THE PENNSYLVANIA RAILROAD

SCHOOLS FOR APPRENTICES

PAMPHLET NO. 5

PRACTICAL MECHANICS

OFFICE OF CHIEF OF MOTIVE POWER
AUGUST 1, 1928

THE PENNSYLVANIA RAILROAD

SCHOOLS FOR APPRENTICES

PAMPHLET NO. 5

PRACTICAL MECHANICS

OFFICE OF CHIEF OF MOTIVE POWER

AUGUST 1, 1928

MECHANICS

FORCE

Mechanics is a science which treats of the action of forces and their effects. A force may be defined as any cause which tends to produce or modify motion. The units by which forces are usually measured in the United States, are the pound and the ton. In the study of mechanics there are two other quantities to be considered, namely, **distance** measured in **inches, feet, etc.,** and the element of **time,** measured in **seconds, minutes** and hours.

Forces may be represented by straight lines and arrow heads. The arrow head indicates the direction of the force and the length of the line, drawn to a suitable scale, the amount or magnitude of the force. If as in Fig. 1, the line is 5 inches long and each inch of length represents a force of 2 pounds, then the total force is 5 x 2 or 10 lbs. The line, therefore, represents a force of 10 pounds acting in the direction of the arrow head, or from left to right.

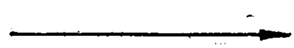


FIG. 1.

Parallelogram of Forces—If two forces acting on an object at a point are represented by two lines, as OA and OB, Fig. 2, the one force that will give the same result as the two forces can be found by the use of the parallelogram method. For example, in Fig. 2, if line BC is drawn parallel to OA and AC is drawn parallel to OB, the diagonal OC will represent the one force that will give the same result as the two forces OA and OB combined and also indicates the direction in which the object would move. The force OC is called the resultant of the two forces OA and OB. **The resultant of two or more forces is the one force that will give the same result as the other forces when acting together.** The resultant of two forces applied at the same point and both acting in the same direction, is equal to the sum of the forces. If two forces act on a point in opposite directions, the resultant is equal to the difference of the two forces and the direction of the resultant is the direction of the greater force.

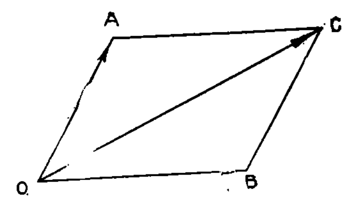


FIG. 2.

Moment of a Force—The moment of a force is the measure of the force to produce rotation about a given point. In Fig. 3, the force F acts at the end of the arm *l*. If *l* equals 12 inches and F equals 10 lbs., the moment of the force is 10 x 12 or 120. If the force is expressed in pounds and the distance or length of the arm is expressed in inches the moment is expressed in **"inch pounds,"** or if *"l"* were given in feet, then the moment

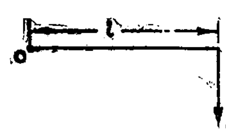


FIG. 3.

would be expressed in **foot pounds.** From the above discussion it is seen that **the moment of a force with respect to a point is the product of the force multiplied by the perpendicular distance from the given point to the line of action of the force.**

GRAVITY

The weight of all objects, regardless of the material of which they are made, is due to a force of attraction between them and the earth. This force of attraction, similar to that which exists between a piece of iron and a magnet, is called **Gravity.** Weight, then, is due to gravity. In other words, a body has weight because it is pulled downward by the force of gravity and the amount that it weighs is a measure of this pull.

The weight of a body varies with its distance from the earth's surface. A body weighs most at the surface of the earth, or more accurately, at sea level, where the attraction is greatest. For bodies above sea level the weight varies inversely as the square of the distance from the center of the earth.

Center of Gravity—Under the influence of gravity, bodies tend to move, or fall downward toward the center of the earth. All bodies are composed of small particles, called molecules, each of which has weight, and each particle or molecule is drawn downward by the force of gravity. A body is, therefore, drawn downward by a large number of forces all of which converge toward the center of the earth. The distance to the center of the earth, however, compared to the size of the object likely to be considered, is so great that the lines of action are assumed to be parallel. The sum of these forces, or the resultant, would act as a single force on the object. It is always assumed, therefore, that gravity acts as a single force at a point in the object called the **Center of Gracity.** There is always one point in an object through which the resultant of the attracting forces will pass, no matter what the shape of the body or in what position it is placed. This point is called the **Center of Gravity. The Center of Gravity is the one invariable point through which the resultant of the attracting forces always passes.**

All heavy rotating parts should be so designed and accurately balanced that the center of gravity will be exactly on the axis of rotation. For example, the center of gravity of a fly-wheel should be exactly on the center line of the shaft on which the wheel is fitted. The wheel will then be so balanced that it will be in stable equilibrium at all times.

If the fly-wheel or any circular part, such as a cylindrical drum or pulley, were mounted in frictionless bearings with the axle or shaft in a horizontal position, it is evident that if one side were even slightly heavier than the other, this heavy side would cause the wheel or drum to turn and the heavy part would be at the lowest point possible after coming to a state of rest. If this unbalanced point were removed or an exact counter balance placed opposite it, so that the wheel or drum would be brought to such a state of balance that it would remain standing when turned about its axis to any position, then it would be said to be in a state of static balance.

A cylindrical body may be in perfect static balance, however, and not be in a balanced state when running. This will be easily seen in the case of a long drum, Fig. 4, where A and B are heavy points, and though they may exactly counterbalance each other, giving perfect static balance, they would tend to throw the shaft out of alignment when rotating at a high rate of speed. The drum, then, would not be in a state of running balance.

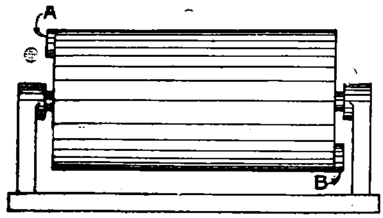


FIG. 4.

To obtain perfect running balance, the exact positions of the heavy sections should be located and balancing effected by either reducing their weights or adding exact counter-weights directly opposite each section or heavy point, in the same plane and at the same distance from the center.

Position of Center of Gravity—If a body is suspended from a point so that it will be free to rotate it will turn about this fixed point until the center of gravity is at its lowest possible position. If a piece of metal, for example, is freely suspended from a point, its center of gravity will lie in a vertical direction or exactly beneath the point of support. If now a vertical line, by means of a plumb-bob, is drawn through the point of support, as point x, Fig. 5-a, the center of gravity will lie on this line. Next, suspend the object from another convenient point, as point y, Fig. 5-b, and repeat the operation. The center of gravity must also lie on this line and will, therefore, be at the intersection of the two lines, as point c.

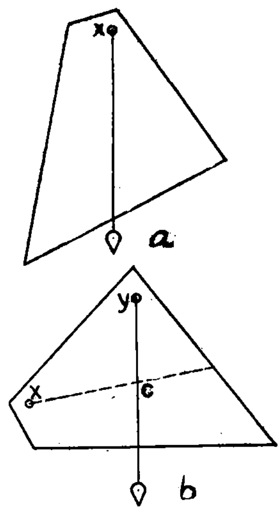


FIG. 5.

The center of gravity of any regular figure will lie at its geometrical center. For example, the center of gravity of the rectangle, Fig. 6, lies at the intersection of the diagonals and is equidistant from the sides. That is, if the length b is 12 inches, and the width is 8 inches, the center of gravity is one-half of 8 or 4 inches above the base and one-half of 12 or 6 inches from the end.

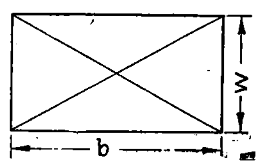


FIG. 6.

Calculation of Center of Gravity—Since the center of gravity of any regular figure lies at its geometrical center, the simplest method of finding the center of gravity of any irregular figure which may be divided into two or more parts each of which is regular is, first to divide it into these parts, then decide upon two "reference axes" at right angles to each other. It is suggested that one of these axes be taken at the extreme left, the other at the bottom of the figure in each problem. The axis at the left in Fig. 7 is designated as "ab" and that at the bottom as "cd." It is well to letter each part and to mark with a dot its center of gravity, which in each case, is at its geometrical center.

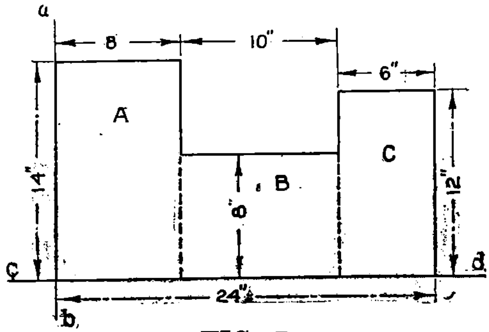


FIG. 7.

The distance of the center of gravity of the entire figure from each axis is found by dividing the sum of the moments of the regular parts by the sum of their areas.

First, find the area of each part thus:

Area A = 8 x 14 = 112 sq. in.
" B = 8 x 10 = 80 " "
" C = 6 x 12 = 72 " "

The moment of each, with reference to "ab," is the product of its area times the distance its center of gravity is from "ab." These distances are as follows:

Figure A: ½ of 8″ = 4″
" B: 8″ + ½ of 10″ = 13″
" C: 8″ + 10″ + ½ of 6″ = 21″

Dividing the sum of the moments by the sum of the areas:

$$\frac{\underset{\text{Moment "A"}}{112 \times 4} + \underset{\text{Moment "B"}}{80 \times 13} + \underset{\text{Moment "C"}}{72 \times 21}}{112 + 80 + 72} = 11.36''$$

Hence, the distance of the center of gravity of the figure from axis "ab" is 11.36″.

The distances of the centers of gravity of the parts from axis "cd" are:

Figure "A": ½ of 14″ = 7″
" "B": ½ of 8″ = 4″
" "C": ½ of 12″ = 6″

Dividing the sum of the moments by the sum of the areas:

$$\frac{\underset{\text{Moment "A"}}{112 \times 7} + \underset{\text{Moment "B"}}{80 \times 4} + \underset{\text{Moment "C"}}{72 \times 6}}{112 + 80 + 72} = 5.82 \text{ in.}$$

The center of gravity of the figure is, therefore, 11.36″ to the right of axis "ab" and 5.82″ above axis "cd."

Rule: **To find the distance of the center of gravity from the respective axes, add the moments of the separate parts with respect to the axis under consideration and divide by the total area.**

If the object is perforated or has holes in it, proceed as above but subtract the moments of the holes and divide by the actual area.

PROBLEMS

1. Find the center of gravity of the sheet of metal shown in Fig. 8.

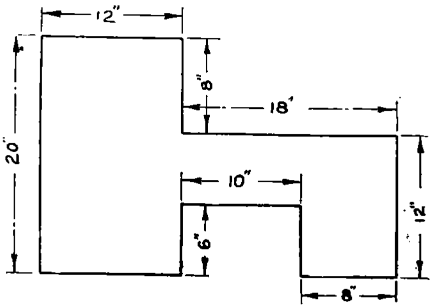


FIG.8.

2. Find the center of gravity of the section shown in Fig. 9.

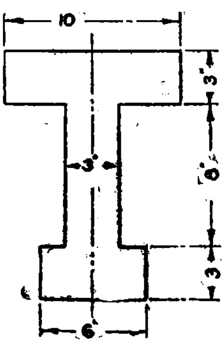


FIG. 9

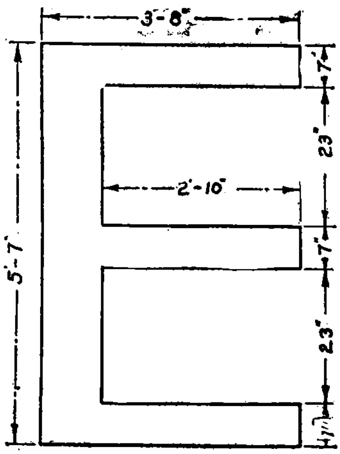


FIG. 10.

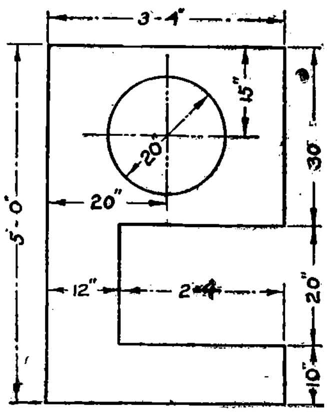


FIG. 11.

3. A sheet of metal has the shape and dimensions shown in Fig. 10. Find its center of gravity.

4. Find the center of gravity of the sheet shown in Fig. 11.

The following illustrations and formulas show how the center of gravity may be found for a number of common figures.

The Triangle—The center of gravity is at the intersection of lines drawn from the apex of the angles to the middle points of the opposite sides, as lines Aa, Bb and Cc, Fig. 12. Or the distance of the center of gravity from any side is equal to one-third of the altitude h drawn to that side. Thus,

$$g = \frac{h}{3}$$

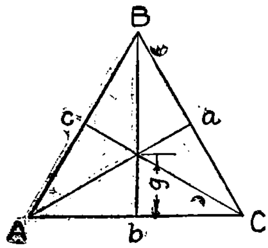


FIG. 12.

The Parallelogram — The center of gravity of the parallelogram Fig. 13, is at the intersection of its diagonals, or

$$g = \frac{h}{2}$$

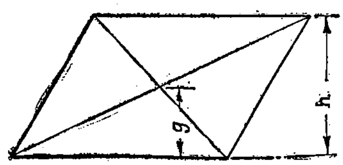


FIG. 13.

The Trapezoid—Divide the trapezoid into two triangles. The center of gravity is at the intersection of a line joining the middle points of the two bases and a line joining the centers of gravity of the two triangles, as shown in Fig. 14.

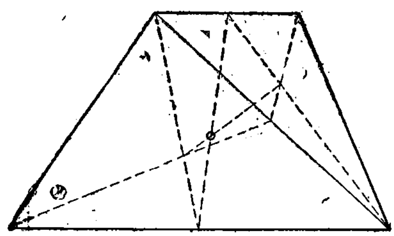


FIG. 14.

The Segment of a Circle—The center of gravity of the segment of a circle, Fig. 15, lies on a radius drawn from the center of the circle to the middle point of the arc of the segment and its distance from the center of the circle is:

$$g = \frac{C^3}{12\,A}$$

In which "C" is the length of the chord of the segment and A is the area of the segment.

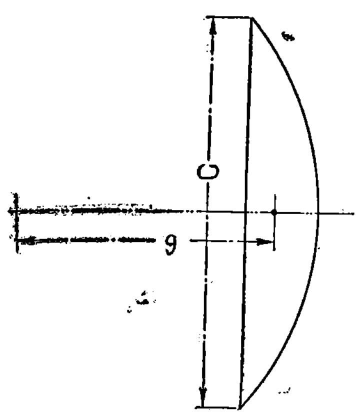


FIG. 15.

Sector of a Circle—The center of gravity of the sector of a circle, Fig. 16, lies on a radius drawn from the center of the circle to the middle point of the arc of the sector and at a distance from the center equal to twice the radius times the length of the chord divided by three times the length of the arc. It is also equal to the radius squared times the length of the chord divided by three times the area of the sector, or

$$g = \frac{2rC}{3a} = \frac{r^2C}{3A}$$

Where, r = radius
C = length of chord
a = length of arc
and A = area of sector

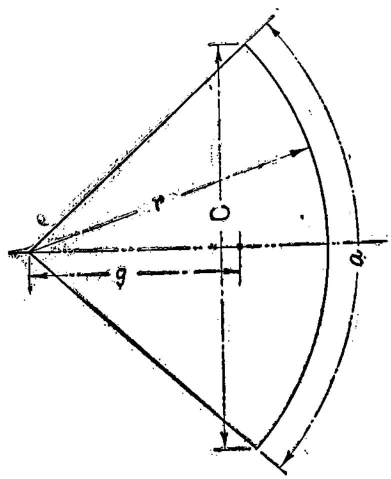


FIG. 16.

Rules for finding the center of gravity of other figures can be found in most any hand book.

PROBLEMS

5. Draw an equilateral triangle measuring 12″ on a side and find the distance of the center of gravity from its base.

6. The upper and lower bases of a trapezoid measure 6″ and 10″ respectively and its altitude is 9″. Draw this figure to scale and find the distance of the center of gravity from the lower base.

7. Find the center of gravity of the segment of a circle whose chord is 47.74″ long and whose radius is 35″. The angle between radii drawn to ends of chords is 86 degrees.

8. The radius of the sector of a circle is 30″, the angle of the sector, formed by the radii from the center of the circle to the ends of the arc of the sector is 40 degrees, and the distance from the center of the circle to the chord of the sector is 28.19″. Find the distance of the center of gravity from the center of the circle.

WORK

Whenever a force acts on a body and produces motion, work is done. Work, then, is the result of two elements—force and motion. Unless the body is moved by the action of the force, no work is done. A man may push against a heavy casting for hours, and unless he moves the casting, no work is done, however tired he may feel at the end of the time. If, however, he moves the casting, he does work on it. It is evident, therefore, that there are two factors to be considered in measuring work—**force** and **distance.** In dragging an object or pulling a truck, work is done. Probably the simplest example of work is that of a body being lifted against the force of gravity. Here the weight of the object corresponds to the force and the vertical height through which it is lifted is the distance. In all cases, then, where work is to be measured, both force and distance must be considered and the product of the two quantities is the work done. Thus,

$$\text{Work} = \text{force times distance, or } W = FD$$

Unit of Work—The unit of work called the **foot-pound** is the work done by a force of **one pound** acting through a distance of **one foot.** If a weight of one pound is raised through a distance of one foot or a force of one pound acts through a distance of one foot, one foot-pound of work is done. If a force of 5 lbs. acts through a distance of 30 ft., then, 5 x 30 or 150 foot-pounds (ft. lbs.) of work are done.

Sometimes the force is measured in tons and the distance in inches in which case we have inch-tons. If inches and pounds are used, the result is inch-pounds. Again, if feet and tons are used, the result is foot-tons.

Example: A man in pulling a truck in the shop, pulls with a force of 60 lbs., and moves through a distance of 250 ft. How much work does he do?

Solution: Force = 60 lbs., distance = 250 feet.

$$W = FD$$

$$W = 60 \times 250 = 15{,}000 \text{ ft. lbs.}$$

Note: All problems should be worked in foot-pounds unless otherwise stated.

PROBLEMS

1. How much work does a half ton steam hammer do in each fall, if the average fall is 18 inches?

2. The hammer of a pile driver weighs 950 lbs. If its average fall is 12 ft., what is the work done in each fall of the hammer?

3. What work is done in loading 32 castings, each weighing 1,200 lbs., on a car, if the average lift is 5 ft. 9 inches?

4. If the hammer in Prob. No. 2 were raised an average of 90 times per hour, how many foot pounds of work would be done by the hammer per hour?

5. What work in foot-pounds is done by a crane in lifting a weight of 3½ tons through a distance of 15 ft.?

6. A single action pump raises 230 gallons of water per minute through a distance of 18½ ft. What is the work done by the pump per minute, if one cu. ft. of water weighs 62.5 lbs.?

7. If a train of 650 tons offers a resistance of 40 lbs. per ton, how much work is done in moving the train through a distance of 1 mile?

8. In an axle testing machine, how much work in foot-pounds is done in raising the weight of 1,640 lbs. a distance of 43 ft.?

POWER

Power is the rate at which work is done, or the performance of a given amount of work in a given time, and is expressed in **foot-pounds per**

minute or in **foot-pounds per second,** though the former is most generally used. Power, then, is the product of the force and the distance, divided by the time. If the force acts through a given distance in a given time, the resultant power will be equal to the force times the distance, divided by the time. If the force is in pounds, the distance in feet, and the time in minutes, the power developed will be:

$$\frac{\text{pounds times feet}}{\text{minutes}} = \text{ft. lbs. per minute. Or}$$

if P = power in ft. lbs. per min.
F = force in lbs.
d = distance in ft.
t = time in minutes.

the formula will be $P = \frac{Fd}{t}$

If a force of 5 lbs. acts through a distance of 12 ft. in one minute, the result is 5 x 12 divided by 1 or 60 ft. lbs. per minute. If now this force of 5 lbs. acted through the 12 ft. in 2 minutes, the result would be 5 x 12 divided by 2 or 30 ft. lbs. per minute.

Example: An electric hoist raises a girder weighing 2,250 lbs. to the top of a building, a distance of 240 ft. in 3 minutes. What is the work done per minute?

Solution: F = 2,250 lbs., force
t = 3 minutes, time
d = 240 ft., distance

$$P = \frac{Fd}{t}$$

$$= \frac{2{,}250 \times 240}{3} = 180{,}000 \text{ ft. lbs. per min.}$$

Horse Power—Power is commonly expressed in units known as **horse power,** abbreviated "H. P.," which is the equivalent of 33,000 ft. lbs. of work per minute, or 550 ft. lbs. per second. **To find the horse power, reduce the foot-pounds of work done in a given time to foot-pounds per minute and divide by 33,000.**

Example: Find the horse power developed by a hoist which raises a load of one ton a distance of 840 ft. in 4 minutes.

Solution: Force = 2,000 lbs., distance = 840 ft. and time 4 minutes.

$$\frac{\text{force in pounds x distance in feet}}{\text{time in minutes}} = \text{ft. lbs. per minute}$$

$$\frac{2{,}000 \times 840}{4} = 420{,}000 \text{ ft. lbs. per minute.}$$

$$\frac{\text{ft. lbs. per min.}}{33{,}000} = \frac{420{,}000}{33{,}000} = 12.7 + \text{H. P.}$$

To express this in a formula, divide the value for (P), power in ft. lbs. per minute, in the formula given above by 33,000 since a horse power is work done at the rate of 33,000 ft. lbs. per minute. The formula then reads:

$$\text{H. P.} = \frac{Fd}{33{,}000\,t.}$$

EFFICIENCY

1. How much work is done by a pump which raises 350 gallons of water per minute, from a well to a tank, through a distance of 35 ft.? What horse power is used by this pump?

2. A water tank for supplying locomotives is 16 ft. in diameter and 16 ft. high. What horse power is required by the pump in filling this tank, if the average lift is 30 ft. and the pump has a 15 x 30 inch cylinder, and makes 20 strokes per minute?

3. What horse power will be required to run a planer at a cutting speed of 64 ft. per min. if the resistance against the cutting tool is 280 lbs.?

4. What is the horse power of an engine that can do 3,300,000 ft. lbs. of work in 5 minutes?

5. A 750-ton train is traveling at the rate of 29 M. P. H. What horse power is required if the resistance offered is 42 lbs. per ton?

6. How high could a 7½ horse power engine raise a weight of 3 tons in 2 minutes?

7. A 200-ton train is moving at the rate of 15 M. P. H. up a grade which rises 18 inches in every 100 ft. What average horse power is necessary merely to lift the train up 3 miles of this grade?

8. What horse power is required to raise an H9s locomotive weighing 225,500 lbs. a distance of 15 ft. in 3 minutes?

9. What horse power is developed by a hydraulic power plant if 2,500,000 gallons of water fall a distance of 30 ft. every 2 hours?

ENERGY

The energy which a body possesses may be defined as its capacity to do work. In other words, energy is the power to do work. In general, all bodies possess energy only because of work having been done upon them.

There are, in general, two kinds of energy, the energy which a body possesses due to its position, known as **Potential Energy,** and the energy of motion, known as **Kinetic Energy.**

Potential Energy—Potential energy is the capacity for doing work, possessed by a body by virtue of its position or condition. A weight suspended by a rope has the power of doing work, because when the rope is cut, the weight will fall and in falling will be capable of overcoming resistance through a distance, the amount of work depending upon the amount of the weight and the extent of the fall. The work done in lifting the weight from the floor to the rope will be equal to the work capable of being done by the weight after it has been attached to the rope.

The formula for finding potential energy is: $P = W H$.

Where $P =$ Potential energy.
$W =$ Weight of object in pounds.
and $H =$ Height in feet above a given point.

Example: What is the potential energy possessed by the 2,200 lb. weight of a pile driver when the weight is suspended 25 ft. above the top of the pile?

Solution:
$$W = 2{,}200 \text{ lbs.}$$
$$H = 25 \text{ ft.}$$
$$P = WH$$
$$= 2{,}200 \times 25 = 55{,}000 \text{ ft. lbs.}$$

Kinetic Energy—A body may also have the capacity for doing work, because it has in some way acquired velocity. A heavy fly wheel will keep machinery running for some time after the power has been shut off. In the same way, an object which is in motion is able to rise against the action of gravity or to set other bodies in motion by colliding with them, or to overcome friction or resistance of any sort.

A body, then, which has motion, is said to possess kinetic energy. The formula for finding the kinetic energy which a moving object possesses is:

$$K = \frac{W V^2}{64.4}$$

Where K = Kinetic Energy.
W = weight of object in lbs.
V = velocity in feet per second.

Example: A freight car weighing 20,000 lbs. is moving with a velocity of 30 feet per second. What is its kinetic energy?

Solution: $W = 20{,}000$ lbs., $V = 30$ ft. per sec.

$$K = \frac{W V^2}{64.4}$$

$$K = \frac{20{,}000 \times 30 \times 30}{64.4} = 279{,}503 + \text{ ft. lbs. per sec.}$$

PROBLEMS

1. A weight of 1.5 tons is moving with a velocity of 12 ft. per second. How much energy is stored up in it?

2. In a drop testing machine when testing No. 12 axles for engine trucks, the weight of 1,640 lbs. is raised to a height of 38½ ft. What is the energy of this weight?

3. What energy is possessed by an E3sd locomotive weighing 175,400 lbs., which has been lifted 20 ft. above the tracks in the erecting shops?

4. The rim of a fly-wheel weighing 2,250 lbs. has a linear velocity of 1,920 ft. per minute. What is its energy in ft. lbs. per second?

5. An L1s locomotive weighing 320,700 lbs. is traveling at the rate of 25 miles per hour. What energy does it possess due to its motion, if the power is shut off?

EFFICIENCY

In all machines, more or less energy or work is lost in overcoming friction, heat, etc., so that the amount of work done by a machine is always less than the amount of work put into it. It will be seen, then, that the energy or work supplied to a machine minus the work used to overcome friction, etc., is equal to the output or the useful work that the machine can do, or

Input minus friction loss = output.

That is, if 49,500 ft. lbs. of energy is supplied to a machine and 12,375 ft. lbs. of energy is lost in overcoming friction, heat, etc., then the output of the machine is:

49,500 — 12,375 or 37,125 ft. lbs.

The efficiency of a machine is the ratio of the output to the input and is expressed in per cent or,

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

Thus, the efficiency of the machine in the above example would be:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{37{,}125}{49{,}500} = .75 \text{ or } 75\%$$

Efficiency of Simple Machines—In simple levers, the friction is usually so small as to be negligible, giving an efficiency of nearly 100%. When inclined planes are used, the friction is also small, so that the efficiency generally lies between 90% and 100%. The efficiency of the block and tackle varies between 40% and 60%. In the screw jack, there is necessarily a large amount of friction so that the efficiency is often as low as 15% and 25%. The differential hoist also, has a low efficiency, ranging around 30%. Gear wheels have an efficiency of 90% to 98% per pair.

PROBLEMS

1. An electric motor delivers 12.75 horse power and requires 15 horse power to drive it. What is its efficiency?

2. A differential hoist lifts a weight of 640 lbs. through a distance of 5 ft. and in so doing requires the expenditure of 10,750 lbs. of work. What is its efficiency?

3. If it is necessary to pull on a block and tackle with a force of 200 lbs. in order to lift a weight of 800 lbs., what is the efficiency of the block and tackle system if the force must move 18 ft. in order to raise the weight 3 ft.?

4. An engine rated at 80 horse power has an efficiency of 75%. What is its output?

5. In testing a certain electric motor it was found that the output at the pulley was 4.68 horse power and the efficiency was 90%. What was the horse power delivered to the motor?

SIMPLE MACHINES

Any machine, however complicated, may be reduced in principle to one or more of six simple machines, known as the **Lever,** the **Wheel and Axle,** the **Pulley,** the **Inclined Plane,** the **Wedge,** and the **Screw.** These six simple machines may again be reduced to only two fundamental types, the lever and the inclined plane. The wheel and axle and the pulley are modified forms of the lever, while the wedge and screw are modified forms of the inclined plane.

By means of any one or of a combination of these machines a comparatively small force moving through a large distance may overcome a large resistance moving through a small distance. The advantage thus gained is termed **Mechanical Advantage.**

Mechanical advantage is found by dividing the distance the force moves by the distance through which the weight is raised, or, if we neglect friction, by dividing the weight lifted by the force exerted. Thus, neglecting friction, if the weight lifted is 60 lbs. and the force is 10 lbs. the mechanical advantage is 60 divided by 10, or 6. Again, if the force of 10 lbs. in lifting the weight moves 36 ft. while the weight moves 6 ft., the mechanical advantage is 36 divided by 6, or 6. Mechanical advantage is, therefore, a ratio of the weight to the force, if we neglect friction, or the ratio of the distance through which the force moves to the distance through which the weight moves.

Many problems in simple machines, where friction is not considered, may be solved easily by the principle of mechanical advantage, simply by **multiplying the force by the mechanical advantage to find the weight,** or by **dividing the weight by the mechanical advantage to find the force,** as the case may be.

It will be seen that if the mechanical advantage is high a comparatively small force will have to move through a large distance. What is gained in force, then, must be made up in the distance moved.

PROBLEMS

1. Find the mechanical advantage of a letter press if the diameter of the hand wheel is 14″ and the pitch of the screw is ¼″. (In the letter press while the force, on the rim of the wheel moves through the circumference of the wheel, the weight moves a distance equal to the pitch of the screw.)

2. Find the mechanical advantage of a lever if the force arm is 12′ long and the weight arm is 2′ long. (The force arm and weight arm are radii of circles through which the force and the weight move.)

3. What is the mechanical advantage of a screw jack with ¾″ pitch and a 24″ handle. (The handle is the radius of the circle through which the force moves.)

4. What is the mechanical advantage of a windlass if the handle is 12″ long, and the diameter of the drum is 8″? (As the handle is turned a complete revolution, the weight is lifted a distance equal to the circumference of the drum.)

5. What is the mechanical advantage of a wedge, if in driving it under a casting 12″, the casting is raised 1½″?

6. Neglecting friction, what is the mechanical advantage of a block and tackle that will lift a weight of 315 lb. with a force of 45 lbs.?

7. The mechanical advantage of a machine is 4, the force moves through a distance of 36 ft. How far does the weight move?

8. The mechanical advantage of a machine is 5. The weight raised is 410 lbs. Neglecting friction what force is required?

The Lever—The lever is probably the most used and the simplest type of machine. It may be defined as a bar or rod so arranged as to be capable of turning about a fixed point called the **fulcrum** and supporting a weight at one point in its length by the application of a force at another point.

Levers may be divided into three distinct classes according to whether the Fulcrum P, the Weight W, or the Force F, respectively, is located between the other two. Fig. 17 shows the **First Class Lever** in which the **fulcrum is between the force and the weight.**

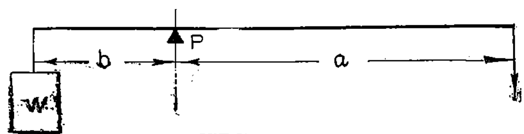


FIG. 17.

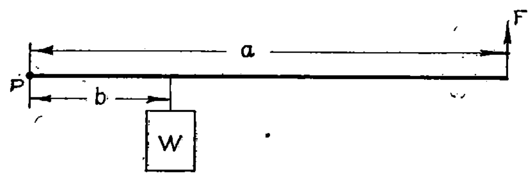


FIG. 18.

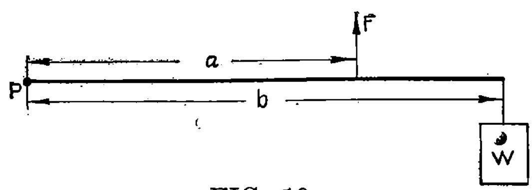


FIG. 19.

Fig. 18 shows the **Second Class Lever** in which the **fulcrum is at one end, the force at the other end** and the weight between them.

Fig. 19 shows the **Third Class Lever** in which the **fulcrum is at one end, the weight at the other end and the force between them.**

The position of the fulcrum determines the effect which the force F applied at one point has toward lifting the weight W applied at another point. If the weight is close to the fulcrum, on a first or second class lever, a comparatively small force may be able to raise the weight, but if the weight is moved away from the fulcrum a greater force is required. If the fulcrum in a first class lever is in the middle, the force and the weight will be equal.

The part of the lever between the weight and the fulcrum is called the **weight arm.**

The part of the lever between the force and the fulcrum is called the **force arm.**

In other words, the weight arm is the distance from the weight to the fulcrum and the force arm is the distance from the force to the fulcrum. It must be understood, however, that this distance must be measured at right angles to the direction in which the force or the weight acts.

In every lever there are two opposing tendencies: First, that of the load or weight W tending to descend; and second, that of the force

F tending to raise the weight. The ability of the weight to descend or to resist being raised depends upon two things—its weight and its distance from the fulcrum. The product of these two is the measure of the tendency of the weight to descend. This product is called the **moment** of the weight. Likewise, the force F has a moment which is the product of the force F and its distance from the fulcrum. If the force and the weight just balance each other, their moments are equal. Then for balance, the following equation holds true:

Force times Force Arm equals Weight times Weight Arm.

Or if F = Force,
a = Length of Force Arm,
W = Weight,
and b = Length of Weight Arm, Figs. 17, 18 and 19,
then Fa = Wb.

Although the force and the weight are really balanced when this formula is fulfilled, the formula is used for calculating the forces necessary to lift weights, because the slightest increase in the force above that necessary for balance will cause the weight to rise, and therefore, it can be said, practically, that the force F will lift the weight W.

The above formula holds true for all classes of levers, whether first, second, or third class, as will be shown in the following examples.

Example: What force F, Fig. 20, 15 inches from the fulcrum is required to balance a weight W of 40 lbs., 5 inches from the fulcrum in a lever of the first class?

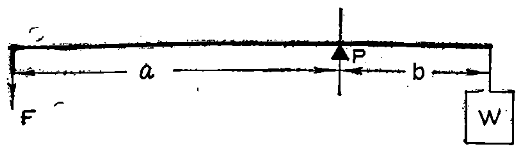


FIG. 20.

Solution: a = 15, b = 5, and W = 40, to find F.

$$Fa = Wb$$
$$F = \frac{Wb}{a}$$
$$= \frac{40 \times 5}{15} = 13\tfrac{1}{3} \text{ lb.}$$

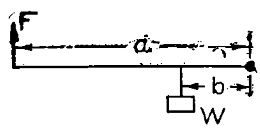


FIG. 21.

Example: In a lever of the second class, Fig. 21, what force 20 inches from the fulcrum, is required to balance a weight of 40 lbs. 5 inches from the fulcrum?

Solution: a = 20, b = 5 and W = 40.

$$Fa = Wb$$
$$F = \frac{Wb}{a}$$
$$= \frac{40 \times 5}{20} = 10 \text{ lbs.}$$

Example: In a lever of the third class, Fig. 22, what force 5 inches from the fulcrum is required to balance a weight of 40 lbs. 20 inches from the fulcrum?

Solution: $a = 5$, $b = 20$ and $W = 40$, to find F.

$$Fa = Wb$$

$$F = \frac{Wb}{a}$$

$$= \frac{40 \times 20}{5} = 160 \text{ lb.}$$

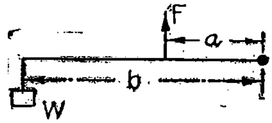


FIG. 22.

PROBLEMS

1. From the explanation already given and using Fig. 20, fill out the following table, giving also, sample calculations to show how results were obtained.

No.	W. Lb.	F. Lb.	a	b
1	30		36″	12″
2		39	2′	6′
3	50	20		18″
4	120	15	2′ 6″	
5	250		5′	1′ 9″
6		35	6′ 3″	5″

2. Using Fig. 21, fill out the following table, giving sample calculations to show how results were obtained.

No.	W. Lb.	F. Lb.	a	b
1	300	75		12″
2		45	12″	3″
3		30	5′	1′
4	90	45		4″
5	60		8½″	6½″
6		96	3′ 4″	6″

3. Using Fig. 22, fill out the following table, giving also, sample calculations to show how results were obtained.

No.	W. Lb.	F. Lb.	a	b
1	75	200	12″	
2	45		9″	12″
3	30		2′	5′
4	45	90		30″
5		60	6½″	8″
6	96		36″	40″

4. Draw a sketch of a first class lever having a force arm of 18 inches, a weight arm of 5 inches, and find what force will be required to balance a weight of 99 lbs.

5. Draw a sketch of a lever of the second class having a force arm 20 inches long, a weight arm 4 inches long, and calculate the force required to balance a weight of 72 lbs.

6. Draw a sketch of a lever of the third class, having a force arm 16 inches long, and a weight arm 22 inches long. What force will be necessary to balance a weight of 56 lbs.?

7. A man uses a piece of timber as a lever. If he is 8 ft. from the fulcrum and the weight is placed 8 inches on the other side of the fulcrum, how great a weight can be lifted by putting his weight of 135 lbs. on the end of the timber? What class lever is this?

8. A man exerts a force of 75 lbs. on the end of a pinch bar 4 ft. from the fulcrum to raise a casting from the floor. If the point touching the casting is 3 inches from the fulcrum, what pressure is exerted on the casting?

9. Fig. 23 shows a lever whose arms are bent at right angles to each other. What weight can be supported at W by a force of 75 lbs. at F?

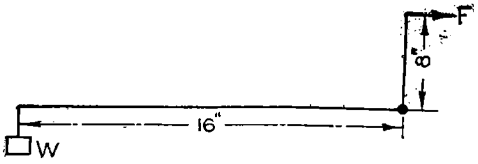


FIG. 23.

10. Find the force required at A to raise a load of 96 lbs. on the lift rod at B, Fig. 24.

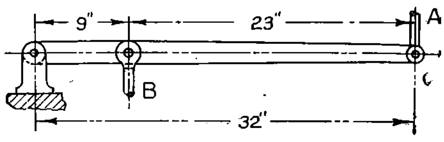


FIG 24.

11. In the hand press shown in Fig. 25, what force is required on the handle at A in order to produce a pressure of 150 lbs. on the press?

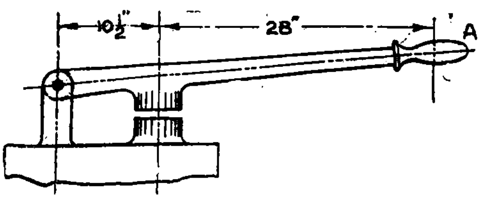


FIG. 25.

12. What pressure will be necessary on the treadle at A, Fig. 26, in order to produce a force of 72 lbs. in the rod B?

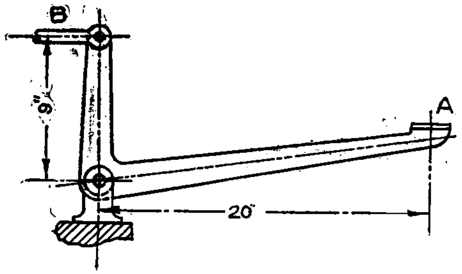


FIG. 26.

13. In Fig. 27, with a cylinder pressure of 60 lbs. per square inch, what force will be produced at the end of the 3-inch arm?

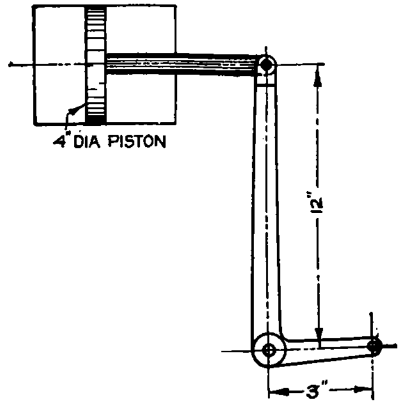


FIG. 27.

14. The brake rod in Fig. 28 is operated through an 8-inch piston in a cylinder with a pressure per square inch of 50 lbs. What pressure will be produced at the wheel?

15. Find the force on the handle of the throttle shown in Fig. 29 necessary to lift the throttle valve if 560 lbs. is required at A on the throttle stem.

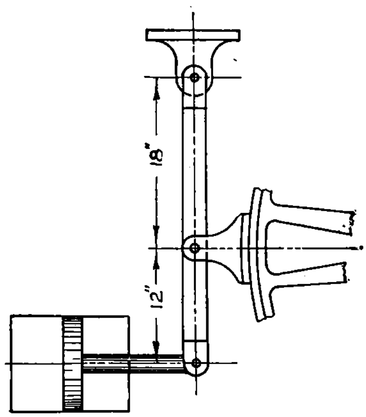


FIG. 28.

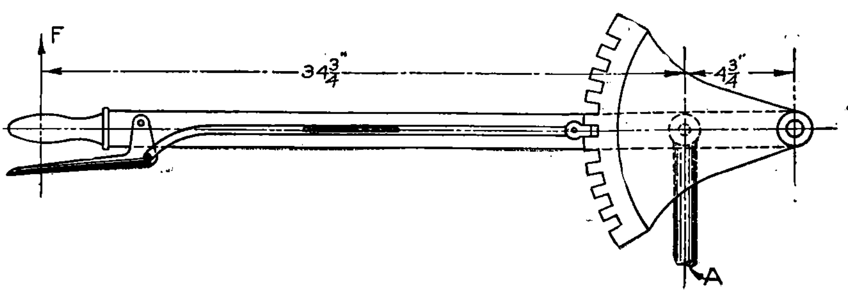


FIG. 29.

16. What force is necessary on the handle, Fig. 30, in order to close the valve if the steam pressure is 150 lbs. per sq. inch?

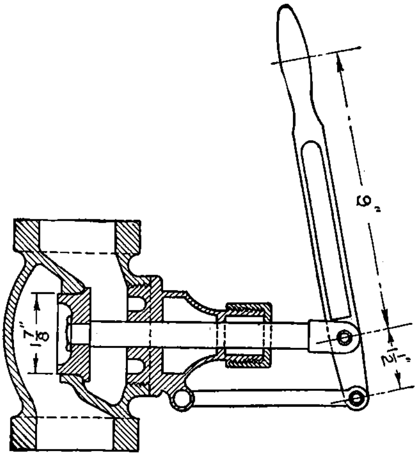


FIG. 30.

17. What force is necessary on the whistle cord A, Fig. 31, to open the whistle valve if the boiler pressure is 120 lbs. per sq. inch?

18. How much force must be placed 20 inches from the fulcrum of a lever of the first class to balance a weight of 650 lbs. placed 65 inches from the fulcrum?

19. In a lever of the first class, a weight of 350 lbs. is placed 36 inches from the fulcrum. The force required to raise the weight is 1,050 lbs. How far from the fulcrum must the force be applied?

20. On a lever of the third class, a weight of 640 lbs. is suspended 36″ from the fulcrum. It takes a force of 652 lbs. to raise the weight. What is the distance from the fulcrum to the point where the force is applied?

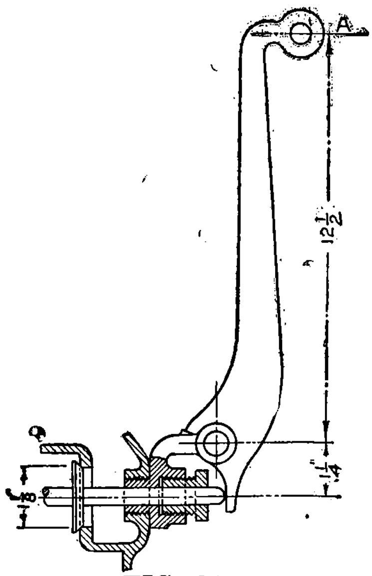


FIG. 31.

21. The weight on a lever of the first class is 320 lbs. This weight is 26 inches from the fulcrum. How far should a force of 832 lbs. be placed from the fulcrum in order to balance the weight?

22. What is the total length of the lever and the total weight on the fulcrum in Prob. No. 21?

Compound Levers—It is sometimes necessary to connect two or more levers, one to the other, forming a series of levers where the desired result cannot be obtained by the use of the single lever. In such cases the levers are called **compound levers.** They are found chiefly in printing presses, testing machines, car brakes and especially in weighing scales.

Problems concerning compound levers are easily reduced to repeated cases of single levers, the force on one lever corresponding to the weight on the next, etc. This is clearly shown in Fig. 32, where a load of 800 lbs. is to be raised with the system of compound levers as shown. Here the force F_1 on the first lever becomes the weight on the second lever and the force necessary to raise the weight of 800 lbs. is F_2 on the end of the second lever.

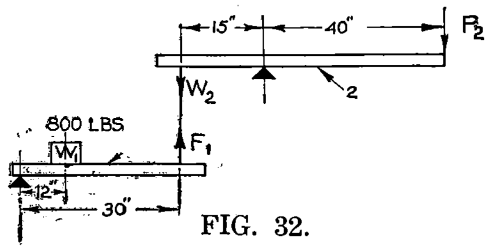


FIG. 32.

Solution:

$$F_1 a_1 = W_1 b_1 \qquad W_1 = 800$$

$$F_1 = \frac{W_1 b_1}{a_1} \qquad a_1 = 30, \quad b_1 = 12$$

$$\text{then} \quad F_1 = \frac{800 \times 12}{30} = 320 \text{ lbs.} = W_2$$

$$F_2 a_2 = W_2 b_2$$

$$F_2 = \frac{W_2 b_2}{a_2}$$

$$F_2 = \frac{320 \times 15}{40} = 120 \text{ lbs.} \qquad \text{ANS.}$$

The resulting force F_2 may also be found thus,

$$F_2 = \frac{800 \times 12 \times 15}{30 \times 40} = 120 \text{ Lbs.}$$

From this the rules for solving compound levers are derived.

Rule: **To find the force, multiply the weight and all the weight arms together and divide this product by the product of the force arms.**

Rule: **To find the weight, multiply the force and all the force arms together and divide this product by the product of the weight arms.**

23. In a shifting arrangement as shown in Fig. 33, what must be the length C of the shifting lever if the force at A is to be 320 lbs. and the force at B is not to exceed 20 lbs.?

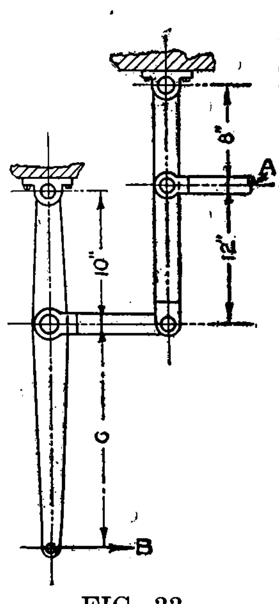


FIG. 33.

24. What force is produced at F in the lever arrangement shown in Fig. 34 if the cylinder pressure is 50 lbs. per sq. inch?

25. If it is desired to have a force of 600 lbs. at F, Fig. 34, what must be the pressure per sq. inch in the cylinder, other conditions remaining the same?

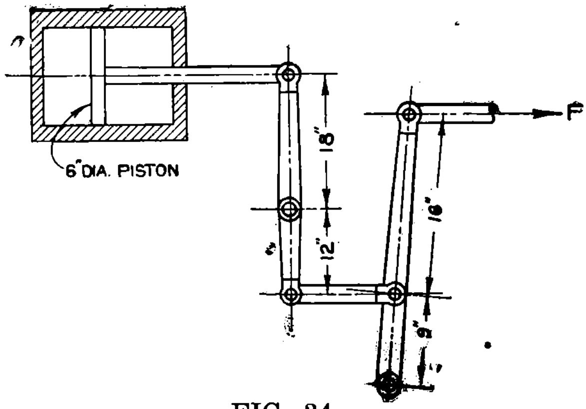


FIG. 34.

26. How far must W be moved from the fulcrum for balance in the lever arrangement for a tensile testing machine shown in Fig. 35, if a=2", c=1½", d=3'-4", e=3', f=4'-2", and the load is 10,000 lbs.?

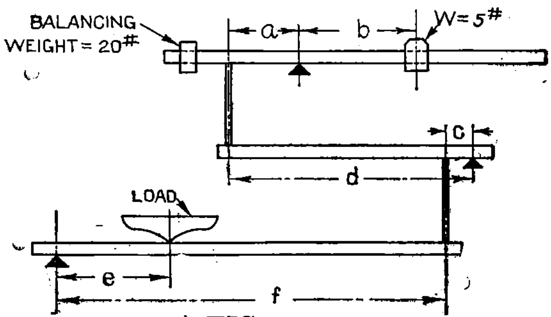


FIG. 35.

27. With a force of 25 lbs. at F, what weight W can be raised with the system of levers shown in Fig. 36?

28. With the system of levers in Fig. 36, what force would be required to raise a weight of 180 lbs.?

29. Assuming that all forces act at right angles to the levers, with what force are the brake shoes pressing against the wheels in the inside hung brake arrangement shown in Fig. 37?

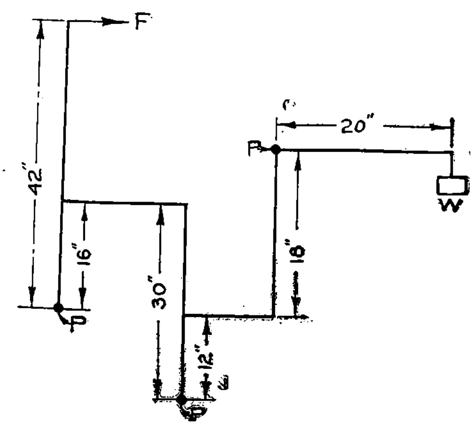


FIG. 36.

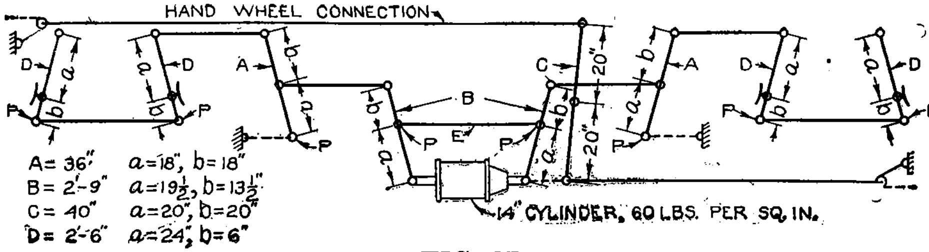


FIG. 37.

Calculation of Lever Arms, First Class Lever—At times it is necessary to find the length of the arms of a first class lever when the force, the weight, and the total length of the lever are known. For example, in Fig. 38, it is desired to find the length of the arms "a" and "b," when the weight and the force are known to be 1,200 lbs. and 3,600 lbs. respectively, and the total length of the lever is 40 inches.

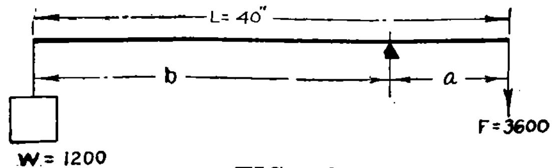


FIG. 38.

Solution: $Fa = Wb$

Since L = total length of lever,

$$b = L - a$$

Substituting L — a for b in the above formula

$$Fa = W\ (L - a)$$

and $Fa = WL - Wa$

$$Fa + Wa = WL$$

$$a\ (F + W) = WL$$

then $a = \frac{WL}{F + W}$

In the same way $b = \frac{FL}{F + W}$

As a check on calculations the sum of "a" and "b" should equal "L." Referring to Fig. 38 the length "a" is found as follows:

$$a = \frac{WL}{F + W}$$

$$a = \frac{1{,}200 \times 40}{3{,}600 + 1{,}200} = 10 \text{ inches.}$$

In like manner $b = \frac{FL}{F + W}$

$$= \frac{3{,}600 \times 40}{3{,}600 + 1{,}200}$$

$$= 30 \text{ inches}$$

As a check on calculations the sum of "a" and "b" should equal "L."

PROBLEMS

30. On a lever of the first class having a total length of 42 inches, a weight of 240 lbs. is balanced by a force of 75 lbs. Find the lengths of the force and weight arms.

31. A weight of 168 lbs. is balanced by a force of 60 lbs. on a lever of the first class. If the total length of the lever is 19 inches, find the lengths of the force and weight arms.

32. A force of 54 lbs. on a first class lever balances a weight of 270 lbs. If the total length of the lever is 18 inches, find the force and weight arms.

33. Using the arrangement and the same levers, but with a cylinder pressure of 50 lbs. per sq. inch, where would the tie rod "E" be connected to the lever "B" in order to produce the same amount of braking force at the wheels as in Prob. No. 29?

Calculations for Levers Including Weight of Lever—So far in calculating levers, the force, weight and lever arms only have been considered. Another element which should be considered in most practical lever problems is the weight of the lever itself. Assume a lever 15 ft. long as in Fig. 39, with the fulcrum 5 ft. from one end. Considering only the weight of the lever, it can readily be seen that the lever would turn about the fulcrum in a counter-clockwise direction because the longer end and consequently the greater weight is on the side indicated by "A." Assume the rod forming the lever to be of uniform dimensions, that is, the same width and thickness throughout its entire length and that it weighs 1.5 lbs. per foot of length. The weight of the lever is considered as being concentrated at the center of gravity of the lever, in this case at the middle point of the lever or one-half of 15 or 7.5 ft. from the end of the lever. Then since the length of the lever arm indicated by "A" is 10 ft. long, the center of gravity is 10—7.5 or 2.5 ft. from the fulcrum. It will be seen that, if the center of gravity of a first class lever falls on the force side, the weight of the lever will aid the force in balancing the weight, requiring a smaller force. Conversely, if the center of gravity falls on the weight side, the weight of the lever will aid the weight, requiring a greater force for a given weight.

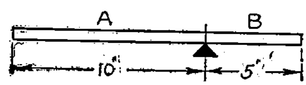


FIG. 39

In calculations of levers involving the weight of the lever, the weight of the lever may be considered as an added weight supported at the center of gravity of the lever. Summing up, if the weight of the lever acts with the force, **the moment of the force equals the moment of the weight minus the moment of the weight of the lever.**

Again, if the weight of the lever acts with the weight, **the moment of the force is equal to the moment of the weight plus the moment of the weight of the lever.**

Expressing the above as a formula letting,

$F =$ force

$a =$ force arm

$W =$ weight

$b =$ weight arm

$W_1 =$ weight of lever

$b_1 =$ distance from center of gravity of lever to fulcrum.

Then $Fa = Wb - W_1b_1$ if the moment of the weight of the lever acts with the force, and $Fa = Wb + W_1b_1$ if the moment of the weight of the lever acts with the weight.

Example: A lever of the first class as in Fig. 40 weighs $1\frac{1}{2}$ lbs. per ft. of length. What force will balance a weight of 80 lbs.?

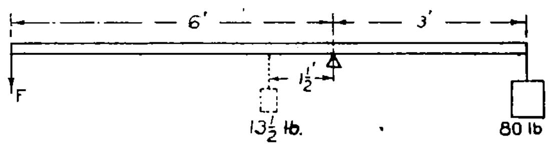


FIG. 40.

Here the center of gravity of the lever is on the same side of the fulcrum as the force, hence the moment of the lever is acting with the force, consequently we use the formula

$$Fa = Wb - W_1b_1$$

Transposing:

$$F = \frac{Wb - W_1b_1}{a}$$

$$W = 80 \text{ lbs.}$$

$$b = 3'$$

$$W_1 = 9 \times 1\tfrac{1}{2} = 13\tfrac{1}{2} \text{ lbs.}$$

$$b_1 = 6' - 4\tfrac{1}{2}' = 1\tfrac{1}{2}'$$

Substituting:

$$F = \frac{80 \times 3 - 13\frac{1}{2} \times 1\frac{1}{2}}{6}$$

$$= \frac{240 - 20.25}{6} = \frac{219.75}{6} = 36.625$$

PROBLEMS

34. A lever of the first class supports a weight of 75 lbs. 4 ft. from the fulcrum. What force is necessary 6 ft. from the fulcrum, if the lever is the same shape and size throughout its length and weighs 2.5 lbs. per foot of length?

35. What force 8 ft. from the fulcrum is required in a lever of the second class to balance a weight of 150 lbs. 2 ft. from the fulcrum, if the lever is of uniform dimensions throughout its length and weighs 5 lbs. per ft. of length?

36. In a lever of the third class, what force 6 ft. from the fulcrum is necessary to balance a weight of 50 lbs. 8 ft. from the fulcrum if the lever is of uniform size and shape throughout its entire length, and weighs 4 lbs. per foot of length?

37. Neglecting the weight of the lever in Fig. 41, what force is necessary to balance the two weights if W = 10 lbs. and Y = 8 lbs.?

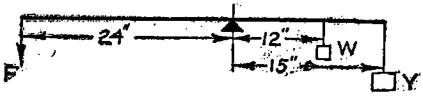


FIG. 41.

38. If the lever in Prob. No. 37 weighs 5 lbs. per foot of length and has the same size and shape throughout its length, what will be the value of the force F?

Beams, Reactions at Supports—When a beam is loaded by weights or forces the sum of the reactions at the supports equals the sum of the loads, the reactions being the supporting forces, at the ends of the beam on the supports. If the load is uniformly distributed as in Fig. 42, or if a concentrated load is supported at the middle point of the beam, the reaction at each end or support will be equal to half the total load. If the load is not evenly distributed but is nearer one support than the other, it is evident that the reaction on the nearer support is greater than the reaction on the support farther away.

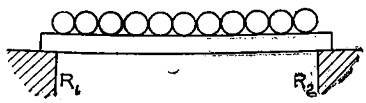


FIG. 42.

To calculate the reaction of a weight on either support assume that support as a force acting upward to lift the weight using the opposite support as a fulcrum. This assumes the beam to be a lever of the second class with, for example, R_1, Fig. 43, as the fulcrum. If it is desired to find the reaction of the weight W on R_2, consider this reaction as a force acting upward at R_2 then solve the lever formula for this force.

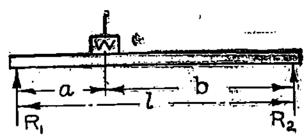


FIG. 43.

The result is the beam formula $R_2 = \frac{Wa}{l}$

The reaction of any other weights on R_2 may be found in like manner by dividing the product of the weight times the distance its center of gravity is from the opposite support by the entire length of the beam. The sum of these reactions will give the total reaction at R_2.

The reactions at R_1 may be found in like manner by assuming the force at R_1 and the fulcrum at R_2.

Example: In Fig. 44 a load "A" of 500 lbs. is supported at a point 6 ft. from the left support and a load "B" of 600 lbs. is supported at a point 12 ft. from the left support. If the reactions at the right and left supports are designated R_2 and R_1 respectively, then the total reaction at R_2 is found by the formula $R_2 = \frac{Wa}{l}$

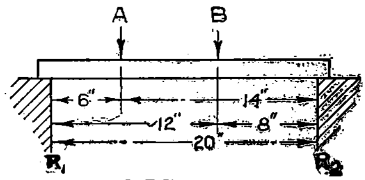


FIG. 44

$$\text{For weight A} \quad R_2 = \frac{500 \times 6}{20} = \mathbf{150}$$

$$\text{For weight B} \quad R_2 = \frac{600 \times 12}{20} = \mathbf{360}$$

$$\text{Total reaction} = 150 + 360 = 510$$

Reaction R_1 is found in like manner using R_2 as fulcrum

$$\text{For weight A} \quad R_1 = \frac{500 \times 14}{20} = 350$$

$$\text{For weight B} \quad R_1 = \frac{600 \times 8}{20} = 240$$

$$\text{Total reaction} = 350 + 240 = 590$$

If the weight of the beam is considered, then an extra force is acting downward on each support equal to one-half the weight of the beam. The total reaction on each support may therefore be found by adding one-half the weight of the beam to both R_1 and R_2 as calculated.

PROBLEMS

1. Referring to Fig. 44, if load A were 1,200 lbs. and load B were 500 lbs., what would be the reactions R_1 and R_2, other conditions remaining the same?

2. A weight of two tons is supported by a beam whose supports are 15 ft. apart and is 6 ft. from one of them. Draw a sketch and find the reaction at the two supports.

3. Two men are carrying a casting weighing 220 lbs. on an iron bar 6 ft. long. Neglecting the weight of the bar, how much must each man carry if the weight is 2 ft. from one end?

4. If the beam in Prob. No. 1 weighs 10 lbs. per foot of length, find the reactions R_1 and R_2, other conditions remaining the same.

5. Other conditions remaining the same and assuming the beam in Prob. No. 2 to be a 10-inch I-beam weighing 25 lbs. per foot of length, what then would be the reactions at the supports?

6. A K4s locomotive weighing 308,900 pounds is standing on a bridge 82 ft. long. Find the reactions R_1 and R_2 if the total weight is assumed to be concentrated at a point 38 feet from R_2.

7. From the diagram, Fig. 45, find the weight supported by the locomotive frame at each of the points A, B and C.

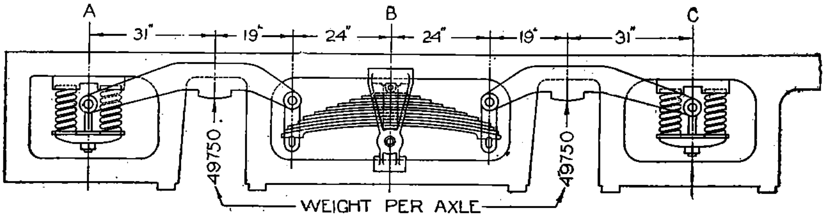


FIG. 45.

THE WHEEL AND AXLE

In its simplest form the wheel and axle consists of a grooved wheel into which fits a rope or chain and to which is rigidly fixed a drum or axle as shown in Fig. 46. Around the axle is wound another rope or chain, on the end of which the weight is suspended as indicated. The wheel and axle is a modification of the lever that can be rotated continuously and thus lift weights through a larger distance with a small force. It has been found that the pulls on the ropes are inversely proportional to the radii of the wheel and axle. A little study will show that the wheel and axle may easily be considered as a modified lever with the force F acting on a lever arm R equal to the radius of the wheel; and the weight W, on a lever arm r equal to the radius of the axle. The formula for the wheel and axle then is

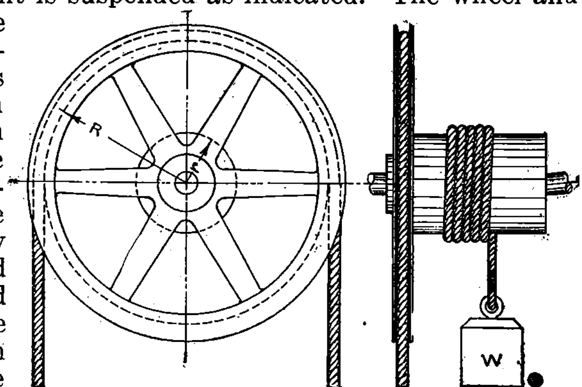


FIG. 46.

$$FR = Wr$$

Probably the simplest example of the use of the wheel and axle is the windlass which is used extensively for hoisting. The geared windlass shown in Fig. 47 may be considered an application of the principle of compound levers. The crank and pinion form the first lever and the large gear and drum form the second lever; the force applied at the crank handle being transmitted through the teeth of the gears to the load through a rope wound around the drum. Example: Assume the

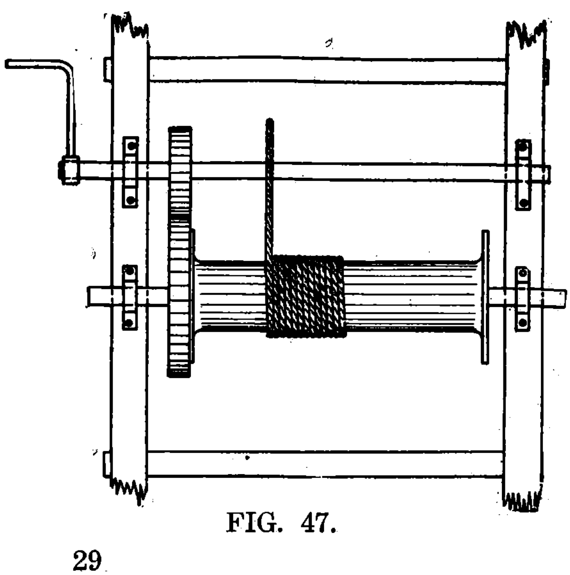


FIG. 47.

crank of the windlass in Fig 47 to be 18″ long, the pinion 6″, the gear 28″, and the drum 12″ in diameter respectively. What load could be raised by a man exerting a force of 50 lbs. on the crank? Solution:

Let $F =$ force exerted.
$R =$ length of crank arm.
$R_1 =$ radius of gear.
$r_1 =$ radius of pinion.
$r =$ radius of drum.
and $W =$ weight.

then $$W = \frac{FRR_1}{r_1 r}$$

or $$W = \frac{50 \times 18 \times 14}{3 \times 6} = 700$$

If the diameters of the gear and pinion are not known, the radii of the gear and pinion may be replaced by the number of teeth on the gear and pinion respectively, in which case, instead of R_1 use T for the number of teeth on the gear and for r_1 use t for the number of teeth on the pinion. The formula then becomes:

$$W = \frac{FRT}{tr}$$

In actual practice, the weight lifted will be somewhat less than that calculated on account of loss due to friction in the gears and bearings.

PROBLEMS

1. Neglecting friction, what force would be necessary to raise a drill press weighing 520 lbs., if the crank of the hoisting crab or windlass in Fig. 47 is 20″ long, the pinion diameter 8″, the gear diameter 30″ and the diameter of the drum 10″?

2. The wheel on a wheel and axle is 48 inches in diameter and the axle is 18 inches in diameter. Neglecting friction, what pull on the rope on the wheel will be necessary to raise a weight of 320 lbs. on the drum?

3. What pull would be necessary on the rope in Prob. No. 2, if the efficiency of the wheel and axle is 95%?

4. How much could a man weighing 150 lbs. raise with the wheel and axle in Prob. No. 2, by putting his whole weight on the rope, if the efficiency is 90%?

5. If the hoist in Fig. 47 has a crank 20 inches long, an 8-inch diameter drum, a 10-inch diameter pinion, and a 36-inch diameter gear, what load can be raised by a force of 50 lbs. on the crank handle, assuming the efficiency to be 65%?

6. If the gear and pinion in the hoist in Prob. No. 5 have diameters of 40 inches and 8 inches respectively, what load can be lifted by a force of 75 lbs., other conditions remaining the same?

7. If the gears in the hoist in Fig. 47 are so arranged as to cause the weight to be lifted one foot for each turn of the 20-inch crank, what is the efficiency of the hoist if a force of 80 lbs. is required to lift a weight of 500 lbs.?

8. In Fig. 46, if the wheel has a diameter of 42 inches and the axle has a diameter of 12 inches, what is the efficiency of the wheel and axle if a force of 30 lbs. is required to raise a weight of 78.75 lbs.?

BLOCK AND TACKLE

Block and tackle is the name given to a simple machine consisting of a rope passing over a grooved pulley, or wheel, turning about a pivot in a frame or shell. It is used extensively for hoisting. A pulley is used to change the direction of application of a force as well as to reduce the value of a force necessary to lift a given weight. Fig. 48 shows a single pulley which serves merely to change the direction of application of the force. Aside from the fact that it is often more convenient to pull downward there is no advantage in an arrangement of this kind. This arrangement may be compared to a first class lever having lever arms each equal to the radius of the pulley and the force, of course, will equal the weight. Fig. 49 shows a single movable pulley in which the force moves in the same direction as the weight. This pulley may be compared to a second class lever in which the force arm is equal to the diameter of the pulley and the weight arm is equal to the radius of the pulley, and

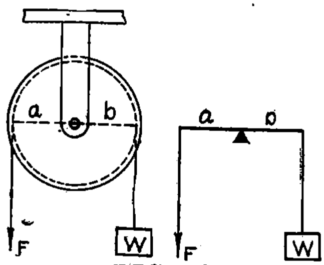


FIG. 48.

$$FD = Wr$$

$$\text{then} \quad F = \frac{Wr}{D}$$

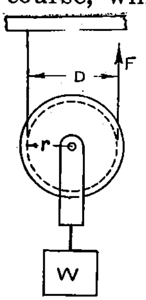


FIG. 49.

Since r is one-half of D, it is seen that the force F in this case is only one-half of the weight. Fig. 50 is a combination of the pulleys in Figs. 48 and 49.

Except for the change in direction of the application of the force there is no change in the relation of the force and the weight in Fig. 50 from that in Fig. 49.

The usual practice is to use two blocks, one fixed to a solid object and the other movable as shown in Fig. 51. It will be seen that the weight is supported by four ropes and the stress in each rope must therefore be equal to one-fourth of the weight. The stress in rope "A" is equal to the force F, therefore, the force F is equal to one-fourth of the weight. Neglecting friction, then, **the force**

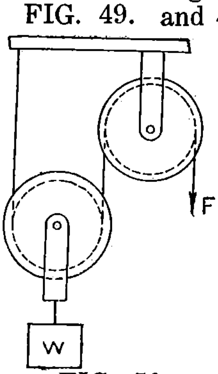


FIG. 50

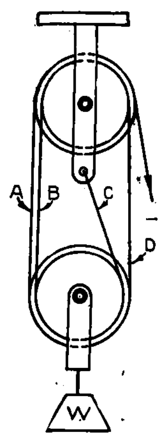


FIG. 51.

required to raise a given weight with a system of block and tackle is equal to the weight divided by the number of ropes holding the load, or

$$F = \frac{W}{N}$$

in which N = No. of ropes holding the load,
while F represents the force
and W represents the weight.

Whenever convenient, it is best to use as the movable block, the one from which the free end of the rope runs. In this case the force will act in the same direction that the weight is to be moved and one more rope is added to the movable block, decreasing the required force. Here, using two pulleys in each block as in Fig. 52, the force equals the weight divided by five or is one-fifth the weight instead of one-fourth as in Fig. 51. It will also be seen that the distance the force moves in comparison to the distance the weight moves increases directly as the number of ropes holding the load increases. In other words, the force in Fig. 52 will travel five times as far as the weight; if the weight is moved 2 feet, then the force must move 5 x 2 or 10 ft.

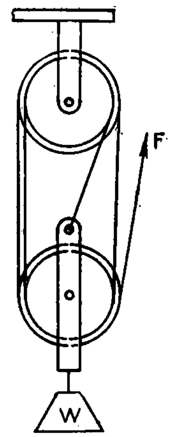


FIG. 52.

In actual practice only about 60% of the theoretical weight can be raised, the other 40% being lost in overcoming friction. Likewise the force required to raise a given load would be such that 60% of its value is equal to theoretical pull.

PROBLEMS

1. With the arrangement shown in Fig. 48, what weight can be raised by a force of 75 lbs.?

2. What force will be necessary to raise a weight of 130 lbs. with the arrangement in Fig. 49?

3. With a force of 60 lbs. applied at F, Fig. 50, what weight can be raised?

4. Neglecting friction and the weight of the lower block and hook, what weight can be raised with the arrangement shown in Fig. 51 by a force of 150 lbs.?

5. If the lower block and hook in Fig. 51 weigh 20 lbs., what weight can be raised by a force of 125 lbs. at F?

6. If the blocks in Fig. 51 were reversed so that the free end of the rope runs over the movable pulley, what then would be the weight raised by a force of 150 lbs. at F?

7. It is desired to raise a weight of 280 lbs. with the arrangement shown in Fig. 52. If the lower block and hook weigh 50 lbs., what force is necessary at F?

8. Draw a sketch of a pair of blocks having 3 pulleys each, and indicate which should be the movable block in order to secure the greatest mechanical advantage.

9. With the arrangement in Prob. No. 8, what would be the pull at F necessary to lift a weight of 650 lbs. if the efficiency is 42%?

10. If the weight in Prob. No. 9 is to be raised 6 ft., what distance would the force on the free end of the rope have to move?

11. An arrangement of two pulley blocks with an efficiency of 55% and containing two pulleys each, is used to lift a casting weighing 275 lbs. from the floor to a bench, a distance of 2½ ft. What downward pull is necessary on the rope? How many feet of rope will leave the blocks?

12. A main rod of a locomotive weighing about 1,285 lbs. is lifted by an arrangement of two pulley blocks with two pulleys in each block. If the pulleys offer a resistance of 12% and the free end of the rope passes over the fixed pulley and two men are put on the job, what pull must each exert to raise the rod?

THE DIFFERENTIAL HOIST

The differential hoist is extensively used for lifting heavy weights by hand. It is somewhat similar to the wheel and pulley, an endless chain being substituted for the wheel and rope and a double sheave for the axle or drum. The differential hoist is capable of lifting heavy loads and the load will remain suspended, because the difference in the diameters of the double sheave at the top is too small to overcome the friction in the hoist and allow the load to descend. In the differential hoist shown in Fig. 53, pulleys A and B are rigidly fastened together and turn on the same center. Pulley C is a single movable pulley to which the hook is attached. The endless chain passes over the pulley A then down around pulley C and then over pulley B. From the figure, it will be seen that if a force acts downward on loop K until pulley A has made one complete turn, then branch G of the chain around pulley C will be shortened a distance equal to the circumference of Pulley A. At the same time, branch E will be lenghthened a distance equal to the circumference of pulley B. Hence, the loop EG will be shortened a distance equal to the difference between the circumferences of A and B, and pulley C will rise one-half of this distance. If D and d represent the diameters of large and small pulleys A and B, respectively, this distance or the amount the loop EG is shortened may be expressed as follows:

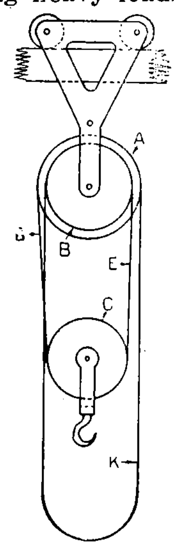


FIG. 53.

$$\pi D - \pi d \text{ or } \pi(D - d)$$

Then the pulley will be raised one-half this distance, or

$$\tfrac{1}{2} \text{ of } \pi(D - d) \text{ or } \frac{\pi(D - d)}{2}$$

To cause this upward motion of pulley C, the force on loop K must move a distance equal to the circumference of pulley A or πD.

Since the load and the force are inversely proportional to the distance through which they must move, the following formula holds true:

$$\frac{F}{W} = \frac{\pi(D - d)}{2\pi D}$$

Since π both multiplies and divides the right hand member of the equation, the formula may be written as follows:

$$\frac{F}{W} = \frac{D - d}{2D}$$

Where F is the applied force and W is the weight to be raised.

Since the mechanical advantage is the distance through which the force moves divided by the distance through which the weight moves,

$$\text{Mechanical advantage} = \frac{\pi D}{\frac{1}{2}\pi(D - d)} = \frac{D}{\frac{1}{2}(D - d)} = \frac{2D}{D - d}$$

The force required to lift a certain weight, then, can be found by dividing the given weight by the mechanical advantage.

Example: A weight of 750 lbs. is to be raised by means of a differential pulley arrangement, such as is shown in Fig. 53. What force is required to raise the weight if the diameters of the large and small pulleys are 12″ and 10″ respectively?

$$\frac{F}{W} = \frac{D - d}{2D}, \quad F = \frac{W\ (D - d)}{2D}$$

$$W = 750 \text{ lbs.}, \ D = 12'', \text{ and } d = 10''$$

$$F = \frac{750 \times (12 - 10)}{2 \times 12} = \frac{750 \times 2}{2 \times 12} = 62.5 \text{ lbs.}$$

Solution by the use of mechanical advantage,

$$\text{Mechanical advantage} = \frac{2D}{D - d} = \frac{2 \times 12}{12 - 10} = 12$$

$$750 \div 12 = 62.5 \text{ lbs. Force.}$$

On account of losses due to friction, the differential hoist of this kind, however, can actually lift only about 30 per cent of this theoretical load with a given force. In other words, to lift the given load would require a force about 3⅓ times that found above. The actual force necessary in the above example would then be,

$$62.5 \div .30 = 208.3 \text{ lbs.}$$

PROBLEMS

1. The pulleys of a differential hoist are 10″ and 7″ in diameter respectively. Neglecting friction, what force would be required to lift a load of 320 lbs.?

2. What force would be necessary in Prob. No. 1, if there is a loss of 70% due to friction in the pulleys?

3. In a differential hoist with pulleys 12″ and 8″ in diameter, a load of 200 lbs. was lifted by the application of a force of 40 lbs. What force was used in overcoming the friction?

4. From the rule of the differential pulley, find the force necessary to lift a tank weighing 260 lbs. if the diameters are 12″ and 9″ and only 25% of the pull is effective.

5. What is the mechanical advantage of the differential hoist in Prob. No. 4?

6. A differential hoist has a mechanical advantage of 10. With an efficiency of 32%, what weight can be lifted by the application of a force of 30 lbs.?

SCREW THREADS

The screw thread is based upon a curve known as the **Helix.** If a point moves around a cylinder at a uniform rate, and at the same time moves at a uniform rate in the direction of the axis of the cylinder, as shown in Fig. 54, the resulting curve will be the helix. The same result will obtain if the point moves in the direction of the axis of the cylinder while at the same time the cylinder rotates at a constant speed.

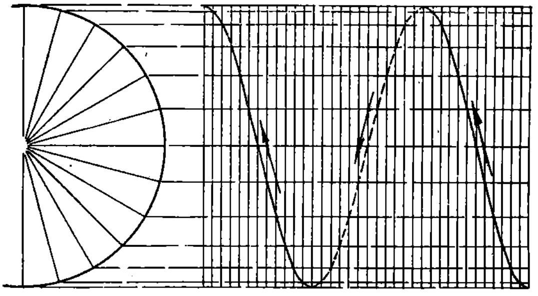


FIG. 54.

A thread is formed by cutting a uniform helical groove around a cylinder, or bar. Fig. 55 shows a right hand thread or one which turns in the direction of the hands of a clock when screwed into a nut. The left hand thread, Fig. 56, is one which turns in the opposite direction to the hands of a clock when screwed into a nut.

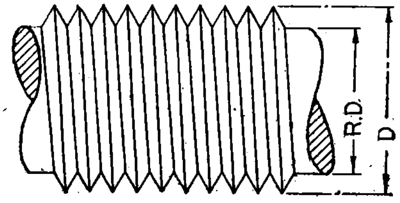


FIG. 55

The point of a thread is the top as point a, Fig. 57.

The root of a thread is the bottom of the groove as b, Fig. 57.

The diameter of a thread is the outside diameter as D, Figs. 55 and 56.

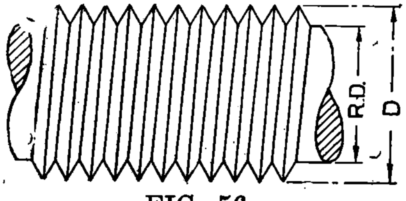


FIG. 56.

The root diameter of a thread is the diameter at the root as R. D., Figs. 55 and 56.

The depth of a thread is the vertical distance from the point to the root as d, Fig. 57.

The pitch of a thread is the distance from a point on one thread to the same point on the next thread as p, Fig. 57.

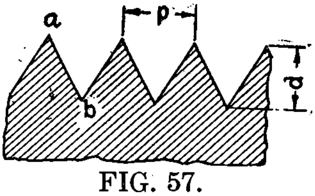


FIG. 57.

The lead of a screw or thread is the distance the screw will move forward, in the direction of the axis of the screw, in one complete turn.

There are numerous threads in use, namely, the V thread, National thread, Whitworth Standard, Buttress, Square, Acme, Pipe, etc. Those commonly used in the United States are the sharp V thread, the National thread, the Square, the Acme, and the Brigg's Pipe threads.

The Sharp V Threads—The sharp V thread, Fig. 58, is cut by a tool having an angle of 60 degrees so that the faces of the thread form an agle of 60 degrees. The threads should have sharp tops when properly cut and a sharp groove at the bottom.

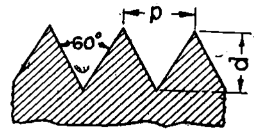


FIG. 58

The National Thread—The National form of thread, Fig. 59, is a modification of the sharp V thread. The advantages of this thread are that it is not so easily injured; taps and dies will retain their shape longer, and screws having these threads are stronger. This thread is the same as the sharp V thread with the tops and bottoms of the threads flattened.

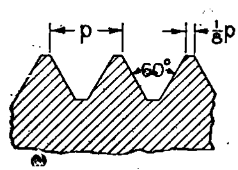


FIG. 59

There are two series of National threads, known as the **National Coarse thread,** formerly the United States Standard thread, and the **National Fine thread,** formerly the S. A. E. thread. The latter is used for work on automobiles and machines where a fine thread is more suitable.

Example: In the National Coarse thread series, a 1-inch diameter bolt has 8 threads per inch while in the National Fine thread series, the 1-inch bolt has 14 threads per inch.

The width across flats of the National thread is always 1/8 of the pitch.

Both the sharp V thread and the National threads are known as fastening threads, that is, they are used for fastening two or more pieces or objects together.

Depth of V and National Threads—If a V thread has a pitch of 1″ it can be shown by the right angle triangle method that the depth is .866″. Fig. 60 shows the profile of a V thread. Since the angle of the V thread is 60 degrees, it will be seen that the sides of the thread and a line connecting the points of two consecutive threads, as points A and B, form an equilateral triangle. A line joining the middle point of line AB and the bottom of the thread as line EC divides the triangle into two equal right triangles. Since the triangle ABC is an equilateral triangle and the pitch is 1″ the sides AC and BC are also equal to the pitch or 1″. The distance AE equals one-half the pitch or ½″. By the right triangle method then the depth d is equal to

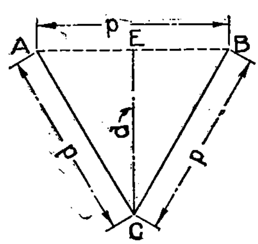


FIG. 60.

$$\sqrt{1^2 - (1/2)^2} \text{ or } .866''$$

To find the depth of any other sharp V thread, divide .866 by the number of threads per inch.

Example: A 1″ diameter bolt has 8 sharp V threads per inch. Find the depth of the threads.

$$\text{Depth of threads, } d = \frac{.866}{8} \text{ or } .1082''$$

Depth of National Threads—Since the National thread is flattened ⅛ of the pitch at the top and bottom, the depth of that part of the thread cut off at both the top and the bottom, represented by the distance (a), Fig. 61, will be equal to ⅛ of .866 or .108. The depth of a National thread having a pitch of 1″ will therefore be,

$$.866 - (2 \times .108) \text{ or } .866 - .216 \text{ or } .65''$$

To find the depth of any National thread divide .65 by the number of threads per inch.

Example: A 1″ diameter bolt has 8 threads per inch of the National form. Find depth of thread.

Solution: $.65 \div 8 = .08125''$.

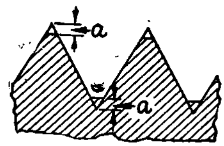


FIG. 61.

To find the diameter at root of threads: The diameter at the root of the threads is equal to the diameter of the bolt less twice the depth of the threads.

For the V thread,

$$\textbf{Root Diam., } \text{R. D.} = D - \frac{.866 \times 2}{N}, \text{ or } D - \frac{1.732}{N}$$

For the National thread,

$$\textbf{Root Diam., } \text{R. D.} = D - \frac{.65 \times 2}{N}, \text{ or } D - \frac{1.3}{N}$$

Where N equals the number of threads per inch.

It is understood that the root diameter is the diameter of the drill that may be used for drilling the hole to be tapped.

The Square Thread—The square thread, Fig. 62, is sometimes used for transmitting power. From the figure it will be seen that all dimensions are equal. In actual practice, the space between the threads is made a trifle larger than the width of the thread in order to provide clearance. This is also true of the depth. There is no definite standard of pitch for the square thread but the number of threads per inch is usually taken as half the number of V or National Coarse threads that would be used on a bar or bolt of corresponding size.

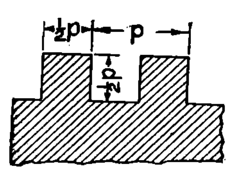


FIG. 62.

The Acme Thread—The Acme thread, Fig. 63, is a modification of the square thread. The angle between the sides of the acme thread is 29 degrees. The depth of the thread is one-half the pitch plus .010″, for clearance. The nut for the acme thread is made .020″ over size. Fig. 64 shows the relation between the diameters of the screw and nut. If D is

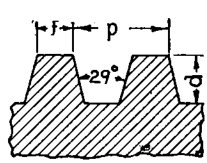


FIG. 63.

the outside diameter and R. D. the root diameter of the screw, the corresponding dimensions of the nut are D + .020″ and R. D. + .020″. If p is the pitch of the thread, f the width of top of thread, and b the width of flat at the root of the thread, the following formulas will give the dimensions of the acme thread:

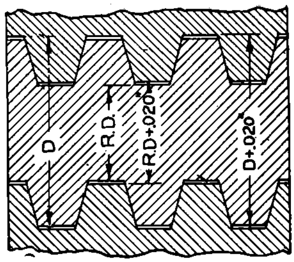


FIG. 64.

For Screw	For Nut
$d = \frac{1}{2}p + .010''$	$d = \frac{1}{2}p + .020''$
$f = .3707p$	$f = .3707p - .0052''$
$b = .3707p - .0052''$	$b = .3707p - .0052''$

Diameter of tap equals diameter of screw + .020″.

Diameter at root of thread equals diameter of screw — (p + .020″).

Brigg's Pipe Threads—Pipe threads are used on the ends of wrought iron and steel pipes and in the holes and fittings into which the pipes are to enter. The pitch of the pipe thread is finer than that of the standard thread for a cylinder of the same diameter as that of the outside diameter of the pipe. There are two reasons for this—1st, to insure tightness of the joint, and 2d, if the pitch were too great the threads would be so deep as to make the pipe weak at the joint. To further insure a tight joint, pipe threads have a taper of 1″ in 32″, that is, for the Brigg's thread, the end of the pipe on which the threads are cut, has a taper of 1″ in 32″ with the axis, which gives a total taper of ¾ of an inch per foot. This thread like the V and National threads, has an angle of 60 degrees but is slightly rounded at top and bottom, so that the depth of the thread instead of being .866 x pitch is only four-fifths of the pitch or .8 x pitch. Fig. 65 shows a profile of the Brigg's pipe thread. The threads are perfect at top and bottom for a distance equal to $(0.8A+4.80)\frac{1}{N}$ where A is the actual outside diameter of the pipe in inches and N is the number of threads per inch. Beyond these perfect threads are two threads which are perfect at the bottom, but imperfect at the top. The remaining threads are imperfect both at top and bottom.

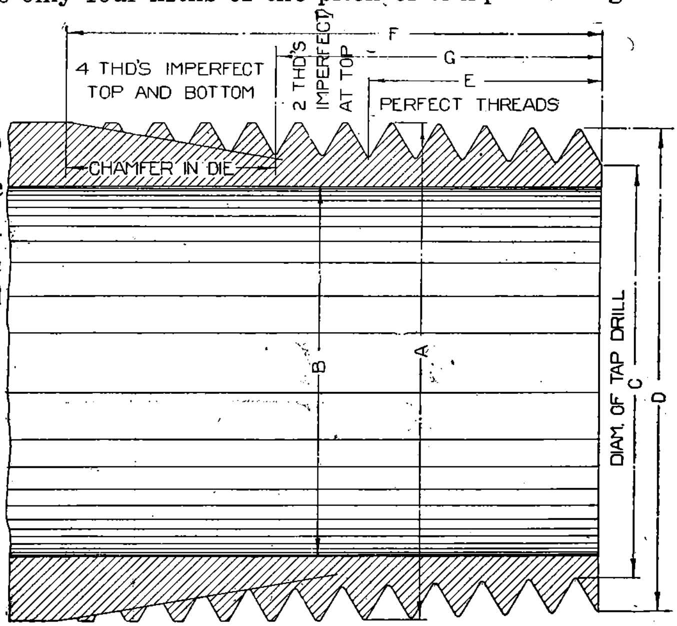


FIG. 65.

STANDARD PIPE AND PIPE THREADS

A = Outside diameter of pipe.
B = Inside diameter of pipe.
C = Root diameter of thread at end of pipe.
D = Outside diameter of thread at end of pipe.
E = Length of perfect thread.
F = Total length of thread.
G = Length of perfect thread plus two threads.

BRIGG'S FORMULA

$$E = \text{Perfect thread} = (4.8 + 0.8A)\frac{1}{N}$$

$$P = \text{Pitch of thread} = \frac{1}{N}$$

N = Number of threads per inch.
F = Length of taper at top.
Taper ¾″ to one foot.

$$\text{Depth of thread} — .8\frac{1}{N}$$

G = Length of taper at bottom.

Multiple Threads—Where a single thread will not produce sufficient motion in the direction of the axis of the thread, a double, triple, or even quadruple thread is used according to the axial speed desired. The double thread consists of two helices or threads winding around the cylinder, a triple thread consists of three threads winding around the cylinder. etc. The single, double, and triple threads are shown in Figs. 66, 67 and 68. It was said that the pitch of a thread is the distance from a point on one thread to the same point on the next thread. This rule holds good for all kinds of threads.

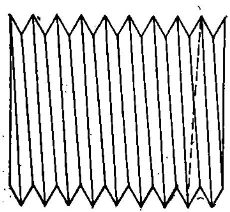


FIG. 66.

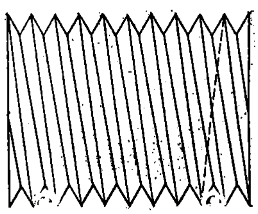


FIG. 67.

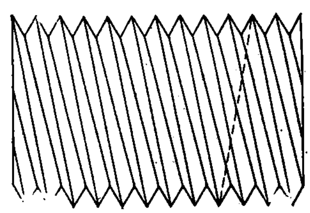


FIG. 68.

A nut will advance in one turn a distance equal to the pitch in the case of the single thread. With the double thread, however, a nut would advance a distance equal to twice the pitch, with the triple thread, the advance would be three times the pitch. The advance in one turn is called the **lead.** In other words, **the lead is equal to the advance in one complete turn.** With the single thread, then, the lead is equal to the pitch, with the double thread, the lead is equal to twice the pitch, with the triple thread the lead is equal to three times the pitch, etc.

Fig. 69 brings out the idea of the triple thread more clearly. The separate threads can easily be followed by referring to the numbers. The second and third threads are not completed in this figure with the idea of bringing out more clearly the three separate threads. Here, too, the difference between the pitch and the lead is easily seen.

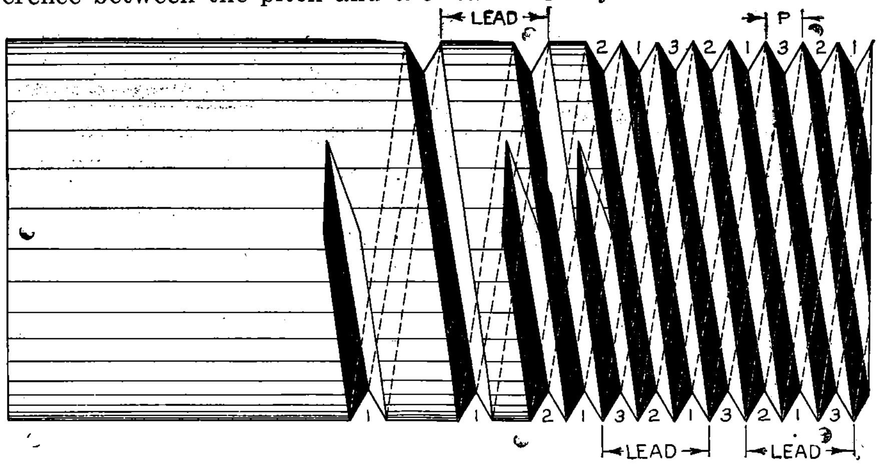


FIG. 69.

Thread Cutting Tools—When a larger number of pieces are to be threaded, especially where accuracy as to pitch is not essential, taps and dies are used. The taps and dies may be operated by hand, but the usual practice is to use power driven machines equipped with dies. Threads may be, and frequently are, cut by a milling process on a thread milling machine. When threads are cut in a lathe, a tool having a point corresponding to the shape of the thread is used, and the lathe carriage is moved along the bed a certain distance for each revolution of the work, the distance depending upon the lead of the screw and the number of threads to be cut per inch. The piece is rotated in the machine and the thread is formed by taking a number of successive cuts.

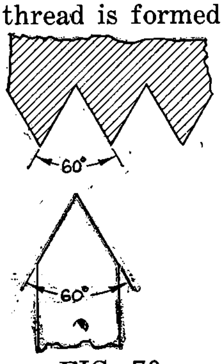


FIG. 70.

The V thread is cut with a tool having a sharp point, the sides of which are ground to an angle of 60 degrees as shown in Fig. 70. The tool used for cutting the National form of thread is similar to that used for cutting the V thread. This tool has the same angle as the V thread tool, but the point is flattened to a width equal to the width of the flat of the National thread as f, Fig. 71.

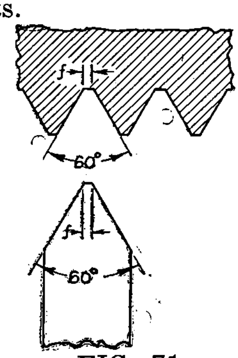


FIG. 71.

A square thread is cut with a square nosed tool similar to a cutting-off tool except that the thread has a side clearance angle to fit the slant of the thread. Such a tool is shown in Fig. 72.

The side clearance angle of the tool must be equal to the angle of slant of the thread. Assume that a square thread having a ½″ pitch is to be cut on a 2-inch diameter bar. The distance the work will travel past the end of the tool in one complete turn is equal to the circumference of the bar or in this case, the circumference of a 2-inch diameter circle and at the same time it will move forward a distance equal to the pitch or ½ inch. The angle of lead and consequently the angle of clearance will then be equal to angle a, Fig. 73, in which the distance BC is equal to the pitch or ½ inch and the distance AB is equal to the circumference of the 2-inch diameter bar.

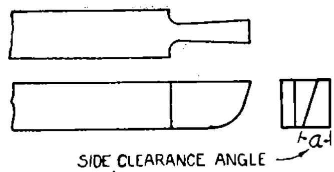


FIG. 72.

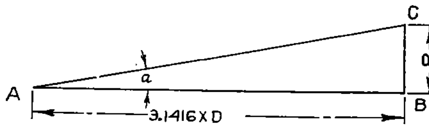


FIG. 73.

For cutting Acme threads a tool similar to that shown in Fig. 74 is used. The angle of the sides of the tool is 29 degrees and the point is ground to a width equal to the width of the flat at the bottom of the thread. The thread is cut to a depth equal to one-half the pitch plus .010″ or ½p + .010″. the tool is usually ground to fit a gauge having notches representing different pitches, which gives the proper angle of 29 degrees and the correct width of point.

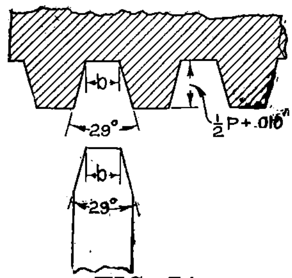


FIG. 74.

PROBLEMS

1. What is meant by the pitch and the lead of a thread?

2. Name the different threads in common use in the United States.

3. What is the advantage of the Acme thread over the square thread?

4. What is the advantage of the National form of thread over the V thread?

5. A 1″ diameter bolt has a single thread, 8 threads per inch, National form. What is its pitch and the lead?

6. A rod 2″ in diameter is threaded with a single National form thread, 4½ threads per inch. What is the pitch and the lead of the thread?

7. Find the width of flat and the depth of the thread in Prob. 6.

8. A 1¾″ diameter rod is threaded with a sharp V thread, 5 threads per inch. What is the depth of this thread? What is the diameter at the root of the threads?

9. What is the diameter at the root of the threads in Prob. No. 6?

10. A double square thread advances $\frac{3}{4}''$ in three complete turns. What is its pitch and lead?

11. What is the pitch and lead of a triple Acme thread which advances $2\frac{1}{4}$ inches in four complete turns?

12. A triple Acme thread is to have a lead of $\frac{3}{4}''$. Find its depth, width across flats at the points of the threads, and the width across flats at the bottom of the threads.

13. A triple thread has a pitch of $\frac{3}{16}''$. What will be the advance in 10 complete turns?

14. Find the size of tap drill for a 1″ diameter tap having 8 sharp V threads per inch.

15. Find the size of tap drill for a $1\frac{1}{4}''$ diameter tap having 7 threads per inch, National form.

16. Find the double depth of a thread of the National form having $3\frac{1}{2}$ threads per inch.

17. A double worm screw with $\frac{3}{4}$-inch pitch is used to drive a planer bed. How far will the planer bed advance with 50 revolutions of the screw?

18. Which will advance the farther in one turn and how much; a triple threaded screw with a $\frac{5}{16}''$ pitch or a double threaded screw with a 1″ lead?

19. The pitch of an Acme thread is $2\frac{1}{2}$ inches. Find the width of flat on top, the width of flat at the bottom and the depth of the thread.

20. What is the tap drill size for a 1-inch nut having 8 threads per inch, National coarse?

21. What is the tap drill size for a 1-inch nut having 14 threads per in, National fine?

22. What is the tap drill size for a $\frac{1}{4}$-inch 20 pitch sharp V thread?

23. What would be the tap drill size in Prob. No. 22 if the threads were of the National form?

24. What is the tap drill size for a $\frac{3}{8}''$ thread 16 threads per inch of the National form?

25. Find the tap drill size for a $\frac{1}{2}$-inch thread 13 threads per inch of the National form.

THE INCLINED PLANE

The inclined plane is a surface which slopes or makes an angle with the horizontal. It is extensively used for raising bodies from one level to another. A wedge is a form of the inclined plane, the powerful effect of which is used in splitting logs, quarrying stone, aligning heavy machinery, etc. The inclined plane, like the tackle blocks, enables a heavy weight to be raised by the application of a smaller force. Here, also, the distance through which the force must move to lift a given weight, increases as the value of the force decreases.

The force acting upon a body tending to move it along a plane may be inclined in several ways as indicated by the arrows A, B and C, Fig. 75, in which A acts parallel to the plane, B acts upward at an angle with the surface of the plane tending to lift the weight from the plane at the same time that it pulls the weight along the plane, and C acts parallel to the base of the plane tending to pull the weight against the plane at the same time that the weight is pulled along the plane. In this discussion only forces parallel to the plane will be considered. Referring to Fig. 76, where F is the force required to pull the weight up the plane, W is the weight to be raised, h is the height of the plane, or the distance the weight is to be raised vertically, l is the length of the plane or the distance through which the force must act in raising the weight. If the weight is to be raised the distance h then the work done is Wh. The force in raising the weight must act through the distance l and the work done by the force is Fl. Neglecting friction, the work required to raise the weight through the distance h and the work done by the force F moving through the distance l are equal, or

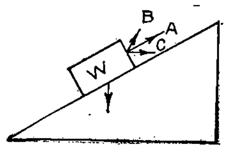


FIG. 75.

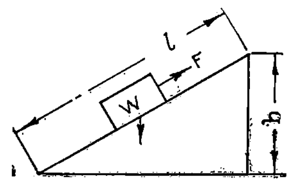


FIG. 76.

$$Fl = Wh$$

In other words the **force times the length of the plane is equal to the weight times the height of the plane.** From this formula, problems involving the inclined plane may be solved.

Example: Neglecting friction, what weight can be held on a plane 15 ft. long and 8 ft. high by a force of 40 lbs.?

Solution:

$$Fl = Wh$$

$$F = 40,\ l = 15, \text{ and } h = 8$$

$$W = \frac{Fl}{h}$$

$$= \frac{40 \times 15}{8} = 75 \text{ lbs.}$$

The Wedge—The wedge, Fig. 77, is a form of the inclined plane and may be considered as two inclined planes placed base to base. With the wedge it will be seen from Fig. 77 that the force will act, as indicated, in the direction of the center line of the wedge, and the weight will be raised a distance equal to h. The work done by the force in driving the wedge will, therefore, be equal to Fl and the work done in raising the weight W will be equal to Wh. Neglecting friction, the work done in driving the wedge is equal to the work done in raising the weight, or

$$Fl = Wh$$

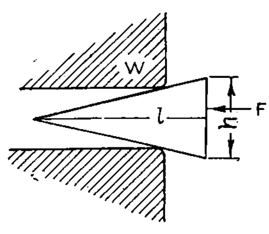


FIG. 77.

A comparison will show that this formula is the same as that for the simple inclined plane, except that l is equal to the length of the wedge, through the center.

The Screw-Jack—The screw-jack is another application of the inclined plane which instead of rising straight, is wrapped around or cut into a piece of round steel forming a screw. If a piece of paper is cut to represent a plane as shown in Fig. 78, and is wound around a cylinder, the result has the form of an inclined plane wrapped around the cylinder, or a thread.

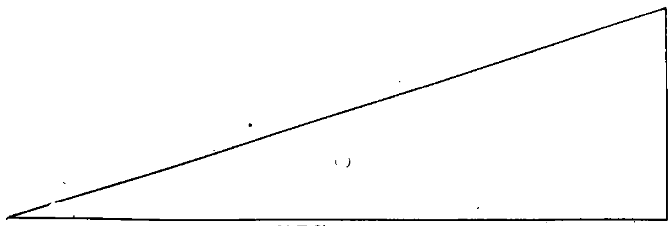
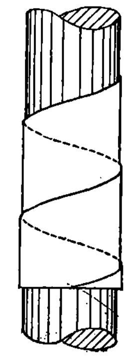


FIG. 78.



The screw-jack is used to raise heavy loads and has the form shown in Fig. 79, in which the weight is raised by turning the screw by means of the handle A. When the screw makes one turn the load will be raised a distance equal to the pitch p of the thread and the work done in raising the load will be equal to Wp. While the load is being raised a distance equal to the pitch, the handle will make one complete turn and the force F on the end of the handle will travel through a distance equal to the circumference of a circle whose radius is equal to the length L of the handle. The work done by the force will, therefore, be equal to the circumference of the circle times the force or $2\pi LF$. Neglecting friction, the work done in raising the weight a distance equal to the pitch will be equal to the work done by the force during the same period, or

$$2\pi LF = Wp$$

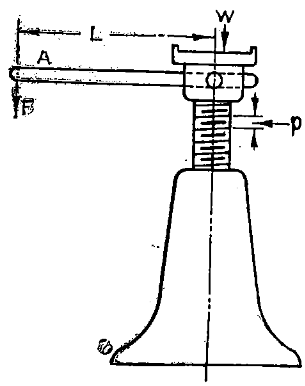


FIG. 79.

It must be remembered that the length L of the handle and the pitch of the thread must be in the same units, that is, they must both be in inches or both in feet.

Example: A load of 2,200 lbs. is to be raised by means of a screw-jack. If the screw has 4 threads per inch, what force will be necessary at the end of the 20-inch handle?

Solution: $L = 20''$, $W = 2{,}200$ lbs., $p = \frac{1}{4}''$

$$2\pi LF = Wp$$

$$F = \frac{Wp}{2\pi L}$$

$$= \frac{2{,}200 \times \frac{1}{4}}{2 \times 3.1416 \times 20} = 4.37 \text{ lbs.}$$

This low value for the force would not obtain in actual practice due to the great amount of friction in the screw-jack.

PROBLEMS

1. The slope of an inclined plane is 250 ft. long and its height is 75 ft. What load can be held on the plane by a force of 360 lbs.?

2. What weight can be held on a plane by a force of 250 lbs. if the plane rises 5 ft. in every 22 ft. of horizontal distance?

3. What force will be necessary to haul a truck weighing 950 lbs. up an incline 25 ft. long and 8 ft. high, neglecting friction? What force will be required with an efficiency of 92%?

4. Neglecting friction, what force is required to haul a casting up an incline which rises 6 ft. in every 15 ft. of horizontal distance, if the casting and truck together weigh 1,250 lbs.?

5. What force is required in Prob. No. 4 if 30% of the force is used in overcoming friction? What is the efficiency in this case?

6. It is desired to load a casting weighing 230 lbs. on a car by sliding it along planks. If the car floor is 5 ft. 9 inches above the level of the ground and 12 ft. planks are used, what force is required to raise the casting if 65% of the force is used up in overcoming friction?

7. A force of 650 lbs. was required to wedge up a weight. If the taper of the wedge was 3 inches per foot, what was the weight moved, neglecting friction?

8. Fig. 80 shows an adjustable pillow block sometimes used for aligning shafts. If the shaft pushes downward with a force of 350 lbs., what force, neglecting friction, will be required to raise the shaft if the wedge has a taper of 3/4″ per foot?

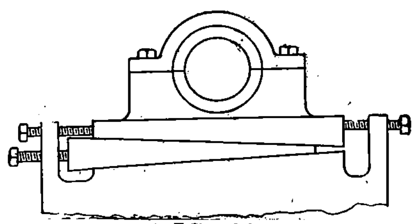


FIG. 80.

9. A screw-jack has 8 threads per inch. What weight, neglecting friction, can be raised by a force of 25 lbs., if the handle is 12 inches long?

10. What weight can be lifted by the screw-jack in Prob. No. 9, if the efficiency is 25%?

11. It is desired to raise a weight of 6,780 lbs. by the use of two screw-jacks. Each jack has three threads per inch and a 16-inch handle. If the efficiency of the jacks is 20%, what force will be necessary on the end of the handles?

12. A certain screw-jack has 4 threads per inch and an efficiency of 22%. What length of handle is required to lift a weight of 9,952 lbs. with a force of 90 lbs.?

PULLEYS AND BELTING

Pulleys or wheels keyed to shafts are extensively used for the transmission of power through belts. Pulleys are made of cast iron, steel, and wood, and a combination of these materials, and may be solid or built up of two or more pieces. Where wood and iron is combined to form a pulley, the usual method is to have a cast iron or steel center or hub to which the wood rim is joined with a solid web of wood. The split pulley consisting of a pulley made up of two pieces and bolted together, has the advantage that it can be placed between two other pulleys on a line shaft without removing either of the pulleys on the shaft. Wood pulleys have the advantage of being lighter than cast iron or steel pulleys, thus reducing the weight on the line shaft and bearings. The modern steel pulley also, has the advantage of lightness. It is either formed by rolling or by rolls and dies and the spokes are usually made up of sheet stock. Steel pulleys are usually of the split type, two pieces, and combine strength with lightness.

Crown Pulleys—Pulleys are usually made larger in diameter at the middle than at the edges. A pulley that is high in the middle is said to be **crowned.** The purpose of the crown is to keep the belt from running off without using guides or other mechanical devices.

To insure that the belt runs in its proper place, the highest point of the crown should be in the exact center and the two edges of the pulley should have exactly the same diameter.

Two methods of crowning pulleys are in general use, as shown in Fig. 81, namely, the taper crown and the curved crown. The position of the belt has been exaggerated to bring out more clearly the effects of crowning the pulley by the taper method. It will be seen by the illustration in Fig. 81-a that the belt will press closest to the pulley at the middle point B of the pulley and will fit more loosely near the edges. The effective driving is, therefore, done between the points A and C. In Fig. 81-b, the crown forms a symmetrical curve on which the belt makes a close contact over the entire width and is, therefore, more effective. The height to which the pulley should be crowned varies with different authorities, from $1/24$ to $1/20$ of the face width, while others advise $1/8$ inch to $1/4$ inch per foot of width of face.

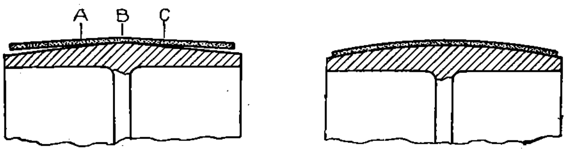


FIG. 81.

Speeds of Pulleys—When one pulley drives another through a belt their speeds in revolutions per minute, R. P. M., are inversely proportional to their diameters. If D is the diameter of the large pulley in Fig. 82, d the diameter of the small pulley and N and n the speeds of the large and small pulleys respectively, then

$$D : d = n : N$$

and $$DN = dn$$

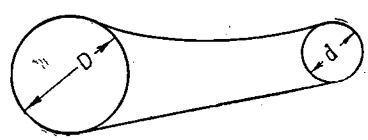


FIG. 82.

Rule 1. To find the diameter of the driven pulley, multiply the diameter of the driving pulley by its speed in R. P. M. and divide by the speed in R. P. M. of the driven pulley, or

$$d = \frac{DN}{n}$$

Rule 2: To find the speed of the driven pulley, multiply the diameter of the driving pulley by its speed and divide by the diameter of the driven pulley, or

$$n = \frac{DN}{d}$$

The speed or diameter of the driving pulley may be found in the same manner.

Example: A pulley on a line shaft makes 90 r. p. m. and is 28 inches in diameter. What must be the diameter of a pulley on a machine that is to be run at a speed of 210 r. p. m.?

Solution: $D = 28'' =$ diam. of pulley on shaft.
$N = 90 =$ r. p. m. of pulley on shaft.
$n = 210 =$ r. p. m. of machine pulley.

To find d. diam. of machine pulley.

$$dn = DN$$

$$d = \frac{DN}{n} = \frac{28 \times 90}{210} = 12 \text{ inches.}$$

PROBLEMS

1. Two pulleys are belt connected. If the first is 36 inches in diameter and runs at a speed of 120 r. p. m., what must be the diameter of the other pulley if it is to have a speed of 360 r. p. m.?

2. A line shaft makes 110 r. p. m. and carries a 30-inch pulley which drives a 24-inch pulley on a counter-shaft. What is the speed of the counter-shaft in r. p. m.?

3. A belt runs over a 48-inch pulley on a line shaft to a second shaft carrying a 16-inch pulley. If the line shaft runs at a speed of 240 r. p. m., what is the speed of the second shaft?

4. A line shaft runs at a speed of 130 r. p. m. and carries a 24-inch pulley which drives a 12-inch pulley on a counter-shaft. A 48-inch pulley on the counter-shaft drives an 8″ pulley on a grinder. What is the speed of the grinder?

5. Other conditions remaining the same as in Prob. No. 4, what should be the diameter of the pulley on the grinder shaft if the speed of the grinder is to be 2,080 r. p. m.?

6. Two cone pulleys A and B as shown in Fig. 83 are connected by a belt. If pulley A runs at a constant speed of 150 r. p. m., at what speed will the cone pulley B run when the 6″ pulley on A drives the 8″ pulley on B? Also what will be the speed of B when the 8″ pulley on A drives the 6″ pulley on B?

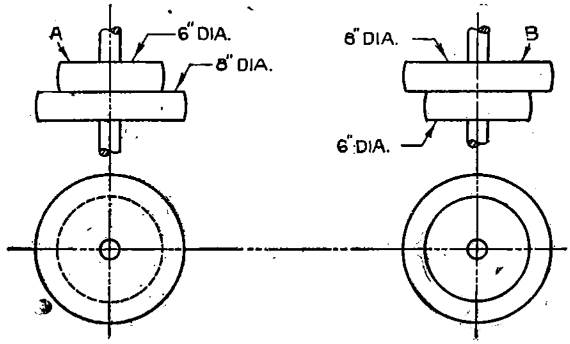


FIG. 83.

7. A motor having a 6″ driving pulley is belt connected to a line shaft through a 52-inch pulley. A 48″ pulley on the line shaft drives a jack-shaft through a 16″ pulley. What is the speed in r. p. m. of the jack-shaft if the motor runs at a speed of 500 r. p. m.?

8. If a fan carrying a 5-inch pulley which is to run at a speed of 200 r. p. m. is driven through a pulley on the line shaft in Prob. No. 7, what must be the size of the pulley on the line shaft?

9. A 12″ emery wheel has a rim speed of 2,400 ft. per minute and is driven by an 8″ pulley on the same spindle. The 8″ pulley on the emery wheel spindle is driven from a pulley on a line shaft which runs at a speed of 382 r. p. m. Find the diameter of the line shaft pulley.

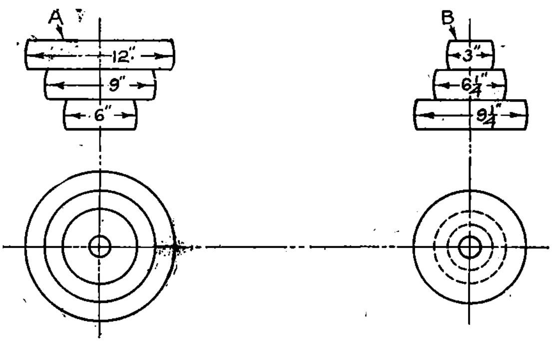


FIG. 84.

10. Two cone pulleys are connected by a belt as shown in Fig. 84. Pulley A runs at a constant speed of 190 r. p. m. Find the different speeds of pulley B as the belt is shifted from one step to another.

11. A motor running at a speed of 450 r. p. m. and carrying an 8″ pulley drives a 12″ diameter grinding wheel through a pulley on the same shaft. If the rim speed of the grinding wheel is to be 4,000 ft. per minute, what must be the diameter of the pulley on the grinder shaft?

Horse Power of Belting—A belt is a means of transmitting power from one shaft to another through pulleys. The driving pulley exerts a pull on the belt through the friction between the belt and the pulley rim and this pull is transmitted through the belt to the rim of the second pulley. The power transmitted by a belt depends on the effective pull on the belt and the speed at which the belt is traveling. For example, if the pull on a belt traveling at 1,000 ft. per minute, is 150 lbs., the power transmitted is 150 x 1,000 or 150,000 ft. lbs. per minute. The horse-power will then be 150,000 divided by 33,000 or 4.54.

The allowable effective pull on a belt depends on the width, the thickness, and the strength of the material of which the belt is made. Leather belts are designated as "single," "double," "triple," or "quadruple," according as they are made of one, two, three or four thicknesses of leather. The most effective speed of belts varies from 4,000 to 4,800 ft. per minute. The most satisfactory working tension is from 575 to 850 lbs. per square inch, which for single belts, gives approximately 35 to 40 lbs. per inch of width, and for double belts, 65 to 80 lbs. per inch of width.

Practice shows that narrow thick belts give better satisfaction than wide thin belts. Authorities claim that it is advisable to use double belts on pulleys 12″ in diameter or over, triple belts on pulleys 20″ in diameter or over, and quadruple belts on pulleys 30″ in diameter or over.

The allowable effective pull on a belt then is the allowable tension per inch of width times the width of the belt in inches, and the horse power will be equal to the width times the pull per inch of width times the speed in feet per minute divided by 33,000, or

$$\text{H. P.} = \frac{\text{W P S}}{33{,}000}$$

Where H. P. = Horse power.
W = Width of belt in inches.
P = Tension in belt per inch of width.
and S = Speed of belt in ft. per minute.

The speed at which belting runs has comparatively little effect upon its life until the velocity is higher than from 2,500 to 3,000 feet per minute. The life is affected principally by the power transmitted, the method of fastening the ends and the care of belting.

PROBLEMS

1. The allowable tension in a certain belt is 70 lbs. per inch of width and the belt is 12 inches wide. If the belt speed is 4,500 ft. per minute, what horse power is transmitted?

2. Find the width of belt to transmit 94½ horse power if the speed of the belt is to be approximately 2,700 ft. per minute and the tension in the belt is 75 lbs. per inch of width.

3. A 24-inch pulley drives a 9-inch pulley through a belt. If the 24″ pulley runs at a speed of 180 r. p. m., what is the speed of the second pulley in r. p. m. and the horse power transmitted by the belt, if the tension in the belt is 35 lbs. per inch of width and the belt is 12 inches wide?

4. A belt passes over a 36″ pulley making 360 r. p. m. If the tension in the belt is to be 65 lbs. per inch of width, find the width of the belt required to transmit 75 horse power.

5. A single belt 5 inches wide transmits 5 horse power. If the tension in the belt is 35 lbs. per inch of width, find the speed at which it is running.

6. What size single belt would be used in delivering to a line shaft 10 H. P. from a motor which carries a 12-inch pulley running at a speed of 450 r. p. m., if the maximum allowable tension in the belt per inch of width is 40 lbs.?

7. Determine the size of pulley advisable which is to run at 115 r. p. m. and transmit 12 H. P. with a 5-inch single belt whose allowable tension per inch of width is 60 lbs.

Length of Belts—If the pulleys are equal in diameter, Fig. 85, the length of open belt required will be equal to the circumference of one pulley plus twice the distance between centers, or

$$L = \pi D + 2l$$

Where D = Diameter of pulley in feet.
l = Distance between centers, in feet.
and L = Length of belt required in feet.

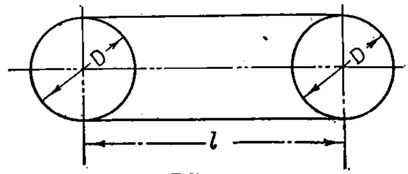


FIG. 85.

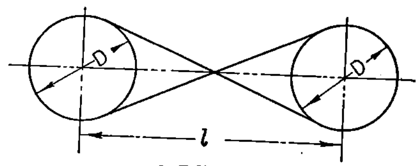


FIG. 86.

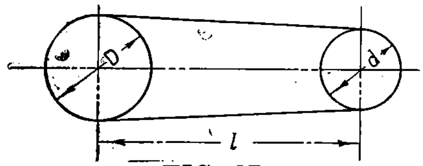


FIG. 87.

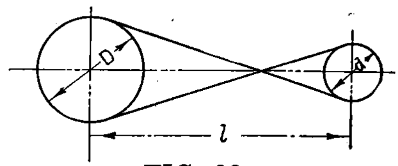


FIG. 88.

If the pulleys are equal in diameter and the belt is crossed as shown in Fig. 86, the length may be found as follows:

$$L = 2\sqrt{(D^2 + l^2)} + \pi D$$

For pulleys of unequal diameters, Fig. 87, the length may be found as follows:

Open Belts

$$L = 2\sqrt{\left(\frac{D-d}{2}\right)^2 + l^2} + \pi\left(\frac{D+d}{2}\right)$$

Crossed Belts

$$L = 2\sqrt{\left(\frac{D+d}{2}\right)^2 + l^2} + \pi\left(\frac{D+d}{2}\right)$$

Note: It is understood that the above formulas are approximate but give satisfactory values for length of belts where measurements cannot be made.

PROBLEMS

1. Two pulleys, each 24 inches in diameter, are connected by a belt. What length of open belt is required if the distance between centers is 12 ft. 6 inches?

2. What length of belt will be required for the pulleys in Prob. No. 1 if the belt is crossed?

3. A 36-inch pulley is driven by a 14-inch pulley through a belt. What length of belt is required if the distance between the centers of the pulleys is 15 ft.?

4. What length of belt would be required for the pulleys in Prob. No. 3, if the belt is crossed?

5. Why is it best to have the slack side of the belt on the top?

6. As a rule why is there less slipping with a crossed belt than with an open belt?

7. Why are belts sometimes crossed?

TOOTH GEARING

The toothed gear is an evolution from the plain friction wheel. If two wheels as in Fig. 89 have their faces in close contact and both are exactly the same size, when wheel A makes one complete turn, wheel B will also make one complete turn, providing there is no slipping between the wheels. Such wheels are termed **Friction Wheels.** In transmitting power by the use of friction wheels there is always more or less slipping which cannot be tolerated in some classes of machine work on account of the accuracy of motion required. To overcome this difficulty the toothed gear which gives exactly the same motion as the friction wheels and eliminates slipping, was adopted. Fig. 90 shows clearly how this result is obtained. The dot and dash circles represent the friction wheels, or they represent the wheels that would be used to give the desired motion if they had no teeth. The teeth, as will be seen, extend partly without and partly within the circle. This circle is known as the **Pitch Circle.** In all calculations involving the speeds of gears the diameter of the pitch circle or the number of teeth in the gear must be used.

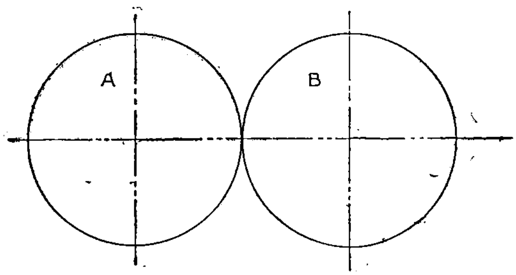


FIG. 89.

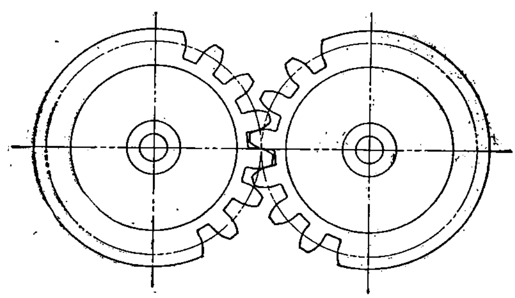


FIG. 90.

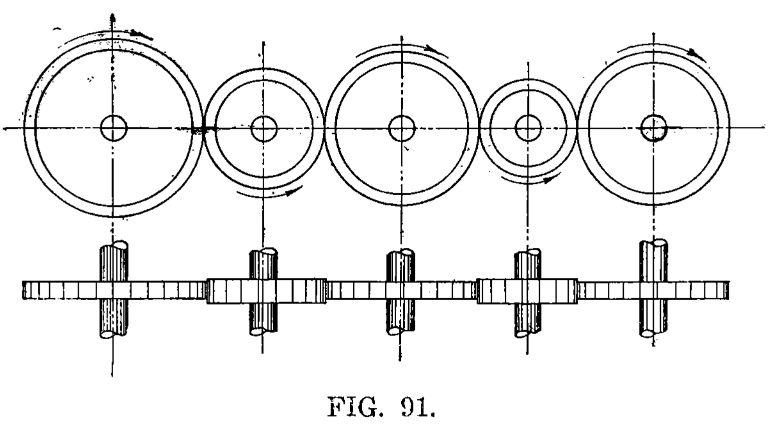


FIG. 91.

Simple Gear Trains—A simple gear train, Fig. 91, is one in which each gear is driven by the one preceding it, and no two gears are on the same shaft. With this method of gearing the linear velocity of the teeth of all gears in the train is the same, but each succeeding gear rotates in a direction opposite from the one that drives it. It will be seen then that every second gear will rotate in a direction opposite to the one before it. From this it will be seen that with an even number of gears, the first and last gears will rotate in opposite directions, and with an odd number of gears the first and last gears will rotate in the same direction.

Speeds of Gears—The speeds of gears are calculated in the same manner as those of belts and pulleys, that is, their speeds are inversely proportional to their pitch diameters, the pitch diameter being the diameter of the pitch circle and will hereafter be spoken of simply as diameter.

Example: Two gears have diameters of 20 and 5 inches. If the large gear makes 60 r. p. m., what is the speed of the small gear?

Solution: Let $D =$ diameter of large gear.
$d =$ diameter of small gear.
$N =$ r. p.m. of large gear.
$n =$ r. p.m. of small gear.

then $DN = dn$

$D = 20,\ d = 5,$ and $N = 60$

$$n = \frac{DN}{n} = \frac{20 \times 60}{5} = 240 \text{ r. p. m.}$$

In any gear the number of teeth is proportional to the diameter. The speeds of two gears will therefore be inversely proportional to the number of teeth in the gears, that is, if

$N =$ r. p. m. of large gear.
$n =$ r. p. m. of small gear.
$T =$ number of teeth in large gear.
and $t =$ number of teeth in small gear.
then $T : t = n : N$
and $TN = tn$

A comparison of this formula with the one involving the diameters will show that this formula can be derived simply by substituting the number of teeth in the respective gears for their diameters.

Example: A 52-tooth gear making 120 r. p. m. drives a 16-tooth gear. What is the speed of the small gear?

Solution: $N = 120,\ T = 52$ and $t = 16.$

$TN = tn$

$$n = \frac{TN}{t} = \frac{52 \times 120}{16} = 390 \text{ r. p. m.}$$

PROBLEMS

1. Two gears have diameters of 20 and 8 inches respectively. If the first gear makes 90 r. p. m., what is the speed of the second gear?

2. Find the diameter of a gear which is to run at a speed of 60 r. p. m. and mesh with a gear 16 inches in diameter which makes 25 r. p. m.

3. Two gears, A and B, have 36 and 96 teeth respectively. If gear A runs at a speed of 80 r. p. m., what is the speed of gear B?

4. A 72-tooth gear running at a speed of 40 r. p. m. is to mesh with a gear which is to run at a speed of 120 r. p. m. How many teeth must the second gear contain?

5. It is desired to run a shaft at 260 r. p. m. from another shaft running at 120 r. p. m. If a gear having 24 teeth is to be put on the first shaft, how many teeth must the gear on the second shaft contain?

6. A simple train of five gears have 96, 32, 48, 72 and 24 teeth respectively. If the first gear makes 40 r. p. m., what is the speed of the last gear? If the first gear turns right handed, in what direction will th last gear turn?

7. A simple gear train has four gears, the number of teeth of which are as follows: 96, 24, 52 and 60. If the last gear turns left handed at a speed of 280 r. p. m., in what direction and at what speed will the first gear turn?

8. Two gears, A and B, have a speed ratio of 1 to 3. If the first gear has 60 teeth, how many teeth has the second gear?

9. Two gears have a tooth ratio of 4.5 to 1. If the smaller gear makes 90 r. p. m., what is the speed of the larger gear?

10. In the punch shown in Fig. 92 what must be the speed of the motor if the punch is to make 20 strokes per minute, the gear having 280 teeth and the pinion 16 teeth?

11. If the motor in Fig. 92 has a speed of 300 r. p. m., what must be the number of teeth in the gear, other conditions remaining the same?

12. Four rolls are connected with gears having teeth as follows: 120, 80, 80, and 72. What is the direction of rotation and the r. p. m. of each roll if the first gear turns right handed at 30 r. p. m.?

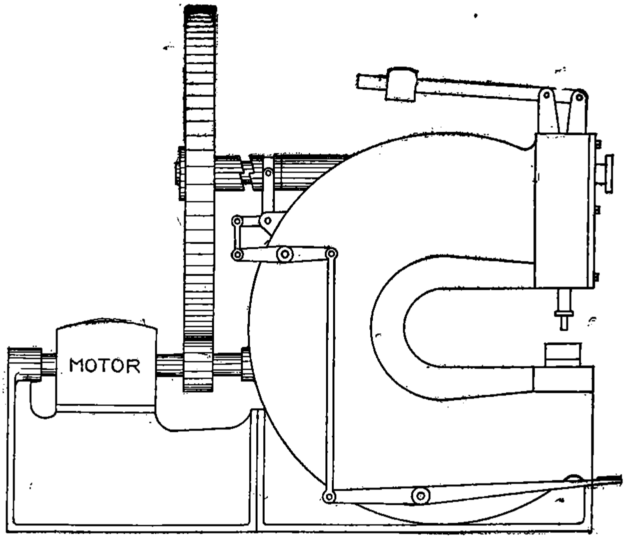


FIG. 92.

Compound Gear Trains—A compound gear train, Fig. 93, is one in which two or more of the gears are on one shaft. In the compound gear train shown in Fig. 93 it will be seen that the gears B and C will have the same speed in r. p. m. since they are on the same shaft.

Compound gears give an increase or reduction in speed in the gear train which cannot be obtained in simple gear trains.

The speeds of compound gears are calculated in the same way as simple gear trains.

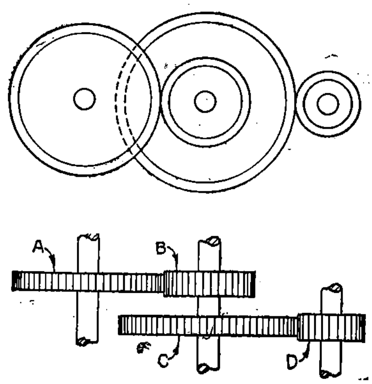


FIG. 93.

Example: If gear A, Fig. 93, has 72 teeth, gear B has 24 teeth, gear C has 52 teeth, gear D has 16 teeth, what is the speed of gear C, if gear A makes 60 r. p. m.?

Solution: $T = 72,\ t = 24$ and $N = 60$.

$$n = \frac{TN}{t} = \frac{72 \times 60}{24} = 180 \text{ speed of gear B.}$$

Since gears B and C are on the same shaft, the speed of gear C will also be 180 r. p. m. Then to find the speed of gear D.

$$N = 180,\ T = 52 \text{ and } t = 16.$$

$$n = \frac{NT}{t} = \frac{180 \times 52}{16} = 585 \text{ r. p. m.}$$

In solving problems in compound gears, separate the train into driving and driven gears. If the first gear in any train is considered as a driver, the third, the fifth, etc., are also drivers while the second, fourth, and sixth are driven gears. The product of the revolutions per minute of the first gear times the number of teeth of the drivers equals the product of the revolutions per minute of the last gear times the number of teeth in the driven gears. Then, **the speed of the last gear equals the speed of the first gear times the number of teeth in the drivers divided by the product of the teeth in the driven gears.**

Example: Find the speed of gear F in the compound gear train in Fig. 94 if gear A makes 40 r. p. m., the gears having teeth as follows; A = 96, B = 36, C = 72, D = 24, E = 120, F = 48.

Solution: The driving gears are A, C and E and the driven gears are B, D and F, then

$$\text{Let}\quad n = \text{r. p. m. of F.}$$
$$N = \text{r. p. m. of A.}$$
$$T,\ T_1,\ T_2 = \text{teeth of drivers.}$$
$$t,\ t_1,\ t_2 = \text{teeth of driven gears.}$$
$$\text{then } n = \frac{R\,T\,T_1\,T_2}{t\ t_1\ t_2}$$
$$n = \text{r. p. m. of F} = \frac{40 \times 96 \times 72 \times 120}{36 \times 24 \times 48} = 800$$

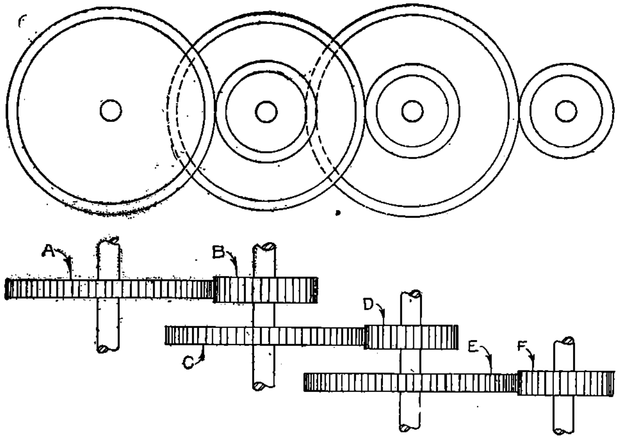


FIG. 94.

PROBLEMS

13. Find the speed of gear F in the gear train shown in Fig. 94, if gear A makes 20 r. p. m. and the number of teeth in the gears are as follows: A = 60 teeth, B = 24 teeth, C = 72 teeth, D = 36 teeth, E = 52 teeth and F = 32 teeth.

14. If gear A, Fig. 94, makes 20 r. p. m. and gear F is to make 500 r. p. m., how many teeth must gear F contain if the other gears have teeth as follows: A = 60 teeth, B = 36 teeth, C = 120 teeth, D = 24 teeth and E = 96 teeth.

15. Fig. 95 shows the arrangement of a hoist. (a) What will be the speed of the drum in

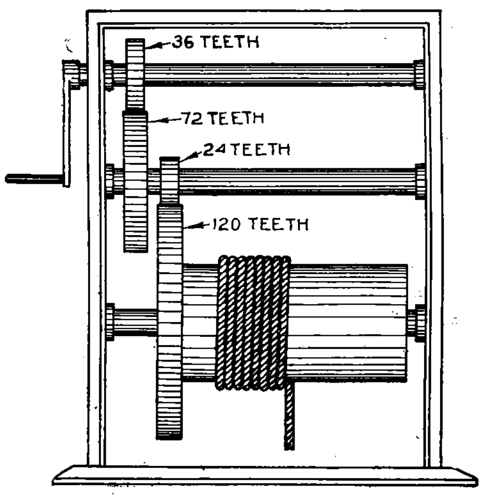


FIG. 95

r. p. m. if the crank makes 15 r. p. m.? (b) How many times will the crank turn for each turn of the drum? (c) how many turns of the crank will be necessary to raise a weight 20 feet if the drum is 12″ in diameter?

16. Fig. 96 shows a gear arrangement such as is used in a lathe. (a) If gear A has 24 teeth, gear B 32 teeth, gear C 48 teeth and gear D 60 teeth, how many turns will the lead screw make for 20 turns of gear A? (b) If gear A turns right handed, in what direction will the lead screw turn?

17. If the lead screw in Fig. 96 has 6 threads per inch, how far will the nut move while gear A makes 60 turns?

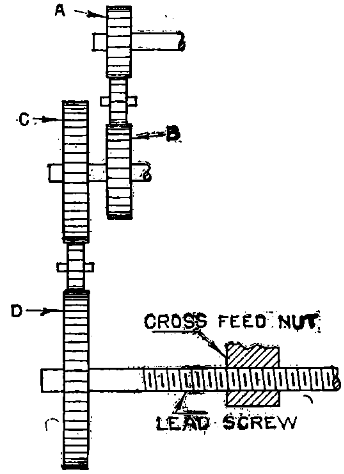


FIG. 96.

18. If it is desired that gear A, Fig. 96, should make 16 turns while the lead screw makes 8 turns, what should be the number of teeth in gear C if gear A has 24 teeth, gear B has 32 teeth and gear D has 48 teeth?

19. Fig. 97 shows the arrangement of gears in a compound geared lathe. Assuming that gear A has 32 teeth, gear B has 32 teeth, gear C has 72 teeth, gear D has 48 teeth, gear E has 24 teeth and gear F has 36 teeth, how many turns will the lead screw make while gear A makes 16 turns?

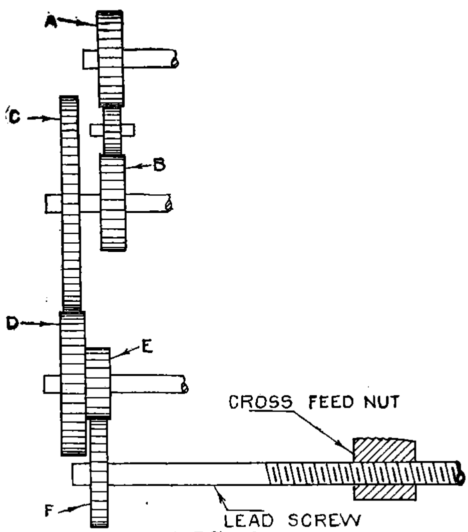


FIG. 9..

Spindle Speed Calculations for Lathe Work—The speed of the spindle varies for different metals and for large and small diameters, and the desired spindle r. p. m. is calculated from the recommended cutting speed in feet per minute of the various metals and diameters of piece to be turned.

A mechanic at the earliest convenience after being assigned to a lathe should determine the speed of his lathe spindle for each possible gearing. This information, available in a table form, as shown below, will enable him to set his machine at the nearest desired speed without any guess work.

An example of speed table to be used is shown below if cone pulleys are used. Spindle speeds are given on a plate attached to the head stock on motor driven lathes.

Counter-shaft cone step	Lathe cone step	Free spindle speed, r. p. m.	Back gear speed, r. p. m.
10″	7½″	240	29.5
8″	8″	180	21
6¾″	9½″	137.3	16
5″	10″	90	10.5

On the older types of engine lathes are found "back gears" which are used for slowing down the spindle for heavy cutting. Modern lathes accomplish this by gears on sliding keys in a gear box in the head stock of the lathe.

The back gears are mounted on a sleeve over the back gear spindle and consist of a large and small gear (simple back gears). The large gear is driven by the cone gear at the small end of the cone. The small back gear in turn drives a large gear keyed to the lathe spindle. Fig. 98 shows the gears in their relative positions. Looking at Fig. 98 to follow the direction of drive, when the back gears are thrown in, the cone pulley and the cone gear A are generally cast in the same piece and both run **free** on the lathe spindle. Gear A drives gear C, the large back gear. Gear D, the small back gear, drives gear B, the spindle gear, which is keyed fast to the lathe spindle. When the back gears are out of mesh with A and B, a higher speed is obtained by inserting a pin through gear B into the cone which then drives the spindle at the same speed as the cone pulley is running.

Example: A 12″ pulley on the counter-shaft running 180 r. p. m., drives the 10″ step of a lathe cone. The cone gear A has 24 teeth, gear C 80 teeth, gear D 20 teeth, gear B 64 teeth. What would be the **free** speed of the spindle? What would be the spindle speed with the back gears in mesh?

$$\frac{12 \times 180}{10} = 216 \text{ r. p. m. of free spindle speed.}$$

$$\frac{12 \times 180 \times 24 \times 20}{10 \times 80 \times 64} = 20\tfrac{1}{4} \text{ r. p. m. of spindle speed with back gears in mesh.}$$

PROBLEMS

1. In the gear arrangement for a lathe shown in Fig. 98, the cone pulley and gear A run loose on the spindle. Gear B is rigidly keyed to the spindle. Assuming gear A has 36 teeth, gear B 96 teeth, gear C 84 teeth and gear D 24 teeth, what will be the speed of the spindle if the cone pulley makes 140 r. p. m.?

When the back gear is not in use, gear B is keyed to the cone pulley and the back gears are unmeshed. What is the ratio of the speeds with the back gears to the ordinary speed?

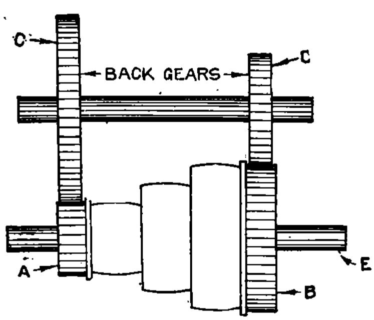


FIG. 98.

2. If a counter-shaft running at 160 r. p. m. has a 5″ diameter pulley bolted to an 8″ pulley on lathe spindle, with gear attached to cone having 32 teeth and gear attached to spindle having 90 teeth, these being in mesh with back gears of 88 and 30 teeth respectively, what is r. p. m. of lathe spindle?

3. When a counter-shaft runs 165 r. p. m. and pulley on counter-shaft is $4\frac{5}{8}$ inches in diameter belted to a $7\frac{5}{8}$-inch diameter pulley on lathe spindle and when the gears are the same as in above example, what is the r. p. m. of lathe spindle?

4. When the pulley on a counter-shaft is $7\frac{5}{8}$ inches in diameter and the cone pulley is $4\frac{5}{8}$ inches in diameter, other sizes same as in Prob. No. 3, find r. p. m. of spindle.

5. When a counter-shaft makes 155 r. p. m. and the pulley is $8\frac{1}{2}$ inches in diameter belted to lathe cone pulley $6\frac{3}{4}$ inches in diameter with back gears 85 and 32 teeth, in mesh with 31 on cone and 84 on spindle, what is the number of r. p. m. of lathe spindle?

6. When a counter-shaft runs 185 r. p. m., and the pulley on counter-shaft is 5-inch diameter belted to an $8\frac{1}{4}$-inch diameter pulley on spindle with gears same as in Prob. No. 5, what is the number of r. p. m. on lathe spindle?

7. When a counter-shaft pulley 6 inches in diameter running 160 r. p. m. is belted to a cone pulley $6\frac{3}{4}$ inches in diameter and back gears with 75 and 20 teeth in mesh with 25-tooth gear on cone and 69-tooth gear on spindle, what is the number of r. p. m. of spindle?

8. When a counter-shaft pulley is $5\frac{1}{8}$ inches in diameter and running 225 r. p. m. is belted to a cone pulley on the lathe spindle $7\frac{3}{4}$ inches in diameter with gears on back gear quill of 75 and 25 teeth in mesh with 25 teeth on cone pulley and 65 teeth on spindle, what is the r. p. m. that a piece will make on lathe centers?

9. The cone pulley of a certain lathe has steps $7\frac{5}{8}$ inch, $6\frac{1}{8}$ inch, $4\frac{5}{8}$ inch, and $3\frac{1}{8}$ inch diameters respectively, belted to the steps of a cone on counter-shaft, the diameters of which are as follows: $4\frac{5}{8}$ inch, $6\frac{1}{8}$ inch, $7\frac{5}{8}$ inch, and $9\frac{1}{8}$ inch. When the counter-shaft runs 170 r. p. m. find the different speeds at which the work on the spindle may be driven. Draw a sketch of the cone pulleys in their relative positions. Small end of lathe cone towards left end of lathe.

10. A lathe has on its driving spindle a four-step cone pulley with diameters as follows: $8\frac{1}{4}$ inch, $6\frac{3}{4}$ inch, 5 inch, and $3\frac{1}{4}$ inch. Belted on this cone is the cone on counter-shaft with steps, $5\frac{1}{4}$ inch, $6\frac{3}{4}$ inch, $8\frac{1}{2}$ inch, and $10\frac{1}{4}$ inches in diameter respectively. Find the different r. p. m. at which work can be turned in the lathe, when the counter-shaft runs 180 r. p. m. Draw a sketch of the cone pulleys in their respective positions. Small end of lathe cone towards left end of lathe.

11. A lathe has a cone on the head spindle with steps $8\frac{1}{2}$ inches, $6\frac{3}{4}$ inches, $5\frac{1}{8}$ inches, and $3\frac{1}{2}$ inches in diameter respectively. If the counter-shaft runs 175 r. p. m. with a cone having steps $4\frac{1}{2}$ inches, $6\frac{1}{4}$ inches,

$7\frac{7}{8}$ inches and $9\frac{1}{2}$ inches in diameter respectively, what different r. p. m. may be given the work on the lathe centers? Draw a sketch of the cone pulleys in their respective positions. Small end of lathe cone towards left end of lathe.

12. The cone steps on a counter-shaft running at 160 r. p. m. are $13\frac{1}{2}$ inches, 12 inches and 11 inches. The lathe cone steps are 9 inches, $10\frac{1}{2}$ inches and $11\frac{1}{2}$ inches. The lathe back gears have 80 and 30 teeth. The cone gear 24 teeth and the spindle gear 64 teeth. Make a table for all speeds obtainable. Draw a sketch of the cone pulleys in their respective positions. Small end of lathe cone towards left end of lathe.

13. Same as Prob. No. 12 but increase the counter-shaft speed to 180 r. p. m.

14. Same as Prob. No. 12 except back gears have 81 and 36 teeth, cone gear 32 teeth and spindle gear 96 teeth.

15. Using the cones and counter-shaft speed in Prob. No. 9 and the back geared lathe in Prob. No. 2, what should be the actual speed in r. p. m. of the lathe cone pulley and which step would come nearest this speed for the following condition. To turn a 6″ diameter shaft at a cutting speed of 36 ft. per minute?

16. How would the lathe in Prob. No. 12 be set to turn a $3\frac{1}{2}$″ cold rolled shaft at a cutting speed of 50 ft. per minute?

Change Gears for Thread Cutting.—Nearly all modern built lathes are indexed so that it is not always necessary to calculate the gears necessary to cut a given number of threads. An explanation of change gears is given here, however, so that the information will be at hand when needed.

When cutting threads on a lathe a definite relation exists between the speeds of the spindle and lead screw. That is, to cut a given number of threads, the lead screw must make a definite number of turns in order that the tool post be moved forward at the proper rate of speed. For example, suppose the lead screw on a lathe has 4 threads per inch and it is desired to cut 12 threads per inch on a cylindrical bar. Since 12 threads are to be cut per inch, the bar, and hence the spindle, will have to make twelve turns while the tool advances 1 inch. Also, since the lead screw has 4 threads per inch, it must make four turns in advancing the tool one inch. The spindle then must make twelve turns while the lead screw makes four turns, or the ratio of the speed of the lead screw to the speed of the spindle is 4 to 12 or 1 to 3. In other words, the spindle must make three turns while the lead screw makes one turn.

When cutting multiple threads, care must be taken that the lead of the thread is used rather than the pitch. For instance, suppose the lead screw has 4 threads per inch and it is desired to cut a double thread having 12 threads per inch. The pitch of the thread to be cut will be $\frac{1}{12}$ of an inch and the lead will be twice the pitch or $\frac{1}{6}$ of an inch. Then each thread will make 6 turns in one inch or the spindle will make six turns while the tool is advancing one inch, and at the same time, the lead screw will make four turns. The ratio of lead screw to spindle, then, is 4 to 6.

There are two different types of lathes for cutting threads, namely, the simple geared lathe and the compound geared lathe. Fig. 99 shows the head stock of a simple geared lathe in which the lead screw is driven through a simple gear train from the gear on the spindle. In this lathe, the stud gear is driven by the spindle gear through the inside stud gear, which is on the same shaft as the stud gear. Usually the inside stud gear has the same number of teeth as the spindle gear, so that the former can be ignored when making calculations. The following explanations are based on the assumption that the spindle gear and inside stud gear have the same number of teeth.

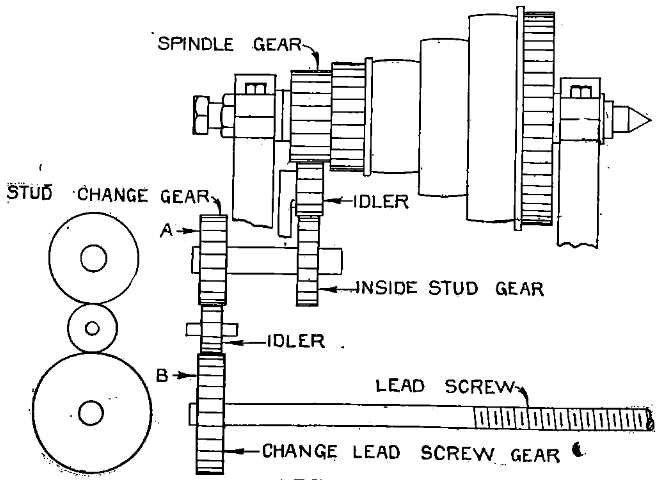


FIG. 99.

The idler gear may also be ignored since its only function is to change the direction of rotation of the lead screw gear. The stud gear A and the lead screw gear B are change gears and the number of teeth in these gears depend upon the ratio of the speeds of the spindle and lead screw. For example, assume that the lead screw has 4 threads per inch, the spindle gear has 24 teeth, and it is desired to cut 12 threads per inch. How many teeth should be in the stud and lead screw gears, if the inside stud gear is the same as the spindle gear?

Since 12 threads per inch are to be cut and the lead screw has 4 threads per inch, the spindle will make 12 turns while the lead screw makes 4 turns. Also, since the inside stud gear is the same as the spindle gear, the spindle and stud gears will have the same speed, or the stud gear will make 12 turns while the lead screw makes 4 turns. It will be only necessary then to select two gears which have a tooth ratio of $4/12$ or $1/3$; say 24 teeth for the stud gear and 72 teeth for the lead screw gear. From the above we have the following formula:

$$\frac{\text{Turns of the lead screw}}{\text{Turns of the spindle or stud gear}} = \frac{\text{A (Teeth on stud gear)}}{\text{B (Teeth on lead screw gear)}}$$

In the above formula, turns of the spindle and lead screw are based on one inch of travel of the carriage and tool. For cutting a single thread the turns of both the spindle and the lead screw are the same as the number of threads per inch on each. For multiple threads the turns of the spindle must be calculated for one inch of travel, or in other words, the lead of the thread is used to find turns per inch of travel. It is now only a simple matter to find the ratio of the lead screw to the spindle and then select two gears that have the same ratio.

A quick method to find the proper gears is to select a **stud gear** and **multiply** the number of teeth on this gear by the ratio. This gives the teeth on the lead screw gear. If it is desired to change the stud gear **divide** the given lead screw gear by the ratio which will give the number of teeth on the stud gear.

Example: Suppose the lead screw has 4 threads per inch and it is desired to cut 16 threads per inch.

The ratio of the lead screw to the spindle will be $4/16$ and

$$\frac{4}{16}=\frac{A}{B}$$

Then select two gears having a tooth ratio of $4/16$ or $1/4$; say 96 teeth for the lead screw gear and 24 teeth for the stud gear.

Usually the number of teeth of the gears on a lathe increase by a common number such as 2, 4 or 6, by which the number of teeth on the gears may be divided without a remainder.

For example, if the smallest gear on a lathe has 24 teeth and the common number is 4, the next larger gear will have 28 teeth, and the next 32 teeth, and so on.

For convenience in working the problems involving change gears the following list of gears is given. No gear not included in this list should be used.

No. Teeth in Gear	Number Available	No. Teeth in Gear	Number Available
24	3	66	1
28	2	68	1
30	2	69	1
32	2	72	1
36	2	76	1
42	1	78	1
48	2	84	1
52	1	92	1
54	1	96	1
56	1	98	1
60	2	108	1
64	1		

PROBLEMS

20. The lead screw on a lathe has 6 threads per inch and it is desired to cut 16 threads per inch on $3/8$-inch stock. Find the ratio of turns of the lead screw to turns of the spindle.

21. Find the ratio of turns of the lead screw to turns of the spindle, if 8 threads per inch are to be cut on the lathe in Prob. No. 20.

22. The lead screw on a simple geared lathe has 4 threads per inch and it is desired to cut 9 threads per inch. Assuming a stud gear having 32 teeth, what would be the number of teeth on the lead-screw gear?

23. In order to obtain two turns of the spindle for one of the lead screw when a 52-tooth gear is used on the lead screw, what size gear must be used on the stud?

24. If a 48-tooth gear is used on the lead screw, what stud gear must be used if the spindle makes three turns while the lead screw makes two turns?

25. Other conditions remaining the same, what lead screw gear must be used in Prob. No. 24, if a 24-tooth stud gear is used.

26. The lead screw on a simple geared lathe has 6 threads per inch and it is desired to cut 15 threads per inch. What lead screw gear must be used with a stud gear having 24 teeth?

27. On a simple geared lathe having a lead screw with 8 threads per inch, how many threads per inch would be cut, using a 72-tooth gear on the lead screw and a 108-tooth gear on the stud?

28. If a 24-tooth gear is used on the stud and a 72-tooth gear on the lead screw, and 12 threads per inch are to be cut on a simple geared lathe, what is the number of threads per inch on the lead screw?

29. A double thread, 4 threads per inch, is to be cut on a simple geared lathe, whose lead screw has 6 threads per inch. If a 72-tooth gear is used on the stud, what gear must be used on the lead screw?

30. A triple thread, 4 threads per inch, is to be cut on a simple geared lathe. If a 48-tooth gear is used on the lead screw, what gear must be used on the stud, the lead screw having 4 threads per inch?

31. Seven threads per inch are to be cut on a lathe having a lead screw with 4 threads per inch. What gears should be used on the stud and lead screw?

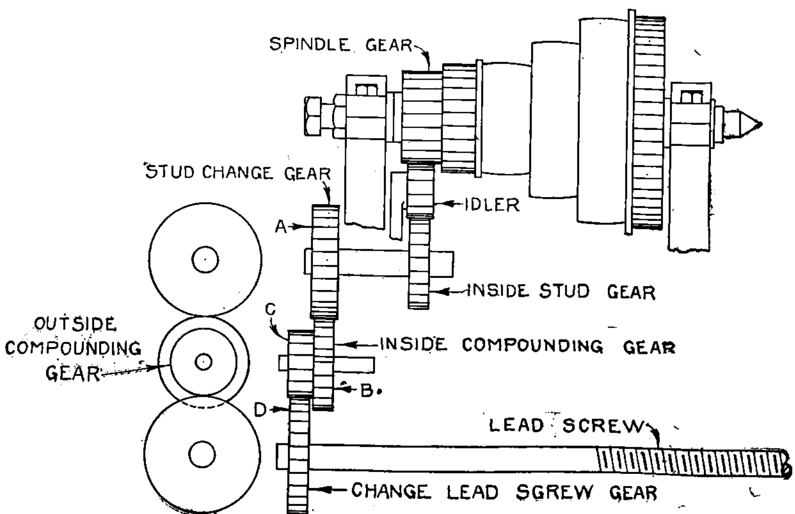


FIG. 100.

Fig. 100 shows a head stock of a compound geared lathe. Here the spindle gear drives the inside stud gear which is on the same spindle as the stud gear A; gear B which is on the same spindle as gear C, is driven by the stud gear A, and the lead screw gear D is driven by gear C. Stud gear A, compounding gears B and C, and lead screw gear D are all change gears.

Just as was the case with the simple geared lathe, the first step in finding the proper gears to cut a given number of threads with the compound geared lathe, is to find the ratio of the turns of the lead screw to the turns of the spindle. This ratio is then broken up into a number of factors, equal to the number of pairs of gears. Each factor may then be multiplied by such a number as will give the number of teeth in gears which are available for use with the lathe.

Example: It is desired to cut 12 threads per inch on a compound geared lathe having a lead screw with 4 threads per inch.

Solution: First, determine the ratio of the turns of the lead screw to the turns of the spindle. In this case the ratio is $4/12$.

Then the ratio of the product of the number of teeth in the driving gears to the product of the number of teeth in the driven gears will be equal to $4/12$, or

$$\frac{4}{12}=\frac{A}{B}\times\frac{C}{D}$$

Where A equals number of teeth on stud gear, B equals number of teeth on inside compounding gear, C equals number of teeth outside compounding gear and D represents teeth on lead screw gear. See Fig. 100.

Now factor the ratio $4/12$ into as many trial factors as there are pairs of gears, in this case two, thus,

$$\frac{4}{12}=\left(\frac{2}{3}\right)\times\left(\frac{2}{4}\right)$$
$$=\left(\frac{A}{B}\right)\times\left(\frac{C}{D}\right)$$

Next, multiply each quantity in parenthesis by such a number as will give the number of teeth in gears which are available for use and still maintain the correct ratio, thus,

$$\frac{12}{4}=\left(\frac{2}{3}\right)\times\left(\frac{2}{4}\right)$$
$$=\left(\frac{2}{3}\right)\times\frac{12}{12}\times\left(\frac{2}{4}\right)\times\frac{14}{14}$$
$$=\frac{24}{36}\times\frac{28}{56}$$

or A has 24 teeth, B has 36 teeth, C has 28 teeth and D has 56 teeth.

To select two gears to pair with two other gears that are already in position, a slightly different method is used. In the formula A and C are drivers while B and D are driven gears.

If one driver and one driven gear are in position on the lathe, make a ratio of them as $\frac{\text{driver}}{\text{driven}}$; this ratio reduced will be one factor. By dividing the original ratio of $\frac{\text{lead screw turns}}{\text{spindle turns}}$ by this factor of given gears, the second factor may be found. This second factor multiplied by a common number to produce gears as given in the table will give the two missing gears.

Place the top gear as the missing driver and the bottom gear as the missing driven gear.

Example: The ratio of the lead screw to the spindle turns of a compound geared lathe is 4 to 6. The stud gear has 48 teeth, lead screw gear has 72 teeth, calculate for compounding gears.

$$\text{Ratio } \frac{4}{6} = \frac{A}{B} \times \frac{C}{D}$$

$$= \frac{48}{B} \times \frac{C}{72}$$

$$\text{given gears} = \frac{48}{72} = \frac{2}{3}$$

$$\text{original ratio} = \frac{4}{6} \div \frac{2}{3} = \frac{2}{2} \text{ factor for missing gears}$$

$$\frac{2}{2} \times \frac{12}{12} = \frac{24}{24} \quad \begin{array}{l}\text{for gear C}\\ \text{for gear B}\end{array}$$

PROBLEMS

32. If 8 threads per inch are to be cut on a compound geared lathe and the lead screw has 4 threads, what gears should be used on the stud and lead screw if the inside and outside compounding gears have 36 and 32 teeth, respectively?

33. In cutting 5 threads per inch on a compound lathe having a lead screw with 6 threads per inch and using 24-tooth and 32-tooth gears for the inside and outside compounding gears, what gears should be used on the stud and lead screw?

34. A lathe having 6 threads per inch on the lead screw is being set up to cut 20 threads per inch. What gears could be used?

35. What suitable compounding gears could be used in Prob. No. 34, if a 40-tooth gear is used on the stud and a 32-tooth gear on the lead screw?

36. On a lathe having 4 threads per inch on the lead screw and using inside and outside compounding gears having 48 teeth and 40 teeth respectively, what suitable stud and lead screw gears could be used to cut 10 threads per inch?

37. It is desired to cut a triple square thread, 4 threads per inch, on a brass rod 2 inches in diameter. Using inside and outside compounding gears having 24 teeth and 72 teeth respectively, and a 24-tooth gear on the lead screw, what gear must be used on the stud if the lead screw has 6 threads per inch?

38. If the inside and outside compounding gears have 24 and 72 teeth, respectively, and the stud gear 36 teeth, what gear would be necessary on the lead screw in order to cut the threads in Prob. No. 37?

39. What is the ratio of the turns of the lead screw to the turns of the spindle in a lathe which has 2 threads per inch on the lead screw if a quadruple thread, 4 threads per inch, is being cut?

40. Using inside and outside compounding gears having 24 teeth and 32 teeth respectively, and a lead screw gear having 64 teeth, what gear must be used on the stud to cut the thread in Prob. No. 39?

41. What other combination of gears could be used to cut the threads in Prob. No. 39?

42. What other combination of gears could be used to cut the threads in Prob. No. 36?

43. What other combination of gears could be used to cut the threads in Prob. No. 37?

44. The lead screw on a compound geared lathe has 2 threads per inch and it is desired to cut 11½ threads per inch. What gears should be used?

45. What gears should be used to cut 3½ threads per inch, using a compound geared lathe having a lead screw with four threads per inch?

46. What gears should be used to cut 2⅜ threads per inch, using the lathe in Prob. No. 44?

47. Using the lathe in Prob. No. 44, what gears should be used in order to cut a thread having a lead of 2½ inches?

48. A worm having a lead of 1½ inches is to be cut on the lathe in Prob. No. 44. What gears should be used?

49. A compound geared lathe has a lead screw with 2 threads per inch. Using this lathe, what gears should be used to cut a triple thread having a lead of 1¾ inches?

PUMPS

A pump may be defined as any mechanical device designed for elevating or conveying liquids from one point to another or for exhausting air or other gases from a closed vessel. Primarily a pump for liquids is intended for elevating liquids from a point below the pump up to the pump or to force the liquid to a higher level or to some distant point through suitable delivery pipes connected to the pump.

While a device for exhausting air or other gases from a closed vessel is called a pump, a device used to pump air or other gases into a closed vessel is known either as a compressor or a blower.

The common types of pumps may be divided into several general classes as follows:

1. Reciprocating pumps having a piston or plunger which is given a reciprocating movement in the cylinder of the pump.

2. Centrifugal pumps which have a rotary wheel or impeller in which the liquid is forced by means of centrifugal force from the center to the periphery, and then through the discharge pipe.

3. Rotary pumps, in which the liquid is forced through the pump by means of rotating impellers independent of centrifugal force.

4. Pumps depending on the direct application of steam or compressed air and without employing the reciprocating piston or the rotating impeller.

The Suction Pump—The common or lift pump consists of a cylinder A, Fig. 101, a piston B, valves C and D, and a suction pipe E which extends below the surface of the liquid. When the pump first starts to operate, cylinder A is filled with air. As the piston is moved downward valves C open upward and valve D closes and the air in the cylinder is forced upward through the valves C. Then as the piston is moved upward, valves C are closed by the pressure of air above and a partial vacuum is formed in the cylinder below the piston. Consequently, as the elastic force of the air in the cylinder is reduced, the atmospheric pressure forces the liquid upward in the suction pipe forcing the air before it through valve D. When the piston is again moved downward the inlet valve D is closed and the air in the cylinder is again forced upward through valves C. By repeated movements of the piston the air is finally removed from the cylinder and the suction pipe and the water or other liquid is forced by the atmospheric pressure up through the suction pipe into the cylinder, thence up through the discharge valves C and into the discharge pipe.

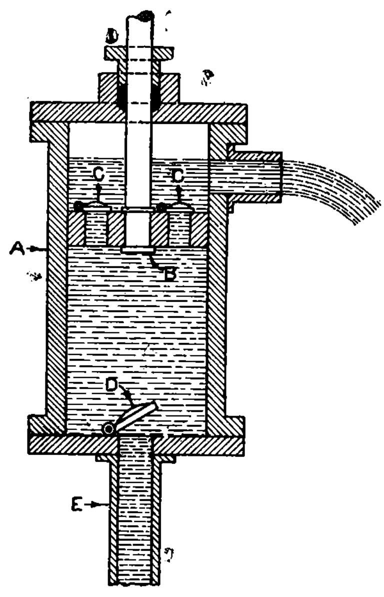


FIG. 101.

The Force Pump—The operation of the force pump is similar to that of the suction pump and the suction pump in Fig. 101 could be used as a force pump by the installation of a valve in the discharge pipe. Fig. 102

shows a simple diagram of a force pump. When the piston is raised, water is forced into the cylinder by atmospheric pressure. When the piston is moved downward, the inlet valve D is closed and the water or other liquid is forced through the outlet valve C into the discharge pipe. When next the piston is raised, the outlet valve C is closed by the pressure of the water, preventing the return of the water into the cylinder.

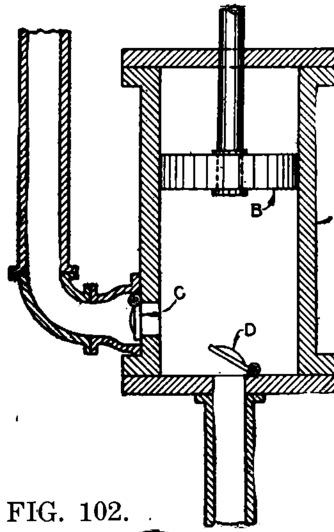


FIG. 102.

Fig. 103 shows a diagram representing one of the most familiar types of double acting steam pumps. Here, steam acting first on one side of the piston and then the other gives a reciprocating motion to the plunger P. A study of this figure will show that the plunger chamber is divided into two sections B and C. Then as the plunger moves to the right as indicated by the arrow, water will be drawn in through the suction pipe and the inlet valves F into the chamber C, the pressure of the water above closing the outlet valves D. At the same time water will be forced out of chamber B through the outlet valves leading to the delivery pipe. When the plunger moves to the left, water is drawn up through the inlet valves G into chamber B and at the same time water is forced out of chamber C through the outlet valves D.

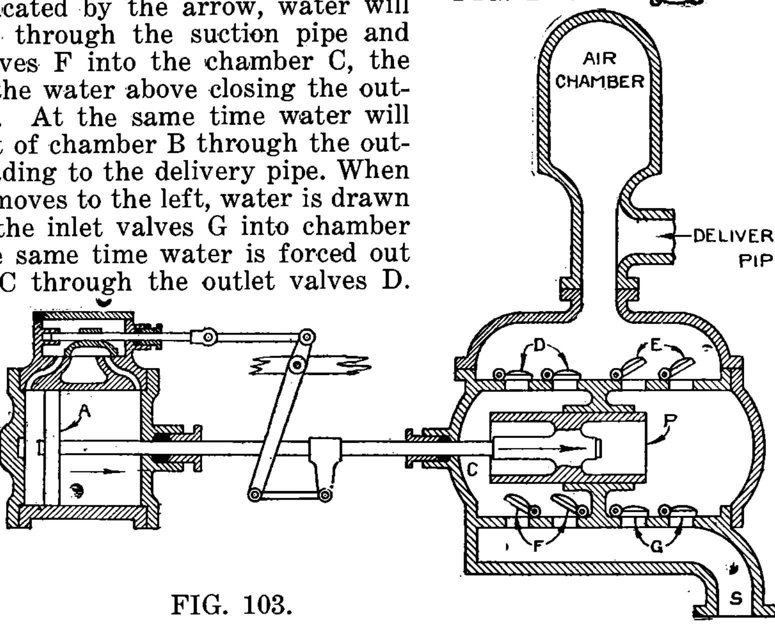


FIG. 103.

Nearly all pumps are provided with an air chamber as indicated in Fig. 103, placed between the outlet valves and the delivery pipe, the object of which is to cause a continuous flow of water. As the water is forced violently into the chamber, the air in the chamber is compressed. Then between the strokes of the plunger, this compressed air tends to react against the water pushing it out into the discharge pipe, thus resulting in a continuous flow of water.

Maximum Lift of Suction Pumps—The maximum distance through which water can be raised by atmospheric pressure depends on that pressure and the pressure acting on the surface of the water at the other end of the column of water. As shown by the barometer, the atmospheric pressure is changing constantly. At sea level the atmospheric pressure is approximately 14.7 lbs. per square inch, which is equivalent to the pressure per square inch exerted by a column of water 33.95 feet high. A column of water approximately 2.31 feet high, exerts a pressure of one pound per square inch. Therefore, if a perfect vacuum were formed in the pump cylinder with a normal atmospheric pressure of 14.7 lbs. per square inch, the height to which water could be lifted would be 14.7 x 2.31 or 33.95 feet, which is the maximum theoretical lift at sea level. On account of the decrease in atmospheric pressure with higher altitudes, this theoretical lift diminishes with an increase in altitude above sea level. It is impossible, however, to obtain a perfect vacuum in the pump cylinder, because of mechanical imperfections and because of air contained in the water and vapor given off by the water. With the best pump the actual lift is only about 82 per cent of the theoretical height and the average pump in good working order will lift only about 75 per cent of the theoretical height or from 25 feet to 26 feet at sea level. As a rule, however, it is advisable to limit the lift to about 60 per cent of the maximum theoretical lift or about 20 feet at sea level, and correspondingly shorter lifts for higher altitudes. It is therefore necessary to place the cylinder of the pump as close to the level of the water as possible. In case it is desired to pump hot water the pump cylinder must be placed below the level of the water, for the reason that a vacuum cannot be formed above the water as it would fill immediately with steam.

The Hydraulic Press—Liquids are nearly incompressible. Liquids subjected to a pressure will regain their former volume immediately after the pressure is removed, which shows their perfect elasticity. This practical incompressibility of liquids is used to great advantage in the hydraulic press.

When a pressure is exerted upon a liquid in a closed vessel, this pressure is transmitted undiminished in all directions, and acts with the same force upon all equal surfaces and at right angles to these surfaces.

Referring to Fig. 104, if the area of the piston in cylinder A is one square inch and the area of the ram in cylinder B is 100 square inches, then a force of one pound applied on piston P in cylinder A will be transmitted by the liquid so as to act with a force of one pound on every square inch of surface on the ram W in cylinder B. Then since the area of the ram W is 100 square inches the total force acting upward against ram W is 1 x 100 or 100 lbs. In the same way, if the area of piston P is 2 square inches and that of ram W 550 square inches and the force applied to piston P is 4 lbs., then the force per square inch acting on the surface of the liquid in cylinder A is $4/2$ or 2 lbs. per square inch and the total force acting upward against ram W is 2 x 550 or 1,100 lbs.

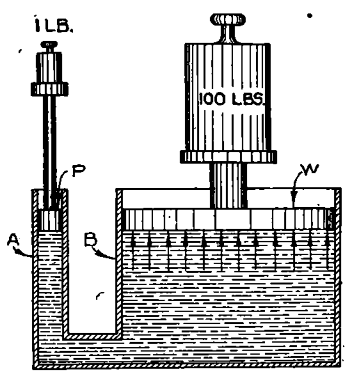


FIG. 104.

This principle is embodied in the hydraulic press where a great pressure may be obtained by the application of a comparatively small force.

Fig. 105 shows a diagram of a hand operated hydraulic press. When the lever handle is raised causing the piston A to move upward, water is drawn into the cylinder through the valve Y, valve V being closed by the pressure of the water in the ram cylinder. Then as piston A moves downward, valve Y is closed and the water is forced through the valve V into the cylinder and acts against the ram P causing it to move upward. A by pass, valve B, is provided by means of which the water can be drained from the cylinder allowing the plunger P to settle downward relieving the pressure at the will of the operator.

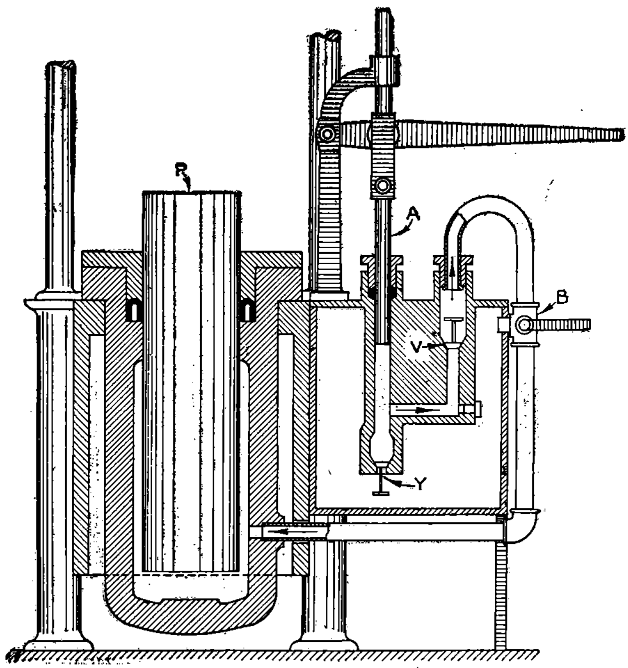


FIG. 105.

Hydraulic presses may also be operated by being connected directly to the water mains where the water pressure is sufficiently great to operate the press.

Usually hydraulic presses are so designed that the ram can be moved in either direction at the convenience of the operator, simply by the movement of an operating lever or valve which causes the water to act in either direction as desired. Such a design is necessary when the ram operates in a horizontal direction or where it acts downward.

Referring to Fig. 104, the unit pressure per square inch is found by dividing the force applied by the area of the piston P.

Expressed in a formula this would be:

$$P = \frac{F}{a}$$

where P = pressure in lbs. per sq. inch.

F = force applied to piston P.

a = area of piston.

Then since the unit pressure is exerted equally in the press, the total capacity or lift of the press may be found by multiplying the unit pressure by the area of the ram W,

or $W = P A$

where W = Total capacity or lift in lbs.

P = Unit pressure.

A = Area of the ram in sq. inches.

These two formulae may be combined by substituting for the value of "P" in the second formula, as

$W = \frac{F A}{a}$, the letters representing the same quantities as before.

Example: In Fig. 104, assuming piston A has an area of 2 square inches, ram P an area of 12 square inches, the length of the lever to be 28 inches, and the distance from the fulcrum to the piston connection to be 4 inches, what pressure is exerted by the ram P with a force of 50 lbs. acting on the end of the handle?

Solution: Using lever formula to find force applied to piston.

$$\frac{50 \times 28}{4} = 350 \text{ lbs. force on piston.}$$

$$\text{then} \quad W = \frac{F A}{a}$$

$$= \frac{350 \times 12}{2}$$

$$= 2{,}100 \text{ lbs. total pressure or lift.}$$

PROBLEMS

1. A hydraulic press having a ram area of 150 sq. inches is connected to a water main in which the water pressure is 90 lbs. per square inch. Find the total pressure exerted by the press.

2. The hydraulic press in Fig. 105 has a piston area of 1.5 sq. in., a ram area of 80.5 sq. in., a lever length of 30 inches and the distance between the fulcrum and the piston rod connection is 5 inches. With a force of 75 lbs. exerted on the end of the lever handle, what pressure is exerted by the press?

3. If the piston diameter is 1¼ inches and the ram diameter 22 inches, what pressure is exerted by the press, other conditions remaining the same as in Prob. No. 2?

4. A hydraulic press is to be connected to a pump producing a pressure of 80 lbs. per sq. inch. What diameter of ram is necessary if the press is to exert a pressure of 15 tons?

5. If the ram of Fig. 105 has a diameter of 12 inches and the press is to exert a pressure of 18 tons, what size piston is required if the total force acting on the piston is 140.62 lbs.?

6. What size piston would be required in Prob. No. 5 if the hydraulic press has an efficiency of 86 per cent?

7. If the efficiency of the press in Prob. No. 2 is 85 per cent, what pressure would be exerted?