts on the pulleys.

Next come the *line* shafts which run through the shop or any part of it. These have less strains but they are of the same kind.

Last on the list is the *transmission* shaft which simply transmits power such as a feed rod.

Both jack and line shafts have not only twisting or torsional strains, but also bending strains from the belts pulling on them between the bearings.

A rule which is often used is:

$$(1)\quad \text{Horse-power} = \frac{\text{Cube of diameter} \times \text{revolutions}}{\text{Constant}}$$

The constants used are:

125 for jack or head shafts.
90 for line shafts.
62.5 for transmission only and having no pulleys.

To find the power which can be transmitted by a 2-inch line shaft at 200 revolutions a minute we have:

$$\frac{2 \times 2 \times 2 \times 200}{90} = \frac{1600}{90} = 17.7 \text{ horse-power.}$$

Transposing this to find how fast this 2-inch shaft must run to transmit 25 horse-power we have:

$$\text{Revolutions} = \frac{\text{Horse-power} \times \text{constant}}{\text{Cube of diameter}} =$$

(2) $\frac{25 \times 90}{8} = 281 +$ turns per minute.

Changing again to find the diameter we have

$\text{Cube of diameter} = \frac{\text{Horse-power} \times \text{constant}}{\text{Revolutions}}$ and if the shaft ran 500 revolutions per minute it could be smaller to transmit the same 25 horse-power.

$\text{Cube of diameter} = \frac{25 \times 90}{500} = 4.5$ and the cube root of this is very close to $1\frac{5}{8}$ inches.

CHAPTER XVII

ACTION AND REACTION

While this sounds a little difficult and outside of the shop, it comes into almost everything we do, from pulling on a rope to running any kind of a machine.

When a part of a machine, such as the cross rail of a planer, is counterweighted by means of a cast-iron block hanging upon a chain which passes over a pulley, how strong must the chain be to support the weight? This is a question which is often raised and has caused much discussion, for some persons insist that the tension in the chain must be equal to the weight of both the cross rail and the counterweight; or twice the weight of the rail.

In order to settle this question if possible, the accompanying sketches are presented, carrying the case from a very homely illustration to the final application in practice. In Fig. 95 will be seen a man standing upon an upper floor and supporting by means of a rope a weight hanging below. It will be agreed by all that if this weight is 100 pounds, neglecting the weight of the rope itself, the man is supporting 100 pounds and, therefore, the total pull in the rope must be 100 pounds. This is proved by the fact that a spring balance put into the rope would admittedly read 100 pounds.

Now, glancing at Fig. 96, we see that the only change is that the man, instead of being upon the floor above, has come down to the lower floor and has attached a pulley to the upper beam, passing the rope over this pulley. The question now is: Is the tension in any part of the rope any different from what it was before? Obviously, the conditions are unchanged, because nothing has been done to the rope except to change its direction and, assuming no friction, the tension throughout the complete length of the rope must be the same; that is, 100 pounds, even in the part passing over the pulley. If, then, we interpose a spring balance in any part of the rope, is it clear enough that this spring balance will read 100 pounds.

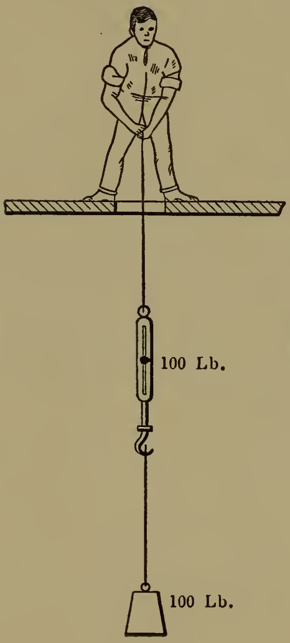

100 Lb.
100 Lb.

FIG. 95.

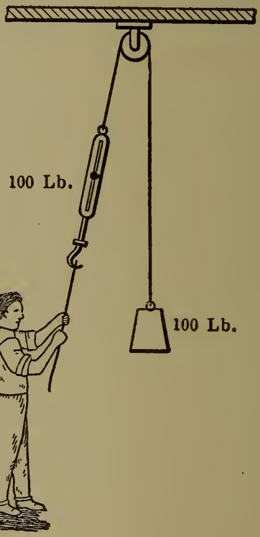

100 Lb.
100 Lb.

FIG. 96.

The Pulley Support

This is all right for the rope, but how strong must the yoke be at the top to support the pulley when carrying the weight and the pull of the man? As the weight is pulling down on one side with 100 pounds, and the man is pulling down on the other side with 100 pounds, it should be plain that the pulley is supporting a total of 200 pounds.

If this is not clear, an examination of Fig. 97 should make it so, for here we have replaced the effort of the man by a 100-pound weight. As far as the rope and pulley are concerned, the conditions in Fig. 97 are exactly the same as in Fig. 96; that is, one weight is pulling down on one side of the pulley and the new weight upon the other side, each with 100 pounds effort, and the tension in the rope, as before, is still 100 pounds at every portion of its length, just as in Fig. 96. This is shown by the two spring balances in Fig. 97.

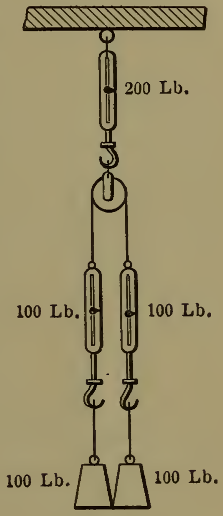


FIG. 97.

As to the yoke carrying the pulley; it is easy to see that, as neither weight has any support except that of the rope hanging from the pulley, the yoke must support both of the weights, or 200 pounds, and a spring balance put in above the pulley, as shown, would register 200 pounds.

The Tension Uniform Throughout The Rope

To overcome the objection of those persons who will insist that as one weight pulls on one side with a force of

100 pounds, and the other weight pulls on the other side with a force of 100 pounds, there must be 200-pound tension in the rope, we may glance at Fig. 98. Here we have two 100-pound weights hanging as before, but in one side of the rope we have one spring balance and in the other side we have two spring balances in tandem. It will be agreed at once that the single spring balance on the left side will be pulled down until its pointer reaches 100 pounds, just as before. Then what will each of the two spring balances on the right read? Let us consider a moment.

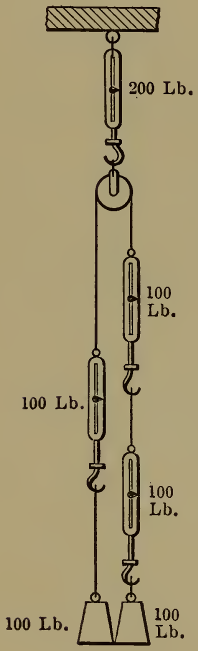


FIG. 98.

When there is one spring balance, the weight draws it down until the effort of the spring becomes so great as to resist the downward pull of the weight; that is, the tension in the spring is 100 pounds. First, considering only the lower spring balance at the right-hand side of Fig. 98; this will obviously be drawn down by the weight until its pointer reads 100 pounds, because it is no concern of the spring balance as to its manner of support; the balance would act in exactly the same manner if it were hanging upon a wooden peg, as upon an iron peg, or a steel hook, or another spring. Whatever it is hanging from must resist the downward tendency by a force of 100 pounds. Therefore, the hook of the upper right-hand spring balance which supports the lower one will have an upward tendency upon the lower balance of 100 pounds. If this pull is 100 pounds, it then follows at once that the spring in the upper balance will be drawn down as long as its upper loop is held by the rope, or any other support, until the tension in its spring reaches 100 pound also. Further than this; it is, of course, obvious that the rope itself still has a tension of 100 pounds in its fibers throughout its length, just as it did when there was only one balance in the rope, or for that manner, as it would if there were no balance at all. It also follows that the balance supporting the pulley will read 200 pounds, just as it did in Figs. 96 and 97, although, at first glance, it must be admitted, Fig. 98 gives the appearance of 200 pounds on the right being supported by 100 pounds on the left; but the reasoning given above should make it clear that the tension throughout the rope is uniform, *and equal to one of the supported weights.* A spring balance, or any number of balances put into the rope at any point would all read 100 pounds.

Application to Practice

We are now in a position to see the application of these principles to the cross rail of the planer and the counterweight, this being shown in Fig. 99. Here the cross rail is on the left and the counterweight on the right, the cross rail weighs 100 pounds and this is supported by a single counterweight. From the previous reasoning it is obvious that the tension in the chain at any point will be 100 pounds when the counterweight is also 100 pounds. From the previous reasoning also, it will be appreciated that the upward thrust of the pulley support, now taking the place

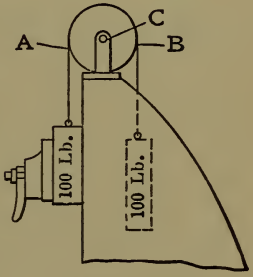


FIG. 99.

of the hook shown in the other illustrations, is 200 pounds because it must support both the cross rail and the counterweight.

Another way of looking at this would be to consider weighing the whole planer. Let us say that the planer without cross rail or counterweight will weigh 2000 pounds. Now let us put on a 100-pound cross rail, clamping it to the uprights, without any counterweight. This will clearly make a total weight of 2100 pounds. Next, if we hang on the counterweight, this weighing 100 pounds, with the cross rail still clamped to the uprights, we can see that the addition of the 100-pound counterweight will increase the total weight of the planer to 2200 pounds. It is not difficult to see that if we now unclamp the planer rail, allowing it to be supported by the counterweight, the total weight of the whole machine will not be changed by this unclamping, but will remain at 2200 pounds. As the counterweight pulley must support the additional weight of both the unclamped rail and the counterweight itself, it is plain that the pulley support holds up a combined weight of 200 pounds, while the tension in the counterweight chain is only 100 pounds at every portion of its length.

When the Cross Rail is Clamped

It may not be clear to everyone just what are the conditions in the counterweight chain and the pulley support, when the cross rail is clamped to the vertical ways. As a matter of fact, the conditions are unchanged; the tension is the same as before in all parts of the chain, and the upward force to support the pulley is 200 pounds, just as before.

This will be made clear by examination of Fig. 100. Here the left-hand portion of the chain, or rope, is attached to a loop in the floor, and the pulley at the top is replaced by the lever arm *A C B*. These letters refer to the some points on the pulley in Fig. 99, as shown. If the left-hand end *A* of the lever is held down by the tension in the left-hand portion of the chain, as it would be if the cross rail were clamped, this end *A* may be regarded as the fulcrum of the lever and the effect of the 100-pound counterweight acting upon the end *B*, will be to exert a force of 200 pounds at the point *C*. This follows because the lever arm *A B* is twice as long as the arm *A C* and the multiplication is, therefore, two. Thus, clamping the cross rail does not in any way change the forces of either the chain or the pulley support.

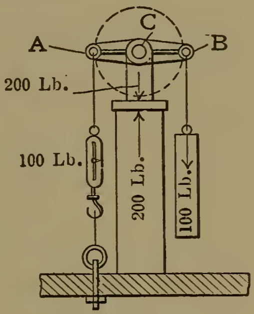


FIG. 100.

Other Applications

Another way of viewing the dicussion above is seen in Figs. 101 and 102. In Fig. 101 we have a man pulling against a rope attached to a hook in the wall. We will assume that he can pull with a certain force which, to make it easy, we will say is 100 pounds. Now in Fig. 102 we see two men pulling against each other with the same rope between them, and we can assume that each of them is exerting the same force which the single man exerted before; namely, 100 pounds. As far as the rope is concerned the conditions are exactly the same in Fig. 102 as they were in Fig. 101. Therefore the tension in the rope in Fig. 102 is only 100 pounds, just as it was in Fig. 101, and the spring balance would so read, although in Fig. 102 each man is pulling with a force of 100 pounds.

A little thought devoted to these homely illustrations should clear up a good deal of haze in the matter of design of parts of machinery, such as the counterweight chain already spoken of, or tie rods, screw bolts, etc.

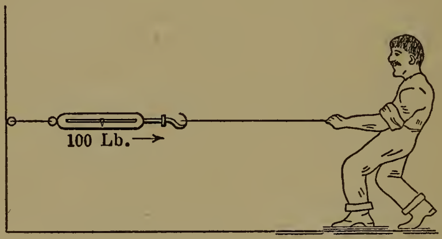


FIG. 101.

This becomes plainer if we consider that one man can pull 100 pounds and the other 150 pounds. For it is clear that as soon as the stronger man pulls enough to overcome the pull of 100 pounds he will pull the smaller man toward him, just as though he was lifting a 100-pound weight. So we see that the strain on the rope can only be the amount the weakest man pulls. Or in the case of a rope fastened to a post it means that the strain is only what the man can pull without pulling the post over.

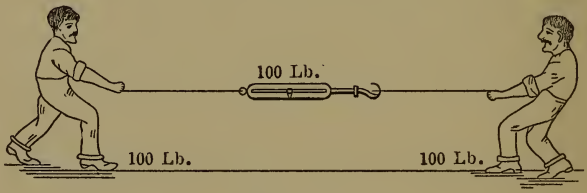


FIG. 102.

This goes to prove that action and reaction are equal. In other words, every action or pull in any machine or other device must be counteracted by an equal reaction in the opposite direction.

When we rest a crowbar on a stone as a fulcrum to lift a heavy object, the stone must resist the downward thrust by an equal upward thrust. If it did not the stone would either be forced into the ground or crushed. The same is true of any part of a machine. When we run a drill down into a piece of metal, there is a reaction on the frame equal to the power required to force the drill into the cut.

CHAPTER XVIII

BEAMS

The laws which govern the use of beams come into so many phases of shop work that we should know a little about them.

Beams are divided into two general classes, those which are supported at both ends and those in which only one end is firmly fixed. There are subdivisions where the beam is supported at two or more points but not at the ends and where it is firmly fixed at one end and merely supported at the other, but the first two are the most common and will be considered. The first kind is illustrated in Fig. 103 and the second in Fig. 104.

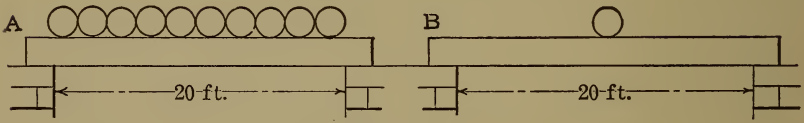


FIG. 103.

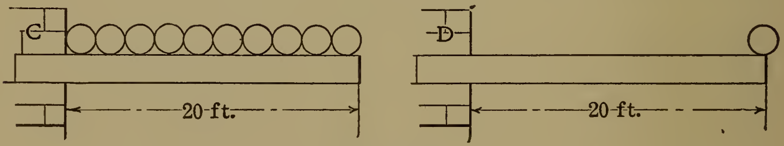


FIG. 104.

With the load uniformly distributed as at *A*, the stress is less than with any other loading. Each support bears half the load and the stress at the center equals one-eighth of the length in inches multiplied by the weight of the load or

$$\frac{\text{load} \times \text{length}}{8} = \text{stress or bending moment.}$$

In case *B*, with the load concentrated in the center, the stress is doubled for the same load or

$$\frac{\text{load} \times \text{length}}{4} = \text{stress.}$$

In case *C* (Fig. 104) we have a beam fixed at one end and not supported at the other.

Here the stress at the point of support is twice as great as with the load at the center of the supported beam and four times as great as in the first case or

$$\frac{\text{load} \times \text{length}}{2} = \text{stress at point of support.}$$

In case *D* is the same beam with the load at the end. This again doubles the stress at the point of support working the rule:

Load × length = stress at point of support.

Remember that the load is *always* taken in pounds and the length of beam in inches.

Assuming the load in each case to be 1 ton or 2000 pounds, and as 20 feet is 240 inches, we have

For A, $\frac{2000 \times 240}{8} = 60{,}000$ inch pounds.

For B, $\frac{2000 \times 240}{4} = 120{,}000$ inch pounds.

For C, $\frac{2000 \times 240}{2} = 240{,}000$ inch pounds.

For D, $2000 \times 240 = 480{,}000$ inch pounds.

The strength of beams depends on the material used and on the shape of the beam. A square beam, 4×4 inches, will support a greater load than a board 1 inch thick by 16 inches wide, though both contain the same number of square inches in cross section. On the other hand, the square beam is not as strong as though it was 2 inches thick and 8 inches deep.

Without going into the design of beams we can say that rectangular beams vary in strength with the square of their depth. In other words, a beam 2 inches wide × 8 inches deep is four times as strong as a 2×4.

A thin, deep beam is very strong against vertical load but is liable to buckle or twist and fail in that manner. So, for plain beams, it is necessary to observe certain proportions to make the beams most efficient.

Steel beams are usually made of I section, the top and bottom flanges resisting the side strain, or tendency to buckle, while the thin web, between the flanges, takes the downward strains. For the strength and deflection of steel beams, the books published by the makers such as the Cambria Steel Company, contain the best information we know of. This also treats briefly of wooden beams.

In machine design, the beam is very freely used in various forms. The lathe bed is a form of beam, the arm of the radial drilling machine as well as its upright, or column, are both beams, one horizontal, the other vertical, and so on through the list of machines.

In many cases, such as columns and arms, these beams are hollow and of various sections. For a beam which is liable to be under load from many different directions, the round beam is strongest.

For the same weight of metal the hollow beam is stronger than a solid beam, the strength varying with the proportion of inner and outer diameters. This is true of almost any section, round or rectangular.

The reason is that the metal that takes the strain is farther away from the center of the beam.

Practical Examples of Beams

One of the best examples of a beam supported at both ends and uniformly loaded is where a beam supports a tank filled with water or other liquid.

For a similar beam with a load at the center or any other point, we have the lathe with the carriage in the center. Here the stress of the work on the tool throws the load in the center or at any other part of the lathe the carriage happens to be.

For an overhanging beam, or one fixed at one end we have the bracket supporting an overhanging balcony or a support for a tank from a wall. This gives a uniform load.

For a concentrated load at one point, we have the jib crane, the arm of the radial drilling machine, and other common examples.

EXAMPLES

1. What are the two general classifications for beams?

2. What is the stress or bending moment at the center in a beam supported at both ends, 10 feet between supports, and with evenly distributed load of 1000 pounds? *Ans.* 15,000 inch pounds.

3. What is the stress with the same beam and the load concentrated at the center? *Ans.* 30,000 inch pounds.

4. How does a beam supported at each end compare with a beam supported at one end only?

5. Where is the stress greatest in a beam supported at one end only?

6. With a beam 8 feet 4 inches long, what will be the stress with a load of 1000 pounds evenly distributed? *Ans.* 50,000 inch pounds.

7. If the same beam has a load of 500 pounds at the outer end, what is the stress? *Ans.* 50,000 inch pounds.

8. Suppose this load of 500 pounds is moved to a point 4 feet 2 inches from the support, what is the stress? *Ans.* Neglecting the weight of the beam itself, the stress is the same as though the beam was only 4 feet 2 inches long or 25,000 inch pounds.

9. Which way will a 2×6 inch timber support the greatest load, horizontally or vertically? *Ans.* Vertically.

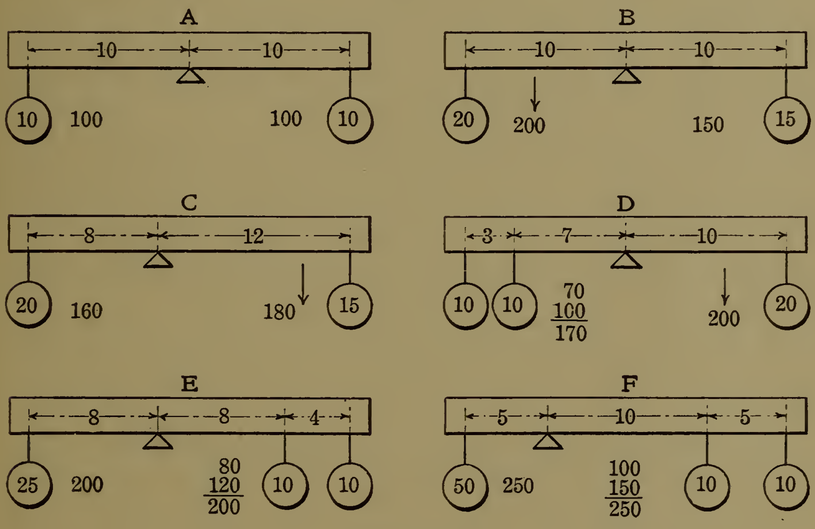
10. When is a round beam the best section to use? *Ans.* When the load comes in different directions.

CHAPTER XIX

MEASURING MOMENTS

In measuring the forces acting on any body it has become customary to use the term "moments" to express the forces acting in any direction.

In *A*, Fig. 105, the fulcrum is in the center of the beam and the weights 10 inches each side of the center. This makes the "moments" equal so that there is no tendency to turn in either direction.


A
10
10
10
100
100
10
B
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10
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200
150
15
C
8
12
20
160
180
15
D
3
7
10
10
10
70
100
170
200
20
E
8
8
4
25
200
80
120
200
10
10
F
5
10
5
50
250
100
150
250
10
10

FIG 105.

In *B* the moments are unequal, the left end being 10 × 20 = 200 and the right 10 × 15 = 150, so that the left end will be carried around the center in the direction of the arrow.

In *C*, the other end has the largest turning moment as can be had seen by multiplying the moments acting each side of the center.

In *D* we have two forces acting on one end against one on the other end and we must consider them separately. On the right we have 10×20=200. On the left we have 10 pounds at 7 inches or 7×10=70 and another 10 pounds at 10 inches always measuring from the fulcrum or turning point. This gives a total of 70×100=170 as against 200, so we see at once that the beam will be turned in direction of the arrow.

Another kind of a case is given at *E*. Instead of the fulcrum being in the center it is nearer the left-hand end as can be seen. There are 25 pounds at the short end giving 8×25=200 and the other weights are 8×10=80 and 12×10=120 or a total of 200 so that the forces balance.

Such a lever, however, would not balance because there is more of the lever on one side than the other and the long arm of the lever would overbalance the other. So that in actual practice we would have to allow for the weight of the lever itself, but in calculations of this kind it is usually omitted.

At *F* is still another example of the same kind, in which the lever itself is still more unbalanced. One end is 5×50=250 and the other end 10×10=100 and 15×10=150 or 250 altogether. The weighted arms balance. But it is plain to be seen that the right-hand end weighs three times as much as the left because it is three times as long.

EXAMPLES

1. What is meant by the term "moment"?
2. How do you find the moments in either direction?

3. With a lever having a 10-pound weight 12 inches from the fulcrum on the left and a 6-pound weight 15 inches from the fulcrum on the right, what are the moments? *Ans.* Left = 120 inch pounds; right = 90 inch pounds.

4. When the lever is not balanced in the fulcrum, what allowance must be made in calculating moments? *Ans.* The weight of lever must be considered.

5. What bodies have "moments?" *Ans.* All bodies can be figured in this way. Bodies at rest have all the moments equal, or the forces are all balanced. In a body in motion, the moments in the direction of its movement overbalance the others.

CHAPTER X

FORCE DIAGRAMS

When we begin looking into the construction of machines of different kinds we find that the forces which operate them act in many different ways. We find that a belt driving a pulley tends to pull the whole shaft toward the driving pulley and to turn the pulley and shaft. As a matter of fact it does both. Two gear wheels are rotated and are also forced apart by the pressure angle of the teeth —the greater the angle the more the pressure tending to force them apart.

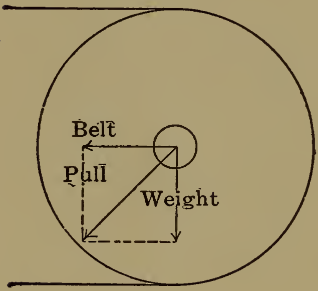

FIG. 106.

The load on a shaft hanger bearing is downward when the shaft is still except for the standing pull of belt, but this belt pull increases greatly when in motion so that we have both a downward pull and a side pull. In the same way we have the crosshead of a steam engine being pushed back and forth by the piston and being forced against the guides by the angle of the connecting rod. These two forces acting in different directions result in a force which acts in a direction between the two and is known as the "resultant force" or the force and direction resulting from two or more forces acting on a body.

Fig. 106 shows an outline of a pulley and belt and shows the direction of belt pull and the direction of the weight of the shaft, pulleys and belts. Assuming these to be equal, which would probably be the case, the resulting pull would be in a direction half way between the two and the amount of this pull would be shown by the length of the arrow which forms the diagonal of the square completed by the dotted lines.

Here is a case where a little drawing is of great service and saves a vast amount of figuring to get result. The school books call it the "parallelogram of forces," but it is very simple and very useful in spite of its long name. We will call it a force diagram and the best way to learn about it is to use it a little.

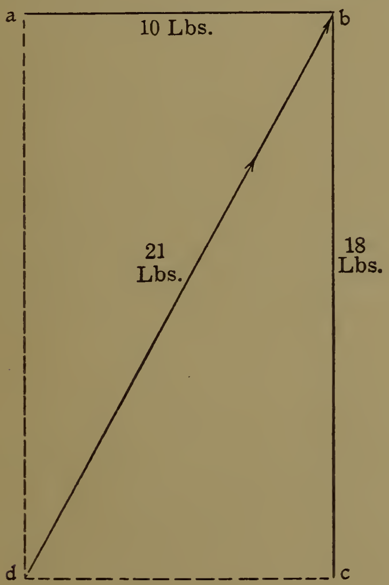

FIG. 107.

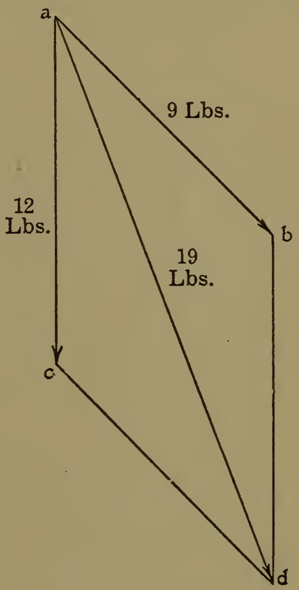

FIG. 108.

Suppose we have two different forces acting at right angles on the point *b* in Fig. 107. The horizontal force *ab* is 10 pounds and the vertical force *bc* is 18 pounds. The first tends to push it to the right and the second to push it up, so it is plain that it will not move in either direction but in a direction between them, being nearest to the greater force. Decide on some scale to use and draw *ab* to represent 10 pounds by that scale. Taking an inch to the pound, draw *ab* 10 inches long and *bc* 18 inches long.

Draw *ad* parallel to *bc* and *cd* parallel to *ab*. Then the distance from *d* to *b*, about 21 inches, shows that the combined forces would push the power *b* in the direction of *db*

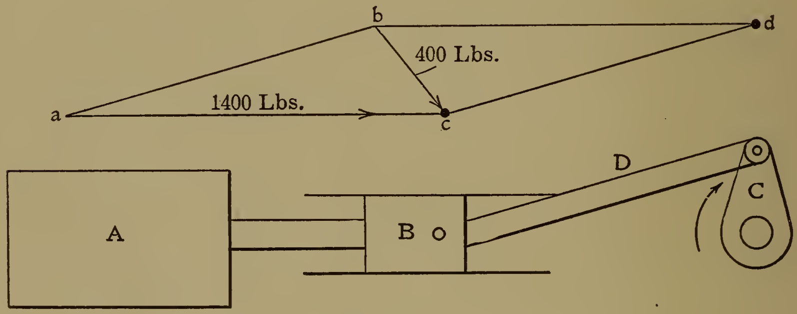

FIG. 109.

and with a force of 21 pounds. As the combined forces of *ab* and *cb* were 28 pounds, it shows that 7 pounds were lost by the two forces or that they pushed against each other to this extent.

Fig. 108 shows a case where the two forces do not act at right angle. Here *ab* is a force of 9 pounds and *ac* a force of 12 pounds, pulling on *a* at the angle shown. Drawing *bd* parallel to *ac* and *cd* parallel to *ab*, we can draw the diagonal *ad* and find both the direction and the amount of the combined pull, the latter being 19 pounds. Here the loss is only 2 pounds due to the pulling in similar directions.

Going to Fig. 109 we have a diagram of a steam engine and above it a force diagram as shown. Calling the total push of the piston 1400 pounds and choosing some convenient scale, draw a horizontal line, *ac*, to represent 1400 pounds. Then draw *cd* the same length, because the crank pin is the resistence and this must always equal the power applied. Draw the line *cd* at the angle of the connecting rod and then complete the figure as before. Then the line *bc* represents the downward thrust on the lower guide with the engine running in the direction shown by the arrow. If running in the reverse direction, this pressure would be against the upper guide.

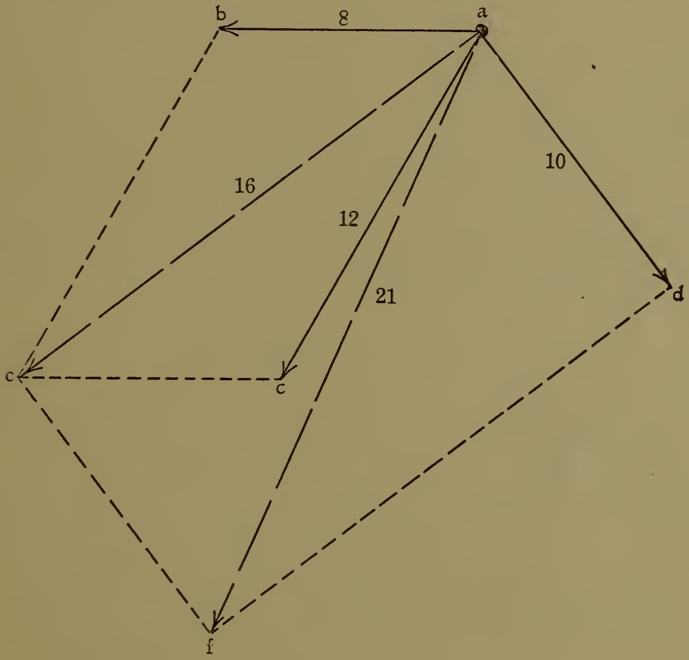

FIG. 110.

It sometimes happens that three or more forces act in different directions on one point, as in Fig. 110. Here three forces, *ab* of 8 pounds, *ac* of 12 pounds and *ad* of 10 pounds, are all pulling at the point *a* in the directions shown.

The method is the same as before only we take *ab* and *ac* first and find *ae* of 16 pounds as the resultant of these two, then work from *ae* and *ad* and get *ab* of 21 pounds as the direction and amount of effective pull on *a*. The result will be the same no matter where we start and can be done just as well from *ad* and *ac* first as the other way. Had there been more than three forces the same thing would be continued.

This shows a loss of 9 pounds due to the pulling in different directions.

A Word of Warning

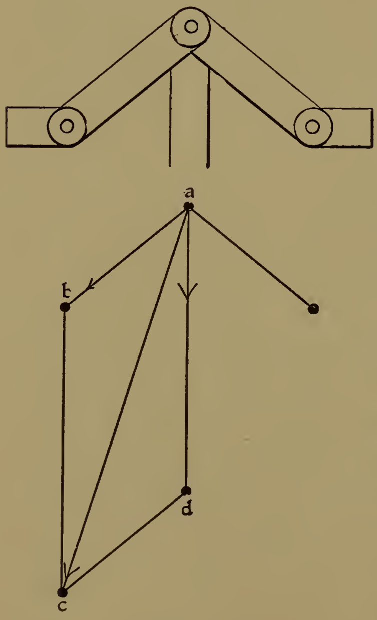

FIG. 111.

It may be wise to say a word of warning here which may save mistakes later and might even lead to doubt as to the plan. Fig. 111 shows a toggle joint which is operated by the bar hanging below it. It is very natural to draw the diagram as shown directly below the toggle but it is clearly wrong because it makes the power transmitted, *ac*, greater than the power we put into it, *ad*, and we know that we never get back all the power put into anything.

The error here is in taking the direction of the power as being downward when it is clearly in the direction of the toggle arm if we stop and think of it. For no matter in which direction the power link pulls, the power is transmitted to the arm of the toggle and must act in the direction in which it moves.

So we draw diagram (Fig. 112) in which the line *ab* represents the power applied, the line *cb* the resistance, which must be the same, and the line *db* shows the downward pressure or loss, so far as the actual work of the toggle is concerned. Subtracting the power lost, *db*, from the power applied, *ab*, we have the power used effectively by the toggle.

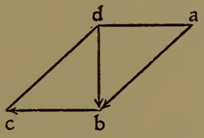

FIG. 112.

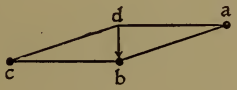

FIG. 113.

In Fig. 113 is another diagram with the toggle nearly straight, showing the loss by downward pressure, *db*, to be very small, and consequently leaving more for effective work.

It will be noted that only one-half the toggle has been used in the diagrams, because, even if the toggle worked in both directions, it cannot utilize more power than it receives. As long as the arms are equal it can be worked out from one side as well as two. Where they are not equal, each side must be worked out separately, with half the power on each, unless they are so arranged that they receive different amounts of power, which is not likely to be the case.

In speaking of inclined planes in Chapter III, we referred to cases where the power was not applied parallel to either the base or the incline. A case of this is shown in Fig. 114; in the first the power is parallel to the plane, the resultant is *ad*.

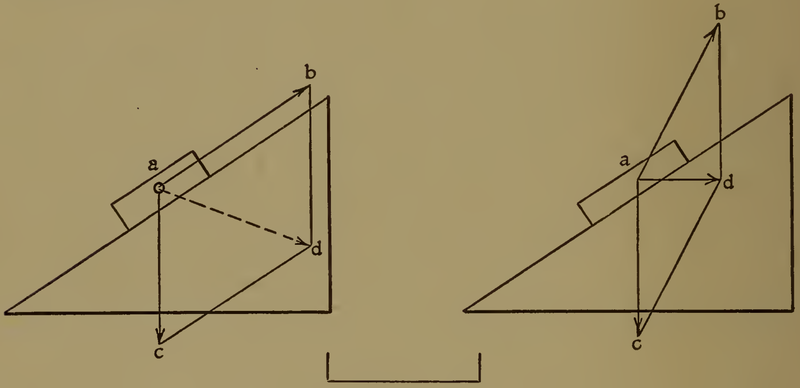

FIG. 114.

In the other case, the pull is up at the angle *ab*. The weight acts downward, as *ac*. The resultant, *ad*, is horizontal in this case and reduces the friction between the surfaces.

This can be easily worked out for any angle and tells the whole story.

The Strains in Crane Members

Jib cranes present a good chance to work out force diagrams and are interesting to experiment with. Taking Fig. 115 as an example we have a load of 2000 pounds suspended at *b*.

Draw a force diagram in exactly the same proportion as the crane itself, using any convenient scale. Draw *ac* to represent the load, say 20 inches to represent 2000 pounds, so that each inch represents 100 pounds. If drawn 10 inches, each inch equals 200 pounds.

Measuring the other lines and multiplying by the pounds per inch, give the stress in each member. Calling *ac* 20 inches, then *ab* will be 22 inches and *bc* 28 inches. This makes the stresses 2000 pounds compression in *ac*, 2200 pounds tension in *ab*, and 2800 pounds compression in *bc*.

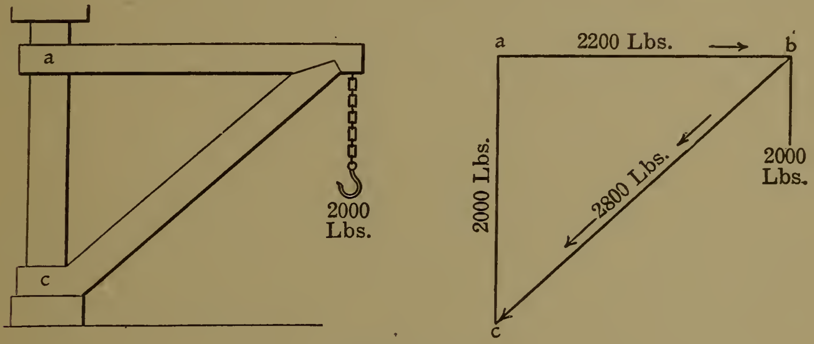
a
c
2000 Lbs.
a
2200 Lbs.
b
2000 Lbs.
2800 Lbs.
2000 Lbs.
c

FIG. 115.

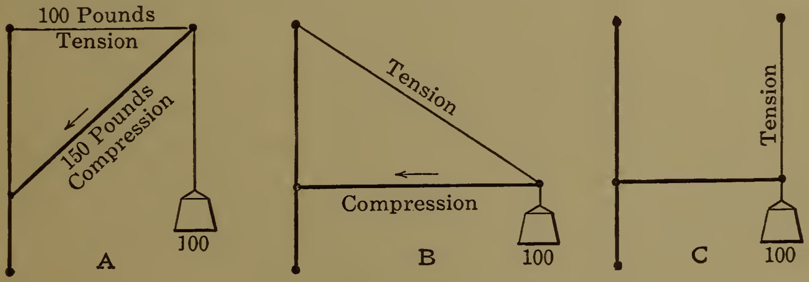
100 Pounds Tension
150 Pounds Compression
100
A
Tension
Compression
B
100
Tension
C
100

FIG. 116.

It is not easy to see how a 2000 pound load can cause a strain of 2800 pounds in *bc*, but if we make a diagram like Fig. 116 we can see more about it. At *A* is a small jib crane with a load of 100 pounds. Taking *B*, we have the boom or arm level so that the load is apparently all taken by the rope in tension. But it is easy to see that the boom is in compression as it must keep the weight away from the upright.

The only way the boom can be free from strain is to have the load suspended as in *C* so that the load does not tend to swing to the wall.

EXAMPLES

1. Give a practical use of the force diagram as shown in Fig. 106. *Ans.* This shows how the strains must be guarded against and where the bearings will wear.

2. What affects the pressure on the guides of an engine as shown in Fig. 109? *Ans.* The angularity of the rod (length of rod as compared with stroke) and steam pressure. Work out a few diagrams to show this.

3. How do you handle cases where three or more forces work together? *Ans.* Work out diagrams for two of the forces; then take the resultant of this as a force and combine with the next one, and so on.

4. What direction of action must we take in the case of a toggle or similar device? *Ans.* Always take the direction of the force, and the direction in which the device acts.

5. Work out a number of strains or force diagrams for jib cranes and beams of different type.

INDEX

INDEX

Absolute zero, 47
Action and reaction, 147
Angle of repose, 45
Automobile differential gears, 96

Balanced pressures, 124
Beams, 156
  rules for, 157
Bearing surfaces, 43
Bell cranks, 14
Belt creep, 61
  holes in floors, 67
  idlers, 63
  tables, 64
  tension, 60
Belting, 60
  rules, 65
Belts, work done by, 75
Bent levers, 16
Bevel gear differentials, 96
Block and tackle, 75, 81
Blow, force of, 126
Bolts, strength of, 19
Breaking strength, 139
Bulging dies, 121

Centrifugal force, 107
  rules for, 109
    in fly wheel, 110
Chinese windlass, 85
Circular wedge, 25
Coefficient of friction, 43
Compound levers, 15
Compound locomotives, 124
Compression, 134
Conical pistons, 123
Counterweights on machines, 151
Creep of belts, 61
Crossed belts, 66
Crowbar, 1, 8, 155
Cutting pliers, 15

Deflection, 131
  of grinder table, 131
Diagrams of forces, 164
Differential gearing, 85
  indexing, 103
  levers, 92
  pulleys, 85
  threads, 89
Distance and weight, 9
  bodies fall, 32
Driving a nail, 128
  small punch through thick metal, 59
Drop hammers, 127

Elastic limit, 140

Elongation, 141
Energy, 6
Expansion of metals, 48, 52
  table of, 53,

Fahrenheit and Centigrade, 54
First class lever, 4
Foot pounds, 78
Force diagrams, 164
  of a blow, 126
Forces in steam engine cross head, 166
Friction, 42
  coefficient of, 43
  gearing, 76
  heat of, 52

Gaining power, 7, 80
Gears, 2
Gravity, 31
  rules for, 34
Grinding, heat of, 51

Head of water, 119
  shafts, 145
Heat, 46
  affects measurements, 49
  and energy, 48
  fools the foreman, 50
  generated in shop, 47
  of friction, 52
  of grinding, 51
Horse power, 76
Hydraulic jack, 115
  pressure acts in all directions, 113
Hydraulics, 113

Inclined planes, 28, 170
Inertia, 56
Jack shafts, 146
Jib crane, 135, 170
Jumping from car, 57

Lead, 19
Leverage, 79
Levers, 1, 3
Line shafts, 146
Long or short belts, 66

Measuring friction, 43
  moments, 161
  power, 77
  work done, 7
Mechanical equivalent of heat, 48
Metals, properties of, 40
Momentum, 57
Moments, measuring, 161
Muley belt drive, 71

Open or crossed belts, 66

Parallelogram of forces, 165
Planetary gears, 93
Plunger pumps, 118
Power of belts, 62
Power of screws, 21
Pressure due to head, 119
Prony brake, 78
Properties of metals, 40
Pulley support, 149
Pulleys, 2
  size of, 60
Pulling on ropes, 153

Quarter turn belts, 68

Reduction of area, 142
Reducing valves, 124
Resultant force, 164
Rules for centrifugal force, 109
Rules for shafting, 145

Screw and wedge, 19, 24
Screws, power of, 19
Second class lever, 4
Shafting, 145
  rules for, 145
Shearing, 137
Short belts, 66
Shifting a load, 12
Size of pulleys, 60
Specific gravity, 36
Specific gravity, rules for, 39
Speed indicator, 87
  of falling bodies, 32
Spur gear differentials, 96
  gearing, 76
Steam pressure, 123
Strain diagrams, 171
  on ropes or chains, 148
Strength of material, 131
Sun and planet gearings, 95
Table of safe loads for metals, 143
Tackle blocks, 75, 81
Tension, 132
Testing machine, 143
Thermometers, 54
Third class lever, 4, 13
Three kinds of levers, 3
  or more forces, 167
Toggle, 26, 168
Torsion, 136
Triplex hoisting block, 100
Twisting, 136
Two principles of mechanics, 1

Ultimate strength, 139

Vise and monkey wrench, 138

Weighing castings, 11
Weight of bodies in water, 36
Why bolts break, 22
Work and leverage, 6

Yield point, 140

Zero, absolute, 47
  Centigrade, 47
  Fahrenheit, 47

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