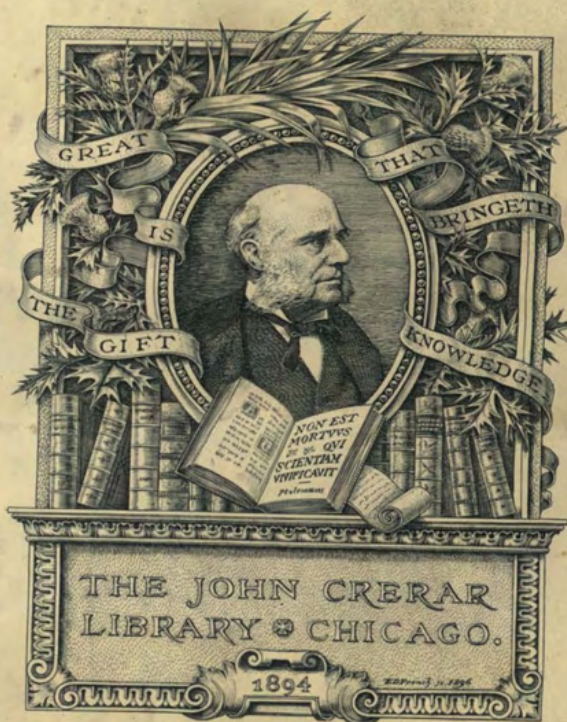


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THE ELEMENTS
OF
MECHANICAL ENGINEERING

PREPARED FOR STUDENTS OF THE
INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

Volume III

MACHINE DESIGN
DYNAMOS AND MOTORS

WITH PRACTICAL QUESTIONS AND EXAMPLES

15470

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INTERNATIONAL TEXTBOOK COMPANY

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E. R.

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MACHINE DESIGN.

INTRODUCTORY.

THE DESIGN OF DETAILS.

1901. Rules and formulas for designing many of the most common details of machines are given in the following pages. In some cases these rules are based on considerations of strength, as developed in the subject of Strength of Materials; in others, the wear to which the parts are to be subjected has been the principal element in determining the given proportions. In all cases, however, the practice of successful designers has been followed in preference to mere theoretical principles.

1902. The first work a young designer is called upon to do is usually that of making drawings of details of machines, the general plans of which have been developed by his superiors. He will be given the leading dimensions of these details, and will be required to make a drawing from which the pattern-makers, blacksmiths, and machinists can finish them ready for their places in the completed machine.

1903. In most shops such parts as bolts, nuts, screws, pipe fittings, etc., and often other simple parts of machines, are bought from factories, where they are made in large quantities by special machinery. If the shop is a large one, there may be a separate department where these parts are made according to fixed standards. The designer should know what the practice of the shop in this regard is, and in all cases make his details to conform with these standards. He should also know the kind of material available, the methods employed by the shop in working this material, and

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the capacity and principal dimensions of the tools and appliances for doing the work, in order that the detail as designed may be built in the most economical manner. When designing a machine part it is well to keep the processes that will be used in making it in mind; this will often prevent constructions that would be very difficult and expensive if built with the machinery in use in the shop for which the design is made.

1904. In making designs of details it is always advisable to draw them to as large a scale as can be used conveniently. The scales commonly used for small details are full size; and for larger ones 6 inches, 3 inches, or $1\frac{1}{2}$ inches = 1 foot may be used. A scale of 4 inches or 2 inches = 1 foot should never be used if it can possibly be avoided.

1905. Remember that the object of a detail drawing of a machine part is to show the workman in the clearest possible manner how the part is to be made and finished, so that it will take its proper place in the completed machine and do the work for which it is intended. The designer must, therefore, be very careful to make the drawing show the form and dimensions of each portion as clearly as possible; the drawing should also show plainly the kind and quality of material to be used, and the finish, if any, to be given the different surfaces. Use sections wherever the general views do not show the form with perfect clearness.

It is well for a designer to imagine himself in the position of a man in the shop who knows nothing of the machine, and study his drawing carefully to see if anything can possibly be lacking that will be required to make the ideas he wants carried out perfectly clear.

1906. Ordinary dimensions are expressed in feet and inches, and the fractions $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, etc., of an inch. Never use the fractions $\frac{3}{8}$, $\frac{5}{8}$, or $\frac{7}{8}$ in dimensions, as the scales which mechanics use are not divided in these fractions. The most common scales in use by mechanics for ordinary work are two-foot rules divided into inches, numbering from 1 to 24:

for this reason many draftsmen give all dimensions less than two feet in inches and fractions of an inch, and dimensions greater than two feet in feet, inches, and fractions of an inch.

Unless great accuracy is required, decimals are never used in giving dimensions. If decimal values are obtained from the calculations they are expressed in the nearest $\frac{1}{8}$, $\frac{1}{16}$, or $\frac{1}{32}$ of an inch, according to the degree of accuracy required. In particular cases, where extreme accuracy is needed, the dimensions may be expressed in decimals; as, for example, the pitch of gear teeth.

THE GENERAL DESIGN OF A MACHINE.

1907. The methods to be employed in the general design of a machine will vary so much with different conditions that no fixed rules or methods of procedure can be given. The first thing necessary is a thorough knowledge of the work the machine must do, together with its location and surroundings and the conditions under which it must do its work. Keeping these in mind, the designer must apply his knowledge of the principles of applied mechanics, strength of materials, and the design and construction of details, in such a way as to accomplish the desired end in the simplest and most direct manner consistent with the conditions imposed.

All machines consist of different combinations of a few simple principles; and, in order to be successful, the designer must become thoroughly acquainted with these principles and the relation they bear to each other. A study of machines that have been built for similar work is of great assistance in suggesting ideas for the new machine.

In many cases it will be necessary to make more or less complete drawings of a number of different plans, before a satisfactory result will be obtained. A combination that appears feasible at first will be found to be impracticable when drawn out in detail, and the parts proportioned so as to give the necessary strength. In other cases the motion of some part may be found to be limited in such

a way as to interfere with the proper working of the machine. The difficulty or expense of manufacture may also make some otherwise good design impracticable.

1908. In all work, whether designing details or more complicated combinations, keep all calculations, notes, and sketches in such a form that they can be preserved for future reference. Date these notes and give them such titles as will be required to make their purpose perfectly clear. In this way ideas that may be impracticable for the particular case for which they were originally developed can be kept for a possible future use; and the results of many hours spent in calculation will be preserved so as to make a repetition unnecessary. Some engineering establishments provide their draftsmen with books made of manila paper bound in board covers; and all calculations, notes, and sketches are made in these books instead of on loose sheets of paper that will soon be lost.

1909. The following practical rules are often neglected by inexperienced designers:

Make all parts that are subject to wear or breakage accessible for the purpose of inspection, repairs, or renewal.

Provide means for adjusting all parts that are subject to wear.

Make careful provision for lubrication.

Use links and rotating pieces for guiding motion in preference to slides.

Use cranks, levers, belts, and gear-wheels for transmitting motion in preference to cams, screws, or worm-wheels.

Wherever possible, make the motion of all parts positive; that is, avoid the use of weights or springs for producing motion.

Use through bolts or T head bolts instead of tap bolts or studs, wherever it can be done.

1910. Designers are often required to furnish an estimate of the weight and cost of a machine from the draw-

ings. This is done in the following manner: The volume of the different details is estimated by means of the principles of mensuration; the weight can then be obtained by multiplying the volume of each piece by the weight of a cubic unit of the material of which it is composed, as given in a table of specific gravities. When the weights are known, the cost of the material is easily found from the known market values. The time that will be required for fitting and finishing the different pieces is then estimated and charged for according to the rates paid for that work. In this way the cost of the machine may be estimated with a degree of accuracy that will depend on the knowledge the estimator has of the time required to do different kinds of work in the shops, and his skill in making approximate calculations of the volumes of irregular-shaped bodies.

MATERIALS USED IN MACHINE CONSTRUCTION.

1911. Cast Iron.—This metal, which has already been briefly referred to in Art. **1332**, etc., is used very largely in the construction of machine parts, particularly those that must be massive; for example, the frames and beds of engines, lathes, planers, etc. It is not well suited for parts subjected to shocks or for parts requiring strength and elasticity.

The great advantage of cast iron is the ease with which it may be given any desired form. Shapes that could not possibly be forged from wrought iron may be cast with comparative ease. The operation of casting is as follows: A pattern is first made of the exact shape of the required part; this pattern is usually made of pine, though metal is sometimes used when the castings are small and a great number are to be made. The pattern is placed in a bed of sand or loam, in which it leaves, after being removed, an impression or cavity called the *mold*. The melted metal is poured into the mold, and, after cooling, the casting is with-

drawn and finished to the required dimensions. Cast iron contracts in cooling about *one-eighth of an inch per foot in each direction*; on account of this contraction, commonly called the **shrinkage**, the pattern must be made that much larger than the required casting. In practice this is always done by using a **shrink rule** in constructing the pattern. The shrink rule is about $\frac{1}{8}$ " longer per foot than the standard rule.

1912. A serious difficulty experienced in the use of cast iron is its liability to be thrown into a state of internal stress, on account of inequality of cooling after being poured into the mold. It is a matter of experience that the amount of contraction depends upon the size and thickness of the casting. In general, thick and heavy parts contract more than thin ones; consequently, a casting composed of both thick and thin parts will sometimes differ from the form desired. Again, one part of a casting may cool and solidify while another part is still in a molten condition.

The contraction of the latter must, therefore, strain the part already solidified. The casting is thus thrown into a state of internal stress which must to some degree reduce its effective strength:

Take, for example, the case of a pulley. When the rim is thin, but rigid, it is liable

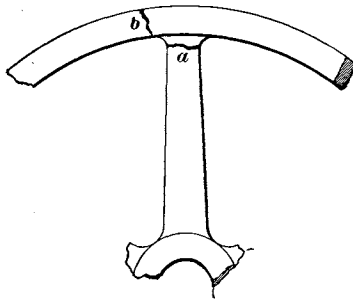


FIG. 592.

to contract and solidify first, and the subsequent contraction of the arm may induce a fracture, as shown at *a*, Fig. 592. If, however, the arms set first, the subsequent contraction of the rim may cause a fracture, as shown at *b*.

1913. When pulleys are cast with thin rims which are not rigid, the casting often takes the form shown in Fig. 593. The rim is drawn in at the points where it joins the arms, because the arms solidify and contract

after the rim has set, and the latter, not being sufficiently rigid to withstand the pull of the arms, is distorted.

These internal stresses make cast iron an unreliable material for the construction of parts requiring strength; and it should be the aim of the designer to prevent these stresses as far as may be by making all parts that are to be cast as uniform in thickness as possible, and avoid having a large boss, or hub, appear in a comparatively thin part, or having a very thick part meet a very thin one.

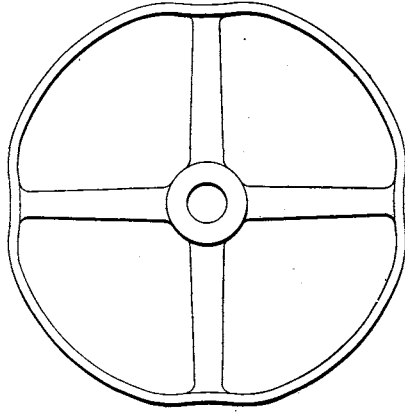


FIG. 593.

1914. It is found that, in cooling, the iron crystals arrange themselves perpendicularly to the surface of the

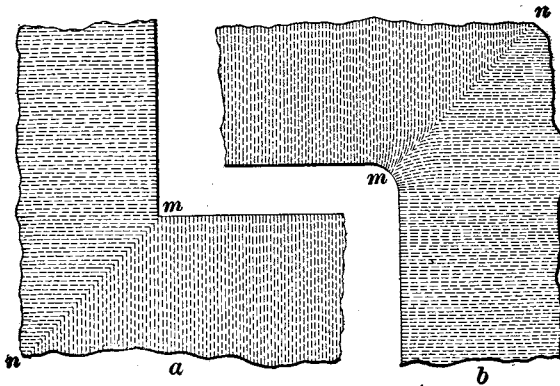


FIG. 594.

casting. For this reason an inside angle (*a*, Fig. 594) is a source of weakness, the casting having a tendency to break through the line *m n*. Such corners should be rounded, as shown at *b*, Fig. 594, in which case the crystalline arrangement renders the casting much stronger.

1915. Chilled castings are made by lining the whole or a part of the mold with cast iron which is protected by a thin coating of loam. The cast-iron lining is a good conductor of heat, and the molten iron is thus cooled off quickly, or *chilled*. The sudden cooling of the casting prevents the carbon from separating from the iron with which it is in chemical combination, and as a result the portion of the casting which is chilled is of white, hard iron. Usually, the chilling extends to the depth of from $\frac{1}{8}$ to $\frac{3}{8}$ inch; the interior of the casting is of soft, gray cast iron, which is best for resisting shocks, while the chilled surface is very hard and durable.

For malleable cast iron see Art. **1337**.

1916. Wrought Iron and Steel.—The leading properties of these metals have already been given. They are used for parts of machines requiring strength and elasticity, such as shafts, bolts, piston rods, and connecting-rods of engines, etc.

Wrought iron or steel machine parts are forged or rolled to approximately the required shape, and then finished upon the lathe, planer, or other tool. Parts may also be cast of steel the same as cast iron. When so made they are called **steel castings**.

1917. Copper.—This metal is used principally for making tubes, steam pipes, expansion joints, and similar details, for condensers, boilers, engines, etc. It can be hammered or rolled into sheets or drawn into wire; it may be cast or forged, but can not be welded. The tenacity of cast copper is about 21,000 lb. per square inch; of forged copper, about 30,000 lb. per square inch. The tenacity of copper may be increased by hammering, wire-drawing, or rolling, but it is at the same time rendered hard and brittle. The toughness may be restored by annealing.

1918. Bronze, or Gun-Metal.—This is an alloy composed of copper and tin, in the proportion of 90 parts of copper to 10 parts of tin. The metal has a tenacity of about 35,000 lb. per square inch. It is largely used for the

bearings of rotating machine parts. The bronze being softer than the iron wears more rapidly, and thus lengthens the life of the rotating part. The hardness of the bronze may be increased by increasing the proportion of the tin; for bearings required to sustain a great pressure the bronze may be composed of 86 parts of copper to 14 parts of tin. A very soft bronze is composed of 92 parts of copper and 8 parts of tin. This quality of bronze is used for making gear-wheels which are subjected to severe shocks.

1919. Phosphor-Bronze.—This is made by alloying ordinary bronze with from 2 to 4 per cent. of phosphorus. It is now being largely used instead of ordinary bronze, and is also employed in place of iron and steel in the construction of propeller blades, pump rods, etc. The softer phosphor-bronze has a tensile strength of about 45,000 lb. per square inch; the hardest varieties may have a tenacity as high as 65,000 lb. per square inch, while hard, unannealed wire has, in some cases, a tenacity of 140,000 lb. per square inch.

1920. Manganese-Bronze.—This is also called white bronze, and is an alloy of ordinary bronze and ferromanganese. It is equal in strength and toughness to mild steel, and may be forged into nuts, bolts, rods, etc. It resists the corroding action of sea water, and is, therefore, much used for propellers. Both manganese-bronze and phosphor-bronze are largely used in marine work.

1921. Brass.—Brass is composed of copper and zinc in the proportion of two parts of the former to one of the latter. Its tenacity is about 25,000 lb. per square inch. Brass is used for condenser tubes and for various fittings, such as valves, cocks, etc.

1922. Wood.—This material is used to a limited extent in machine construction; for example, oak and *lignum-vitæ* are sometimes used for bearings; beech and hornbeam for cogs of mortise wheels; pine, cherry, and mahogany for patterns.

FASTENINGS.

SCREWS, BOLTS, AND NUTS.

1923. Screws are used in machine construction for three different purposes:

1. As a fastening for clamping or joining parts together.
 2. For the transmission of motion.
 3. For producing pressure.
- Screws used as fastenings are called **bolts**.

FORMS OF SCREW THREADS.

1924. The V Thread.—Screw threads are usually triangular or square in section, the triangular form being best for bolts, and the square form best for screws transmitting motion. The **Seller's triangular** or **V thread**, commonly called the **American thread**, or **United States standard**, which is used in the United States, is shown in Fig. 595. Fig. 596 is an enlarged section of the thread.

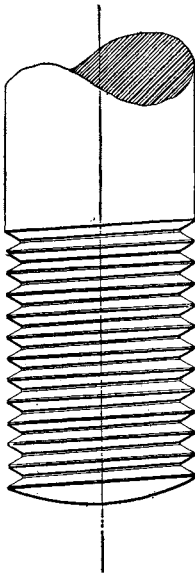


FIG. 595.

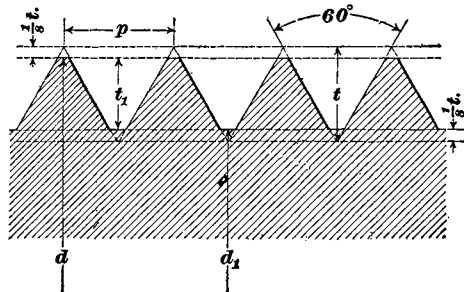


FIG. 596.

The *angle* between the sides of the thread is 60° . The distance p from one thread to the next is called the **pitch** of the screw. As shown in the figure, a section of a single thread is an equilateral triangle, the altitude of which is t ; to form the United States standard thread $\frac{1}{8}$ the altitude

of the triangle is cut off from the apex, and the angle at the root is filled in to a like depth. Hence, the *real depth* of the thread, t_1 , is $\frac{3}{4}$ the altitude of the triangle; that is, $t_1 = \frac{3}{4} t$.

$$\text{But } t = p \cos 30^\circ = .866 p;$$

$$\text{hence, } t_1 = \frac{3}{4} t = .65 p. \quad (207.)$$

1925. V threads are sometimes cut without the flat top and bottom, the section being a full equilateral triangle; in this case they are commonly called **sharp V threads**.

1926. The pitch of the thread depends upon the diameter of the bolt; it may be obtained approximately by the following formula, in which d represents the diameter of the bolt:

$$p = .24 \sqrt{d + .625} - .175". \quad (208.)$$

The diameter d_1 at the root of the thread may be found by the following formula:

$$d_1 = d - 2 t_1 = d - 1.3 p. \quad (209.)$$

The diameter d_1 must always be used in calculating the strength of a bolt.

Letting n represent the number of threads per inch in a screw, we have

$$n = \frac{1}{p}. \quad (210.)$$

$$\text{Consequently, } d_1 = d - \frac{1.3"}{n}. \quad (211.)$$

EXAMPLE.—The external diameter of a bolt is $1\frac{1}{8}$ inches. Find the pitch, the number of threads per inch, the depth of thread, and the diameter of bolt at root of thread.

SOLUTION.—

$$p = .24 \sqrt{1.375 + .625} - .175" = .164".$$

$$n = \frac{1}{p} = \frac{1}{.164} = 6, \text{ nearly. Use 6 threads per inch, then, } p = \frac{1}{6} = .167". \quad \text{Ans.}$$

$$t_1 = .65 p = .65 \times .167 = \frac{7}{84}" = \frac{1}{12}" \text{, nearly. Ans.}$$

$$d_1 = d - 2 t_1 = 1\frac{1}{8} - \frac{2}{12} = 1\frac{5}{8}" \text{. Ans.}$$

Table 43 gives the number of threads per inch, diameter of bolt at root of thread, and effective area of bolt at root of thread, United States standard sizes:

TABLE 43.

Diameter of Screw in Inches.	Number of Threads per Inch.	Diameter at Bottom of Threads in Inches.	Area at Bottom of Threads in Square Inches.
<i>d.</i>	<i>n.</i>	<i>d₁.</i>	<i>a.</i>
$\frac{1}{8}$	20	.185	.0269
$\frac{5}{16}$	18	.240	.0452
$\frac{3}{8}$	16	.294	.0679
$\frac{7}{16}$	14	.345	.0935
$\frac{1}{2}$	13	.400	.1257
$\frac{9}{16}$	12	.454	.1619
$\frac{5}{8}$	11	.507	.2019
$\frac{3}{4}$	10	.620	.3019
$\frac{7}{8}$	9	.731	.4197
1	8	.838	.5515
$1\frac{1}{8}$	7	.939	.6925
$1\frac{1}{4}$	7	1.064	.8892
$1\frac{3}{8}$	6	1.158	1.0532
$1\frac{1}{2}$	6	1.283	1.2928
$1\frac{5}{8}$	$5\frac{1}{2}$	1.389	1.5153
$1\frac{3}{4}$	5	1.490	1.7437
$1\frac{7}{8}$	5	1.615	2.0485
2	$4\frac{1}{2}$	1.711	2.2993
$2\frac{1}{4}$	$4\frac{1}{2}$	1.961	3.0203
$2\frac{1}{2}$	4	2.175	3.7154
$2\frac{3}{4}$	4	2.425	4.6186
3	$3\frac{1}{2}$	2.629	5.4284
$3\frac{1}{4}$	$3\frac{1}{2}$	2.879	6.5099
$3\frac{1}{2}$	$3\frac{1}{2}$	3.100	7.5477
$3\frac{3}{4}$	3	3.317	8.6414
4	3	3.567	9.9930
$4\frac{1}{4}$	$2\frac{7}{8}$	3.798	11.3292
$4\frac{1}{2}$	$2\frac{1}{2}$	4.027	12.7366
$4\frac{3}{4}$	$2\frac{5}{8}$	4.255	14.2197
5	$2\frac{1}{2}$	4.480	15.7633
$5\frac{1}{4}$	$2\frac{1}{2}$	4.730	17.5717
$5\frac{1}{2}$	$2\frac{3}{8}$	4.953	19.2676
$5\frac{3}{4}$	$2\frac{3}{8}$	5.203	21.2617
6	$2\frac{1}{4}$	5.423	23.0978

1927. The Square Thread.—In Fig. 597 is shown a screw with a **square thread**, and in Fig. 598 an enlarged section of the thread. As the name implies, the section of the thread is a square, each side of which is one-half the pitch.

The pitch of the square thread is usually taken *double* that of the triangular thread

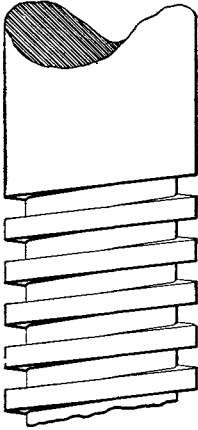


FIG. 597.

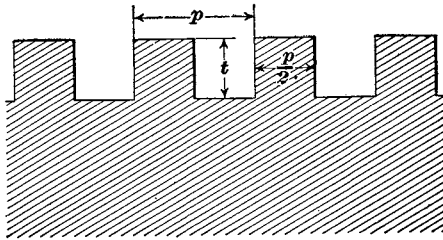


FIG. 598.

for the same diameter of bolt; for example, the pitch of a square thread on a 2-inch bolt or rod is $\frac{1}{2}$ inch. Approximately, the pitch is $\frac{1}{5}$ the diameter of the screw; that is,

$$p = \frac{d}{5} = \frac{d_1}{4}. \quad (212.)$$

$$\text{Hence, } d_1 = \frac{4}{5} d. \quad (213.)$$

$$\text{Also, } t = \frac{p}{2} = \frac{d}{10} = \frac{d_1}{8}. \quad (214.)$$

The edges of the threads should be very slightly rounded off so as to prevent them from being accidentally flattened, which would cause a nut to bind upon the thread of the screw. When this rounding off is carried far enough, the thread takes the form shown in Fig. 599. This thread is especially adapted to withstand rough usage.

1928. The modification of the square thread, shown in Fig. 600, is frequently used for the lead screws of lathes. The section of the thread, instead of being square, tapers slightly from root to point. This taper is given not only because a thread of this form is much easier to cut than the

square thread, but because it enables the nut, which is made

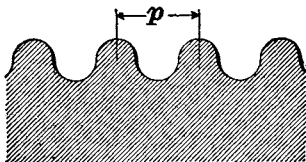


FIG. 599.

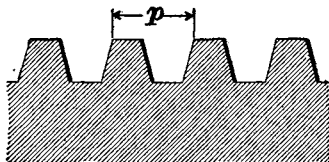


FIG. 600.

in two parts, to readily engage or disengage with the screw.

1929. The **trapezoidal screw thread** is shown in Fig. 601. One face of the thread is perpendicular to the axis of the screw, and the other is inclined at an angle of 45° . From the construction of the figure it is evident that $t = p$, the pitch. To form the actual thread an amount equal to $\frac{1}{8}t$ is cut off from top and bottom of the triangle; hence, the real depth t_1 is $\frac{3}{4}t$.

When this thread is used, it is generally for communicating motion, or where great resistance without any bursting tendency is required.

The usual dimensions are given by the following formulas, in which the letters have the same meaning as before:

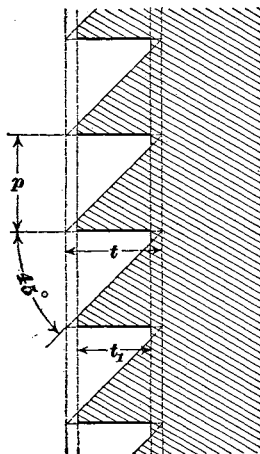


FIG. 601.

$$p = \frac{2d}{15} = \frac{d_1}{6}. \quad (215.)$$

$$t_1 = \frac{d}{10} = \frac{d_1}{8}. \quad (216.)$$

For example, supposing the diameter of the screw to be $1\frac{1}{2}$ inches, the pitch of a trapezoidal thread is $p = \frac{2d}{15} = \frac{2 \times 1\frac{1}{2}}{15} = \frac{1}{5}$; the number of threads per inch is $\frac{1}{p} = \frac{1}{\frac{1}{5}} = 5$, and the depth of the thread is $t_1 = \frac{d}{10} = \frac{1\frac{1}{2}}{10} = .15$.

1930. The relative advantages of the various forms of screw threads may be shown by a consideration of the

forces acting on the thread. Usually the load on a bolt or screw acts in the direction of its axis; that is, a bolt used as a fastening is in tension, while a screw used to produce pressure is in compression. In either case the load is carried by the reaction between the surface of the thread of the screw and the surface of the thread in the nut. Suppose, in Fig. 602, the load to be upon the side ml of the thread, and let the reaction of the thread at the point A be represented by R , which must, of course, be perpendicular to ml . This reaction R may be resolved into two forces, one, P , parallel to the axis of the bolt, and the other, Q , perpendicular to the axis. Then, P represents the portion of the load carried by the surface A of the screw, while the force Q tends to burst the nut. Now, for a given load the force P will remain the same whatever the angle of the thread may be. On the other hand, the forces Q and R will increase as the angle mln decreases. The friction between two surfaces is proportional to the perpendicular pressure between them. Consequently, *the greater the angle of a screw thread, the greater is the friction between the bolt and nut, and also the greater is the force tending to burst the nut.*

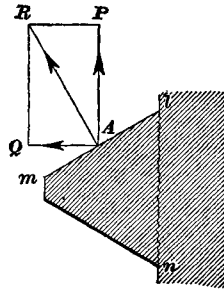


FIG. 602.

In the case of the square thread, the angle between the sides is zero, and hence there is no force tending to burst the nut. The reaction R becomes equal to the load P ; therefore, the friction of a square thread is less than that of a triangular thread. On the other hand, the triangular thread is nearly twice as strong as a square thread. Thus, in Fig. 602, the shearing surface of a single triangular thread is $\pi d_1 \times \text{distance } nl$, or $\pi d_1 p$, nearly, while it will be seen by referring to Fig. 598 that the shearing surface of a single square thread is $\pi d_1 \times \frac{1}{2} p = \frac{\pi d_1 p}{2}$.

It follows, therefore, that the triangular thread is better for fastenings, and the square thread for transmitting motion.

The trapezoidal thread combines the good features of both the triangular and the square threads. It has the same shearing section as the former, and the same friction as the latter. In this care must be taken, however, to use the screw so that the pressure comes on the flat side of the thread, for if it is put upon the inclined side the friction and bursting force on the nut are both greater than for a 60° triangular thread. The trapezoidal thread is used in the breech mechanism of large guns.

In England the **Whitworth system** of triangular threads is in use. The angle of the Whitworth thread is 55° and the point is rounded instead of being cut flat.

1931. Multiple-Threaded Screws.—It is plain that a nut will advance a distance equal to the pitch of the thread for each revolution of the screw. When a screw is used to transmit motion, it is often desirable to have the nut advance a considerable distance for one revolution, and this may necessitate a pitch altogether too large for the diameter of the screw. This difficulty is obviated by cutting two or more parallel threads, each having the same pitch.

These screws are termed **multiple-threaded** screws; when the screw has two threads, it is called a **double-threaded** screw; when it has three threads, a **triple-threaded** screw, and when it has four threads, a **quadruple-threaded** screw.

In Fig. 603 is shown a single square-threaded screw, and in Fig. 604 a double square-threaded screw, both screws

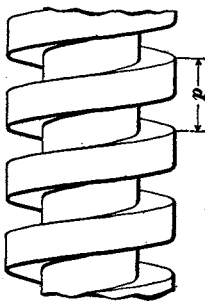


FIG. 603.

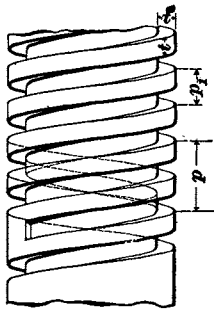


FIG. 604.

having the same diameter and pitch. It is apparent that the root diameter of the double-threaded screw is much larger than that of the single-threaded one; it is, consequently, stronger, and is, therefore, to be pre-

ferred. The distance (p , Fig. 604) between *two consecutive threads* of a multiple-threaded screw is equal to the pitch p , divided by the number of threads (2, 3, or 4, according to whether the screw is double, triple, or quadruple-threaded), and is called the **divided pitch** of the thread.

The dimensions of the thread are based upon this divided pitch; that is, $t = \frac{p}{2}$. Besides being stronger for the same pitch than the single thread, the multiple thread has the advantage of having a greater wearing surface than the single thread.

1932. Gas-Pipe Threads.—The rules for the pitches and depth of screw threads do not apply to gas-pipe threads, since the calculated depth of the thread would in that case be greater than the thickness of the pipe.

The following table gives the standard dimensions of steam, gas, and water pipes:

TABLE 44.

Nominal Diameter in Inches.	Thickness in Inches.	Actual Internal Diameter in Inches.	Actual External Diameter in Inches.	Threads per Inch. <i>n</i> .	Pitch of Threads.
$\frac{1}{8}$	.068	.270	.405	27	.037
$\frac{1}{4}$	.088	.364	.540	18	.056
$\frac{3}{8}$	.091	.494	.675	18	.056
$\frac{1}{2}$	.109	.623	.840	14	.071
$\frac{3}{4}$	.113	.824	1.050	14	.071
1	.134	1.048	1.315	11 $\frac{1}{2}$	.087
1 $\frac{1}{4}$	.140	1.380	1.660	11 $\frac{1}{2}$	.087
1 $\frac{1}{2}$	.145	1.611	1.900	11 $\frac{1}{2}$	.087
2	.154	2.067	2.375	11 $\frac{1}{2}$	.087
2 $\frac{1}{2}$	.204	2.468	2.875	8	.125
3	.217	3.061	3.500	8	.125
3 $\frac{1}{2}$	.226	3.548	4.000	8	.125
4	.237	4.026	4.500	8	.125
4 $\frac{1}{2}$	.247	4.508	5.000	8	.125
5	.259	5.045	5.563	8	.125
6	.280	6.065	6.625	8	.125
7	.301	7.023	7.625	8	.125
8	.322	7.982	8.625	8	.125
9	.344	9.001	9.688	8	.125
10	.366	10.019	10.750	8	.125

1933. Threads may be right-handed or left-handed. To determine whether a screw is right or left-handed, hold it so that its axis will be horizontal; if the slope of the thread (from top to bottom) is from left to right, it is right-handed; otherwise the thread is left-handed. For nuts the above rule should be reversed. The threads of screws for general use are right-handed, and are so shown in the previous figures. Screws having left-handed threads are made only for special purposes.

STRENGTH OF SCREW BOLTS.

1934. Usually the stress on a bolt acts in the direction of its axis; that is, the bolt is in tension.

Let W = load on bolt in pounds;

S_t = safe working stress in pounds per square inch;

a = area of cross-section of bolt at root of thread;

d = nominal (outside) diameter of bolt in inches;

d_1 = diameter at root of thread in inches.

Then, if the bolt is in tension,

$$W = a S_t; \text{ or, } a = \frac{W}{S_t}. \quad (217.)$$

The value of the nominal diameter d (corresponding to the value of a) obtained from formula **211** may be found from Table 43.

1935. For bolts subjected to a constant tension, S_t may be 8,000 lb. per sq. in. More often the tension varies between zero and its maximum value; in this case S_t may be taken as 6,000 lb. per sq. in. For cylinder-head bolts, and, in general, for bolts used to make a steam-tight joint, S_t may vary from 3,000 lb. for small cylinders to 6,000 for very large ones. Ordinarily S_t may be taken as 4,000 or 4,500 lb. per sq. in. All the above values are for wrought-iron bolts.

EXAMPLE.—Find the diameter of a wrought-iron bolt which is to sustain a steady load of $4\frac{1}{2}$ tons.

SOLUTION.—From formula **217**,

$$a = \frac{W}{S_t} = \frac{4\frac{1}{2} \times 2,000}{8,000} = 1.125 \text{ sq. in.}$$

From Table 43, the value of d lies between $1\frac{3}{8}$ " and $1\frac{1}{2}$ ". The latter value should be taken. Ans.

1936. For screws transmitting motion, the following formula may be used:

$$\begin{aligned} W &= 3,000 d_1^2 = 1,920 d^2 \text{ (since } d_1 = \frac{4}{5} d \text{),} \\ \text{or } d_1 &= .0183\sqrt{W} \\ d &= .0228\sqrt{W} \end{aligned} \quad (218.)$$

For screws of this character, the least number of threads in the nut that are necessary to prevent excessive wear is given by the following formula, in which n_1 = the number of threads in the nut:

$$n_1 = \frac{W}{300 d^2} = .0052 \frac{W}{d^2}. \quad (219.)$$

The above formula applies to square and trapezoidal threads, and is based upon the assumption that the pressure on the thread per square inch of projected area should not be greater than 700 lb. per sq. in.

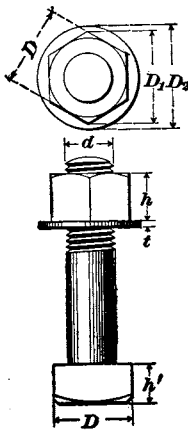


FIG. 605.

EXAMPLE.—A square-threaded screw $1\frac{1}{2}$ inches in diameter transmits motion to a load of 4,000 pounds. What is the least allowable number of threads in the nut?

SOLUTION.—

$$n_1 = .0052 \frac{W}{d^2} = \frac{.0052 \times 4,000}{(1\frac{1}{2})^2} = 9\frac{1}{2}. \quad \text{Ans.}$$

PROPORTIONS OF BOLTS AND NUTS.

1937. The dimensions of the nut and bolt head are made to depend upon the diameter of the bolt. The standard form of bolt and nut is shown in Fig. 605. The bolt has a square head and hexagonal nut with washer. The washer is used to give a smooth seat for the nut to be screwed up against.

The following proportions are usually adopted;

Diameter of nut or head across flats,

$$\left. \begin{aligned} D &= 1\frac{1}{2} d + \frac{1}{8}'' \text{ for rough work.} \\ D &= 1\frac{1}{2} d + \frac{1}{16}'' \text{ for finished work.} \end{aligned} \right\} \quad (220.)$$

Height of nut,

$$\left. \begin{aligned} h &= d \text{ for rough work.} \\ h &= d - \frac{1}{16}'' \text{ for finished work.} \end{aligned} \right\} \quad (221.)$$

$$\text{Thickness of washer, } t = .15 d. \quad (222.)$$

$$\text{Diameter of washer, } D_2 = 1\frac{1}{2} D_1. \quad (223.)$$

The above proportions for diameters D hold for both hexagonal and square nuts. The diameter across corners D_1 may be found from the geometry of the figure. Thus, for hexagonal nuts,

$$D_1 = \frac{D}{\cos 30^\circ} = \frac{D}{.866} = \begin{cases} 1.73d + .14'' \text{ for rough nuts.} \\ 1.73d + .07'' \text{ for finished nuts.} \end{cases} \quad (224.)$$

For square nuts,

$$D_1 = \frac{D}{\cos 45^\circ} = D\sqrt{2} = \begin{cases} 2.12d + .18'' \text{ for rough nuts.} \\ 2.12d + .09'' \text{ for finished nuts.} \end{cases} \quad (225.)$$

Height of head,

$$\begin{aligned} h' &= \frac{3}{4}d + \frac{1}{16}'' \text{ for rough bolts.} \\ h' &= d - \frac{1}{16}'' \text{ for finished bolts.} \end{aligned} \quad (226.)$$

EXAMPLE.—Required, the various dimensions of a finished bolt and hexagonal nut, the bolt being $1\frac{1}{2}$ inches in diameter.

SOLUTION.—Diameter of nut across flats $= D = 1\frac{1}{2}d + \frac{1}{16} = 1\frac{1}{2} \times 1\frac{1}{2} + \frac{1}{16} = 2\frac{5}{16}$ in.

Diameter of nut across corners $= D_1 = \frac{D}{.866} = \frac{2.3125}{.866} = 2\frac{11}{16}$ in., nearly. Ans.

Side of square bolt head $= D = 2\frac{5}{16}$ in. Ans.

Height of nut $= h = d - \frac{1}{16} = 1\frac{1}{2} - \frac{1}{16} = 1\frac{7}{16}$ in. Ans.

Height of bolt head $= h' = d - \frac{1}{16} = 1\frac{1}{2} - \frac{1}{16} = 1\frac{7}{16}$ in. Ans.

Diameter of washer $= D_2 = 1\frac{1}{2} D_1 = 1\frac{1}{2} \times 2\frac{11}{16} = 3$ in., nearly. Ans.

Thickness of washer $= t = .15d = .15 \times 1\frac{1}{2} = \frac{3}{4}$ in., nearly. Ans.

WRENCHES.

1938. The usual forms of solid wrenches are shown in

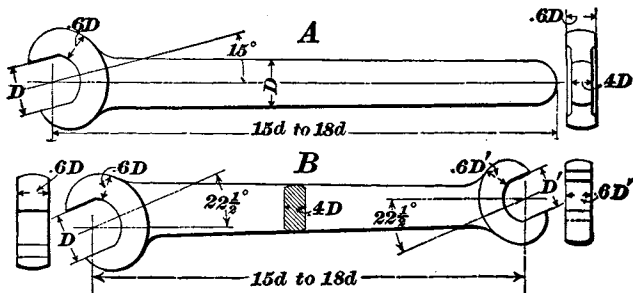


FIG. 606.

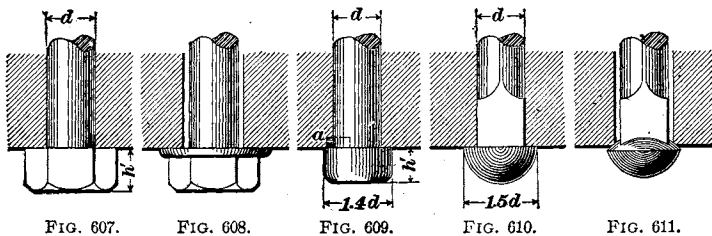
Fig. 606, in which that shown at A is used for hexagonal nuts, and that at B for square nuts. The length may be

from 15 to 18 times the diameter of the bolt for which it is to be used. In the figures d represents the diameter of the bolt. The other proportions are given in terms of the diameter across the flats of the nut as shown in the figure.

FORMS OF BOLT HEADS.

1939. The ordinary square bolt head has been shown in Fig. 605. Other forms are shown in Figs. 607 to 615. In Fig. 607, the hexagonal bolt head is similar to a hexagonal nut, and has the same dimensions except that the height h' may be less. Usually $h' = \frac{2}{3} d$ to d .

Fig. 608 shows a hexagonal head with a collar or flange, which is added to give an increased bearing surface. A



cylindrical head is shown by Fig. 609, and a hemispherical head by Fig. 610. The height h' of the former may be from $.5d$ to $.8d$; that of the latter is $\frac{3}{4}d$. The diameter of these heads is as shown by the figures. Fig. 611 shows a bolt head with a hemispherical bearing surface resting on a seat of the same shape. This bolt may lean to one side while the head will still remain in contact with its seat all the way round.

An eye-bolt is shown in Fig. 612. The cross-section of the eye through the hole should equal or exceed the area of the bolt.

That is, referring to this figure, $2 a b = \frac{1}{4} \pi d^2$ or $a b = .39d^2$.

In good practice $a b$ is at least equal to $\frac{1}{2}d^2$. To calculate the diameter d_1 of the pin passing through the eye, we observe that the pin is in double shear, the shearing surface being twice the area of it; or $2 \left(\frac{\pi d_1^2}{4} \right) = \frac{1}{2} \pi d_1^2$.

The strength of this pin in shear should equal the strength of the eye-bolt in tension; therefore, letting S_s represent

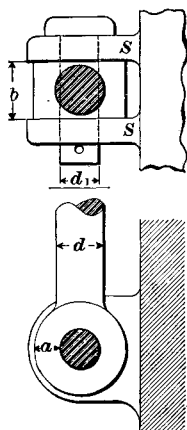


FIG. 612.

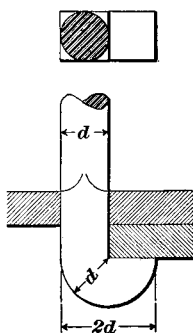


FIG. 613.

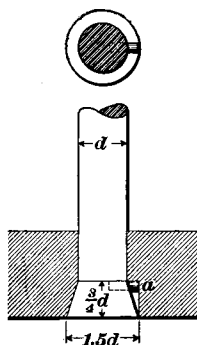


FIG. 614.

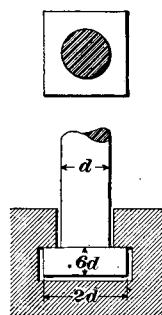


FIG. 615.

the *safe* shearing stress per square inch, and S_t the *safe* tensile strength, we have

$$\frac{1}{2} \pi d_1^2 S_s = \frac{1}{4} \pi d^2 S_t,$$

$$\text{or } d_1 = d \sqrt{\frac{S_t}{2S_s}}.$$

But the ratio $\frac{S_t}{S_s}$ is usually about 1.25;

$$\text{hence, } d_1 = d \sqrt{.625} = .8 d, \text{ nearly.} \quad (227.)$$

If, however, the pin is overhung; that is, if there is but one of the nibs S, S , instead of two, as shown in Fig. 612, it will be in a single shear, and

$$d' = d \sqrt{\frac{S_t}{S_s}} = 1.1 d, \text{ nearly.} \quad (228.)$$

Fig. 613 shows the head of a **hook bolt**. This form of bolt is used when it is undesirable to weaken one of the connected pieces by a bolt hole. The proportions are shown in the figure. The **countersunk head** is shown by Fig. 614, and the **T head** by Fig. 615.

1940. The ordinary method of *attaching a bolt to stonework* is shown in Fig. 616. The head is long and rectangular, and is made *jagged* with a cold chisel; the hole is made

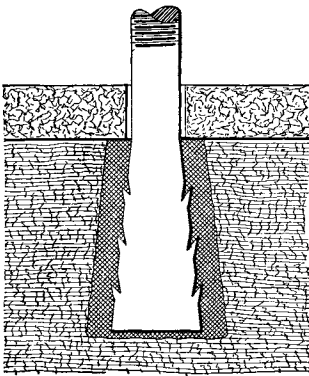


FIG. 616.

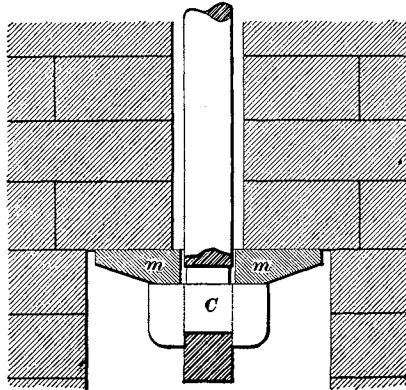


FIG. 617.

larger at the bottom than at the mouth. The bolt head is placed in the hole and the remaining space is then filled with melted lead or sulphur.

1941. The ordinary method of fixing the **foundation bolts** which fasten an engine bed to its foundation is shown in Fig. 617. These foundation bolts have no solid heads, but are long rods threaded on one end for a nut, and have a slot in the other end through which passes a **cotter** *C*, which rests against a cast-iron or wrought-iron washer *m*. This washer and cotter form the head of the bolt.

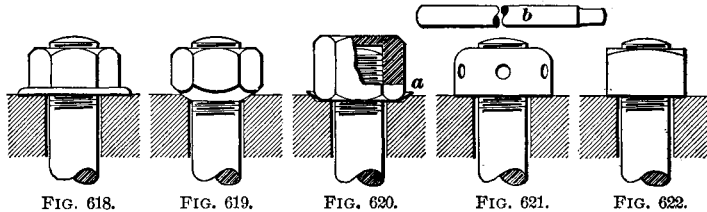
The bolt head is within a recess formed in the foundation, so arranged as to be accessible. The area of the washer bearing against the foundation, multiplied by the safe compressive strength of the material of the foundation, should be equal to the tension carried by the bolt. For example, the tensile strength of wrought iron is about 20 times the compressive strength of brick. Hence, the bearing area of a washer resting against a brick foundation should be 20 times the cross-section of the bolt.

1942. Various devices are used to prevent a bolt from *turning* while the nut is being screwed up. A common

method is to make the neck of the bolt next to the head **square**, as shown in Figs. 610, 611, and 613. The *bolt hole* is also made square. Another way is to insert a *pin a* into the neck, close to the head, as shown in Figs. 609 and 614. The projecting part of the pin fits into a recess cut out to receive it.

FORMS OF NUTS.

1943. The *common hexagonal nut* has been shown in Fig. 605. Ordinarily, both hexagonal and square bolt heads and nuts are *chamfered off* at an angle of 30° or 40° . Other forms of nuts are shown in Figs. 618 to 622. The **flanged**



nut, Fig. 618, is useful when the bolt hole is larger than the bolt, as it covers the hole and gives a greater bearing surface. Fig. 619 shows a nut with a **spherical bearing surface** and the seat shaped to correspond. This nut will bear upon the seat all around, whether the bolt be perpendicular or inclined to the seat. A **cap nut** is shown in Fig. 620. This form of nut is used to prevent the leakage of a fluid past the screw threads. To prevent leakage past the seat, the nut is screwed down on a soft, thin copper washer *a*. Fig. 621 shows a **round nut**, and Fig. 622 an ordinary **square nut**. The round nut is provided with holes in its circumference, as shown, and is screwed up by inserting a bar *b* in one of the holes.

LOCKING NUTS.

1944. All nuts are slightly loose on their bolts, a small clearance being necessary to permit them to turn freely. When a nut is subject to vibration it is liable to slack back and

allow the bolt to become loose. To prevent this slacking back, various locking arrangements have been devised. A common device is the **locknut**, or **jam nut**, shown in Fig. 623. Two nuts are used, one of which is about half as thick as the ordinary nut. The load is thrown on the outer nut, which should, therefore, be the thicker one. In practice it is common to place the thin one on the outside, because the wrench is generally too thick to act on it when placed below the other. The jam nut is not always satisfactory as a method of locking.

1945. The nut may be effectively locked to the bolt by the use of a set-screw, as shown in Fig. 624. To prevent the point of the set-screw from injuring the thread, a piece of iron or steel *m* may be let into the nut. The piece is screwed along with the nut, and acts as a shield interposed between the set-screw and thread.

1946. A good method of locking a nut is shown in Fig. 625. The lower portion of the nut is turned down, and a

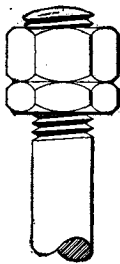


FIG. 623.

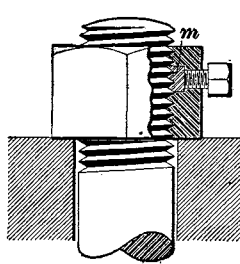


FIG. 624.

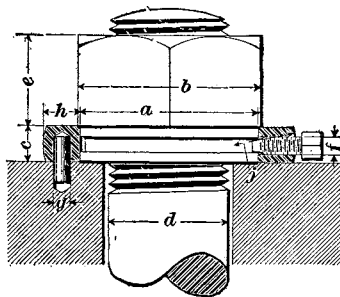


FIG. 625.

groove is cut in the center of the circular portion. A collar is fastened by means of a pin to one of the pieces to be connected, and the circular part of the nut is fitted into this collar. The nut is then bound to the collar by a set-screw passing through the latter, the point of the set-screw engaging into the groove turned in the nut. The following proportions have proved very satisfactory, in which d , the diameter of the bolt, is taken as a unit. All dimensions are in inches:

$$\left. \begin{aligned} a &= 1\frac{1}{2}d - \frac{1}{8}''; & f &= \frac{1}{8}d + \frac{1}{8}''; \\ b &= 1\frac{1}{2}d + \frac{1}{8}''; & g &= \frac{1}{8}d + \frac{1}{8}''; \\ c &= \frac{1}{4}d + \frac{1}{4}''; & h &= \frac{1}{4}d + \frac{1}{4}''; \\ & e &= \frac{3}{4}d. \end{aligned} \right\} \quad (229.)$$

1947. Fig. 626 shows a device for locking a nut by means of a **stop plate**. The plate is fastened to one of the pieces through which the bolt passes.

It is so shaped that the bolt may be locked at intervals of $\frac{1}{2}$ of a revolution. Suitable proportions for this stop plate are shown in the figure, in which d , the diameter of the bolt, is taken for the unit, except the distance between the center of the bolt and screw for which D , the diameter between the parallel sides of the nut, is taken for the unit. All dimensions are in inches.

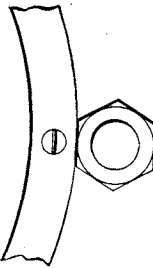


FIG. 627.

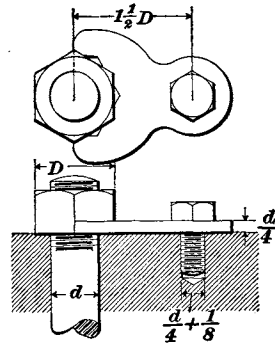


FIG. 626.

1948. In Fig. 627 is shown another form of *stop plate*, which may be conveniently used when the bolts are set in a circle, as, for example, on engine cylinder heads.

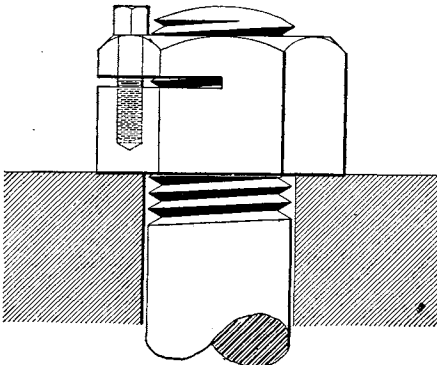


FIG. 628.

1949. In Fig. 628 is shown a different manner of locking the nut. In this the nut is sawed half way through, and the parts connected by a small screw. When the nut is screwed home the small screw is tightened, thereby

greatly increasing the friction between the bolt and the nut.

1950. A convenient locking device is **Grover's spring washer**, shown in Fig. 629. The washer when not held

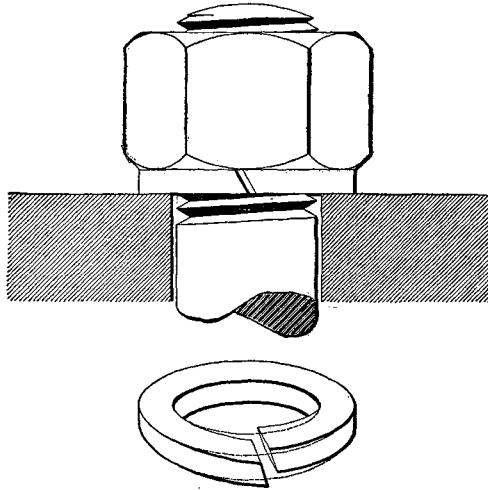


FIG. 629.

down by the nut has the form shown in the lower part of the figure; when the nut is screwed down tightly, the washer is flattened out and its elasticity keeps the nut tight on the bolt.

FORMS OF BOLTS AND SCREWS.

1951. Bolts.—A **stud bolt**, or **stud**, is shown in Fig. 630. Each end of the stud has a screw thread cut on it. One end screws into one of the pieces to be connected, the other carries a nut.

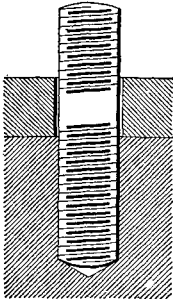


FIG. 630.

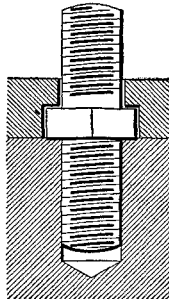


FIG. 631.

A stud having a **collar** is shown in Fig. 631. The collar may be square or round; it serves as a shoulder against which to screw up the stud, and, when square, is a convenient place to apply a wrench.

A **tap bolt**, shown in Fig. 632, is a bolt not requiring a nut. It is screwed directly

into one of the pieces to be connected, the head pressing upon the other piece.

Fig. 633 shows a tap bolt having a countersunk head. This style of bolt is called a **patch bolt**, and, as its name implies, it is used in making patches in boilers, etc. The diameter of the neck of the projection to which the wrench

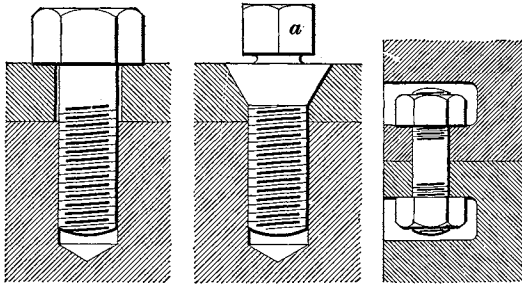


FIG. 632.

FIG. 633.

FIG. 634.

is applied is smaller than the root diameter of the bolt, so that the projection will break off instead of breaking the bolt when too much force is applied to it.

Fig. 634 shows a bolt having a nut at each end instead of a head and nut.

1952. Screws.—In Figs. 635, 636, and 637 are shown different forms of machine screws slotted for a screwdriver. Fig. 635 is called a **countersink head screw**; Fig. 636,

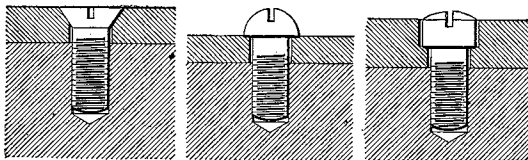


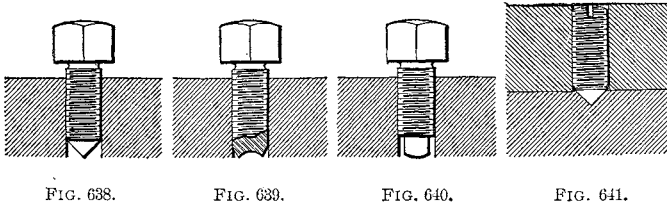
FIG. 635.

FIG. 636.

FIG. 637.

a **button head screw**, and Fig. 637, a **fillister head screw**. When the countersink head screw is used, the hole in the piece which is to be held tight is countersunk so that the head of the screw is flush as shown.

953. Set-screws are screws or bolts which are used to press against a piece, and by friction to prevent it from



moving or rotating relatively to another piece. For example, a set-screw may be screwed through the hub of a pulley, and by pressing against the shaft will prevent the pulley from turning on the shaft. Various forms of set-screws are shown in Figs. 638, 639, 640, and 641.

Fig. 638 is called a **cone-point set-screw**; Fig. 639, a **cupped set-screw**; Fig. 640, a **round pivot-point set-screw**, and Fig. 641, a **headless cone-point set-screw**.

1954. Bolts in Shear.—Usually bolts are in direct tension, but constructions occur in which a bolt may be placed in shear.

The strength of a bolt in shear is about $\frac{4}{5}$ that of a bolt in tension; that is, the shearing strength of wrought iron is about $\frac{4}{5}$ the tensile strength. Hence, the diameter of a bolt in single shear should be $\sqrt{\frac{5}{4}} = 1.1$ that of a bolt in tension under the same load; and the diameter of a bolt in double shear should be $\sqrt{\frac{5}{4 \times 2}} = .8$ that of a bolt in tension under the same load.

1955. Knuckle Joint.—The knuckle joint, Fig. 642, is an example of a bolt in shear. Since the bolt is in double shear, it need be theoretically only .8 the diameter of the rod. The bolt wears, however, and since it should at no time be less than .8 the diameter of the rod, the bolt and rod are made equal in diameter.

The other proportions are in terms of the diameter of the bolt. All dimensions are in inches.

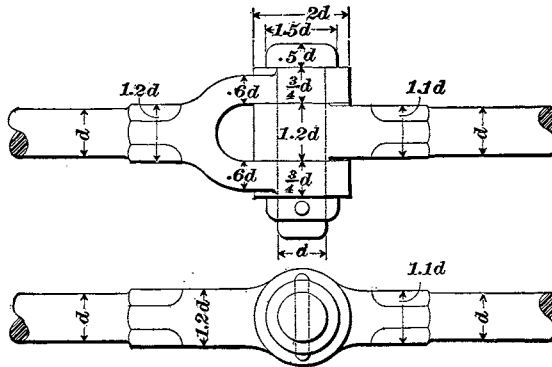


FIG. 642.

Other examples of bolts in shear may be seen in pin-connected iron bridges.

EXAMPLES FOR PRACTICE.

1. Calculate the diameter of a wrought-iron bolt which is to sustain a varying load of 2,300 pounds. Ans. $\frac{7}{8}$ in.
2. What steady load may be safely sustained by 5 bolts $1\frac{1}{8}$ " in diameter? Ans. 13.86 tons.
3. A screw with square threads transmits motion to a load of 1,500 pounds. Calculate the diameter of the screw, the number of threads per inch, and the necessary number of threads in the nut.

Ans. $\left\{ \begin{array}{l} \text{Diameter} = \frac{7}{8} \text{ in.} \\ \text{Threads per inch} = 6. \\ \text{Threads in nut} = 10. \end{array} \right.$

KEYS.

1956. Keys are iron or steel wedges used to secure wheels, cranks, or pulleys to shafts. It is the duty of the key to prevent the relative rotation of the pieces connected; if, for example, the pieces in question are a pulley and shaft, the function of the key is to prevent the pulley from turning on the shaft. Generally, the key will also prevent a wheel or pulley from moving lengthwise along the shaft.

FORMS OF KEYS.

1957. The **concave key** is shown in Fig. 643. The key is hollowed out to fit the shaft, and holds by friction alone; hence, it is suitable only for light work.

Fig. 644 shows a shaft with a **flat key**. A flat surface is cut on the shaft to receive the key, which is, consequently, more effective than the concave key.

1958. The **sunk key**, Fig. 645, is much more effective than either of the above mentioned, since it is impossible for the pulley to slip on the shaft without shearing off the key.

A slot called the **key-way** is cut lengthwise in the shaft,

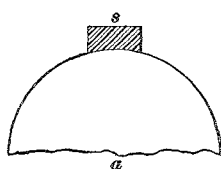


FIG. 643.

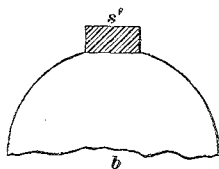


FIG. 644.

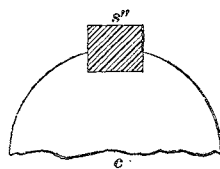


FIG. 645.

and another one is cut in the hub of the pulley. The key is accurately fitted and driven in.

Two kinds of sunk keys are in common use: 1. The

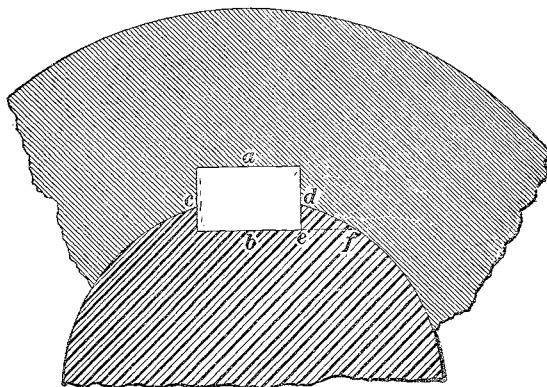


FIG. 646.

rectangular keys of the form shown in Fig. 646, which are used for fastening cranks, gear-wheels, etc. 2. Square keys,

Fig. 645, which are used on machine tools, and, in general, on work requiring accurate fitting.

The keys of the former class are driven in tightly and usually fit at the top and bottom as well as at the sides; they are unsuited for parts which require nice fitting, because they are liable to spring the parts out of true. The square key, on the other hand, does not fit tightly at the top and bottom, but rather at the sides.

1959. Large wheels or pulleys may be fastened to the shaft by using two, three, or four keys. Fig. 647 shows a method of keying a piece to a square shaft. When several keys are thus used the wheel or pulley may be centered on

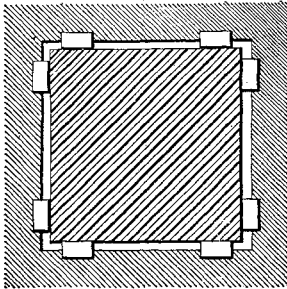


FIG. 647.

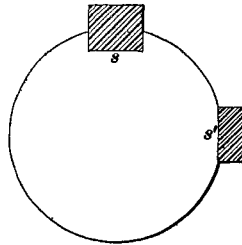


FIG. 648.

the shaft by means of the keys. If a pulley is accidentally bored a little too large for the shaft, it may be prevented from rocking by using both a sunk key and a flat key, as shown in Fig. 648.

The flat key is placed at a distance around the shaft of about 90° from the sunk key, and the pulley is thus made to bear on the shaft at three points.

When a key cannot be conveniently driven out from the small end,



FIG. 649.

it is necessary to make it with a gib head *a*, as shown in Fig. 649. The head forms a shoulder to drive against.

1960. Sliding, or feather, keys are used where it is desired to prevent a piece from rotating on a shaft, and, at the same time, allow it to slide lengthwise. The key is

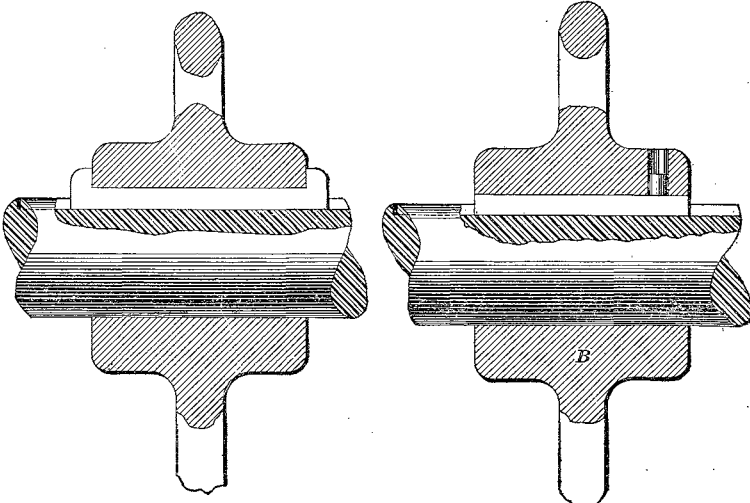


FIG. 650.

FIG. 651.

usually fastened to the piece, and is free to slide in the keyway of the shaft, though the operation is sometimes reversed, and the key is fastened to the shaft. Various methods of fixing the key to the wheel or pulley are shown in Figs. 650, 651, and 652. In Fig. 652, the key is dovetailed in section, and driven tightly into the hub *m*.

When the hub of a wheel in which there is a feather abuts against a collar or a bearing it is evident that the feather must not project, and in such a case the feather key, Fig. 652, or the flush feather key, Fig. 651, may be used; otherwise, the key may have gib heads, as shown in Fig. 650.

1961. Round, or pin, keys may be used when the piece is shrunk on to the shaft, as for example, a small crank, as shown in Fig. 653. A hole is drilled partly in the shaft and partly in the crank, and a round pin is driven in the hole, as shown in the figure.

1962. To facilitate the driving in and the removal of keys they are usually tapered. The taper varies from $\frac{1}{64}$ to $\frac{1}{100}$ or $\frac{1}{150}$, the smaller tapers being used on the most

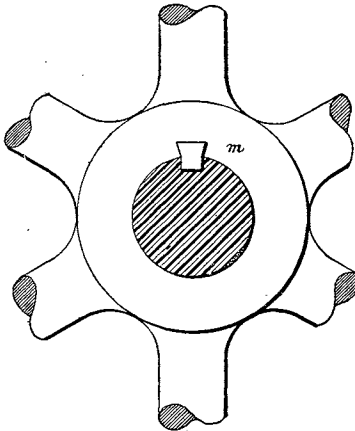


FIG. 652.

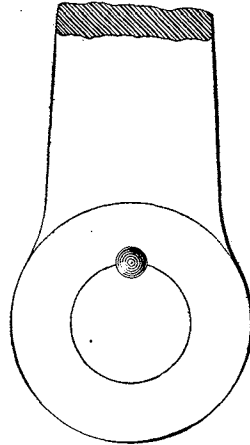


FIG. 653.

accurate work. By a taper of $\frac{1}{84}$ is meant that the decrease in thickness is $\frac{1}{84}$ the length of the key. Square keys and feather keys do not require a taper.

NOTE.—To prevent any misunderstanding, the word *taper*, when used in this subject, will mean the gradual diminution in size of a slender object. Thus, should it be stated that a certain conical piece has a taper of 2 inches per foot, it would be meant that were the conical piece one foot long the diameter at one end would be 2 inches larger than at the other.

STRENGTH AND PROPORTIONS OF KEYS.

1963. A sunk key is subjected to two kinds of stresses. The twisting of the piece on the shaft tends to shear the key, and also to crush it by compression.

Let b = width of key in inches;

t = thickness of key in inches;

l = length of key in inches;

S_s = *safe* shearing stress allowable in pounds per square inch;

S_c = *safe* crushing stress allowable in pounds per square inch;

P = force in pounds acting at rim of wheel or pulley;

R = radius of wheel or pulley in inches;

d = diameter of shaft in inches.

The shearing area of the key is $b l$; hence, the safe resistance of the key to shearing is $b l S_s$. Taking moments about the center of the shaft, we have

$$b l S_s \times \frac{1}{2} d = P \times R,$$

$$\text{or} \quad b l = \frac{2PR}{S_s d}. \quad (a)$$

Suppose the key to be half bedded in the shaft, the crushing area is $\frac{1}{2} t l$, the resistance to crushing $\frac{1}{2} t l S_c$. If the key is designed to be equally strong against shearing and crushing, the shearing resistance must equal the crushing resistance, or

$$b l S_s = \frac{1}{2} t l S_c,$$

$$\text{or} \quad b = \frac{1}{2} t \frac{S_c}{S_s}. \quad (b)$$

If now we assume the crushing strength of the material to be double the shearing strength, $\frac{S_c}{S_s} = 2$; and we obtain $b = t$. S_c is really not double S_s , but on account of the friction between the key and shaft, there is little danger of crushing, and a small factor of safety may be used. In any case, b is not to be less than t , and for practical reasons it is generally made greater.

For shearing, we may use a factor of safety of about 10, giving a safe shearing stress S_s of 5,000 lb. per sq. in. for wrought iron, and 7,000 lb. for steel. Then equation (a) above becomes

$$\left. \begin{aligned} b l &= \frac{PR}{2,500 d} \text{ for wrought iron.} \\ b l &= \frac{PR}{3,500 d} \text{ for steel.} \end{aligned} \right\} \quad (230.)$$

Instead of the twisting moment PR of formula **230**, it may be more convenient to use the horsepower transmitted by the shaft, and its number of revolutions.

Let N = number of revolutions per minute;

H = horsepower.

Then, a point on the circumference of the wheel or pulley moves $2\pi RN$ inches per minute, or $\frac{2\pi RN}{12}$ feet per minute.

Hence, if a force P constantly acts at the circumference of the wheel, the work done per minute is $\frac{2\pi RN}{12} \times P$ foot-pounds.

Therefore, $\frac{2\pi RN P}{12} \div 33,000 = H$, the horsepower.

$$\frac{12 \times 33,000 \times H}{2\pi N} = PR = 63,025 \frac{H}{N}. \quad (231.)$$

Formula **231** will be frequently used hereafter, and should be carefully studied.

Substituting the value of PR from formula **231**, in formula **230**, we have

$$\left. \begin{aligned} bl &= \frac{25H}{dN} \text{ for wrought iron.} \\ bl &= \frac{18H}{dN} \text{ for steel.} \end{aligned} \right\} \quad (232.)$$

Formulas **230** and **232** may be used in calculating the sizes of keys for large work. For small shafts the sizes given by **230** and **232** are much smaller than are used in actual practice.

1964. Designers usually adopt some standard ratio between the depth and width of the key, the ratio varying from $\frac{1}{2}$ to $\frac{5}{6}$. We shall adopt the ratio $\frac{2}{3}$; that is, $t = \frac{2}{3}b$.

EXAMPLE.—The maximum pressure on an engine crank-pin is 12,500 pounds, and the length of crank is 10 inches. Suppose the diameter of the shaft to be 5 inches, and the length of the key the same. What should be the dimensions of a wrought-iron key to hold the crank to the shaft? The crank is not to be shrunk on the shaft.

SOLUTION.—Using formula **230**,

$$b = \frac{PR}{2,500 dl} = \frac{12,500 \times 10}{2,500 \times 5 \times 5} = 2". \quad \text{Ans.}$$

$$t = \frac{2}{3}b = \frac{2}{3} \times 2 = 1\frac{1}{3}", \text{ say } 1\frac{1}{2}". \quad \text{Ans.}$$

1965. In common designing, the sizes of keys are determined by empirical formulas, which give an excess of strength. For an ordinary sunk key, the following proportions may be adopted:

$$\left. \begin{aligned} b &= \frac{1}{4}d. \\ t &= \frac{2}{3}b = \frac{1}{6}d. \end{aligned} \right\} \quad (233.)$$

Using formula **233** in the example of the crank-shaft above,

$$\begin{aligned} b &= \frac{1}{4}d = \frac{1}{4} \times 5 = 1\frac{1}{4}" \\ t &= \frac{1}{6}d = \frac{5}{6} = 1\frac{3}{6}", \text{ nearly.} \end{aligned}$$

The key is sunk for $\frac{1}{2}$ its depth in the shaft.

The following empirical formulas give good results:

$$\left. \begin{aligned} b &= \frac{d}{7} + \frac{1''}{4}. \\ t &= \frac{d}{12} + \frac{3''}{16}. \end{aligned} \right\} \text{ For driven pulleys.} \quad (234.)$$

$$\left. \begin{aligned} b &= .2d + .16". \\ t &= .1d + .16". \end{aligned} \right\} \text{ For driving pulleys.} \quad (235.)$$

$$\text{When } d \text{ is less than } 1\frac{3}{16} \text{ in.,} \quad \left. \begin{aligned} b &= \frac{d}{3}. \\ t &= \frac{d}{5}. \end{aligned} \right\} \quad (236.)$$

Formulas **233** and **235** give nearly the same results; thus, for a $2\frac{1}{2}$ -inch shaft, **233** gives $b = \frac{2\frac{1}{2}}{4} = \frac{5''}{8}$, and $t = \frac{3''}{8}$, nearly. **235** gives $b = .66 \text{ in.} = \frac{1\frac{1}{8}''}{8}$, and $t = .41'' = \frac{7}{16}''$. Unless otherwise stated, the student may use formula **233** in solving his problems.

For sliding feather keys, the following formulas give the proportions used in ordinary practice :

$$\left. \begin{aligned} b &= \frac{d}{8} + \frac{1''}{16}. \\ t &= \frac{3}{16}d + \frac{1''}{16}. \end{aligned} \right\} \quad (237.)$$

1966. In some instances pulleys may be keyed to a large shaft and yet transmit a small amount of power. In such cases the dimensions of a key, if based upon the actual diameter of the shaft, would be much too large, and the proportions should be based upon the diameter of a shaft which would be necessary to transmit the power of the pulley in question, and no more. Letting H represent the horsepower transmitted by the pulley, and N represent the revolutions per minute of the shaft, we may take

$$d = 5 \sqrt[3]{\frac{H}{N}}, \quad (238.)$$

and use this value of d in formula **236**.

EXAMPLE.—A pulley transmitting 2 horsepower is keyed to a shaft 4 inches in diameter making 120 revolutions per minute. Determine the dimensions of the key.

SOLUTION.—The diameter of a shaft to transmit 2 horsepower is

$$d = 5 \sqrt[3]{\frac{H}{N}} = 5 \sqrt[3]{\frac{2}{120}} = 1.28". \quad \text{Ans.}$$

From formula **236**,

$$b = \frac{d}{3} = \frac{1.28}{3} = \frac{7}{16}" \quad \text{Ans.} \qquad t = \frac{d}{5} = \frac{1.28}{5} = \frac{1}{4}" \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. Calculate the dimensions of an ordinary sunk key for a shaft $3\frac{1}{2}$ inches in diameter. Ans. $\frac{9}{16}" \times \frac{7}{8}"$.
2. Calculate the dimensions of a feather key for a shaft $2\frac{3}{4}$ inches in diameter. Ans. $\frac{1\frac{3}{8}" \times \frac{9}{16}"$.
3. A wrought-iron key is used to fasten a fly-wheel on a 6-inch shaft. If the maximum pressure on the crank-pin is 15,000 lb., and the crank radius is 16 inches, what should be the dimensions of the key, its length being 8 inches? Ans. $2" \times 1\frac{11}{16}"$.
4. A pulley transmits $3\frac{1}{2}$ horsepower, and is keyed to a shaft 5 inches in diameter, making 150 revolutions per minute. Calculate the dimensions of the key. Ans. $\frac{1}{2}" \times \frac{5}{16}"$.

COTTERS.

1967. A **cotter** is an iron or steel bar which is driven through one or both of two pieces to be connected, and holds them together by its resistance to shearing at two *transverse*

cross-sections. An example of a cotter was shown in Fig. 617. The cotter C passes through the foundation bolt, and is subjected to a shearing stress along the dotted lines.

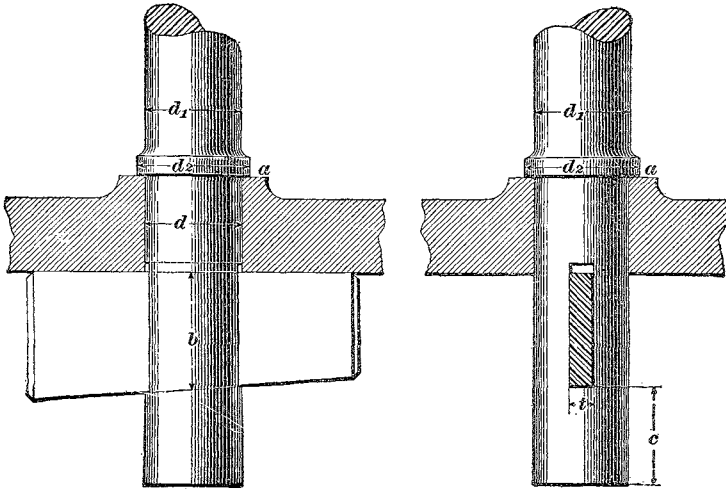


FIG. 654.

A simple form of a cotter is shown in Fig. 654. The cotter passes through the rod only, and acts when the rod is in tension. The enlargement, or collar a , on the rod prevents any downward movement, and, therefore, resists thrust.

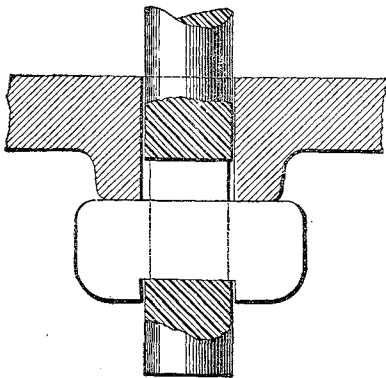


FIG. 655.

Fig. 655 shows a cotter with gib ends. Since in this case the rod is not provided with a collar, this arrangement will resist tension only. In the arrangement shown in Fig. 656, the cotter is divided into two parts, the

one with hooked ends being called the **gib**, and the other the cotter.

In this construction the rod should be placed in tension only. If it is necessary to provide for thrust the end of the rod should be tapered as shown in Fig. 657.

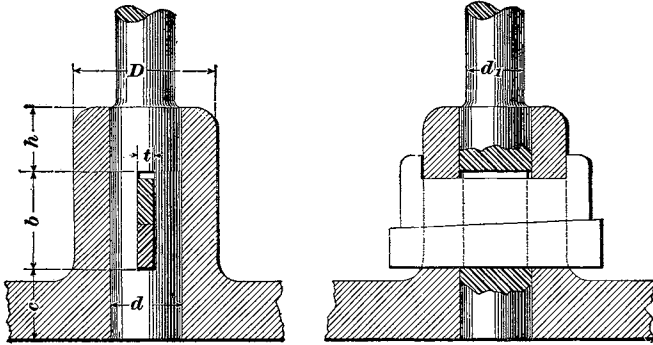


FIG. 656.

Fig. 658 shows an arrangement in which a rod is cottered into a socket. As shown in Figs. 656 and 658, the cotter is long and tapered; it serves, therefore, as a means of adjusting the length of the connected pieces. By driving the cotter farther in, the total length of the two pieces is lessened, and *vice versa*.

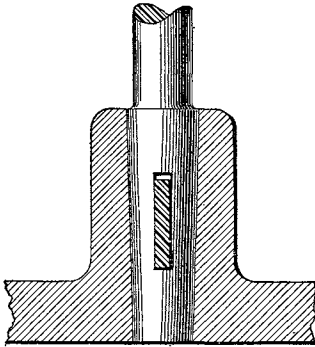


FIG. 657.

A cotter may be used to connect two straps m and n to a rod l shown in Fig. 659. When driven down the friction between the cotter and lower strap must cause the latter to open out as shown by the dotted lines. Hence, it is desirable in such a case to use a cotter combined with a gib, as shown in Fig. 660, or with two gibs as shown in Fig. 661.

The gibs serve to keep the straps from spreading. In Fig. 662 the side $a b$ of the gib and $c d$ of the cotter

are parallel to each other, and perpendicular to the axis of the rod, and the taper comes between the gibs and cotter.

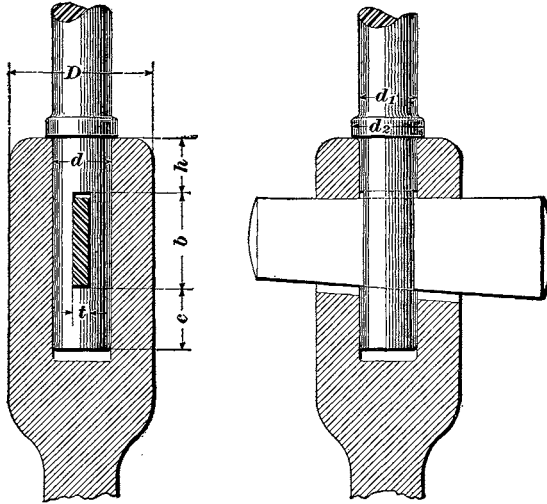


FIG. 658.

1968. Strength and Proportions of Cotters.—In designing a cotter connection the following points must be taken into account:

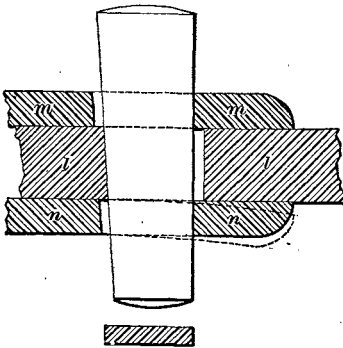


FIG. 659.

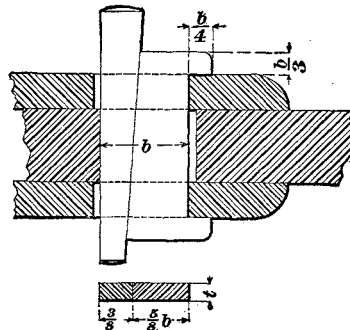


FIG. 660.

Referring to the illustration of the cotter, Fig. 654—

1. The cross-section $b t$ of the cotter must be sufficient to withstand the shearing force.

2. The thickness t must be great enough to provide against failure by crushing.

3. The two diameters d_1 and d should be so designed that the rod is of uniform strength throughout.

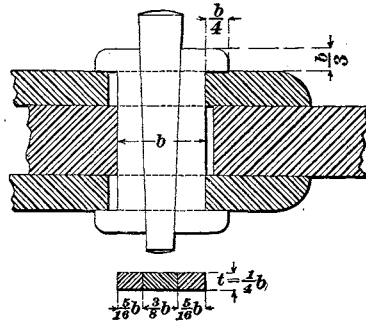


FIG. 661.

Let P = force in pounds exerted on the rod;

S_s = *safe* shearing strength of cotter in pounds per square inch;

S_c = *safe* compressive strength of cotter or rod in pounds per square inch;

S_t = *safe* tensile strength of rod in pounds per square inch.

The various diameters and other dimensions are indicated on the figures.

Consider the arrangement shown in either Fig. 656 or Fig. 657 and conceive a section taken through the cotter hole. The net area of the rod is $\left(\frac{\pi}{4}d^2 - dt\right)$, very nearly; the shearing area of the cotter is $2bt$; the area of the cotter subject to crushing is dt , very nearly; the area of the socket subject to tension is $\frac{\pi}{4}(D^2 - d^2) - (D - d)t$; finally, the area of the smaller part of the rod is $\frac{1}{4}\pi d_1^2$.

$$\text{Hence, } P = \left(\frac{\pi}{4}d^2 - dt\right)S_t. \quad (a)$$

$$P = 2btS_s. \quad (b)$$

$$P = dtS_c. \quad (c)$$

$$P = \left[\frac{\pi}{4}(D^2 - d^2) - (D - d)t\right]S_t. \quad (d)$$

$$P = \frac{\pi}{4}d_1^2S_t. \quad (e)$$

Suppose both rod and cotter are made of the same material, either wrought iron or steel, and take $\frac{S_s}{S_t} = \frac{4}{5}$, as was done before in Art. 1954.

Experience shows that S_c may be double S_t ; that is, $\frac{S_c}{S_t} = 2$.

$$\text{Hence, } \frac{S_c}{S_s} = \frac{2}{\frac{4}{5}} = 2\frac{1}{2}.$$

Now, combining equations (b) and (c),

$$2 b t S_s = d t S_c; \text{ or, } b = \frac{d S_c}{2 S_s} = \frac{d}{2} \times 2\frac{1}{2} = 1.25 d.$$

Combining equations (a) and (c), we have

$$\left(\frac{\pi}{4} d^2 - d t \right) = d t \frac{S_c}{S_t} = 2 d t;$$

whence, $3 d t = \frac{\pi}{4} d^2$, and $t = \frac{\pi}{12} d = .26 d = \text{say } \frac{1}{4} d$.

Combining equations (a) and (d), and taking $t = \frac{\pi}{12} d$, it will be found that

$$D = \frac{4}{3} d = 1.3 d.$$

Combining equations (a) and (e), and taking $t = \frac{\pi}{12} d$,

$$\begin{aligned} \frac{\pi}{4} d_1^2 &= \frac{\pi}{4} d^2 - d t = \frac{\pi}{4} d^2 - \frac{\pi}{12} d^2; \text{ whence,} \\ d_1^2 &= \frac{2}{3} d^2, \text{ and } d_1 = .816 d. \end{aligned}$$

It was shown above that to have the same tensile strength as the rod, the diameter D of the socket or boss should be $1.3 d$.

To prevent failure from crushing, however, the bearing surface of the socket should equal that of the rod, or

$$(D - d) t = d t. \quad \text{Hence, } D = 2 d.$$

The diameter d_2 of the collar, Fig. 658, should be such that the bearing surface of the collar is at least equal to that of the cotter in the rod. Hence,

$$\frac{\pi}{4}(d_2^2 - d^2) = dt = \frac{\pi}{12}d^2;$$

whence, $\frac{\pi}{4}d_2^2 = \frac{\pi}{3}d^2$, and $d_2 = d\sqrt{\frac{4}{3}} = 1.15d$.

Collecting the above results, we have

$$\left. \begin{aligned} b &= 1\frac{1}{4}d; \\ t &= \frac{1}{4}d; \\ d_1 &= .816d; \\ D &= 2d; \\ d_2 &= 1.15d; \\ h = c &= \frac{3}{4}d \text{ to } 1\frac{1}{4}d. \end{aligned} \right\} \quad (239.)$$

1969. If a steel cotter be used in a wrought-iron rod, b may be made equal to d , the other dimensions remaining the same as above.

For a cotter of the form shown in Fig. 660 or 661 it is good practice to make $t = \frac{1}{4}b$, and $b t = \frac{5}{4} \times$ sectional area of strap.

The width b is the same whether a single cotter, a gib and cotter, or two gibs and cotter are used. The other proportions are shown on the figures.

EXAMPLE.—Suppose in Fig. 661 the strap is $\frac{7}{8}'' \times 3\frac{1}{2}''$; find the thickness of the cotter, and combined width of gibs and cotter.

SOLUTION.— $b t = \frac{5}{4} \times \frac{7}{8} \times 3\frac{1}{2} = \frac{245}{64}$. Making $t = \frac{1}{4}b$, as stated above,

$$b t = \frac{1}{4}b^2 = \frac{245}{64};$$

$$\text{whence, } b = \sqrt{\frac{245}{16}} = 3.91'' = 3\frac{15}{16}''. \text{ Ans.}$$

$$t = \frac{1}{4}b = 1 \text{ inch, nearly. Ans.}$$

The width of cotter is, then, $\frac{2}{3}b$, or $1\frac{1}{2}''$, and the width of each gib is $\frac{5}{16}b$, or $1\frac{7}{8}''$.

1970. Taper of Cotters.—The greatest allowable taper that a cotter may have without danger of slacking back is about $\frac{1}{4}$.

Usually, the taper is $\frac{1}{24}$ to $\frac{1}{48}$ when the cotter is not secured. If fastened by a set-screw or bolt and nut the

cotter may have a taper of $\frac{1}{8}$ or $\frac{1}{16}$. The taper is found by dividing the increase in width by the length of cotter. Thus, if a cotter is 2 inches wide at one end, $2\frac{1}{2}$ inches wide at the other, and 12 inches in length, the taper is $(2\frac{1}{2} - 2) \div 12 = \frac{1}{24}$.

1971. Locking arrangements for cotters are shown in Figs. 662 and 663. In Fig. 662 the cotter is held

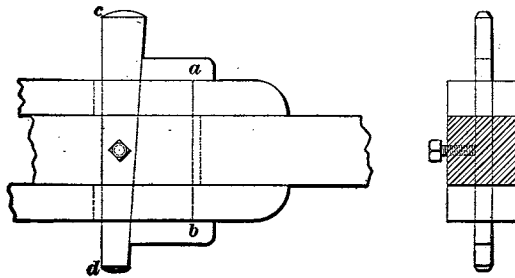


FIG. 662.

by a set-screw, the point of which fits into a groove cut into the cotter. The diameter of the set-screw may be $\frac{1}{8} b + \frac{1}{8}''$. In the arrangement shown in Fig. 663 the end of the cotter

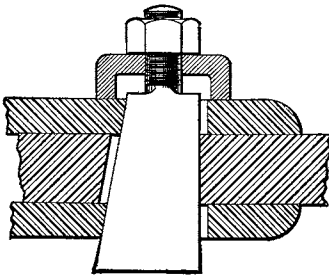


FIG. 663.



FIG. 664.

is a screw, and the cotter is secured by a nut on an extra seat. This method is used where the cotter has an excessive taper.

1972. A split pin is a form of cotter which is used not to firmly connect

two pieces, but to prevent them from separating entirely. Small split pins are of the form shown in Fig. 664. When large pins are used for this purpose they are solid and tapered.

EXAMPLES FOR PRACTICE.

1. Find the dimensions of a rod and socket of the form shown in Fig. 658, assuming $S_t = 6,000$ pounds. The load or pull on the rod is 4,600 pounds.

$$\text{Ans. } \begin{cases} d = 1\frac{3}{16} \text{ in.}; & b = 1\frac{1}{2} \text{ in.}; \\ d_1 = 1 \text{ in.}; & t = \frac{1}{8} \text{ in.}; \\ d_2 = 1\frac{3}{8} \text{ in.}; & D = 2\frac{3}{8} \text{ in.}; \\ h = 1 \text{ in.} \end{cases}$$

2. A cotter of the form shown in Fig. 655, resists a pull of 3,200 pounds. Find the necessary breadth and thickness on the assumption that S_s is 4,000 pounds, and that the thickness is one-fourth the breadth.

$$\text{Ans. } \begin{cases} b = 1.27 = 1\frac{1}{4} \text{ in.} \\ t = \frac{5}{16} \text{ in.} \end{cases}$$

3. A cotter and two gibs connect two straps to a rod, as shown in Fig. 661. Supposing the pull on the rod to be 9,000 pounds, and taking $S_s = 5,400$ for steel, find the dimensions of cotter and gibs.

$$\text{Ans. } \begin{cases} t = \frac{5}{8} \text{ in.} \\ \text{Width of cotter} = \frac{11}{8} \text{ in.} \\ \text{Width of gibs} = \frac{9}{8} \text{ in.} \end{cases}$$

4. In example 3, (a) what should be the *net* section of the strap to be equal in strength to the cotter? Assuming the thickness of strap to be $\frac{1}{4}$ the width, (b) what would be its actual dimensions?

$$\text{Ans. } \begin{cases} (a) .85 \text{ sq. in.} \\ (b) 2\frac{1}{8} \text{ in.} \times \frac{1}{8} \text{ in.} \end{cases}$$

5. Calculate the dimensions of a steel cotter which fastens a wrought-iron rod $2\frac{3}{8}$ in. in diameter.

$$\text{Ans. } 2\frac{3}{8} \text{ in.} \times \frac{1}{8} \text{ in.}$$

6. A cotter is $1\frac{1}{2}$ inches wide in the middle and tapers on each side. If the cotter is 18 inches long, what is its width at each end? Assume that the taper is $\frac{1}{2}$ inch to the foot.

$$\text{Ans. } 2\frac{1}{8} \text{ in. and } 1\frac{1}{8} \text{ in.}$$

ROTATING PIECES.

JOURNALS.

1973. Journals are the cylindrical portions of rotating pieces which turn within bearings and form the supports. Journals which are situated at or near the end of a shaft, axle, or other rotating piece, are termed **end journals**. Any journal situated between two end journals is called a **neck journal**.

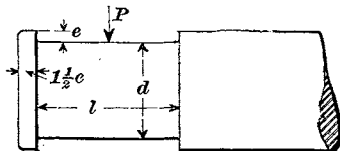


FIG. 665.

The ordinary form of an end journal is shown in Fig. 665. It consists simply of a

cylinder with collars at each end to prevent end play in the bearing.

The length of the step, seat, or bearing on which the journal rests, is, however, often made slightly shorter than the journal, permitting a slight motion lengthwise, and securing uniform wear.

SIZE AND PROPORTIONS OF END JOURNALS.

1974. The chief element in the design of a journal moving slowly or intermittently is strength. When journals run constantly at considerable velocity, strength is not so important a consideration as durability and freedom from liability to heat.

The dimensions of an end journal to give sufficient strength may be calculated by considering the journal as a cantilever uniformly loaded.

Let l = length of journal in inches;
 d = diameter of journal in inches;
 P = total load on journal in pounds;
 S_f = safe stress of material in flexure.

Then, from the Table of Bending Moments, the bending moment is $\frac{wl^2}{2} = \frac{Pl}{2}$, and the resisting moment is $\frac{S_f I}{c}$, which for a circular section is (see Table of Moments of Inertia),

$$S_f \frac{\pi d^4}{64} = S_f \frac{\pi d^3}{32}.$$

$$\text{Hence, } \frac{Pl}{2} = S_f \frac{\pi d^3}{32}, \quad (a)$$

$$\text{or } d = \sqrt{\frac{16P}{\pi S_f} \times \frac{l}{d}} = 2.26 \sqrt{\frac{P}{S_f} \times \frac{l}{d}}. \quad (240.)$$

Formula **240** gives the diameter of the journal when the ratio $\frac{l}{d}$ is assumed.

EXAMPLE.—Find the diameter and length of a wrought-iron journal on which there is a load of 1,200 pounds. Assume $S_f = 8,500$ pounds and $\frac{l}{d} = 1.4$.

SOLUTION.—Using formula **240**,

$$d = 2.26 \sqrt{\frac{P}{S_f} \times \frac{l}{d}} = 2.26 \sqrt{\frac{1,200}{8,500} \times 1.4} = 1", \text{ nearly. Ans.}$$

$$l = 1.4 d = 1.4". \text{ Ans.}$$

1975. The **bearing surface**, or **projected area**, of a journal is the length multiplied by the diameter; that is, it is the area of the projection of the journal on a plane. The total load on the journal divided by the projected area gives the pressure per square inch of projected area—a quantity which will be denoted by p .

$$\text{Hence, } p = \frac{P}{ld}, \text{ or } P = pld. \quad (b)$$

In order that the journal may not heat, the pressure p must not exceed a certain limit determined by experience. When this pressure is too great, the oil used to lubricate the journal is squeezed out, and the journal heats rapidly.

$$\text{From equation (a), } P = \frac{\pi S_f d^3}{16l}.$$

$$\text{From equation (b), } P = pld.$$

$$\text{Hence, } \frac{\pi S_f d^3}{16l} = pld, \text{ or } \pi S_f d^2 = 16 p l^2; \text{ and}$$

$$\frac{l}{d} = \sqrt{\frac{\pi S_f}{16 p}} \quad (c)$$

Substituting this value of $\frac{l}{d}$ in **240**, we obtain, after a slight reduction,

$$d = \sqrt{\frac{4P}{\pi S_f p}} = 1.5 \sqrt{\frac{P}{S_f p}} \quad (241.)$$

$$\text{From equation (b), } l = \frac{P}{dp}. \quad (242.)$$

Formula **241** may be used to compute the diameter of a journal when the pressure p per square inch of projected area is fixed. The length may then be obtained from formula **242**.

EXAMPLE.—Compute the length and diameter of a steel journal sustaining a load of 12,000 pounds. The safe stress S_f is 14,000 pounds, and the pressure per square inch of projected area is not to exceed 750 pounds.

SOLUTION.—Using formula **241**,

$$d = 1.5 \sqrt{\frac{P}{S_f p}} = 1.5 \sqrt{\frac{12,000}{14,000 \times 750}} = 2.89'', \text{ say } 2\frac{7}{8}''. \quad \text{Ans.}$$

$$\text{Hence,} \quad l = \frac{P}{d p} = \frac{12,000}{2\frac{7}{8} \times 750} = 5\frac{9}{16}''. \quad \text{Ans.}$$

1976. The pressure p per square inch of projected area may be taken at from 400 to 800 pounds, when the journal runs constantly at a speed under 150 revolutions per minute. For journals which run slowly or intermittently, p may be much greater, while for journals running faster than 150 revolutions per minute, the pressure p should vary inversely as the number of revolutions. That is, letting N = number of revolutions per minute, $p = \frac{a}{N}$, where a is a constant.

Another consideration affecting the allowable pressure p is the direction of the load. In some journals the load acts only in one direction, generally downwards; in others, as, for example, crank-pins and cross-head pins, the direction of the load changes at every revolution. In the latter case, the pressure p may be twice as great as in the former, because the change in the direction of the load permits a more perfect lubrication of the bearing. When, however, the direction of the load is variable, the safe stress S_f must be taken smaller than when the direction is constant.

1977. The following values of p for different kinds of journals are taken from Unwin:

TABLE 45.

PRESSURE ON BEARINGS AND SLIDES.

Kind of Journal Bearing.	Pressure per Sq. In. of Projected Area, p .
Bearings on which the load is intermittent and the speed slow, such as crank-pins of shearing machines	3,000 lb.
Cross-head neck journals.....	1,200 lb.
Crank-pins of large, slow-speed engines....	800 to 900 lb.
Crank-pins of marine engines, usually.....	400 to 500 lb.
Main crank-shaft bearings—marine engines (slow)	600 lb.
Main crank-shaft bearings—marine engines (fast)	400 lb.
Locomotive driving axle journal.....	180 to 350 lb.
Railway journals.....	200 lb.
Fly-wheel shaft journals.....	150 to 250 lb.
Small engine crank-pins.....	150 to 200 lb.
Slipper slide blocks, marine engines.....	100 lb.
Stationary engine slide blocks.....	25 to 125 lb.
Stationary engine slide blocks, usually.....	30 to 60 lb.
Propeller thrust bearings.....	50 to 70 lb.
Shaft in cast-iron steps or seats.....	15 lb.

For journals not given above, the value of p must be determined by the judgment of the designer. The value adopted should seldom or never exceed 750 pounds. For journals running faster than about 150 revolutions per minute, p should vary inversely as the number of revolutions. For example, if a given journal is allowed a bearing pressure of 300 pounds at 150 revolutions, it should only be allowed a bearing pressure of $\frac{300 \times 150}{250} = 180$ pounds if it is required to run at 250 revolutions.

1978. The permissible working stress S_f may be taken as follows:

TABLE 46.

Direction of Load Constant.	Direction of Load Variable.
Steel..... $S_f = 14,000$	Steel..... $S_f = 12,000$
Wrought iron... $S_f = 8,500$	Wrought iron... $S_f = 7,000$
Cast iron..... $S_f = 4,000$	Cast iron..... $S_f = 3,000$

NECK JOURNALS.

1979. A neck journal similar to an engine cross-head pin may be considered as a beam supported at both ends and uniformly loaded. Consequently, the bending moment is $\frac{wl^2}{8} = \frac{Pl}{8}$. (See Table of Bending Moments and Deflections.)

Hence, $\frac{Pl}{8} = \frac{S_f \pi d^3}{32}$, (see (a), Art. 1974),

$$\text{and } d = \sqrt{\frac{4P}{\pi S_f} \times \frac{l}{d}} = 1.13 \sqrt{\frac{P}{S_f} \times \frac{l}{d}}. \quad (243.)$$

Formula **243** may be used to calculate a neck journal when $\frac{l}{d}$ is given or assumed.

But, $P = p dl$, (see (b), Art. 1975).

$$\text{Hence, } \frac{Pl}{8} = \frac{p dl^2}{8} = \frac{S_f \pi d^3}{32}, \text{ or } \frac{l}{d} = \sqrt{\frac{\pi S_f}{4p}}. \quad (d)$$

Substituting this value of $\frac{l}{d}$ in formula **243**, we obtain

$$d = 1.06 \sqrt{\frac{P}{\sqrt{p S_f}}}. \quad (244.)$$

$$\text{From } P = p dl, \quad l = \frac{P}{p d}. \quad (245.)$$

The same values of S_f and p may be taken as for end journals.

It will be seen by comparing formulas **241** and **244** that for the same load the neck journal need be but about $\frac{2}{3}$ the diameter of the end journal; and a comparison of

equations (c) and (d) shows that the ratio $\frac{l}{d}$ is double in a neck journal what it would be in an end journal.

NOTE.—In using formulas **241** and **244** it will be found most convenient to use logarithms. Thus, applying logarithms to formula **241** it becomes $\log d = \log 1.5 + \frac{1}{2} [\log P - \frac{1}{2} (\log p + \log S_f)]$.

EXAMPLE.—Find the length and diameter of a wrought-iron neck journal, the load being 9,600 pounds, variable in direction. Allow a bearing pressure of 600 lb. per square inch.

SOLUTION.—Using formula **244**,

$$d = 1.06 \sqrt{\frac{P}{\sqrt{p} S_f}} = 1.06 \sqrt{\frac{9,600}{\sqrt{600 \times 7,000}}}, \text{ or}$$

$$\log d = \log 1.06 + \frac{1}{2} [\log P - \frac{1}{2} (\log p + \log S_f)] = .02531 + \frac{1}{2} [3.98227 - \frac{1}{2} (2.77815 + 3.84510)] = .36063;$$

$$\text{whence, } d = 2.295'' = 2\frac{1}{8}'' \text{, or nearly } 2\frac{5}{16}'' \text{. Ans.}$$

$$l = \frac{P}{p d} = \frac{9,600}{600 \times 2\frac{5}{16}} = 7'' \text{, nearly. Ans.}$$

1980. It may sometimes be desirable to make the length of a journal greater than the calculated value, simply as a matter of taste. To give the journal the same strength, its diameter must be increased in the proportion given by the following formula:

$$\frac{l_1}{l} = \left(\frac{d_1}{d} \right)^2, \quad (246.)$$

where l and d are the original and l_1 and d_1 the new lengths and diameters of the journal, respectively.

For example, suppose a wrought-iron end journal to be subjected to a load of 350 pounds. Assuming $\frac{l}{d} = 1.4$, the dimensions of the journal will be

$$d = 2.26 \sqrt{\frac{P}{S_f} \times \frac{l}{d}} = 2.26 \sqrt{\frac{350}{8,500} \times 1.4} = .5426''.$$

$$l = 1.4 d = 1.4 \times .5426 = .7596''.$$

Say the diameter is $\frac{9}{16}''$ and the length $\frac{3}{4}''$.

Though a journal of these dimensions would be sufficiently stiff and durable for the load, it is rather small to

look well. Suppose the length is made double the calculated value; that is, $l_1 = 2l$. Then, from formula **246**,

$$d_1 = d \sqrt[3]{\frac{l_1}{l}} = .5426 \sqrt[3]{2} = .6837'' = \frac{11}{16}'', \text{ nearly.}$$

$$l_1 = 2l = 2 \times \frac{3}{4} = 1 \frac{1}{2}.$$

FRICTION OF JOURNALS.

1981. The work expended in overcoming the friction of a journal is

$$W = fPN \frac{\pi d}{12} \text{ foot-pounds per minute;}$$

where f = coefficient of friction,
and N = revolutions per minute.

It is therefore apparent that with the same load and speed, the work expended against friction is directly proportional to the diameter of the journal. Consequently, when a journal runs under a steady, uniform load, it is preferable to make the diameter as small as possible, consistent with strength, and obtain the desired projected area by adding to the length of the journal.

For example, take two journals, one 2 inches in diameter and 6 inches long, the other 4 inches in diameter and 3 inches long. They each have the same projected area, 12 inches. The latter journal, however, requires double the work to overcome friction that the former requires, and, besides, contains twice as much material. Hence, the $2'' \times 6''$ journal is preferable for a steady load. On the other hand, the $4'' \times 3''$ journal is $\frac{4^3 \times 6}{2^3 \times 3} = 16$ times as strong as the other, and would be preferred in situations where the load is variable, and the journal is liable to shocks, as in the case of crank-pins of high-speed engines.

1982. The height of the journal collars, Fig. 665, may be

$$e = \frac{d}{10} + \frac{1''}{8}. \quad (247.)$$

The width of the outer collar is $1\frac{1}{2} e$. It is good practice to turn the journal with a fillet in the corner, as the shaft or axle is more liable to crack and fracture if the shoulder is turned with a square corner.

The fillet may be a circular arc drawn with a radius equal to $\frac{e}{2}$.

PIVOTS AND COLLAR JOURNALS.

1983. A **pivot journal** is shown in Fig. 666. It differs from an ordinary journal in that the direction of pressure is parallel to the axis of the shaft instead of perpendicular to it. The bearing area is, therefore, the area of the end of the pivot, $\frac{1}{4} \pi d^2$.

The diameter of a flat pivot may, therefore, be found at once by assuming a value for the pressure per square inch of projected area and solving for the area. The following formulas give good results for ordinary cases:

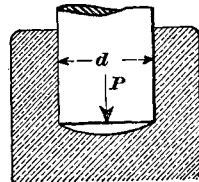


FIG. 666.

Let P = load on pivot;
 d = diameter of pivot;
 N = revolutions per minute of pivot.

TABLE 47.

	Wrought-Iron or Steel Pivot on Gun-Metal Bearing.	Cast-Iron Pivot on Gun-Metal Bearing.	Iron or Steel on Lignum- vitæ Bearing, Moistened with Water.
Case I—Pivot turning very slowly or intermittently ...	$d = .035 \sqrt{P}$	$d = .05 \sqrt{P}$	 (248.)
Case II—Revolutions per minute less than 150....	$d = .05 \sqrt{P}$	$d = .07 \sqrt{P}$	$d = .035 \sqrt{P}$ (249.)
Case III—Revolutions per minute more than 150...	$d = .004 \sqrt{PN}$	.....	$d = .035 \sqrt{P}$ (250.)

EXAMPLE.—What should be the diameter of a steel pivot on gun-metal bearings, the load being 200 lb., and the number of revolutions 320 per minute?

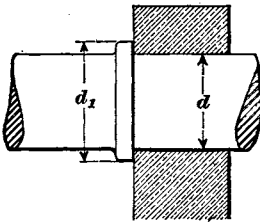


FIG. 667.

SOLUTION.—

$$d = .004 \sqrt{PN} = .004 \sqrt{200 \times 320} = 1", \text{ nearly. Ans.}$$

1984. In a **collar journal** the direction of the load is parallel to the axis of the shaft, but the bearing area is formed by a collar raised on the shaft. A journal with one collar is shown in Fig. 667, and one with several collars in Fig. 668.

Letting d_1 and d represent the diameters of collars and shaft, respectively; b , the number of collars; p , the pressure per square inch of projected area, and P , the total load or thrust, we have

$$\frac{1}{4} \pi (d_1^2 - d^2) b p = P.$$

The value of p is usually taken at 60 lb. per square inch for the thrust bearings of propeller shafts, and this value should not be much exceeded in any case.

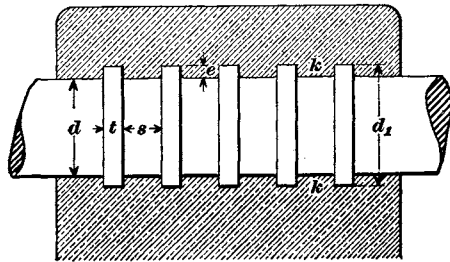


FIG. 668.

$$\text{Then, } d_1^2 - d^2 = \frac{P}{15 \pi b}$$

$$\text{or } d_1 = \sqrt{d^2 + \frac{P}{15 \pi b}}. \quad (251.)$$

The number of collars b depends upon the judgment of the designer. The larger the number the smaller is the diameter, and the less will be the wear and work of friction. On the other hand, when many collars are used, there is danger of bringing all the thrust on one or two.

In Fig. 668 the dimension $e = \frac{1}{2} (d_1 - d)$. Usually the thickness t of the collars is $= .8 e$, and the width s of the space is equal to the thickness t , unless the annular encircling

rings k are hollow for water circulation, or unless they are lined with white metal.

In the latter case, $s = 2$ to $2\frac{1}{2} t$.

EXAMPLES FOR PRACTICE.

1. Find the proportions of a cast-iron end journal, turning slowly under a steady load of 15,000 lb., assuming the length equal to the diameter.

Ans. $4\frac{3}{8}'' \times 4\frac{3}{8}''$.

2. Find the proportions of a wrought-iron end journal, turning under a load of 8,600 lb., assuming the safe pressure per square inch of projected area to be 650 lb. The direction of the load is variable.

Ans. $3'' \times 4\frac{7}{16}''$.

3. Find the dimensions of a steel neck journal, working under a load of 12,000 lb., direction variable, the allowable bearing pressure to be 1,200 lb. per sq. in.

Ans. $1\frac{7}{8}'' \times 5\frac{5}{16}''$.

4. Find the minimum dimensions of a wrought-iron end journal, the required conditions being that the bearing pressure shall not exceed 750 pounds, and the length shall be one and one-fourth times the diameter. The load on the journal is 9,600 pounds, and variable in direction.

Ans. $3\frac{1}{8}'' \times 3\frac{3}{8}''$.

5. Find the diameter of a wrought-iron pivot running at a speed of 80 revolutions per minute and bearing a load of 800 pounds, gun-metal bearing.

Ans. $1\frac{7}{16}$ in.

6. Assuming 5 thrust collars on a shaft 10 inches in diameter subjected to an end thrust of 20,000 pounds, find the diameter and thickness of collars.

Ans. $\begin{cases} d_1 = 13.6'' \\ t = 1\frac{7}{16}'' \end{cases}$.

SHAFTS.

1985. Shafts may be divided into three classes, according to the kind of stress to which they are subjected:

(1) Shafts subjected chiefly to torsion or twisting, as, for example, line shafting in mills and shops, and, in general, shafts used to transmit power.

(2) Shafts subjected chiefly to bending action, such as the axles of gears, etc.

(3) Shafts subjected to both twisting and bending, such as engine crank-shafts.

LINE SHAFTING.

1986. Line shafting is a term applied to the long and continuous lines of shafting used in mills, factories, and shops for the distribution of power. The shaft is principally

strained by torsion, but there is always in addition a bending action due to the weight of the shaft itself, and the pulleys carried by it, and also due to the tension of belting or the thrust of gearing.

In calculating the diameter of a shaft for a given twisting moment, two things must be considered: 1. Strength. 2. Stiffness. Very large shafts or short shafts need be calculated for strength only; but in long lines of shafting of small diameter attention must be paid to stiffness and rigidity.

The twisting moment is PR , where P is the twisting force and R the distance between the line of action of the force and the center of the shaft. In case of a belted pulley, shown in Fig. 669, the force P is the difference in the ten-

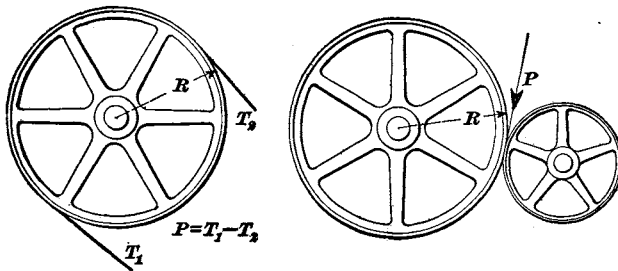


FIG. 669.

sions of the tight and slack sides of the belt; the distance R is the radius of the pulley. Or, again, R may be the radius of a gear attached to the shaft in question.

It is usually more convenient to express the twisting moment in terms of the horsepower transmitted by the shaft, and number of revolutions.

By formula **231**, $PR = 63,025 \frac{H}{N}$. The resistance of a shaft to twisting is given by a formula similar to formula **116**, $M = S_s \frac{I}{c}$, Art. **1398**.

Let S_s = the safe shearing strength of shaft;
 J = polar moment of inertia of cross-section of shaft
 about neutral axis;
 c = distance from neutral axis to outermost fiber.

Then, the moment of resistance to twisting is $\frac{S_s J}{c}$.

Where a plane section revolves, or is conceived to revolve, about a line lying in the plane of the section, as, for example, a circular section revolving about its diameter, the moment of inertia obtained with reference to this axis is termed the **rectangular moment of inertia**, and is nearly always denoted in text-books by I . When, however, the section revolves about an axis perpendicular to the plane of section, as, for example, a buzz saw or fly-wheel, the moment of inertia found with respect to this axis is termed the **polar moment of inertia**, and is nearly always denoted in text-books by J . Those moments of inertia used in the subject of Strength of Materials were rectangular moments. For a solid circular section, $J = 2 I = 2 \times \frac{\pi d^4}{64} = \frac{\pi d^4}{32}$; and for a hollow circular section,

$$J = \frac{\pi(d^4 - d_1^4)}{32}.$$

The reason for using the safe shearing stress S_s in the expression $\frac{S_s J}{c}$ is that its value agrees very closely with the value for torsion; it is quite different from the safe stress for flexure. The student may obtain the value of S_s by simply dividing the ultimate shearing stress by the proper factor of safety; i. e., $S_s = \frac{S_3}{f}$.

Placing the twisting and resisting moments equal to each other, we have

$$PR = 63,025 \frac{H}{N} = \frac{S_s J}{c} = S_s \frac{\frac{\pi d^4}{32}}{\frac{d}{2}} = S_s \frac{\pi d^3}{16}.$$

$$\text{Whence, } d = \sqrt[3]{\frac{16 PR}{\pi S_s}} = 1.72 \sqrt[3]{\frac{PR}{S_s}}. \quad (252.)$$

$$\text{Or, } d = \sqrt[3]{\frac{16 \times 63,025 H}{\pi N S_s}} = 68.5 \sqrt[3]{\frac{H}{N S_s}}. \quad (253.)$$

$$\text{Let } \sqrt[3]{\frac{16}{\pi S_s}} = k, \text{ and } \sqrt[3]{\frac{16 \times 63,025}{\pi S_s}} = k_1.$$

$$\text{Then, } d = k \sqrt[3]{PR} = k_1 \sqrt[3]{\frac{H}{N}}, \quad (254.)$$

as in formula **124**, Art. **1416**.

The values of k and k_1 depend upon the value of the safe stress S_s assumed for the material of the shaft.

If we take $S_s = 3,400$ for cast iron;

$S_s = 6,800$ for wrought iron;

$S_s = 9,000$ for steel,

we obtain the values of k and k_1 given in Table 32, Art. **1416**.

1987. Formulas **252** and **253** are general, and may be used for any material; the proper value of S_s being left to the judgment of the designer. Ordinarily, the values of S_s given above are those used in good practice. Under exceptional circumstances it may be necessary to use lower values, particularly if the shaft is subjected to shocks, or if the stress changes suddenly or violently.

It has been shown that for strength the diameter of a shaft is proportional to the cube root of the twisting moment. A similar theoretical treatment would show that for *stiffness* the diameter of the shaft is proportional to the *fourth root* of the twisting moment.

Hence, for shafts of small diameter or of considerable length the diameter may be calculated by the formula

$$d = c \sqrt[4]{Pr} = c_1 \sqrt[4]{\frac{H}{N}} \text{ and Table 31, Art. } \mathbf{1415}.$$

1988. Speed of Line Shafting.—The speed of a shaft is fixed largely by the speed of the driving belt or the diameters of the pulleys upon it. In general, machine shop

shafts run about 120 to 150 revolutions per minute; shafts driving woodworking machinery, about 200 to 250 revolutions per minute; in cotton mills, the practice is to make the shaft diameter smaller, and run at a higher speed. Line shafts should generally not be less than $1\frac{3}{4}$ inches in diameter.

1989. Distance Between Bearings.—This distance should not be great enough to permit a deflection of more than $\frac{1}{1000}$ " per foot of length. Hence, when the shaft is heavily loaded with pulleys, the bearings must be closer than when it carries only a few pulleys.

Below are given the maximum distances between the bearings of different sizes of continuous shafts which are used for the transmission of power:

TABLE 48.

Diameter of Shaft in Inches.	Distance Between Bearings in Feet.	
	Wrought-Iron Shaft.	Steel Shaft.
2	11	11.5
3	13	13.75
4	15	15.75
5	17	18.25
6	19	20
7	21	22.25
8	23	24
9	25	26

Pulleys which give out a large amount of power should be placed as near a hanger as possible.

SHAFTS SUBJECTED TO BENDING.

1990. Under this head are included the axles of large water-wheels, gear-wheels, etc., which are loaded transversely. The axle is not generally strained by twisting, and

may be treated as a beam transversely loaded. The mode of procedure may, perhaps, be best shown by an example.

EXAMPLE.—An axle 12 feet long, between centers of bearings, carries a wheel weighing 9 tons; the wheel is 4 feet from one end of the shaft. The axle is of wrought iron. Required, the dimensions.

SOLUTION.—Let the line mn , Fig. 670, represent temporarily the axle in question; P , the load of 9 tons, and R_1 and R_2 , the reactions.

Lay off to scale the load P on the vertical through R_1 , and, choosing a pole O , draw the rays $O1$, $O3$, and ab , and cb parallel to them. Then, abc is the bending moment diagram. $O2$ is drawn parallel to ac , and gives the reaction $R_1 = 1.2 = 3$ tons, and $R_2 = 2.3 = 6$ tons.

The lengths and diameters of the journals may now be calculated. For the journal nearest the load, we have, from formula 241,

$$d = 1.5 \sqrt[4]{\frac{R_2}{S_f p}}, \text{ and}$$

assuming that $p = 700$ and $S_f = 8,500$,

$$d = 1.5 \sqrt[4]{\frac{12,000}{8,500 \times 700}} = 3\frac{3}{8}" \text{, nearly.}$$

$$l = \frac{R_2}{p d} = \frac{12,000}{700 \times 3\frac{3}{8}} = 5\frac{1}{8}" \text{, nearly.}$$

For the other journal,

$$d' = 1.5 \sqrt[4]{\frac{R_1}{S_f p}} = 1.5 \sqrt[4]{\frac{6,000}{8,500 \times 700}} = 2\frac{3}{8}" \text{.}$$

$$l_1 = \frac{6,000}{700 \times 2\frac{3}{8}} = 3\frac{5}{8}" \text{.}$$

$$d_1 = d' + 2e, \text{ where } e = \frac{1}{10} d' + \frac{1}{8}" = .3625" = \frac{3}{8}" \text{, nearly.}$$

$$\text{Hence, } d_1 = 2\frac{3}{8}" + \frac{3}{8}" = 3\frac{1}{8}" \text{.}$$

$$\text{Likewise, } d_2 = d + 2(\frac{1}{10} d + \frac{1}{8}") = 4\frac{5}{16}" \text{.}$$

The resisting moment of a beam is $S \frac{I}{c}$ (see Art. 1398), and since the safe stress S remains constant for the same beam, the resisting moment is proportional to $\frac{I}{c}$. For a beam of circular section.

$$\frac{I}{c} = \frac{\frac{\pi d^4}{64}}{\frac{d}{2}} = \frac{\pi d^3}{32}$$

Hence, since $\frac{\pi}{32}$ is a constant quantity, the resisting moment at any section of a circular shaft is proportional to the cube of the diameter at that section. Conversely, the diameter of the shaft at any section must be proportional to the cube root of the resisting moment at that

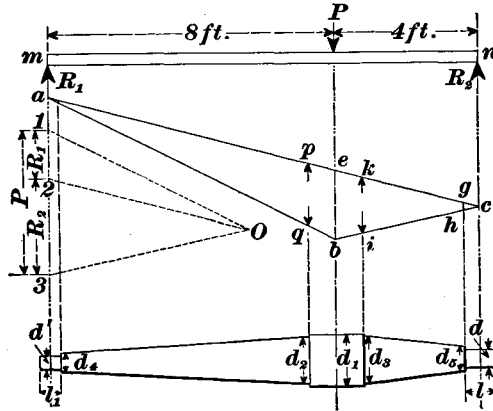


FIG. 670.

section, and to have the shaft of equal strength throughout, the diameter at each section should be proportional to the cube root of the *bending moment* at that section.

$$\text{Hence, } \frac{d_1}{d} = \sqrt[3]{\frac{\text{moment } b e}{\text{moment } g h}}.$$

By measurement, the moment $b e$ is 288 inch-tons, and the moment $g h$ is $15\frac{3}{8}$ inch-tons.

$$\text{Whence, } \frac{d_1}{d} = \sqrt[3]{\frac{288}{15\frac{3}{8}}} = 2.65;$$

$$\text{or, } d_1 = 2.65 d = 2.65 \times 3\frac{3}{8} = 9 \text{ inches, nearly.}$$

The shaft should be bossed at this point to allow for cutting the key-way. The depth of the sunk key = $\frac{1}{8} d_1 = 1\frac{1}{8}$ in. (See formula 233.)

The depth of the key-way is, therefore, $\frac{3}{4}$ inch, and the diameter of the bossed portion $10\frac{1}{8}$ inches at least. The diameters d_2 and d_3 may be easily found by measuring the moments $p q$ and $k i$, whence,

$$d_2 = d_1 \sqrt[3]{\frac{q p}{b e}}, \text{ and } d_3 = d_1 \sqrt[3]{\frac{i k}{b e}}.$$

In a similar manner may be found the dimensions of an axle bearing two or more transverse loads.

The axle may or may not be tapered as shown in Fig. 670. If it is not tapered, its diameter must be calculated from the maximum bending moment (*b e*, in this case). A straight shaft is easier to construct, but the end journals must be, of course, larger, and there is considerable loss by friction on that account.

SHAFTS SUBJECTED TO COMBINED BENDING AND TWISTING.

1991. A good example of a shaft coming under this head is an engine crank-shaft carrying a heavy fly-wheel.

Let B = bending moment;

T = twisting moment;

T_1 = the twisting moment, which would have the same effect as B and T acting together.

$$\text{Then, } T_1 = B + \sqrt{B^2 + T^2}. \quad (255.)$$

The twisting moment T_1 is called the **ideal twisting moment**, and should be used in formula **252** to determine the diameter of the shaft.

EXAMPLE.—Calculate the diameter of a steel crank-shaft for an engine from the following data: The length of stroke is 10 feet. The maximum tangential force acting on the crank-pin is 25 tons. The shaft is 10 feet long between centers of bearings, and carries midway between bearings a fly-wheel weighing 55 tons. Assume the safe stress to be 9,000 lb. = $4\frac{1}{2}$ tons.

SOLUTION.—The twisting moment T = maximum tangential force $\times$ length of crank = 25 tons $\times$ 5 feet = 125 foot-tons = 1,500 inch-tons.

The bending moment = $\frac{1}{2} Pl = \frac{55 \times 10}{4} = 137.5$ foot-tons = 1,650 inch-tons.

Then, $T_1 = B + \sqrt{B^2 + T^2} = 1,650 + \sqrt{1,650^2 + 1,500^2} = 3,880$ inch-tons.

Now, using formula **252**,

$$d = 1.72 \sqrt[3]{\frac{PR}{S_s}} = 1.72 \sqrt[3]{\frac{T_1}{S_s}} = 1.72 \sqrt[3]{\frac{3,880}{4.5}} = 16\frac{1}{2}'', \text{ nearly. Ans.}$$

It will be noticed that, in the above solution, the units selected are inches and tons. Generally, when the bending and twisting moments are large, it is more convenient to use tons than pounds. Care must be taken, however, to

make the units consistent; for example, it would have been wrong to have taken the moments in *inch-tons*, and the safe stress in *pounds*.

1992. It is sometimes convenient to put formula **255** in another form.

Let $\frac{B}{T} = Z$; then, formula **255** becomes

$$T_1 = ZT + \sqrt{Z^2 T^2 + T^2} = T(Z + \sqrt{Z^2 + 1}).$$

Let $Z + \sqrt{Z^2 + 1} = k$; then, $T_1 = kT$.

But, by formula **252**, the diameter is proportional to the cube root of the twisting moment. Therefore, if d is the diameter of shaft required by the twisting moment T , and d_1 the diameter required by the twisting moment T_1 , $\frac{d_1}{d} = \sqrt[3]{\frac{T_1}{T}} = \sqrt[3]{k}$, or $d_1 = d\sqrt[3]{k}$.

The following table gives the values of $\sqrt[3]{k}$ for varying values of Z :

TABLE 49.

Z	$\sqrt[3]{k}$	Z	$\sqrt[3]{k}$	Z	$\sqrt[3]{k}$
.2	1.068	1.2	1.403	2.2	1.665
.4	1.139	1.4	1.461	2.4	1.710
.6	1.209	1.6	1.516	2.6	1.753
.8	1.277	1.8	1.568	2.8	1.794
1.0	1.341	2.0	1.618	3.0	1.833

This table may be used advantageously for computing the diameter of shafts subjected to twisting and bending. The diameter is first computed for twisting alone, and is then multiplied by the value of $\sqrt[3]{k}$ corresponding to the ratio Z between the bending and twisting moments.

EXAMPLE.—A wrought-iron shaft transmits 150 horsepower at 125 revolutions per minute, and is at the same time subjected to a bending moment of 60,000 inch-pounds. Calculate the diameter of the shaft.

SOLUTION.—For twisting only,

$$d = 3.62 \sqrt[3]{\frac{H}{N}} = 3.62 \sqrt[3]{\frac{150}{125}}$$

See Art. **1416**.

By formula **231**, $T = P R = 63,025 \frac{H}{N} = 75,630$ in.-lb.

$$B = 60,000.$$

Then, $\frac{B}{T} = Z = \frac{60,000}{75,630} = .8$, nearly.

From the above table $\sqrt[3]{k} = 1.277$.

Hence, $d = 1.277 \times 3.62 \sqrt[3]{\frac{150}{125}} = 4\frac{5}{8}$. Ans.

HOLLOW SHAFTS.

1993. It is plain that the outer fibers of a shaft are much more useful in resisting a twisting or bending strain than the fibers near the center; hence, if a shaft is made hollow, its weight will be diminished in much greater proportion than its strength. In other words, a hollow shaft is stronger than a solid one containing the same amount of material per unit length.

Let d_1 = outside diameter of hollow shaft;

d_2 = inside diameter of hollow shaft;

d = diameter of solid shaft having the same strength as hollow shaft.

The resisting moment (see Art. **1398**) is $\frac{S I}{c}$. Taking the axis of the shaft as the neutral axis, I becomes J ; the values of J for both hollow and solid shafts are double those given in the Table of Moments of Inertia, where the neutral axis is the diameter of a cross-section.

$$\text{For a solid shaft, } \frac{S_3 J}{c} = \frac{\frac{S_3 \pi d^4}{32}}{\frac{d}{2}} = \frac{S_3 \pi d^3}{16}.$$

$$\text{For a hollow shaft, } \frac{S_3 J}{c} = \frac{\frac{S_3 \pi (d_1^4 - d_2^4)}{32}}{\frac{d_1}{2}} = \frac{S_3 \pi (d_1^4 - d_2^4)}{16 d_1}.$$

Hence, if the shafts are to be equally strong,

$$\frac{S_s \pi d^3}{16} = \frac{S_s \pi (d_1^4 - d_2^4)}{16 d_1},$$

$$\text{or } d^3 = \frac{d_1^4 - d_2^4}{d_1} = d_1^3 \left(1 - \frac{d_2^4}{d_1^4}\right).$$

$$\text{Let } \frac{d_2}{d_1} = m. \quad \text{Then, } d^3 = d_1^3 (1 - m^4),$$

$$\text{or } d_1 = d \sqrt[3]{\frac{1}{1 - m^4}}. \quad (256.)$$

EXAMPLE.—Suppose we wish to find the diameter of a hollow shaft which will have the same strength as a solid shaft 8 inches in diameter, assuming the hole to be one-half the diameter.

SOLUTION.—Applying formula 256, $m = \frac{1}{2}$, and

$$d_1 = d \sqrt[3]{\frac{1}{1 - m^4}} = 8 \sqrt[3]{\frac{1}{1 - (\frac{1}{2})^4}} = 8.174, \text{ say } 8\frac{8}{16}'' \text{ outside diameter,}$$

and $4\frac{3}{8}''$ inside diameter. Ans.

Hollow steel shafts are much used for marine engines.

SHAFT COUPLINGS.

1994. Couplings are used to connect the ends of shafts, and are of three kinds: 1. Fast or permanent couplings. 2. Loose couplings, or clutches, by means of which shafts may be connected or disconnected at pleasure. 3. Friction clutches, which are loose couplings that hold by friction.

1995. Box, or Muff, Couplings.—This coupling, as shown in Fig. 671, consists of a cast-iron cylinder which fits

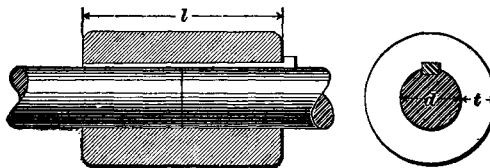


FIG. 671.

over the ends of the shaft. The two ends are prevented from moving relatively to each other by the sunk key. The key-way is cut half into the box and half into the shaft

ends. Quite commonly the ends of the shafts are enlarged to allow the key-way to be cut without weakening the shaft.

The key may be proportioned by the formulas already given. For the other dimensions take

$$\left. \begin{aligned} l &= 2\frac{1}{2}d + 2". \\ t &= 4d + .5". \end{aligned} \right\} \quad (257.)$$

EXAMPLE.—Find the dimensions of a muff coupling for a shaft $2\frac{1}{2}"$ in diameter.

SOLUTION.—For the key we use formula 233.

$$\left. \begin{aligned} b &= \frac{1}{4}d = \frac{1}{4} \times 2\frac{1}{2} = \frac{5}{8}" \\ t &= \frac{1}{8}d = \frac{1}{8} \times 2\frac{1}{2} = \frac{5}{16}" \end{aligned} \right\} \text{Ans.}$$

For the muff, we use formula 257.

$$\left. \begin{aligned} l &= 2\frac{1}{2}d + 2" = 2\frac{1}{2} \times 2\frac{1}{2} + 2" = 8\frac{1}{4}" \\ t &= .4d + .5" = .4 \times 2\frac{1}{2} + .5" = 1\frac{1}{2}" \end{aligned} \right\} \text{Ans.}$$

1996. A **clamp coupling** is shown in Fig. 672. The faces for the joint are first planed off, the holes are drilled, and then the two halves are bolted together with pieces of

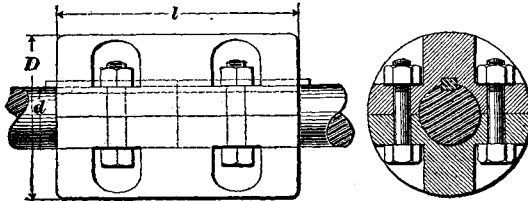


FIG. 672.

paper between them, after which the coupling is bored out to the exact size of the shaft. The pieces of paper upon being removed leave a slight space between the halves, and the coupling when bolted to the shaft grips it firmly.

This form of coupling is very easily removed or put on; it has no projecting parts, and may be used as a driving pulley, if desired. The key is straight, and fits only at the sides.

The following are the proportions used in practice;

d = diameter of shaft;

Diameter of coupling $D = 2\frac{1}{2}d + \frac{1}{2}"$;

Length of coupling $l = 4d$.

The diameter of the bolts may be $\frac{5}{8}"$ for shafts under $2\frac{1}{2}"$ in diameter; $\frac{3}{4}"$ for $2\frac{1}{2}"$ shaft, and $\frac{7}{8}"$ for larger shafts.

For shafts up to 3 inches in diameter use 4 bolts; for larger shafts use 6 bolts.

1997. The **flange coupling** is shown in Fig. 673. Cast-iron flanges are keyed to the ends of the shafts. To insure a perfect joint the flange is usually faced in the lathe after being keyed to the shaft. The two flanges are then brought face to face and bolted together. Sometimes the ends of the shafts are enlarged to allow for the key-way.

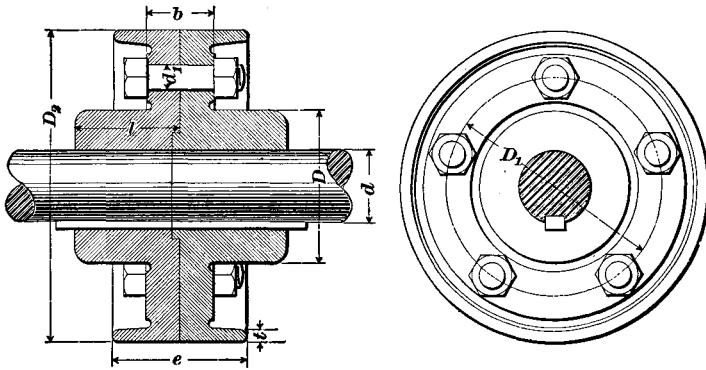


FIG. 673.

To prevent the possibility of the shafts getting out of line, the end of one may enter the flange of the other, as shown.

The following proportions may be used for the form of flange coupling shown in Fig. 673:

d = diameter of shaft.

$$\left. \begin{aligned} D &= 1\frac{3}{4}d + 1''; \\ \text{Diameter of bolt circle } D_1 &= 2\frac{1}{2}d + 2''; \\ l &= 1\frac{1}{8}d + 1''; \\ \text{Number of bolts } n &= 3 + \frac{d}{2}; \\ \text{(Take the nearest even number.)} \\ \text{Diameter of bolts } d_1 &= \frac{d}{n} + \frac{1}{4}''; \\ \text{Diameter of coupling } D_2 &= 1.4 D_1; \\ b &= \frac{1}{2}d + \frac{5}{8}''; \\ e &= 2b; \\ t &= \frac{1}{8}d. \end{aligned} \right\} \quad (258.)$$

The key may be proportioned by the formulas already given for keys.

1998. Solid flange couplings, shown in Fig. 674, are used largely to connect the sections of propeller shafts.

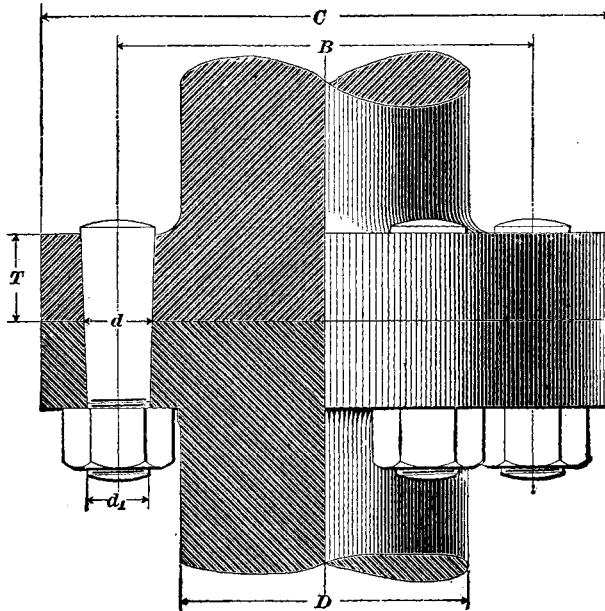


FIG. 674.

The flanges are forged on the ends of the shafts, and are connected by tapered bolts.

Let n = number of bolts uniting flanges;

d = diameter of the bolts at the joint formed by the flanges;

D = diameter of shaft;

B = diameter of bolt circle.

The shearing resistance of the bolts is $\frac{\pi d^2}{4} n S_s$, and the moment of this resistance about the center of shaft is

$$\frac{\pi d^2}{4} n S_s \times \frac{B}{2} = \frac{\pi d^2 n S_s B}{8}.$$

Now, it was shown in the derivation of formula **253** that the moment of resistance of the shaft when subjected to twisting is $\frac{\pi D^3}{16} S_s$. If the bolts and shafts are of equal strength,

$$\frac{\pi d^2 n S_s B}{8} = \frac{\pi D^3 S_s}{16},$$

$$\text{or} \quad d^2 n B = \frac{D^3}{2}.$$

Approximately, $B = 1.6 D$. Using this value, we obtain

$$1.6 d^2 n D = \frac{D^3}{2}, \text{ or } d = \frac{D}{\sqrt{3.2 n}}.$$

But more nearly, $B = D + 2d$.

Substituting for d its value just found,

$$B = D \left(1 + \frac{2}{\sqrt{3.2 n}} \right).$$

$$\text{Whence, } d^2 n D \left(1 + \frac{2}{\sqrt{3.2 n}} \right) = \frac{D^3}{2},$$

$$\text{or } d = D \sqrt{\frac{\sqrt{3.2 n}}{2n(\sqrt{3.2 n} + 2)}} = k D \quad \textbf{(259.)}$$

The values of $k = \sqrt{\frac{\sqrt{3.2 n}}{2n(\sqrt{3.2 n} + 2)}}$ for different values of n are as follows:

TABLE 50.

$n =$	3	4	5	6	7	8	9	10
$k =$	.318	.283	.258	.239	.224	.212	.201	.192

The following are the proportions of the other parts of the coupling:

$$\left. \begin{aligned} n &= \frac{1}{3}D + 2; \\ B &= D + 2d; \\ C &= D + 4\frac{1}{4}d; \\ T &= \frac{2D + 1}{7}; \\ d_1 &= \frac{7}{8}d + \frac{1}{8}'' \end{aligned} \right\} \quad (260.)$$

The bolts are tapered $\frac{3}{8}$ inch per foot of length.

1999. Seller's Cone Coupling.—This coupling is shown in Fig. 675. It consists of an outer box or muff

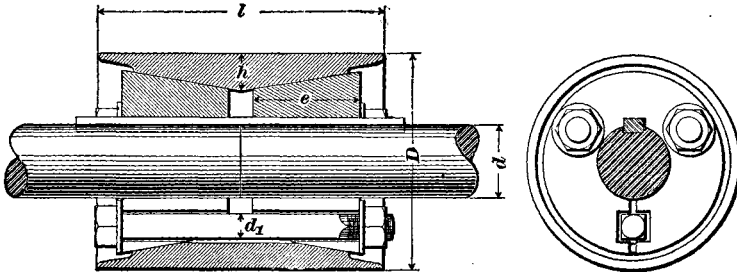


FIG. 675.

which is cylindrical externally, but has the form of a double truncated cone on the inside. Within the muff are placed two slotted sleeves, which are turned on the outside to fit the muff, and also bored out to fit the shaft. These sleeves are pulled together by three bolts, and as they are drawn farther into the muff, they grip it and the shafts firmly.

The bolt holes pass through both the sleeves and muff, and are square in cross-section. The friction between the sleeves and shaft is generally sufficient to prevent slipping, but to be on the safe side, the sleeves are usually keyed to the shaft. The key should have no taper, and fit at the sides only; its proportions may be obtained by formula **233**.

The other proportions may be taken as follows:

$$\left. \begin{aligned} d &= \text{diameter of shaft;} \\ l &= 4d; \quad d_1 = \frac{1}{3}d; \\ D &= 3d; \quad e = 1\frac{1}{2}d; \\ h &= \frac{1}{2}d. \end{aligned} \right\} \quad (261.)$$

The conical sleeves may be tapered 4 inches per foot of length. In putting up lines of shafting, the couplings should be placed, if possible, near bearings, and on the side of the bearing farthest from the driving point.

2000. Universal Joints, or Flexible Couplings.—The principal forms of these joints have already been described in Arts. 1458, 1459, and 1460.

In Fig. 676 is shown a common form of these joints which, when constructed of wrought iron, may have the following proportions:

$$\left. \begin{aligned} d &= \text{diameter of shaft;} \\ a &= 1.8 d; \quad e = 1.6 d; \\ b &= 2 d; \quad g = .6 d; \\ c &= d; \quad h = .5 d; \\ k &= .6 d. \end{aligned} \right\} \quad (262.)$$

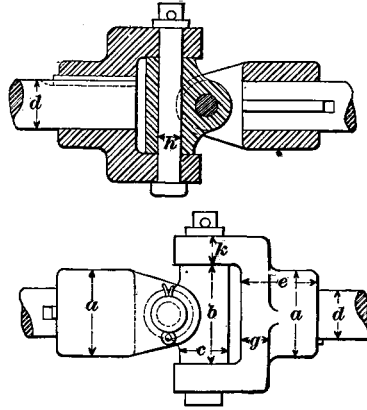


FIG. 676.

2001. Loose Couplings.—These couplings are used

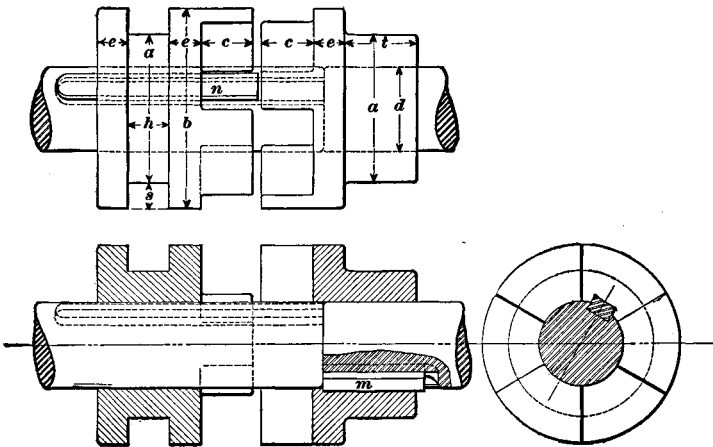


FIG. 677.

when the shafts are to be alternately connected and disconnected. For large slow-moving shafts, the *claw coupling* shown in Fig. 677 may be used. This coupling somewhat resembles the flange coupling, Fig. 673, except that the flanges, instead of being bolted together, are provided with a set of lugs c which fit into each other. One flange is permanently fastened to the shaft by a sunk key m , while the other is fastened to its shaft by a feather key n ,

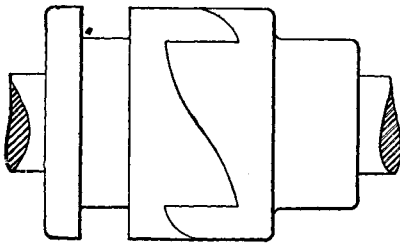


FIG. 678.

and may be moved back and forth, thus throwing the coupling, or clutch, in or out of gear. The movement of the clutch is effected by a forked lever fitting into the recess h .

The lugs or claws may be given in the form shown in Fig. 679, in which case the couplings are more easily put in gear, but will drive in only one direction.

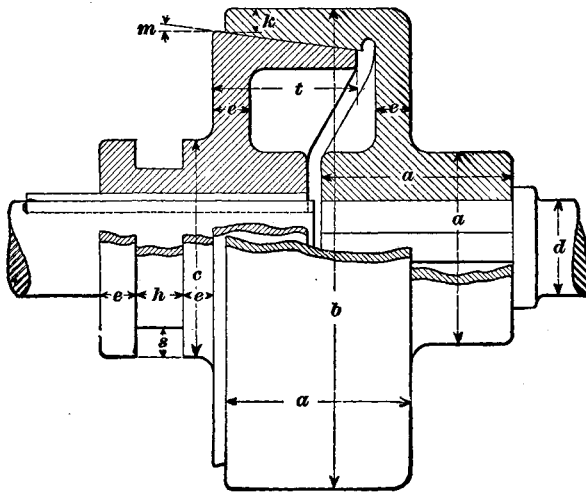


FIG. 679.

Cast-iron claw couplings may have the following proportions:

$$\left. \begin{array}{l} d = \text{diameter of shaft;} \\ a = 1\frac{3}{4}d; \quad e = \frac{3}{8}d; \\ b = 2\frac{3}{8}d; \quad h = \frac{1}{2}d; \\ c = \frac{5}{8}d; \quad s = \frac{5}{16}d; \\ t = \frac{7}{8}d. \end{array} \right\} \quad (263.)$$

2002. Friction couplings, or clutches, are used as loose or disengaging couplings on shafts running at high speeds. They are often used to couple wheels or pulleys to shafts. The form shown in Fig. 679 is simple in construction, but it is open to the objection that it is hard to put in gear. Besides, the horizontal component of the pressure between the conical surfaces causes an end thrust on the shaft.

The average diameter of the conical part may be from 4 to 8 times the shaft diameter, according to the amount of power to be transmitted. The angle m of the cone may be from 4° to 10° . The other proportions are as follows:

$$\left. \begin{array}{l} d = \text{diameter of shaft;} \\ a = 2d; \quad e = \frac{3}{8}d; \\ b = 4 \text{ to } 8d; \quad h = \frac{1}{2}d; \\ c = 2\frac{1}{4}d; \quad s = \frac{5}{16}d; \\ t = 1\frac{1}{2}d; \quad k = \frac{1}{4}d. \end{array} \right\} \quad (264.)$$

A better form of friction clutch is shown in Fig. 680. The shaft n carries a flange or cylinder A , and the shaft m

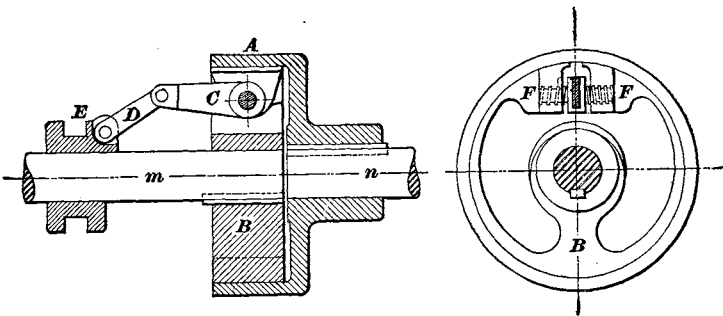


FIG. 680.

has keyed to it a ring B . The ring is split and fits inside

the flange or cylinder *A*. The split ends are connected by a screw with right and left hand threads. The screw is turned by the lever *C*, which is connected by the link *D* to the sleeve *E*. When the sleeve is pushed towards the clutch, the rotation of the screw throws the ends *F*, *F* of the ring *B* apart, and thereby causes the ring *B* to grip the flange *A* tightly. A clutch of this form is easy to operate, and produces no end thrust on the shaft.

Another form of clutch differs from the preceding in having the friction band *B* on the outside of the flange. The principal proportions of these clutches are about the same as given above for Fig. 679.

2003. Shifting Gear for Clutches.—A clutch is usually put in or out of gear by means of a forked lever, the

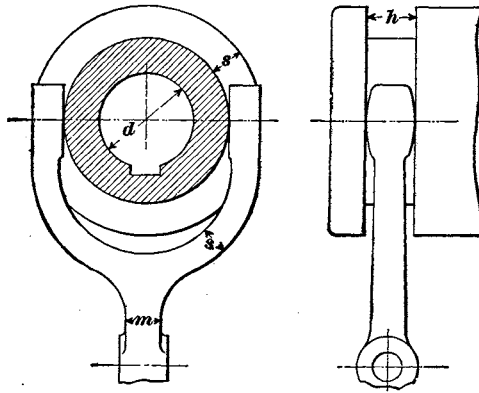


FIG. 681.

prongs of which fit into the groove cut in the sliding part of the clutch. The lever is usually worked by hand, though for large clutches the end of the lever may be moved by a screw and hand wheel. The ordinary design of the forked end of the lever is shown in Fig. 681. To increase the wearing surface a strap may be used, as shown in Fig. 682. The strap completely fills the groove, and is often made of brass.

The dimensions h and s are the width and depth of the

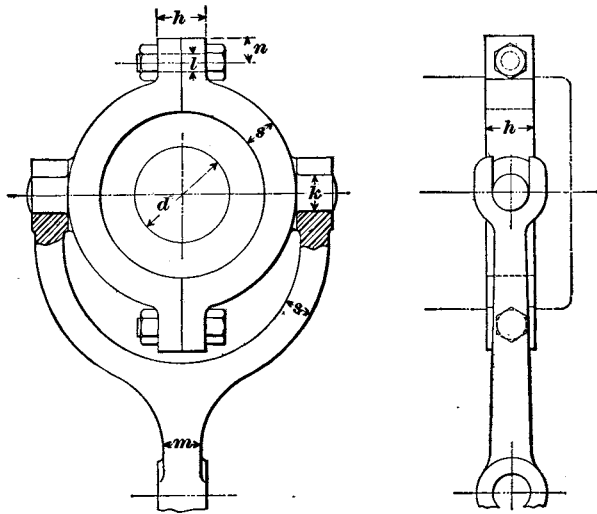


FIG. 682.

groove, respectively, which are to be determined by the rules already given for the proportions of the clutch.

Proportions for clutch lever:

d = diameter of shaft;

$h = \frac{1}{2} d$;

$k = \frac{3}{8} d$;

$l = \frac{3}{16} d$;

$s = \frac{5}{16} d$;

$m = \frac{3}{8} d$;

$n = \frac{1}{4} d$.

(265.)

MACHINE DESIGN.

(CONTINUED.)

BEARINGS.

2004. Solid Journal Bearings.—The simplest form of bearing for a journal is merely a hole in the frame which supports the rotating piece. Such a bearing is shown in Fig. 683. Motion endwise is prevented by two collars, in Fig. 683. Motion endwise is prevented by two collars,

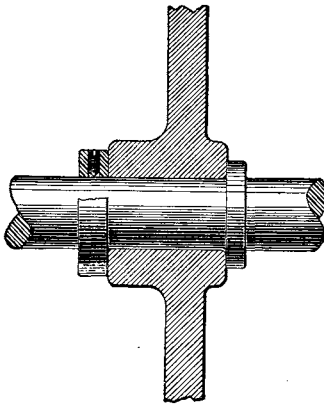


FIG. 683.

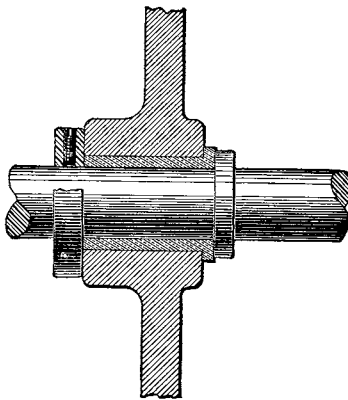


FIG. 684.

one of which may be forged on the shaft, and the other made separately and held in place by a set-screw or pin. A boss is cast upon the frame, as shown in the figure, in order to give the journal the necessary length and bearing area.

Such a bearing has no means of adjusting to take up the wear; for this reason it is better to use the form of solid bearing shown in Fig. 684. Here the hole is bored out larger than the journal, and lined with a bushing made of

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brass or other metal. The wear thus comes on the bushing, which can easily be replaced.

2005. Divided Bearings.—In many cases solid bearings are undesirable, and in others it will be impossible to use them. The bearing is then divided, and the parts held

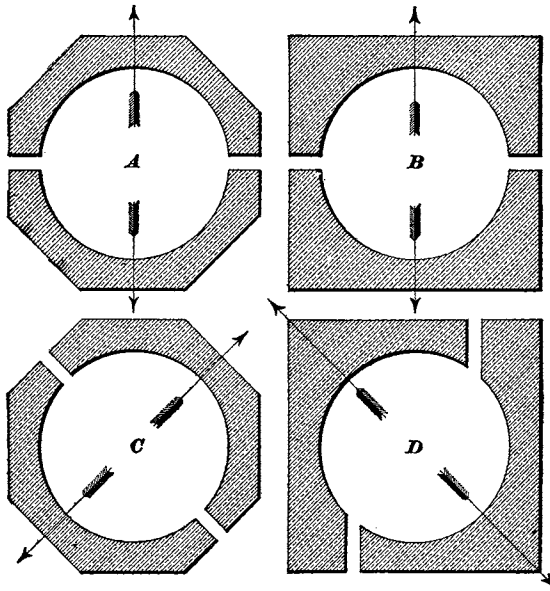


FIG. 685.

together by bolts. When this is done, the parts of the bushing are called *seats* or *steps*. The division of the bearing permits its adjustment for wear.

The load on a bearing usually acts constantly in one direction, and the bearing should be divided so that the line of division is perpendicular, or nearly so, to the direction of the load. Fig. 685 shows various methods of dividing the seats. In *A* and *B* the direction of the load is vertical; consequently, the seats are divided horizontally.

Naturally, the wear will come on the top and bottom of the seats, and the hole will become oval, with the long

diameter vertical. The seats are then screwed closer together until the hole regains its original circular form. The necessity of making the division perpendicular to the direction of the load is thus apparent. In *C* the direction of the load is oblique, and the adjustment perpendicular to it; in *D* the direction of the load is oblique also, but the seats are divided to allow a horizontal adjustment.

A simple form of divided bearing is shown in Fig. 686. It is of cast iron, with no separate seats, but with means of

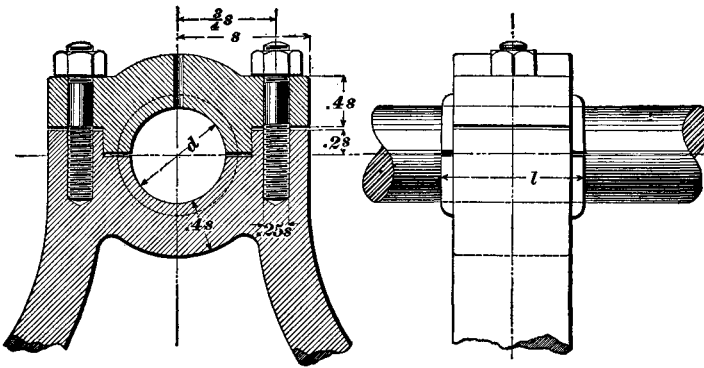


FIG. 686.

adjustment. The bearing forms part of the frame of the machine. This form of bearing is used only on cheap work. Sometimes, however, it has a recess, or groove, cast in it, which is filled with babbitt metal, upon which the journal rests.

The proportional unit for this bearing is

$$s = 1.15 d + .4.$$

The dimensions l and d of the bearing are the same as those for a journal; the other proportions are given in terms of the unit s , and are shown in the figure.

2006. Seats, or Steps.—Carefully made bearings are always lined with so-called **seats**, or **steps**, which are made of brass, gun-metal, phosphor-bronze, white metal or babbitt metal, although other alloys are also used. When

made of a metal resembling brass in color, seats are often called **brasses**. The seats when worn out may be easily replaced, and being made of softer material than the journal, the latter wears but very little.

An ordinary form of seat is shown in Fig. 687. A part of the seat at each end is made octagonal in cross-section. This part is fitted into an octagonal recess in the **pillow-block**, or **pedestal**, which holds it, and the seats are thus prevented from turning. Sometimes the octagonal parts

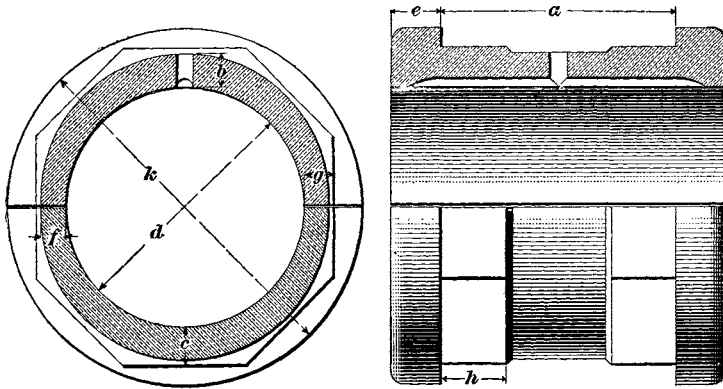


FIG. 687.

are dispensed with, and the seats are turned in a lathe, the pillow-blocks, or pedestals, being bored to receive them. It is then necessary to provide the seats with a lug, or pin, to prevent them from turning.

These seats may be made according to the following proportions, in which d , the diameter of the journal, is the proportional unit:

$$b = \frac{1}{10}d + \frac{3}{16}''.$$

$$c = \frac{1}{8}d + \frac{3}{16}''.$$

$$e = \frac{1}{8}d + \frac{1}{8}''.$$

$$f = \frac{1}{10}d.$$

$$g = \frac{1}{8}d.$$

$$h = \frac{1}{4}d.$$

$$k = 1\frac{1}{2}d.$$

$$d = \text{diameter of journal.}$$

The dimension a should be made to fit the pillow-block for which the seats are intended.

Seats should be well supplied with grooves and channels, so that oil may be conducted to every part of the journal.

It is a good plan to place a groove parallel to the axis of the journal in the upper half of the seat, where it may be in direct communication with the oil holes. Then, the advancing side of the journal will always carry a thin film of oil along with it. The grooves may be from $\frac{1}{8}$ " to $\frac{1}{2}$ " wide, according to the size of the journal.

2007. Lining for Seats.—Seats for large bearings are often lined with babbitt metal, or antifriction metal. It has been found by experience that a bearing will run

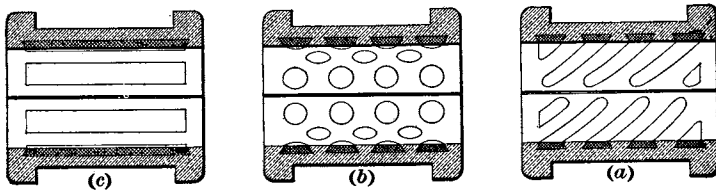


FIG. 688.

cooler when so lined, probably because the babbitt metal, being softer, accommodates itself to the journal more readily than the more rigid gun-metal.

Some of the common methods of lining the seats are shown in Fig. 688.

At (a), the babbitt metal is shown cast into shallow helical grooves; at (b), into a series of round holes, and at (c), into shallow rectangular grooves. Consequently, the journal rests partly on the brass and partly on the babbitt metal.

In cheap work, the seats are frequently made entirely of babbitt metal. A mandrel, the exact size of the journal, is placed inside the bearing, and the melted babbitt metal is poured around it. In better work, a smaller mandrel is used. After the metal hardens it is hammered in; the bearing is then bored out to the exact size of the journal.

PEDESTALS.

2008. The names **pedestal**, **pillow-block**, **bearing**, and **journal-box**, are used indiscriminately. They are all a form of bearing, and mean a support for a rotating piece.

2009. A form of journal-box frequently used for small shafts is shown in Fig. 689. It consists of two parts: (1) the box which supports the journal, and (2) the cap which is screwed down to the box. In this journal-box the seats are of babbitt, or, as it is commonly expressed, the box is bab-bitted. The cap is held in place by what are called cap-screws—an invariable method in small pedestals.

2010. The proportioning of a pedestal is largely a matter of experience. Few or none of the parts are calculated for strength.

All the proportions of the pedestals which follow are based on the diameter of the journal d as the unit; the length of the seats is the same as that of the journal.

For the journal-box shown in Fig. 689, the following proportions may be used for sizes of journals from $\frac{1}{2}$ " to 2" diameter, inclusive. The diameter of shaft d = the unit.

$a = 2.25 d.$	$l = .08 d.$
$b = 1.75 d.$	$m = .25 d + .1875".$
$c = d.$	$n = .5 d.$
$e = .375 d.$	$o = .625" \text{ (constant).}$
$f = .08 d + .0625".$	$p = 1.5 d.$
$g = 1.75 d.$	$q = 1.333 d.$
$h = 2.45 d.$	$r = .08 d.$
$i = .3 d.$	$s = .125" \text{ (constant).}$
$j = .33 d.$	$t = .16 d.$
$k = .25 d + .125".$	$u = 1.333 d.$
$v = .125 d.$	

2011. In Fig. 690 is shown a common form of pedestal which is used for somewhat larger journals than the one shown in Fig. 689.

It consists of (1) a foundation plate which is bolted to the foundation on which the pedestal rests; the plate is essential when the pedestal rests on brickwork or masonry, but may be dispensed with when the pedestal rests on the frame of the machine; (2) the block which carries the seats and supports the journal; (3) the cap which is screwed down over

the seats. The bolt holes in both foundation plate and block are oblong, so that the pedestal may be readily adjusted.

The following proportions may be used for this kind of pedestal, with journals from 2" to 6", inclusive. An oil cup

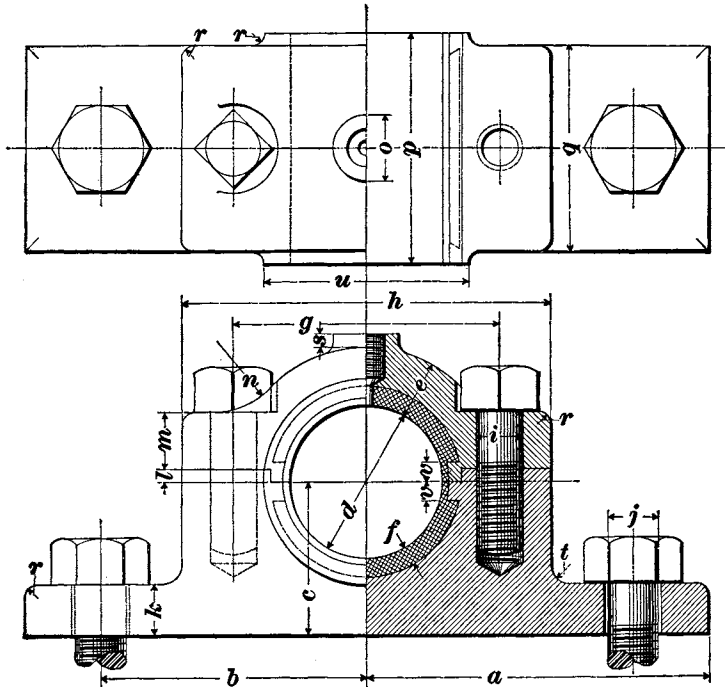


FIG. 689.

having a $\frac{1}{4}$ " pipe tap shank may be used on pedestals for journals having diameters from 3" to 4", and $\frac{3}{8}$ " pipe tap shank for larger sizes up to 6" diameter.

NOTE.—The shanks of oil cups and grease cups bought in the market are made with a $\frac{1}{8}$ ", $\frac{1}{4}$ ", $\frac{3}{8}$ ", or $\frac{1}{2}$ " pipe thread. The amount of oil or grease the cup holds when filled is usually expressed in ounces.

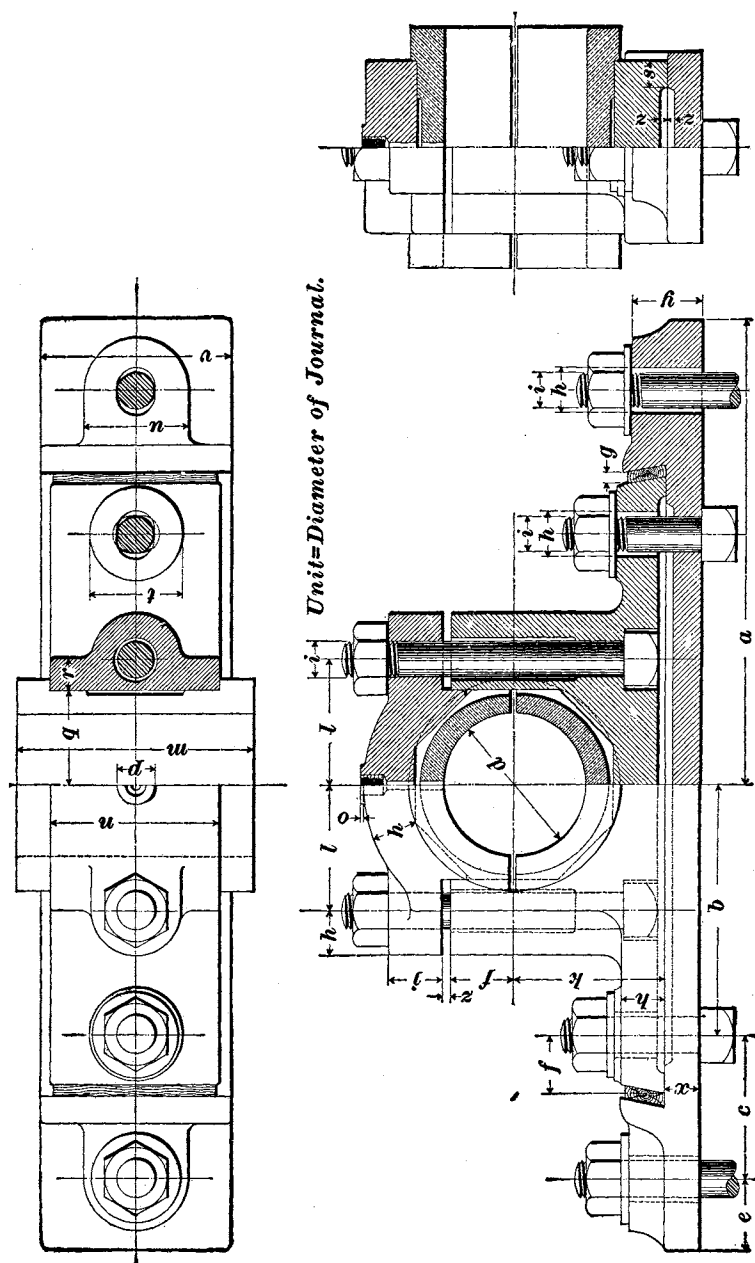


FIG. 690.

The diameter of journal d = the unit;

$$\begin{aligned}
 a &= 3.25 d. \\
 b &= 1.75 d. \\
 c &= d. \\
 e &= .5 d. \\
 f &= .4375 d. \\
 g &= .09 d. \\
 h &= .3125 d. \\
 i &= .25 d. \\
 j &= .375 d. \\
 k &= 1.0625 d. \\
 l &= .875 d. \\
 m &= 1.75 d. \\
 n &= 1.25 d. \\
 o &= .125'' \text{ (constant).} \\
 p &= .875'' \text{ (constant).} \\
 q &= .625 d. \\
 r &= .25 d. \\
 s &= .1875 d. \\
 t &= .65 d. \\
 u &= .75 d. \\
 v &= 1.375 d. \\
 x &= .25 d. \\
 y &= .5 d. \\
 z &= .0625 d.
 \end{aligned}$$

2012. Crank-Shaft Pedestals.—The load on a crank-shaft bearing is due partly to the weight of the shaft and fly-wheel, and partly to the alternate push and pull of the connecting-rod. The direction of the resultant of these two forces is, therefore, more or less oblique, and, consequently, the pedestal is often divided obliquely.

2013. A pedestal of this kind is shown in Fig. 691, which may be proportioned by taking the diameter d of the journal as the unit, and using the following proportions:

The line AB is at an angle of 45° to the base line.

This pedestal, as shown, is babbitted. The babbitt is held

in place and prevented from turning with the journal by providing the surfaces with which the babbitt comes in contact

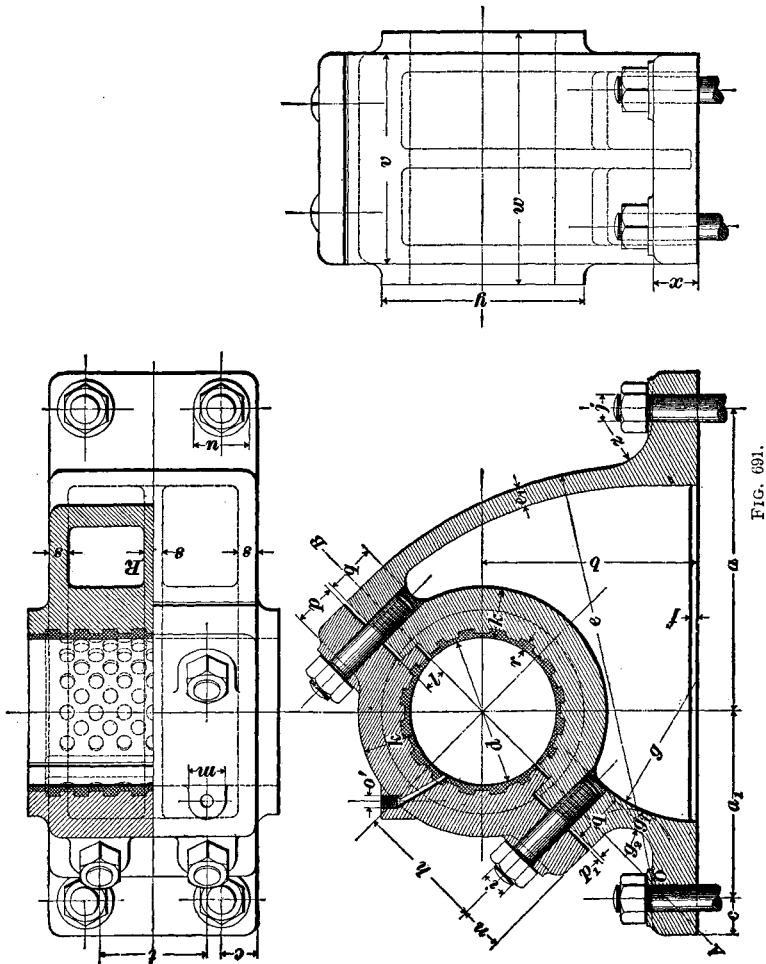


FIG. 691.

with round projections as shown. The projections are about one inch in diameter for the larger sizes of pedestals.

$$\begin{aligned}
a &= 2d + 1''. \\
a_1 &= 1.2d + 1''. \\
b &= 1.5d. \\
c &= .22d + .5''. \\
e_1 &= .1d + .25''. \\
f &= .5'' \text{ (constant)}. \\
g_1 &= .1d + .25''. \\
h &= .9d. \\
i &= .15d + .25''. \\
j &= .15d + .375''. \\
k &= .3d + .625''. \\
l &= .1d + .375''. \\
m &= .25d. \\
n &= .3d. \\
p &= .25d + .25''. \\
p_1 &= .04d. \\
q &= .35d. \\
r &= .02d + .3125''. \\
s &= .1d + .25''. \\
t &= .75d. \\
u &= .27d + 1.125''. \\
v &= 1.45d. \\
w &= 1.75d. \\
x &= .25d + .625''. \\
y &= 1.3d + 1''. \\
z &= .25d + 1''.
\end{aligned}$$

To find the radius e draw a line parallel to the base line, and at a distance x above the base line. The point of intersection O of this line with the line AB is the center of the arc having the radius e . The radius g_2 is found by trial. The center of the arc must lie on the line AB . With a radius $g_2 + g_1$ describe an arc from the same center. Draw a line parallel to the face of the bearing at a distance from it determined by q . The radius g is to be found by trial, the center being on the base line, and the arc tangent to the line determined by q and to the arc determined by $g_2 + g_1$. The rib R may be used on all pedestals above 6" diameter of journal. o' may be tapped with a $\frac{1}{4}$ " pipe tap for 3" to 4"

journal, $\frac{3}{8}$ " pipe tap up to 6" journal, $\frac{1}{2}$ " up to 9" journal, and $\frac{3}{4}$ " for all sizes above 9".

Two oil cups may be used on all bearings above 8" diameter of journal. This style of pedestal may be used for journals from 3" up to 15" diameter, inclusive.

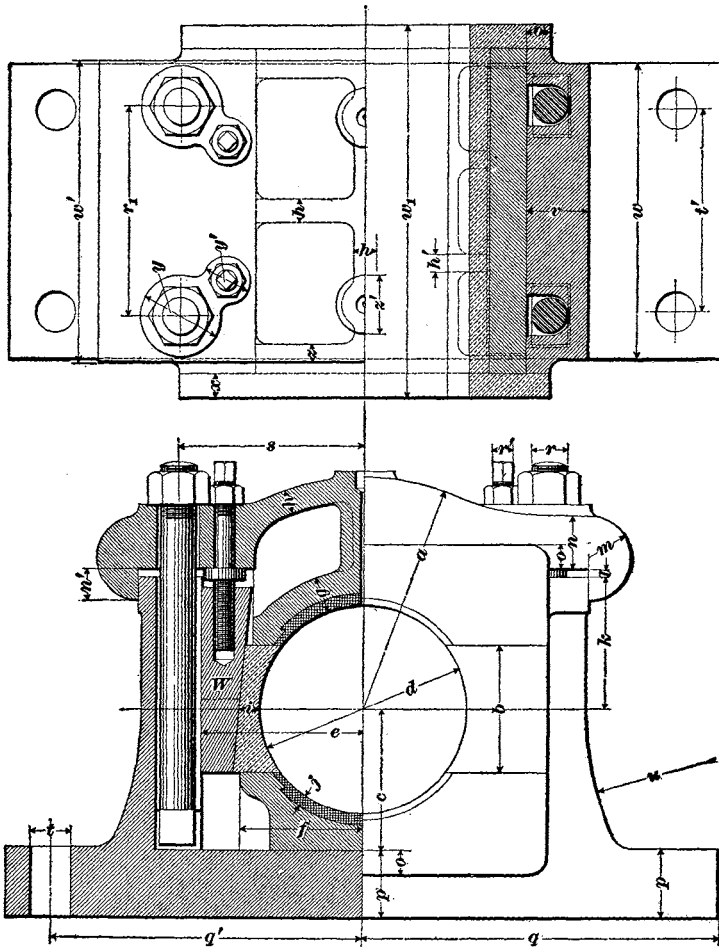


FIG. 692.

2014. Fig. 692 shows a pedestal suitable for the crankshaft of a horizontal engine with journals from 8" to 20" in

diameter. The block may be complete in itself, as shown in the figure, but more often it forms part of the engine bed.

The seats are in three parts, and may be adjusted horizontally by means of the wedges *W*. The lower seat may be raised by placing packing pieces under it. To obtain its dimensions, use the following proportions, which are based on the unit *d* = the diameter of the crank-shaft journal:

$a = d + 1''$.	$q' = 1.5 d$.
$b = .5 d + 1''$.	$r = .15 d$.
$c = .66 d$.	$r' = .1 d$.
$e = .825 d - .25''$	$r_1 = d$.
$f = .6 d$.	$s = .9 d$.
$g = .1 d + .5625''$.	$t = .15 d + .375''$.
$h = .1 d + .25''$.	$t' = .9 d$.
$h' = .08 d$.	$u = 1.5 d$.
$i = .11 d$.	$v = .25 d + .375''$.
$j = .625''$ (constant).	$w = 1.45 d$.
$k = .5 d + 1.25''$.	$w' = 1.47 d$.
$l = .375''$ (constant).	$w_1 = 1.75 d$.
$m = .175 d + .3125''$.	$x = .1 d$.
$n = .25 d + .25''$.	$y = .3 d + .75''$.
$n' = .1 d + .375''$.	$y' = .2 d + .5''$.
$o = 1''$ (constant).	$z = .09 d$.
$p = .25 d + .625''$.	$z' = 2.5''$ (constant).
$q = 1.75 d$.	

Taper of adjusting wedge, 1 : 10.

Further details of the bottom seat and the cap are shown in Fig. 693, in which the unit is the same as in Fig. 692, and the proportions are as follows:

$a = 1''$ (constant).	$c = .08 d$.
$b = 1.65 d - .5''$.	$d = .1 d$.

2015. The foundation, or bed casting, is shown in Fig. 694, and has dimensions to suit the pedestal shown in Fig. 692. Its proportions are as follows, the diameter of the crank-shaft journal *d* being taken as the unit:

$$a = 2.45 d + 7.25''.$$

$$b = 2.3 d + 5.25''.$$

$$c = .5 d + 3.5''.$$

$$e = 3.5 d + 2''.$$

$$f = .25 d + .5''.$$

$$g = .25 d + 1.75''.$$

$$h = .25 d + 2.25''.$$

$$n = 1.55 d + 2.5''.$$

$$o = .25 d + 2''.$$

$$o' = .25 d + .5''.$$

$$o'' = .5 d + 4.5''.$$

$$p = .08 d.$$

$$q = 1.5 d.$$

$$r = .15 d + .375''.$$

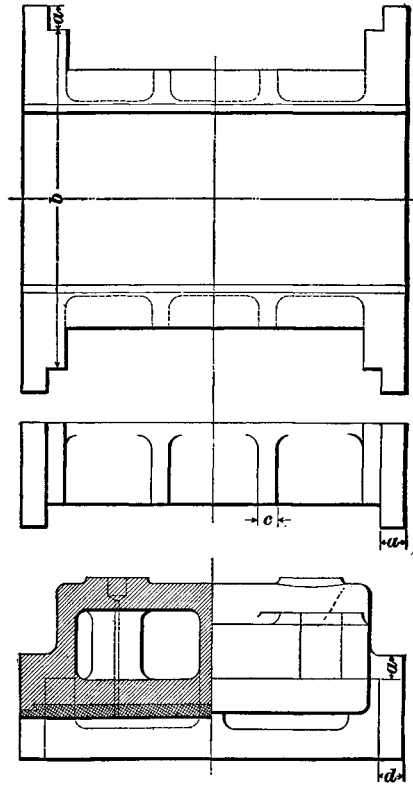


FIG. 693.

$$i = .05 d + .5''.$$

$$j = .05 d + 1.125''.$$

$$k = .05 d + .75''.$$

$$l = .25 d + .75''.$$

$$m = .4 d.$$

$$m' = .6 d.$$

$$s = .15 d + .375''.$$

$$t = .9 d.$$

$$u = .15 d + .875''.$$

$$v = .2 d.$$

$$w = 1.5 d.$$

$$x = 1.65 d.$$

2016. Ball-and-Socket Bearings.—These bearings, now largely used in the United States, were first introduced by William Sellers & Co., of Philadelphia. They have very long steps made of *cast iron* bored to fit the journal. In some cases, however, the steps are cast with a recess in which a babbitt lining is poured to form a bearing surface for the journal. The steps have a spherical enlargement at the center, which fits into corresponding hollows in the block and cap, thus making a ball-and-socket joint, which leaves

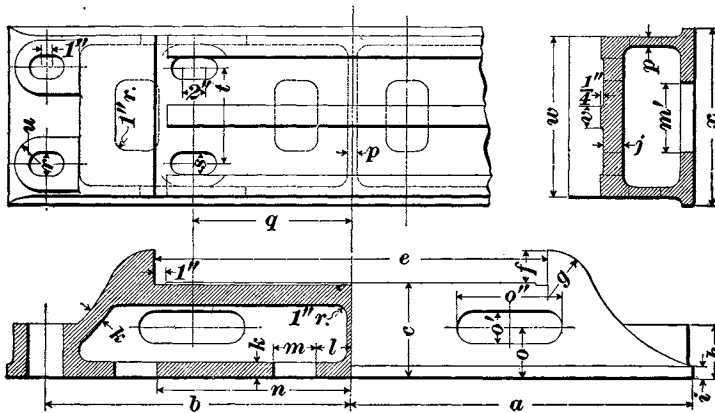


FIG. 694.

the bearing free to move slightly in any direction to conform to an inequality or want of alinement in the shaft. When rigid bearings are used, they must necessarily be short on account of unavoidable deflections of the shaft due to belt pull, thrust of gearing, etc. Pivoted bearings, on the contrary, by reason of their flexibility, may be made long, thereby giving a large wearing surface and increased durability.

2017. Fig. 695 shows a pedestal with ball-and-socket bearing. The steps are of cast iron, and have a length of four times the diameter of the journal.

Ordinarily the journal is lubricated through the oil hole in the center of the cap, but the upper step also has two cups, filled with a mixture of tallow and oil which melts at about 100° F. If the bearing becomes heated this mixture melts, and thus helps in the lubrication.

The dimensions of this bearing are obtained from the following proportions, which are based on the diameter of the journal d as the unit:

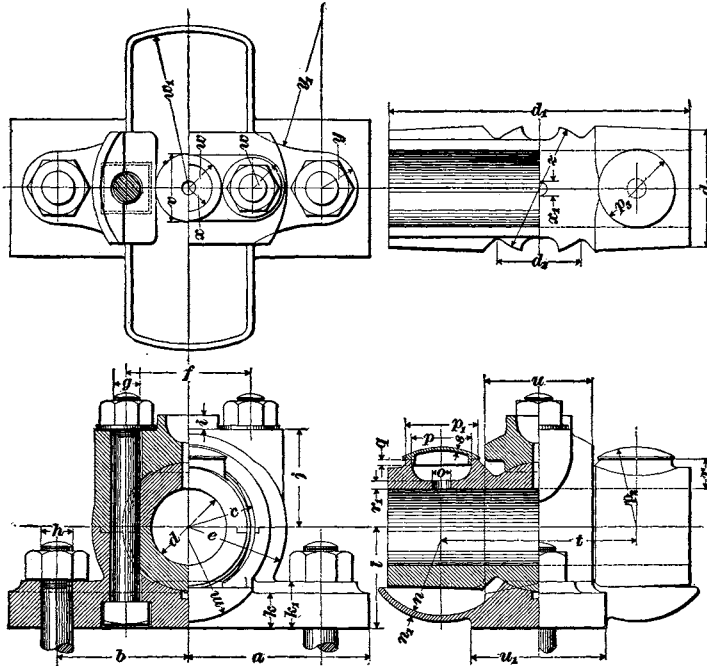


FIG. 695.

$$a = 2.375 d.$$

$$b = 1.75 d.$$

$$c = .875 d.$$

$$d_1 = 4 d.$$

$$d_2 = 1.1 d.$$

$$d_3 = 1.25 d + .5".$$

$$e = 1.3 d.$$

$$f = 1.65 d.$$

$$g = .2 d + .25".$$

$$h = .2 d + .375".$$

$$i = .1875 d.$$

$$j = 1.27 d.$$

$$k = .3 d + .25".$$

$$k_1 = .4 d + .375".$$

$$l = 1.33 d.$$

$$m = d + .125".$$

$$n = d.$$

$$n_1 = .125" \text{ (constant).}$$

$$o = .25 d.$$

$$p = .8 d.$$

$$p_1 = .95 d.$$

$$p_2 = d.$$

$$p_3 = d.$$

$$q = .07 d.$$

$$r = .4 d.$$

$$r_1 = .1 d.$$

$s = .0625''$ (constant).	$w_1 = 2.06 d.$
$t = 2.5626 d.$	$x = .18 d + 2.5''.$
$u = 1.45 d.$	$x_1 = .1875 d.$
$u_1 = 1.8 d.$	$y = .25 d + .375''.$
$v = .875 d.$	y_1 to be found by trial.
$w = .2 d + .375''.$	$z = 1.5 d + .3125''.$

WALL BRACKETS AND HANGERS.

2018. Wall Brackets, or Post Hangers.—A shaft must sometimes be supported by a bearing fixed to a wall or pillar. In such a case the bearing is generally supported by a **wall bracket**. It will readily be seen that the bracket is a cantilever with practically a uniform load, due to its own weight, and a concentrated load, due to the weight of the shaft; hence, the bending moment diagram resembles that shown in Fig. 332, Art. 1391.

Now, in order that a cantilever should be equally strong at all sections, the resisting moment, $\frac{SI}{c}$, of that section should be proportional to the bending moment at that section. Suppose the bracket in question to be a plate of a constant thickness b . Then, at any section, the bending moment $M = \frac{SI}{c} = \frac{S \frac{1}{12} b h^3}{\frac{1}{2} h} = \frac{1}{6} S b h^2$.

Since $\frac{1}{6} S b$ remains constant for all sections, the h^2 is proportional to the bending moment; or, in other words, the height of a cantilever at any section should be proportional to the square root of the bending moment at that section. It can be shown mathematically that, supposing the cantilever to have a constant width, it should have a parabolic form when the load is concentrated at the end, and it should have a triangular form when the load is uniformly distributed. In practice, a bracket or other machine part of the cantilever class is given a form which is often neither exactly parabolic nor triangular, but approximates closely to one or the other, according to the taste and judgment of the designer.

2019. A good design for a wall bracket is shown in Fig. 696. The bearing proper resembles that of the pedestal, Fig. 695. The spherical enlargement at the center

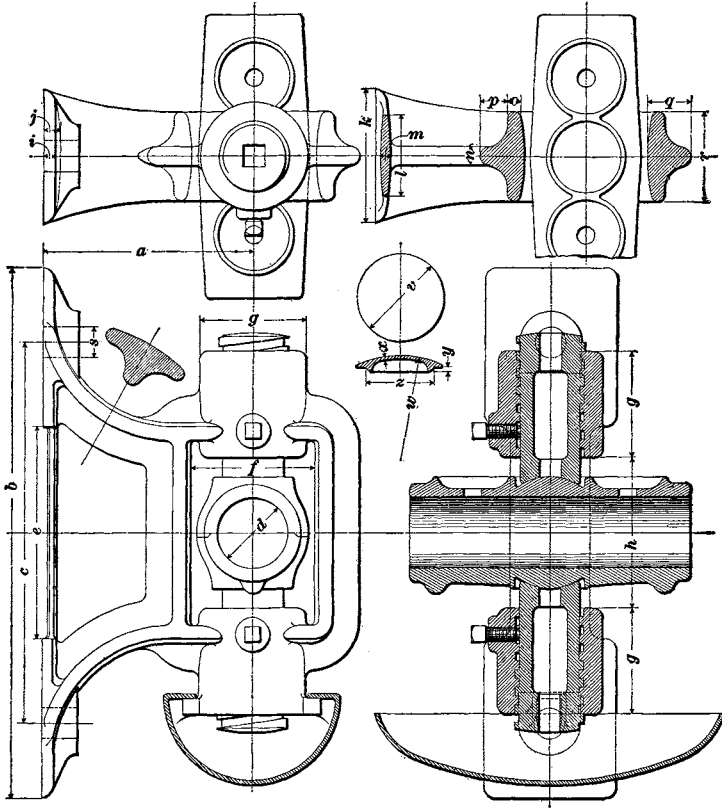


FIG. 696.

of the steps is held between the ends of two hollow cast-iron plugs, which are threaded at their outer ends, and screw into bosses cast on the bracket.

The bearing may be raised or lowered by screwing the plugs up or down. In order to turn the plugs the hole at the end is made square to receive a key. When the plugs are in the desired position they are locked by the set-screws.

The length of the bearing is 4 times the shaft diameter; the other dimensions are to be obtained from the figure and by the following proportions:

Diameter of shaft d = unit;

$a = 3 d.$	$k = 1.875 d.$
$b = 7.5 d.$	$l = 1.125 d.$
$c = 5.375 d.$	$m = .125 d.$
$e = 3 d.$	$n = .25 d.$
$f = 1.75 d.$	$o = .1875 d.$
$g = 1.5 d.$	$p = .375 d.$
$h = 2.125 d.$	$q = .625 d.$
$i = .16 d.$	$r = 1.25 d.$
$j = .25 d.$	$s = .25 d + .5".$

Proportions of oil or grease cup covers:

$v = 1.125 d + .1875".$	$y = .0625 d.$
$w = 1.5 d.$	$z = d - .0625".$
$x = .125" \text{ (constant).}$	

The proportions of boxes, bosses, plugs, drip pans, etc., are to be made the same as those of the shaft hanger shown in Fig. 697.

2020. Hangers.—A hanger is used when a shaft bearing is to be suspended from the ceiling. Fig. 697 shows a form of a hanger made by a leading manufacturing company.

The bearing is the same as that of the wall bracket, Fig. 696. The frame of the hanger is divided, and the parts connected by bolts. With such a form the shaft may be more easily removed than when the hanger frame is a solid piece.

The units for determining the leading dimensions of a shaft hanger are the diameter d of the shaft and the drop D of the hanger.

The following proportions are suitable for shafts ranging from $1\frac{1}{2}"$ up to $4\frac{1}{2}"$ in diameter:

$A = 6 d + .45 D.$	$E = 2 d + .25 D.$
$A_1 = 2 d + .03 D.$	$F = .5 d + .01 D.$
$B = 4 d + .35 D.$	$F_1 = 1.5 d + .05 D.$
$C = 2 d + .3 D.,$	$G = 1.25 d.$

$H = 2 d.$	$j = .25 d + .25''.$
$I = .4 d.$	$j_1 = .125 d + .0625''.$
$J = .125 d + .01 D.$	$k = 2.2 d.$
$K = .5 d + .5''.$	$l = 4 d.$
$L = .25 d + .5''.$	$m = 1.4 d + .375''.$
$M = .75 d + .6875''.$	$n = d.$
$N = .25 d + .375''.$	$o = .25 d.$
$O = 1.25 d.$	$o_1 = .0625 d.$
$O_1 = .094 d + .002 D.$	$p = d.$
$P = .375 d + .008 D.$	$p_1 = .0625 d.$
$Q = .375 d + .008 D.$	$q = .4 d.$
R and R_1 (see note).	$q_1 = .15 d.$
$S = .25 d + .005 D.$	$r = 2.125 d.$
$S_1 = .125 d + .003 D.$	$s = 1.5 d.$
$T = .125 d + .01 D.$	$s_1 = .125 d.$
T_1 (see note).	$t = 2 d.$
$U = 2 d.$	$t_1 = .5 d.$
$V = .5 d.$	$t_2 = d.$
$W = .75 d.$	$t_3 = .25 d.$
$X = .375 d.$	$u = .95 d.$
$Y = .25 d + .125''.$	$u_1 = .85 d.$
$Z = .625 d.$	$v = .25 d + .125''.$
$a = .15 d + .375''.$	$v_1 = .5 d.$
$a_1 = 2.4 d + .3125''.$	$w = d.$
$b = .08 d.$	$w_1 = .125''$ (constant).
$c = .125 d + .0625''.$	$x = .25 d.$
$e = .2 d.$	$x_1 = d.$
$e_1 = .4 d.$	$x_2 = 4 d + 2''.$
$e_2 = .2 d.$	$y = 1.25 d.$
$f = .375 d + 1''.$	$y_1 = .75 d + .0625''.$
$f_1 = .09 d + .25''.$	$y_2 = .4 d + .0625''.$
$g = .75 d.$	$z = .06 d + .25''.$
$g_1 = 1.3125 d + .125''.$	$z_1 = .12 d + .75''.$
$h = 1.25 d + .1875''.$	$z_2 = .3125''$ (constant).
$i = .1 d.$	

Thread of plugs, $.5''$ pitch for all sizes.

NOTE.—To find R_1 , draw the arc J ; also, draw the arc Q tangent to P ; then, draw a straight line tangent to these arcs, and R_1 will be

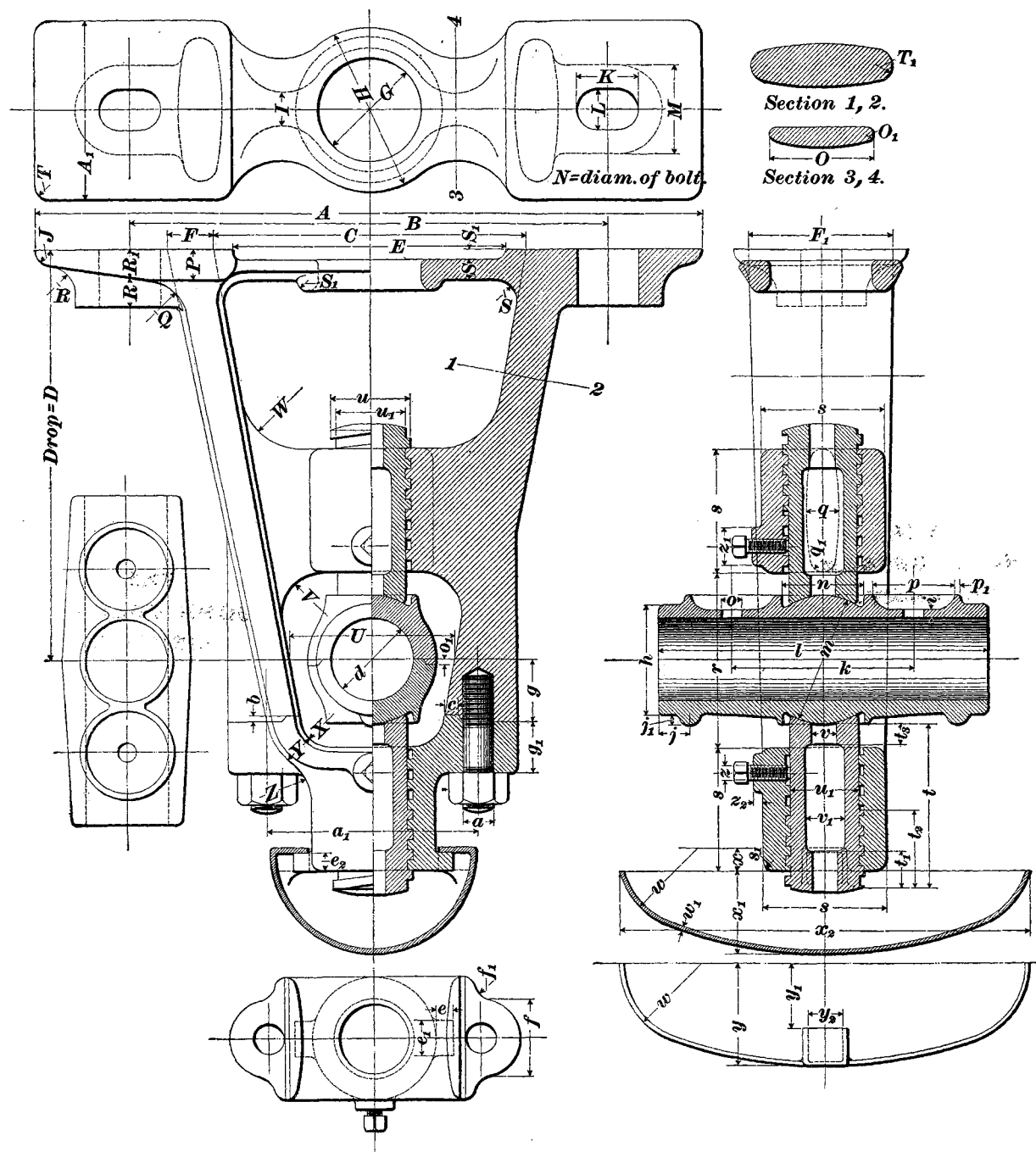


FIG. 697.

the distance along the center line determined by B included between this tangent and the upper face of the hanger. Having found R_1 , make R equal to it.

The radius T_1 is made equal to $\frac{3}{8}$ the thickness at the middle.

The steps of the ball-and-socket bearings shown in Figs. 695, 696, and 697 are of cast iron, and are bored to fit the journal without lining or brasses. The ball, and the recesses in the ends of the plugs, into which the ball is fitted, should be faced. The screw threads on the plugs, Figs. 696 and 697, may be cast on the plugs or turned, the latter being preferable. It is customary to use two threads per inch for all sizes of plugs.

2021. Pivot or Foot-step Bearings.—These bearings are used to support the ends of vertical shafts. An ordinary pivot bearing is shown in Fig. 698. The end of the pivot rotates on a disk A , which may be of steel, brass, or bronze. The brass bush B prevents the pivot from moving side-wise. The end of the pivot should be of steel, and it may be flat on the end or slightly cup shaped. The proportions are given in terms of the diameter d of the pivot as a unit.

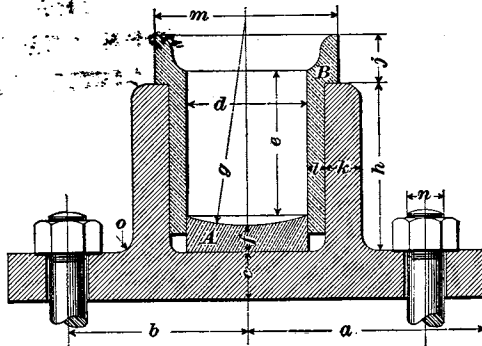


FIG. 698.

Its proportions are as follows:

$a = 2d.$	$j = .4d.$
$b = 1.5d.$	$k = .3d.$
$c = .25d + .375".$	$l = .15d.$
$e = 1.25d.$	$m = 1.5d.$
$f = .2d + .125".$	$n = .2d + .25".$
$g = 1.75d.$	$o = .15d.$
$h = 1.4d.$	

2022. Pivots with Loose Disks.—When pivots are required to run at great speed, the relative speed of the surfaces in contact may be reduced by placing a number of loose disks between the pivot and the foot-step, as shown in Fig. 699.

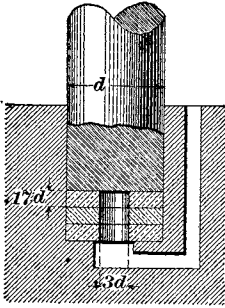


FIG. 699.

If a = the number of disks and n = the revolutions per minute of the pivot, then the relative speed of any of the surfaces in contact is $\frac{n}{a+1}$ revolutions per minute. Suppose, for example, a pivot runs at 3,000 revolutions per minute, and it is desired to reduce the speed between adjacent surfaces to 750 revolutions per minute; then, $750 = \frac{3,000}{a+1}$, or $a = 3$, the number of disks required. The pivot and disks may be lubricated by a channel, as shown in the figure. The disks may be made of gun-metal or phosphor-bronze. Proportions are given in the figure.

TOOTH GEARING.

SPUR AND BEVEL GEARS.

NOTE.—Before reading this section, the student should carefully review the portion of Applied Mechanics which relates to gear teeth.

2023. Materials of Gearing.—Gearing is ordinarily made of cast iron. If great strength is required steel may be used. Gears which are called upon to resist shocks may be made of gun-metal or phosphor-bronze. Fast-running gears are sometimes made with *wooden cogs*, or of *rawhide*, or *fiber*, instead of *metal*.

Gear-wheels are either cast with teeth and all complete, or with a blank rim in which the tooth spaces are afterwards cut with a milling cutter. Gears with cast teeth are less expensive; those with cut teeth are more accurate. Gear-cutting machines are now made, however, which can easily

cut teeth on both spur and bevel gears of the largest size; hence, cut gears are quite generally used, except on very large or rough work.

STRENGTH OF GEAR TEETH.

2024. A gear tooth may be considered as a cantilever whose length is l , depth, t , and breadth, b , see Fig. 700.

Let p = the pressure acting at the pitch line, and, as an extreme case, let the total pressure come on the edge of one tooth, as shown in the figure. (Usually the pressure will be divided among two or three teeth.)

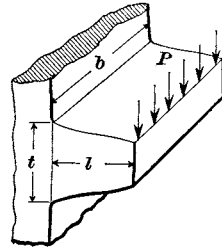


FIG. 700.

Then, the bending moment = $p l$.

$$\text{The resisting moment} = \frac{S I}{c} = S \frac{\frac{1}{2} b t^3}{\frac{1}{2} t} = \frac{S b t^2}{6}.$$

$$\text{Therefore,} \quad p l = \frac{S b t^2}{6}. \quad (a)$$

The thickness t at the root of the tooth may be taken equal to $\frac{1}{2} C$, and $l = .7 C$ from the proportions given in Table 34, Art. 1555. C = the circular pitch.

Substituting these values in equation (a), we obtain

$$.7 C p = \frac{S (b \frac{1}{2} C)^2}{6} = \frac{S b C^2}{24}.$$

$$\text{Or,} \quad b C = 16.8 \frac{p}{S}. \quad (266.)$$

The value of the working stress S depends upon the velocity of the pitch circle of the gear, since, as the speed increases, the teeth become more liable to shocks.

Let v = velocity of a point in the pitch circle in feet per minute. Then, if v is equal to or less than 100, take $S = 4,200$ lb. per sq. in. for cast iron.

If v is greater than 100 feet per minute, the safe stress S may be obtained from the following formula:

$$S = \frac{9,600,000}{v + 2,160}. \quad (267.)$$

To find the pitch C from formula **266**, the relation between b and C must be known. The following proportions are those generally used in practice:

For wheels moving slowly or intermittently, as in hoisting apparatus

$$b = 2 C \text{ to } 2\frac{1}{2} C.$$

For more rapidly moving cast gears, for example, transmitting gears,

$$b = 2\frac{1}{2} C \text{ to } 3 C.$$

For gears moving more rapidly, and with cut teeth,

$$b = 3 C \text{ to } 3\frac{1}{2} C.$$

For very rapidly moving gears with small pitch,

$$b = 3\frac{1}{2} C \text{ to } 4 C.$$

EXAMPLE.—A cast gear 3 feet in diameter makes 40 revolutions per minute, and transmits 16 horsepower. Determine the circular pitch of the teeth, and number of teeth.

SOLUTION.— R = radius of gear = 18 inches.

From formula **231**, Art. **1963**,

$$P = \frac{63,025 H}{\pi R} = \frac{63,025 \times 16}{40 \times 18} = 1,400 \text{ lb.}$$

From formula **267**,

$$S = \frac{9,600,000}{v + 2,160} = \frac{9,600,000}{3\pi \times 40 + 2,160} = 3,784 \text{ lb. per sq. in.}$$

Hence, from formula **266**,

$$b C = 16.8 \frac{P}{S} = \frac{16.8 \times 1,400}{3,784} = 6.2.$$

Assume $b = 2\frac{1}{2} C$. Then, $b C = 2\frac{1}{2} C^2 = 6.2$ sq. in., or $C = 1.575$ in.

Taking $C = 1.5708$ in., the diametral pitch is exactly 2, and the number of teeth $36 \times 2 = 72$. Ans.

Hence, $C = 1.5708$. Ans.

$$P = \frac{\pi}{C} = 2.$$

Number of teeth $N = D P = 36 \times 2 = 72$. Ans.

Breadth of tooth $b = 2\frac{1}{2} C = 3.93$ ", say $3\frac{15}{16}$ ".

In calculating cast-steel gears, or gears with wooden cogs, the above method is applicable, but the value of S should be multiplied by $3\frac{1}{2}$ for steel teeth, and by .6 for wooden cogs.

2025. Wear of Teeth.—Though gear teeth may be amply strong, they may, if poorly designed, wear rapidly. To ensure durability, the dimensions of the tooth should fulfil the following conditions:

Let p = pressure acting at pitch line;
 b = breadth of tooth;
 n = number of revolutions per minute;
 H = horsepower transmitted;
 D = diameter of gear in inches.

Then,
$$\frac{p n}{b} = 28,000, \text{ or } b = 4\frac{1}{2} \frac{H}{D}. \quad (268.)$$

In the example above, we have $4\frac{1}{2} \frac{H}{D} = \frac{4\frac{1}{2} \times 16}{36} = 2 \text{ in.}$, and since the breadth calculated for strength is $3\frac{1}{16}"$, the gear will wear well. It is usually necessary to apply formula 268 to pinions of small diameter.

2026. Shrouded Gear Teeth.—The teeth of a gear-wheel are said to be **shrouded** when the rim is made wider

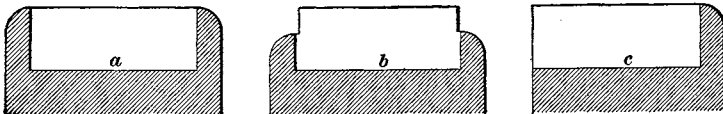


FIG. 701.

than the tooth, and carried outwards so as to unite the ends of the teeth.

Three methods of shrouding are shown in Fig. 701. At a the shrouding is carried on both sides to the end of the tooth. In this case it is evident that only one of the pair of wheels gearing together can be shrouded. At b the shrouding is carried to the pitch line, and, consequently, both wheels of the pair may be shrouded. At c the shrouding is carried up on one side only.

Pinions with few teeth are most benefited by shrouding, since the teeth in that case are weak at the roots, and also because more wear comes on the pinion.

PROPORTIONS OF SPUR AND BEVEL GEAR WHEELS.

2027. Rims.—Various rim sections are shown in Fig. 702. It is good practice to make the rim thickness c equal to the tooth thickness on the pitch circle for gears

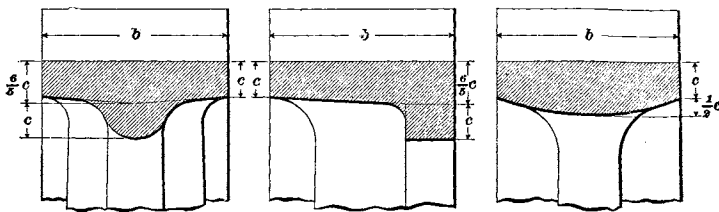


FIG. 702.

whose circumferential pitch is greater than $1\frac{1}{2}$ inches. For gears with small pitch, we may take

$$c = .4 C + \frac{1}{8}'' = \frac{5}{4P} + \frac{1}{8}'' \quad (269.)$$

EXAMPLE.—Calculate the thickness of the rim of a gear-wheel whose diametral pitch is 4.

SOLUTION.—By formula 269,

$$c = \frac{5}{4P} + \frac{1}{8}'' = \frac{5}{16} + \frac{1}{8} = \frac{7}{16}'' \quad \text{Ans.}$$

2028. The rim of a bevel wheel may have the proportions shown in Fig. 703, where c is to be computed by the rules given in the last article.

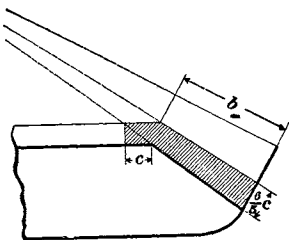


FIG. 703.

2029. When wooden cogs are mortised into a gear-wheel, the rim may have the proportions shown in Fig. 704.

Usually only one of the wheels in a pair that gear together is furnished with wooden teeth, or cogs, in which case the wooden cogs may be made $1\frac{1}{2}$ times as thick as the iron teeth meshing with them; that is,

for the wooden cogs, $t = .6 C$;

for the iron teeth, $t = .4 C$, or less.

Fig. 704 shows two common methods of fastening the cogs to the rim.

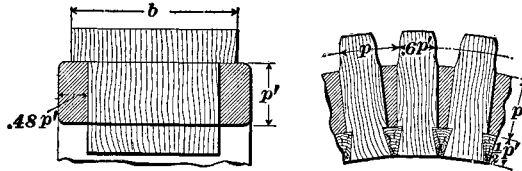


FIG. 704.

2030. Arms of Wheels.—The form of the cross-section of the arms of a gear-wheel depends upon the form

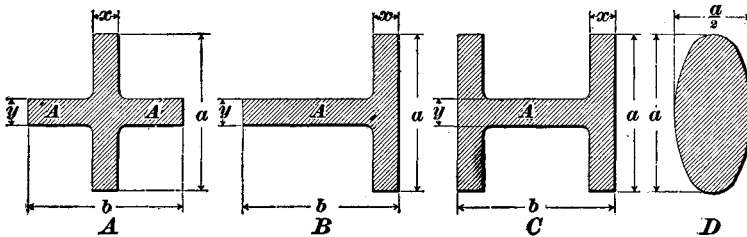


FIG. 705.

of rim used. The forms in ordinary use are shown in Fig. 705. The cross-shaped form *A* is the one mostly used for spur gears; and the section shown at *B*, for bevel gears. The section shown at *C* is good for heavy gears, while the oval form *D* is a neat form for light gears.

In all of the above forms the dimension *a* lies in the plane of the wheel, and the dimension *b* at right angles to this plane, or parallel to the axis of the wheel.

In calculating the strength of the arm, the ribs *A, A* are not taken into account, as they are intended to give the arm lateral stiffness, and not to add strength.

- Let z = number of arms in wheel;
 a = width of arm, measured at center of wheel;
 x = thickness of arm;
 S_1 = allowable safe stress in arm;
 R = radius of wheel in inches;
 p = pressure between gears at pitch line.

We may consider each arm as fixed at the center of the wheel, and free at the end, which, though not strictly true, is on the safe side. Then, the total bending moment is pR inch-pounds, and the bending moment on each arm is $\frac{pR}{z}$.

The moment of resistance is

$$\frac{S_1 I}{c} = S_1 \frac{\frac{1}{12} a^3 x}{\frac{1}{2} a} = \frac{1}{6} S_1 a^2 x.$$

Hence,
$$\frac{pR}{z} = \frac{1}{6} S_1 a^2 x.$$

To avoid strains and breakage in casting, all parts of the wheel should be of nearly the same thickness; therefore, the thickness of the arm may be made about equal to the thickness of the tooth or of the rim.

That is,
$$x = \frac{1}{2} C.$$

But,
$$C = \frac{16.8 p}{b S}. \quad (\text{See formula 266.})$$

Hence,
$$x = \frac{1}{2} C = \frac{8.4 p}{b S};$$

or,
$$\frac{pR}{z} = \frac{1.4 S_1 p a^2}{b S};$$

whence,
$$a^2 = \frac{p R b S}{1.4 S_1 p z} = \frac{R b S}{1.4 S_1 z}.$$

Owing to the initial strain set up in the contraction of the casting, S_1 should have a low value, say 3,000 lb. S may have the value given above; that is, 4,200 lb.

Then,
$$a^2 = \frac{R b \times 4,200}{1.4 \times 3,000 \times z} = \frac{R b}{z};$$

or,
$$\left. \begin{aligned} a &= \sqrt{\frac{R b}{z}} \\ x &= \frac{1}{2} C. \end{aligned} \right\} \quad (270.)$$

For a case in which the proportions given by formula 270 do not give an arm whose appearance is satisfactory, the value of x may be varied a little in either direction, and a new value of a may then be calculated so as to give the required moment of resistance.

EXAMPLE.—A gear-wheel $2\frac{1}{2}$ feet in diameter, with six arms, has a pitch of 2 inches, and the breadth of tooth is 5 inches. Find the dimensions of the arm.

SOLUTION.—Use formula **270**.

$$a = \sqrt[3]{\frac{Rb}{z}} = \sqrt[3]{\frac{15 \times 5}{6}} = \sqrt[3]{12\frac{1}{2}} = 3\frac{1}{2}'', \text{ nearly. Ans.}$$

$$x = \frac{1}{3}C = 1''. \text{ Ans.}$$

For arms of oval or elliptical cross-section, the moment

of resistance is $\frac{S_1 I}{c}$, which equals $\frac{S_1 \pi a^3 (\frac{1}{2}a)}{64 \cdot \frac{1}{2}a}$. (See Table of Moments of Inertia).

Hence,
$$\frac{pR}{z} = \frac{S_1 \pi a^3}{64}.$$

Combining this equation with formula **266**, we obtain, after reducing,

$$\left. \begin{aligned} a &= 1.2 \sqrt[3]{\frac{bCR}{z}} \\ \text{Or, } a &= 1.75 \sqrt[3]{\frac{bR}{Pz}} \end{aligned} \right\} \quad (271.)$$

EXAMPLE.—A gear-wheel 12 inches in diameter has 48 teeth and 4 arms. The rim is $2\frac{1}{2}$ inches wide. Supposing the arms to be of elliptical cross-section, find their dimensions, the thickness being half the breadth.

SOLUTION.—Using formula **271**,

$$a = 1.75 \sqrt[3]{\frac{bR}{Pz}} = 1.75 \sqrt[3]{\frac{2\frac{1}{2} \times 6}{\frac{48}{4} \times 4}} = 1.70''.$$

$$a = 1\frac{3}{8}\frac{3}{4}''. \text{ Ans.}$$

$$\frac{1}{2}a = \frac{7}{8}'', \text{ nearly. Ans.}$$

Formulas **270** and **271** give the width of arm measured at the center of wheel. The arm is tapered from center to circumference. For small gears the taper may be $\frac{1}{32}$ on each side; for larger gears, $\frac{1}{48}$ on each side. The thickness x remains constant, but in the elliptical form the arm is tapered in both width and thickness, so that the latter is constantly equal to half the former.

The average thickness of the stiffening ribs A , Fig. 705, may be $.4 C$. The ribs are tapered slightly to allow the pattern to be easily drawn from the mold. At the hub the

width of the rib may be b , the same as the length of the tooth. The rib is tapered so that at the rim the width is $\frac{3}{4}b$ to $\frac{7}{8}b$.

The number of arms to be used in a given gear-wheel is largely a matter of judgment. Reuleaux gives the following formula:

$$z = .55 \sqrt[4]{N^2 C}, \quad (272.)$$

where z is the number of arms; N , the number of teeth, and C , the circular pitch.

EXAMPLE.—How many arms should be given a gear 4 feet in diameter, diametral pitch $1\frac{1}{2}$?

SOLUTION.— $N = 4 \times 12 \times 1\frac{1}{2} = 72$.

$$C = \frac{\pi}{P} = \frac{\pi}{1.5} = 2.09'.$$

Hence, from formula 272,

$$z = .55 \sqrt[4]{72^2 \times 2.09} = 5.61.$$

Therefore, use 6 arms. Ans.

If the formula gives an odd number of arms, the nearest even number may be used, if desired.

2031. Hubs or Naves of Gear-Wheels.—The thickness of the hub is often made equal to the radius of the shaft on which the wheel is placed. If the shaft is enlarged for the wheel seat, the thickness of the hub is made equal to the radius of the main portion of the shaft. Then, if d represents the diameter of the shaft, $1.2d$ = the diameter of the enlarged portion, and $\frac{1}{2}d$ is the thickness of the hub.

The above rule is very generally used, and gives good proportions when the wheel transmits the full power of the shaft. If, however, a gear transmits only a fraction of the power of the shaft, the hub thickness may be calculated from the following formula, which may also be used for finding the thickness of the hub of any gear-wheel:

$$w = \frac{1}{3} \sqrt[3]{b C R}, \quad (273.)$$

where w is the thickness of the hub, and b , C , and R the same as in the previous formulas.

The length of the hub varies from b to $1.4b$.

The hubs of large and heavy wheels may be split as shown in Fig. 706. This relieves the hub from the initial strains due to unequal contraction in cooling.

Strips of metal are placed in the slots, and the segments

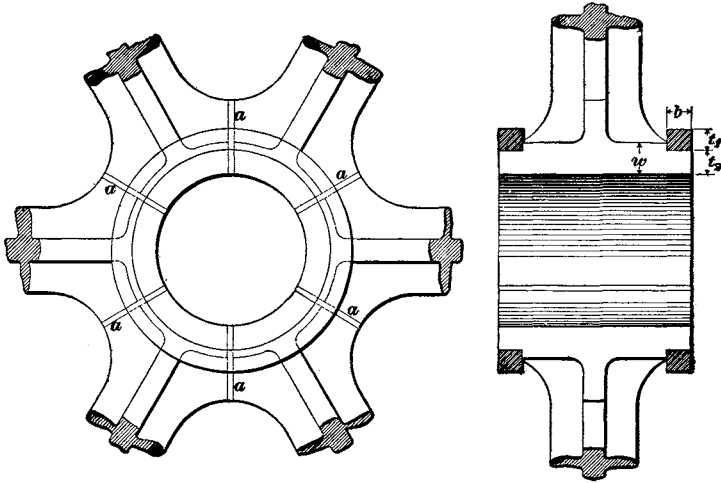


FIG. 706.

are held together by iron or steel bands shrunk on. The proportions are as follows:

$$t_1 = \frac{2}{3} w; \quad t_2 = \frac{3}{4} w; \quad b = \frac{7}{12} w.$$

2032. Built-Up Wheels.—For convenience in casting, and also for convenience in transportation, large and heavy wheels are made in sections, which are assembled and bolted together. The division of the wheel may be made in various ways. The hub and arms may be cast separately, and the rim in segments; the hub and arms may be cast together, and the rim in segments; or, finally, each division may include a portion of the hub, an arm, and a segment of the rim. Fig. 707 shows one method of bolting the rim, segments, and arm.

Fig. 708 shows a method in which the rim and hub of the gear are parted and held together by bolts.

EXAMPLE.—Compute the leading dimensions for a spur wheel to work under the following conditions:

Diameter of pitch circle = 5 ft. 6 in.

Revolutions per minute = 45.

Horsepower transmitted = 240.

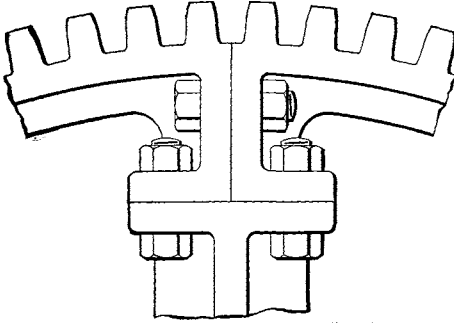


FIG. 707.

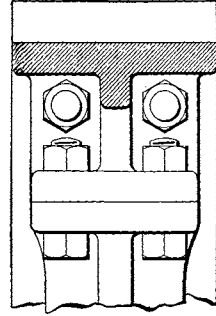


FIG. 708.

SOLUTION.—The velocity of a point in the pitch circle is $\pi D n$
 $= 3.1416 \times 5\frac{1}{2} \times 45 = 778$ ft. per minute.

Hence, from formula **267**,

$$S = \frac{9,600,000}{778 + 2,160} = 3,270 \text{ lb. per sq. in., in round numbers.}$$

From formula **231**, Art. 1963,

$$p = \frac{63,025 H}{R n} = \frac{63,025 \times 240}{33 \times 45} = 10,186 \text{ lb.}$$

Now, from formula **266**,

$$b C = 16.8 \frac{p}{S} = \frac{16.8 \times 10,186}{3,270} = 52.3 \text{ sq. in.}$$

Assume $b = 3 C$;

Then, $3 C^2 = 52.3$;

$C = 4.17''$.

$$\text{Number of teeth} = \frac{\text{circumference of wheel}}{4.17} = \frac{3.1416 \times 66}{4.17} = 49.7.$$

Taking 50 for the number of teeth, we have

$$C = \frac{3.1416 \times 66}{50} = 4.147 \text{ inches.}$$

Breadth of face = $b = 3 C = 3 \times 4.147 = 12.44 = 12\frac{7}{8}"$. Ans.

Thickness of tooth = $t = .475 C = .475 \times 4.147 = 1.97"$ Ans.

Height above pitch line = $.3 C = .3 \times 4.147 = 1.24"$. Ans.

Depth below pitch line = $.4 C = .4 \times 4.147 = 1.66"$. Ans.

For the size of the shaft we may use formula **123**, Art. **1415**.

$$d = 4.92 \sqrt[4]{\frac{H}{n}} = 4.92 \sqrt[4]{\frac{240}{45}} = 7\frac{1}{2}" \text{, nearly. Ans.}$$

The enlargement for the wheel seat will then have a diameter of

$$1.2 d = 1.2 \times 7.5 = 9". \text{ Ans.}$$

For the thickness of the hub we use formula **273**.

$$w = \frac{1}{8} \sqrt[3]{b C R} = \frac{1}{8} \sqrt[3]{12.44 \times 4.147 \times 33} = 4" \text{, nearly. Ans.}$$

The length of hub may be

$$1.4 b = 1.4 \times 12.44 = 17\frac{7}{8}" \text{, nearly. Ans.}$$

For the number of arms, formula **272** gives

$$z = .55 \sqrt[4]{N^3 C} = .55 \sqrt[4]{50^3 \times 4.147} = 5.5.$$

Therefore, use 6 arms. Ans.

For the width of arm at the center of the wheel, formula **270** gives

$$a = \sqrt{\frac{R b}{z}} = \sqrt{\frac{33 \times 12.44}{6}} = 8.27, \text{ say } 8\frac{1}{4}" \text{. Ans.}$$

Supposing the arms to taper $\frac{1}{8}$ on each side, the width of arm at pitch line is

$$8\frac{1}{4} - (3 \times 33 \times \frac{1}{8}) = 6\frac{7}{8}" \text{. Ans.}$$

The thickness of the arm is $\frac{1}{2} C = \frac{1}{2} \times 4.147 = 2.07 = 2\frac{1}{16}"$. Ans.

The thickness of the stiffening rib is $.4 C = .4 \times 4.147 = 1.66 = 1\frac{11}{16}"$.
Ans.

2033. Proportions of Bevel Gears.—The rules and formulas used in designing spur gears are equally applicable to bevel gears. For the circular pitch C , used in spur-gear formulas, should be substituted the mean circular pitch of the bevel gear; that is, the circular pitch measured at the *middle* of the tooth face.

Denote this mean circular pitch by the symbol C_m . Then, the bevel wheel may be designed by formulas **266** to **273** by placing C_m for C , and P_m for P .

$$\text{Then,} \quad b C_m = 16.8 \frac{P}{S}. \quad (266a.)$$

$$c = .4 C_m + \frac{5}{8}" = \frac{5}{4 P} + \frac{1}{8}" \text{.} \quad (269a.)$$

$$\left. \begin{aligned} a &= \sqrt{\frac{Rb}{z}} \\ x &= \frac{1}{2} C_m. \end{aligned} \right\} \quad (270a.)$$

$$\left. \begin{aligned} a &= 1.2 \sqrt[3]{\frac{b C_m R}{z}} \\ a &= 1.75 \sqrt[3]{\frac{b R}{P_m z}} \end{aligned} \right\} \quad (271a.)$$

$$z = .55 \sqrt[4]{N^3 C_m}. \quad (272a.)$$

$$w = \frac{1}{3} \sqrt[3]{b C_m R}. \quad (273a.)$$

WORM GEARING.

2034. Construction of Worm Gearing.—Worm-

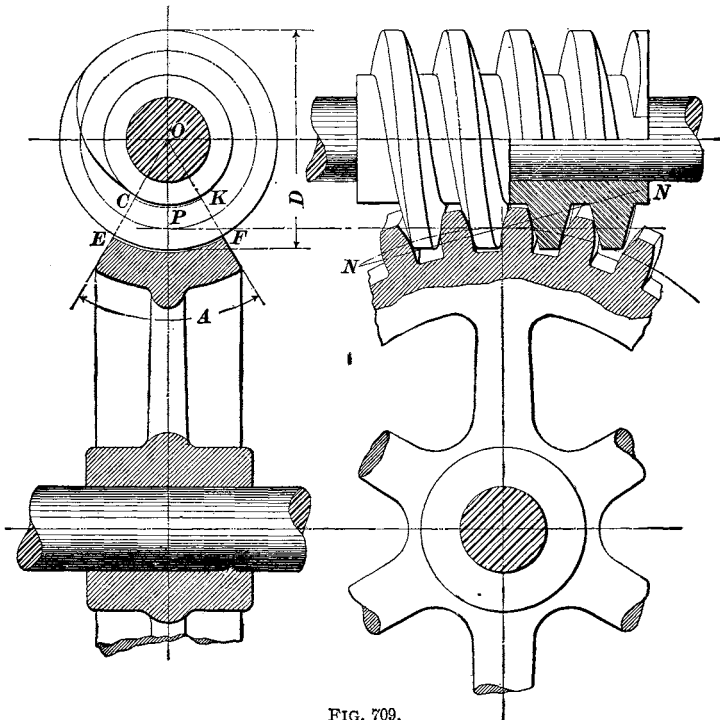


FIG. 709.

wheels may be constructed in various ways. The wheel may be similar to a spur wheel, except that the teeth make an

angle with the axis of the wheel equal to that of the threads of the worm measured at the pitch diameter. (See Fig. 709.)

For careful and accurate work, the wheel is cut by a special milling tool called a **hob**. This hob is a steel worm which has been cut in a lathe, notched to form a milling cutter, and then hardened and tempered. The teeth cut by this hob must evidently have the correct form to gear with a worm having the same pitch as the hob. When the wheel teeth are constructed by this method, there is much closer contact between the worm and the wheel. Therefore, the durability and efficiency of the mechanism are largely increased.

2035. Friction of Worm Gearing.—Since the threads of the worm slide on the teeth of the wheel, there is considerable work expended in overcoming friction. It, therefore, becomes necessary to consider the form of worm and wheel which will work with least friction.

Let R_1 = radius of pitch circle of wheel;

R = radius of pitch circle of worm;

p = the axial pitch of the worm;

p_1 = circular pitch of wheel, and divided axial pitch of worm;

N = number of threads in worm;

N_1 = number of teeth in wheel;

P = resistance to turning at circumference of worm-wheel;

Q = actual force acting at pitch line of worm necessary to turn worm;

Q' = force required to turn worm if there were no friction between it and wheel;

e = efficiency of worm gearing;

α = angle between tangent to worm thread and any plane perpendicular to axis of worm.

The efficiency of the gear is the ratio of the useful work to the total work. Assuming the coefficient of friction to be about .15 or .16, the efficiency may be obtained by the following formula:

$$e = \frac{Q'}{Q} = \frac{Np_1}{Np_1 + R}. \quad (274.)$$

Hence, for maximum efficiency, the radius R of the pitch circle of the worm should be made as small as possible, and the number of threads should be as large as possible.

EXAMPLE.—If the radius of pitch circle of worm is 3 times the divided axial pitch p_1 , and if the worm has 2 threads, what is its efficiency?

SOLUTION.—From formula 274,

$$e = \frac{N p_1}{N p_1 + R} = \frac{2 p_1}{2 p_1 + 3 p_1} = .40 = 40 \text{ per cent.} \quad \text{Ans.}$$

If the radius R were only $2 p_1$, the efficiency would be

$$e = \frac{2 p_1}{2 p_1 + 2 p_1} = 50 \text{ per cent.}$$

On the other hand, if the number of threads were 1, the efficiency would only be

$$e = \frac{p_1}{p_1 + 3 p_1} = 25 \text{ per cent.}$$

The leading problem, therefore, in designing a worm gear is to make the ratio $\frac{R}{p_1}$ as small as possible, and at the same time allow the worm shaft a sufficient diameter for strength.

The twisting moment acting on the worm shaft is

$$Q R = \frac{Q' R}{e}.$$

From the principle of work we have $2 \pi R Q' = P p$.

Hence,
$$\frac{Q' R}{e} = \frac{P p}{2 \pi e},$$

which is the twisting moment to be used in calculating the worm shaft.

EXAMPLE.—The circular pitch of a worm-wheel is $.7854 = \frac{\pi}{4}$; it has 40 teeth, and transmits 2 horsepower at 30 revolutions per minute. The worm has 1 thread, and the radius of its pitch circle is 2 inches. Calculate the twisting moment on the shaft, and the size of the shaft, if made of wrought iron.

SOLUTION.—Diametral pitch of wheel $= \frac{\pi}{4} = 4$.

$$\text{Diameter of wheel} = \frac{40}{4} = 10".$$

Radius of wheel $= R_1 = 5''$.

From formula **231**, Art. **1963**,

$$P = \frac{63,025 H}{R_1 n} = \frac{63,025 \times 2}{5 \times 30} = 840 \text{ lb., nearly.}$$

From formula **274**,

$$e = \frac{N p_1}{N p_1 + R} = \frac{.7854}{.7854 + 2} = 28 \text{ per cent.}$$

Hence, twisting moment $= \frac{P p}{2 \pi e} = \frac{840 \times \frac{\pi}{4}}{2 \pi \times .28} = 375 \text{ in.-lb. Ans.}$

Using formula **123**, Art. **1415**,

diameter of shaft $d = .31 \sqrt[3]{375} = 1.364$, say $1\frac{3}{8}''$. Ans.

The pitch of the worm-wheel may be calculated from the formula for the pitch of spur gears.

$$b p_1 = 16.8 \frac{P}{S}.$$

2036. The rim and arms of the worm-wheel may be given the same proportions as the rim and arms of a spur wheel of the same diameter and pitch, except that the width of the face of the wheel is generally made equal to double the pitch.

The rim may have the forms shown in Fig. 710. The

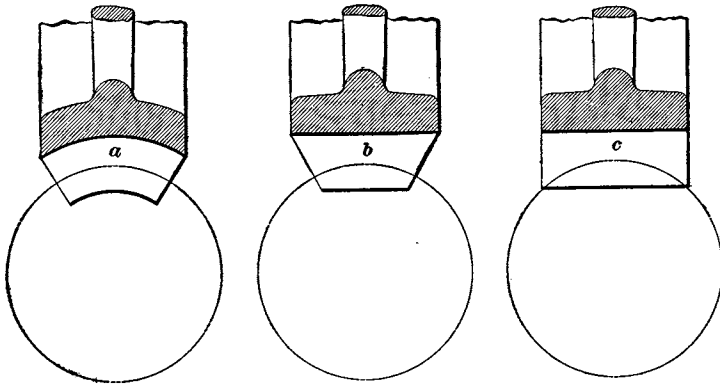


FIG. 710.

form *a* is best, as there is line contact between the thread and tooth.

The ratio $\frac{R}{p_1}$ may vary from 1 to 4 or 6. When the worm is cut on the shaft, the lower values may be used. When, however, the worm is cast and keyed on the shaft, the

ratio must be made greater. As has been shown, the smaller this ratio the greater the efficiency. The number of threads in the worm varies from 1 to 4, depending upon the velocity ratio to be transmitted.

Letting N and N' represent the number of threads on worm and teeth on wheel, respectively, and w the velocity ratio, we have

$$w = \frac{N'}{N}.$$

Usually it is undesirable to give the worm-wheel less than 30 teeth; hence, if the desired velocity ratio is less than 30, the worm must have more than one thread. For example, if the worm shaft is to make 20 revolutions while the wheel shaft makes one revolution, we may have either $N' = 40$ and $N = 2$, or $N' = 60$ and $N = 3$.

The length of the worm is from 3 p to 6 p , usually 4 p ; that is, there are usually 4 turns, as shown in Fig. 709.

FRICITION GEARING.

2037. Friction gearing may be used for the transmission of small powers; it should not be used for heavy work.

In this style of gearing the smooth faces of a pair of wheels are pressed together, and one drives the other by means of the friction between the surfaces in contact.

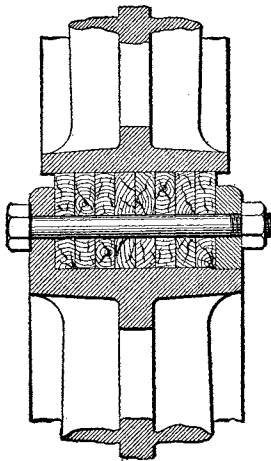


FIG. 711.

If the resistance to turning offered by the driven wheel is less than the frictional resistance between the surfaces of the two wheels, motion will be transmitted; otherwise the surfaces will slide over each other, and the gearing will not work.

It is the usual practice to face the rim of one of the wheels with leather, wood, or paper. Fig. 711 shows a friction wheel thus faced with wood.

As shown, the grain of the wood lies along the working surface. When leather or paper is used, the edges of the layers are used as the driving surface. The pulley which is covered with wood or paper must be the driver; the driven pulley is usually of cast iron.

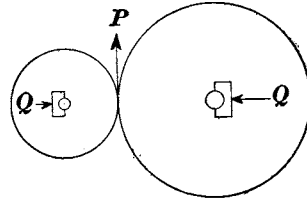


FIG. 712.

Let P (see Fig. 712) = driving force at circumference of friction wheels;

Q = force acting on the bearings to press the wheels together;

f = coefficient of friction between surfaces.

Then,
$$Qf = P, \text{ or } Q = \frac{P}{f}. \quad (275.)$$

The coefficient of friction f has about the following values:

Metal on metal..... $f = .15$ to $.25$.

Wood on metal..... $f = .25$ to $.40$.

Paper on metal..... $f = .20$.

Leather on metal..... $f = .25$ to $.30$.

The power transmitted by a pair of friction gears can be easily calculated. The following example shows the method:

EXAMPLE.—Suppose a friction wheel faced with leather to drive another $2\frac{1}{2}$ feet in diameter at 300 revolutions per minute. The force pressing the wheels together is 450 pounds. Assuming $f = .3$, calculate the horsepower transmitted.

SOLUTION.—By formula **275**, $P = Qf = 450 \times .3 = 135$ lb.

$$R = \text{radius of wheel in inches} = \frac{2\frac{1}{2} \times 12}{2} = 15'.$$

From formula **231**, Art. **1963**,

$$H = \frac{P R N}{63,025} = \frac{135 \times 15 \times 300}{63,025} = 9.64 \text{ horsepower. Ans.}$$

The calculations for bevel friction gears are more complicated, but may be easily made.

The proportions of the rim, hub, and arm of a friction gear-wheel may be made the same as those of a toothed gear-wheel transmitting the same power.

FLEXIBLE GEARING.

BELT GEARING.

BELT MATERIALS.

2038. Leather.—The material mostly used for belts is leather tanned from ox hides. The leather is about $\frac{5}{16}$ inch thick, and is obtained in strips up to 5 feet in length. Belts are made of any required length by joining these strips together.

Single belts are made of one thickness of leather; **double belts** from two thicknesses of leather.

Cotton may be used for belts which are exposed to dampness. Cotton belts can be made very wide, and without the many joints necessary in leather belts. The necessary thickness is obtained by sewing together from 4 to 10 plies of cotton duck. Cotton belting is cheaper and stronger than leather belting, but probably less durable.

Rubber belts are made by cementing together plies of cotton duck with india rubber. Rubber belts are more adhesive than leather belts, and, hence, have greater driving capacity. Rubber belts are considered to be the best to use in damp situations.

Dimensions of Belts.—Practical formulas for computing the dimensions of belts are given in Arts. **1483** to **1489** inclusive.

BELT PULLEYS.

2039. Fig. 713 shows a **solid**, and Fig. 714 a **split, cast-iron belt pulley**. The general form of these pulleys corresponds very closely to the best modern American practice. The split pulley has the advantage of being more easily put on the shaft, especially when the shaft is in position or has other pulleys already on it.

When the amount of power to be transmitted by a pulley is small, it may be fastened to the shaft by set screws. Split pulleys are also made so that the bolts through the hub will serve as a clamp to draw the hub tight enough on the shaft to prevent slipping with small loads. When the amount of

power to be transmitted is considerable, pulleys should be fastened with keys, and in some cases both keys and set-screws are provided.

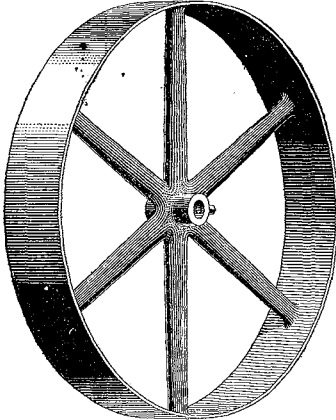


FIG. 713.

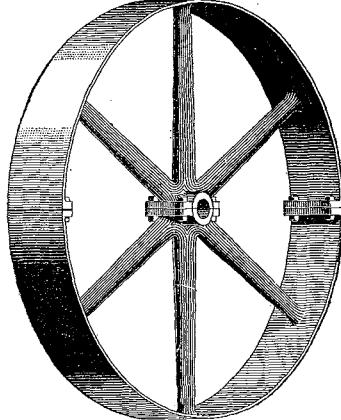


FIG. 714.

In the rules and formulas for dimensions of pulleys, the following symbols will be used to represent the various dimensions:

- b = breadth of belt running on pulley;
- B = breadth of pulley rim;
- d = diameter of shaft on which pulley is keyed;
- t = thickness of pulley rim at edge;
- a = width of arm at center of pulley;
- w = thickness of hub of pulley;
- l = length of hub of pulley;
- n = number of arms;
- D = diameter of pulley;
- R = radius of pulley;
- s = swell at center of pulley rim.

All dimensions to be in inches.

NOTE.—To obtain a , the arms are supposed to extend through the hub to the center of the pulley. (See Fig. 720.)

2040. Rim of Pulley.—The rim is usually of the form shown in Fig. 715. If the rim is crowning, the curve may be struck with a radius of from $3B$ to $5B$, in which

case $s = \frac{B}{20}$ to $\frac{B}{40}$, about. The width B is made from $\frac{3}{8}b$ to $\frac{5}{4}b$; i. e., $B = \frac{3}{8}b$ to $\frac{5}{4}b$.

For the thickness t , the following formula gives results which agree well with the practice of good shops:

$$t = \frac{B + D}{200} + \frac{1}{16}'' \quad (276.)$$

For double belts, $\frac{1}{8}''$ may be added to the thickness obtained by the above formula.

2041. Flange Pulleys.—When there is a liability of the belt frequently slipping, caused by fluctuations in the

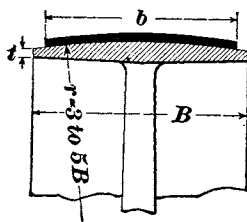


FIG. 715.

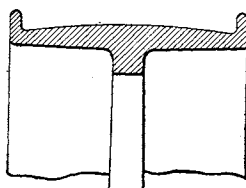


FIG. 716.

power transmitted, the pulley rim may be cast with flanges, as shown in Fig. 716. See also Figs. 381 and 382, Art. 1500.

2042. Arms of Pulleys.—The arms are usually of oval section, as shown in Fig. 717, *A* and *B*. It is customary to make the thickness $\frac{1}{2}$ the width.

The arms are generally straight, as in Figs. 713 and 714, though curved arms are occasionally used.

The number of arms to be used is largely a matter of judgment, but in practice, for all sizes of pulleys and engine band-wheels, under 10 feet in diameter, by far the greater number are made with 6 arms; 8 or 10 arms are sometimes used for pulleys above 6 feet in diameter, and for very small sizes, 4 arms are sufficient.

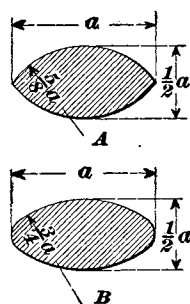


FIG. 717.

To calculate the width a of the arm, we may assume, as in gear-wheels, that the bending moment is pR , and that, consequently, the bending moment for each arm is $\frac{pR}{n}$.

The resisting moment of the section shown in Fig. 717 is practically $.04 a^3 S$, where S is the allowable safe stress. If we allow 2,500 lb. per sq. in. as the safe stress, we have

$$\frac{pR}{n} = 100 a^3, \text{ or } a = \sqrt[3]{\frac{pR}{100n}}.$$

$p = T_1 - T_2$, the difference of the belt tension is usually not known exactly. Its maximum value can, however, easily be found, as follows:

For single belts $\frac{7}{32}$ " thick, an average tension of 320 lb. per sq. in. of section may be allowed. Then,

$$T_1 = \frac{7}{32} \times 320 = 70 \text{ lb. per inch of width of belt.}$$

Usually P is not more than $\frac{1}{2}$ of T_1 , and its *maximum* value may be taken at say 50 lb. per inch of width. For double belts, take $P = 100$ lb. per inch of width.

Then, $p = 50 B$ for single belts.

$p = 100 B$ for double belts.

Substituting these values of p in the above equation,

$$\left. \begin{aligned} a &= \sqrt[3]{\frac{BR}{2n}}, \text{ for single belts.} \\ a &= \sqrt[3]{\frac{BR}{n}}, \text{ for double belts.} \end{aligned} \right\} \quad (277.)$$

The taper in the width of the arms towards the rim may be made $\frac{1}{2}$ " per foot, and the thickness at the rim $\frac{1}{2}$ the width.

EXAMPLE.—Calculate the size of the arms of a 6-arm pulley, 30 inches in diameter, with a 6-inch face.

SOLUTION.—For single belt, we have, from formula 277,

$$a = \sqrt[3]{\frac{BR}{2n}} = \sqrt[3]{\frac{6 \times 15}{2 \times 6}} = 2 \text{ in., nearly. Ans.}$$

At the rim the width is $2'' - (\frac{1}{2} \times 1\frac{1}{2}) = 2'' - \frac{3}{4}'' = 1\frac{1}{4}''$. Ans.

Thickness at center $= 2 \times \frac{1}{2} = 1''$. Ans.

Thickness at the rim $= 1\frac{1}{4}'' \times \frac{1}{2} = \frac{11}{8}''$. Ans.

For very wide pulleys it is sometimes desirable to use two sets of arms, as shown in Fig. 718.

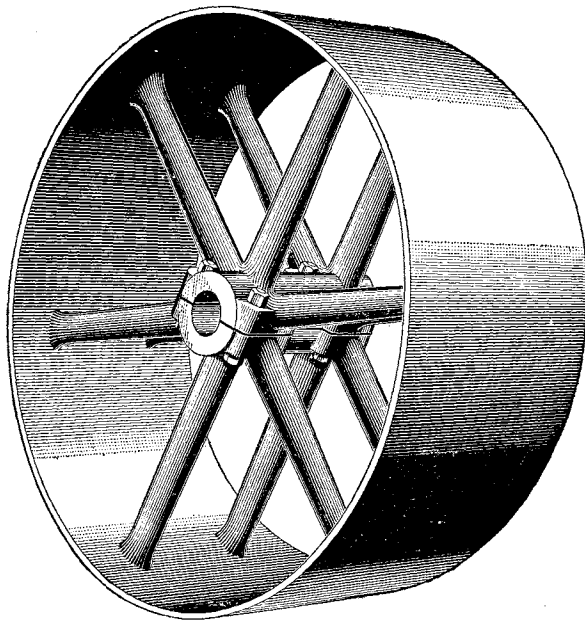


FIG. 718.

To calculate the size of the arms in this case, the pulley may be considered as made of two pulleys each of width $\frac{1}{2} B$. Then, find the dimensions of the arms as before, and multiply these dimensions by $\sqrt[3]{\frac{1}{2}} = .8$, nearly.

2043. Hub of Pulley.—The thickness of the hub may be obtained from the following formula:

$$w = \frac{(B + R)}{32} + \frac{1}{8}'' \quad (278.)$$

The length of the hub may be, $l = \frac{2}{3} B$ to B .

The key-way may be calculated by the rules given in Art. 1965, etc.

2044. Loose Pulleys.—Pulleys which run loose on a shaft should have longer hubs than those keyed fast; the hubs may also be lined with brass bushings, if desired.

Where a fast and a loose pulley are placed together on a shaft, as shown in Fig. 719, the length l of the hub of the loose pulley may be $l = 1.2 B$, and that of the fixed pulley $l' = .8 B$. The thickness of the hub of the loose pulley may be less than that of the fast pulley on account of its increased length.

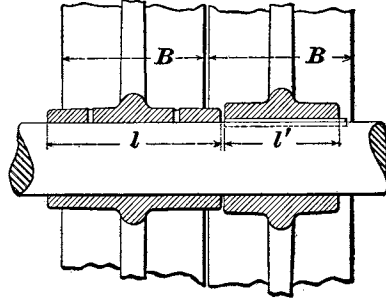


FIG. 719.

Some arrangement must be provided for oiling the loose pulley; generally one or two oil holes are drilled through the hub.

2045. For split pulleys the size of the bolts at rim and hub may be determined as follows:

Let A = area of cross-section of rim;
 A' = area of cross-section of hub along the line of division;
 S = net section of bolt or bolts at rim;
 S' = net section of bolt or bolts at hub.

$$\left. \begin{aligned} \text{Then, } S &= \frac{A}{4} + \frac{1}{4} \text{ square inch.} \\ S' &= \frac{A'}{4} \text{ square inch.} \end{aligned} \right\} \quad (279.)$$

EXAMPLE.—The hub of a split pulley is 4 inches long and $1\frac{1}{4}$ inches thick. If the hub is held by 4 bolts, what should be the diameter of the bolts?

SOLUTION.— $A' = 4 \times 1\frac{1}{4} = 5$ sq. in.

By formula **279**,

$$S' = \frac{A'}{4} = \frac{5}{4} \text{ sq. in.} = \text{net section of 4 bolts.}$$

$$\frac{5}{4} \div 4 = \frac{5}{16} \text{ sq. in.} = \text{net section of 1 bolt.}$$

Hence, from Table 43, Art. **1926**, the diameter of bolt is $\frac{3}{4}$ inch. Ans.

2046. Wrought-iron pulleys are coming into extensive use, and possess important advantages over those made of cast iron. They are lighter and stronger, and are free

from the initial stresses to which cast-iron pulleys are liable. Owing to the stresses due to centrifugal force, cast-iron pulleys can not be safely run at very high speeds; wrought-iron pulleys, however, may be used at almost any reasonable speed, because of the greater tenacity of the material of which they are made. Wrought-iron pulleys are usually *split*.

2047. Maximum Speed of Cast-Iron Pulleys.—

When a pulley rotates, each portion of the rim tends to fly outwards in the direction of a tangent to the rim. This tendency is due to the *centrifugal force*, so called.

The centrifugal force on each element of the rim acts radially outwards, and the pulley under its action is analogous to a section of a steam boiler under the pressure of steam. The rim tends to break at two sections which are at the opposite ends of a diameter.

Table 51 gives values of the stress per square inch produced in a pulley rim by centrifugal force for various velocities:

TABLE 51.

Velocity of rim in feet per second.....	60	80	100	150	200
Velocity of rim in feet per minute.....	3,600	4,800	6,000	9,000	12,000
Stress in rim in pounds per sq. in.:					
Cast iron	351	624	975	2,194	3,900
Wrought iron.....	378	672	1,050	2,362	4,200

To the stress given in the above table must be added the initial stresses due to contraction in cooling, and the stress caused by the belt pull.

It is usually considered unsafe to run a cast-iron pulley, gear-wheel, or fly-wheel at a higher rim speed than 100 feet per second. Since the centrifugal force increases in direct proportion to the cross-section of the rim, it is evident that it is useless to try to provide against it by putting more material in the rim.

TABLE 52.

Diam-eter.	Face.	Rim.		Arm.		Hub.		Boss.		
		A	B	C	D	E	F	G	H	I
6"	4	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{4}$	$\frac{7}{16}$	3	$\frac{3}{8}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	....	..	..	..	$3\frac{1}{2}$	$\frac{1}{2}$	..	..	..
	8	....	..	..	..	..	..	..	..	..
	10	....	..	..	..	4	..	..	..	..
	12	....	..	..	..	..	..	..	..	..
8	4	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{13}{16}$	$\frac{7}{16}$	3	$\frac{3}{8}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	....	..	..	..	$3\frac{1}{2}$	$\frac{1}{2}$	..	..	..
	8	$\frac{5}{32}$	$\frac{1}{4}$	$1\frac{1}{16}$	$\frac{9}{16}$	$4\frac{1}{2}$	..	..	..	..
	10	....	..	..	..	$5\frac{1}{2}$	..	..	..	..
	12	....	..	..	..	..	..	..	..	..
10	4	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{15}{16}$	$\frac{9}{16}$	3	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	$\frac{5}{32}$	$\frac{1}{4}$	$1\frac{1}{16}$	..	$3\frac{1}{2}$	..	..	..	..
	8	....	..	..	..	$4\frac{1}{2}$	..	..	..	..
	10	....	..	$1\frac{5}{16}$	$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	12	....	..	..	..	..	..	..	..	..
12	4	$\frac{5}{32}$	$\frac{1}{4}$	1	$\frac{7}{16}$	$3\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	....	..	$1\frac{1}{4}$	$\frac{7}{8}$	4	..	..	..	..
	8	....	..	..	..	5	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	10	$\frac{3}{16} +$	$\frac{5}{16}$	$1\frac{1}{2}$	$\frac{3}{4}$	$5\frac{1}{2}$	..	..	..	..
	12	....	..	..	..	$6\frac{1}{2}$	..	..	..	..
14	4	$\frac{5}{32} +$	$\frac{1}{4}$	$1\frac{1}{8}$	$\frac{1}{2}$	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	....	..	..	..	$4\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	8	$\frac{3}{16}$	$\frac{5}{16}$	$1\frac{5}{16}$	$\frac{9}{16}$	5	..	..	..	..
	10	....	..	..	..	6	..	..	..	..
	12	....	..	$1\frac{11}{16}$	$\frac{13}{16}$	$6\frac{1}{2}$	..	..	..	..
16	4	$\frac{5}{32} +$	$\frac{1}{4}$	$1\frac{3}{8}$	$\frac{9}{16}$	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{4}$
	6	....	..	..	..	$4\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{8}$
	8	$\frac{3}{16} +$	$\frac{5}{16}$	$1\frac{7}{16}$	$\frac{3}{8}$	5	..	..	..	..
	10	....	..	..	..	6	..	..	..	..
	12	$\frac{7}{32}$	$\frac{11}{32}$	..	..	$6\frac{1}{2}$	$\frac{3}{4}$	..	..	..
18	16	....	..	$1\frac{1}{2}$	$\frac{15}{16}$	$8\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	..
	4	$\frac{3}{16}$	$\frac{5}{16}$	$1\frac{5}{16}$	$\frac{9}{16}$	4	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	..	..	$4\frac{1}{2}$	..	..	..	..
	8	$\frac{7}{32}$	$\frac{11}{32}$	$1\frac{1}{2}$	$\frac{11}{16}$	$5\frac{1}{2}$	$\frac{3}{4}$	..	..	..
	10	....	..	..	..	6	..	..	..	..
20	12	....	..	..	..	$7\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{3}{8}$	..
	16	$\frac{1}{4}$	$\frac{3}{8}$	$2\frac{1}{4}$	$1\frac{1}{4}$	8	..	..	..	..
	20	....	..	..	..	9	..	..	..	..
	4	$\frac{3}{16} +$	$\frac{5}{16}$	$1\frac{3}{8}$	$\frac{5}{8}$	4	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	..	..	$4\frac{1}{2}$	..	..	..	..
20	8	....	..	..	..	5	$\frac{3}{4}$	..	..	..
	10	$\frac{7}{32}$	$\frac{11}{32}$	$1\frac{1}{2}$	$\frac{3}{4}$	6	..	..	..	..
	12	....	..	..	..	7	..	..	..	..
	16	$\frac{9}{32}$	$\frac{7}{16}$	$2\frac{1}{4}$	$1\frac{1}{8}$	8	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{4}$	..
	20	....	..	..	..	10	1	..	..	..

TABLE 52.—Continued.

Diam- eter.	Face.	Rim.		Arm.		Hub.		Boss.		
		A	B	C	D	E	F	G	H	I
22	4	$\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	4	$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	....	....	$4\frac{1}{2}$	$\frac{3}{4}$	..	..	..
	8	....	..	....	....	5	....	..	..	..
	10	$\frac{7}{32} +$	$\frac{1}{32}$	$1\frac{3}{4}$	$\frac{1}{16}$	$6\frac{1}{2}$	....	..	..	..
	12	....	..	....	....	....	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	..
	16	....	..	....	....	$8\frac{3}{4}$	1	..	..	..
	20	$\frac{9}{32} +$	$\frac{7}{16}$	$2\frac{1}{2}$	$1\frac{1}{4}$	11	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
24	4	$\frac{7}{32}$	$\frac{11}{32}$	$1\frac{9}{16}$	$\frac{11}{16}$	4	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	....	....	$4\frac{3}{4}$	$\frac{3}{4}$	..	..	..
	8	....	..	....	....	$5\frac{1}{2}$	....	..	..	..
	10	$\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{8}$	....	7	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	..
	12	....	..	....	....	....	....	..	..	..
	16	....	..	....	....	$9\frac{1}{2}$	1	..	..	..
	20	$\frac{5}{16}$	$\frac{15}{32}$	$2\frac{1}{4}$	$1\frac{3}{8}$	....	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
26	24	....	..	....	....	11	....	..	..	..
	4	$\frac{7}{32}$	$\frac{11}{32}$	$1\frac{11}{32}$	$\frac{3}{4}$	$4\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	....	....	5	....	..	..	..
	8	....	..	....	....	6	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	..
	10	$\frac{1}{4}$	$\frac{3}{8}$	2	$\frac{7}{8}$	7	....	..	..	..
	12	....	..	....	....	$7\frac{1}{2}$	....	..	..	..
	16	....	..	....	....	10	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
28	20	$\frac{5}{16} +$	$\frac{15}{32}$	$2\frac{15}{16}$	$1\frac{7}{16}$	$10\frac{1}{2}$	....	..	..	..
	24	....	..	....	....	11	....	..	..	..
	4	$\frac{7}{32} +$	$\frac{15}{32}$	$1\frac{3}{4}$	$\frac{3}{4}$	$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	....	....	$5\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{8}$	..
	8	....	..	....	....	7	....	..	..	..
	10	....	..	....	....	$7\frac{1}{2}$	....	..	..	..
	12	$\frac{1}{4} +$	$\frac{3}{8}$	$2\frac{1}{2}$	$\frac{1}{2}$	8	1	..	..	..
30	16	....	..	....	....	10	....	..	..	..
	20	$\frac{5}{16}$	$\frac{15}{32}$	....	....	11	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	24	$\frac{11}{32}$	$\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{2}$	....	....	..	..	..
	4	$\frac{7}{32} +$	$\frac{11}{32}$	$1\frac{7}{8}$	$\frac{1}{16}$	$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{8}$
	6	....	..	....	....	$5\frac{1}{2}$	$\frac{3}{4}$	..	..	..
	8	....	..	....	....	$6\frac{1}{4}$	....	$\frac{3}{4}$	$1\frac{3}{8}$	..
	10	....	..	....	....	$6\frac{1}{2}$	....	..	..	..
32	12	$\frac{9}{32}$	$\frac{7}{16}$	$2\frac{1}{4}$	1	8	1	..	..	..
	16	....	..	....	....	$8\frac{1}{2}$	....	..	..	..
	20	....	..	....	....	$11\frac{1}{2}$	$1\frac{1}{4}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	24	$\frac{3}{8}$	$\frac{9}{16}$	$3\frac{5}{16}$	$1\frac{3}{8}$	13	....	..	..	..
	4	$\frac{1}{4} +$	$\frac{3}{8}$	$2\frac{3}{4}$	$\frac{15}{16}$	$4\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{3}{8}$
	6	....	..	....	....	$5\frac{1}{2}$	....	..	..	..
	8	....	..	....	....	$6\frac{1}{2}$	1	..	..	..
32	10	....	..	....	....	$7\frac{1}{2}$	....	..	..	..
	12	$\frac{5}{16}$	$\frac{15}{32}$	$2\frac{7}{16}$	$1\frac{1}{16}$	8	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	16	....	..	....	....	$9\frac{1}{2}$	....	..	..	..
	20	....	..	....	....	11	$1\frac{1}{2}$	..	..	..
	24	....	..	....	....	13	....	..	..	..

TABLE 52.—Continued.

Diam-eter.	Face.	Rim.		Arm.		Hub.		Boss.		
		A	B	C	D	E	F	G	H	I
34	4	$\frac{1}{4} +$	$\frac{3}{8}$	$2\frac{1}{8}$	$1\frac{5}{16}$	$4\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{8}$
	6	....	..	....	....	$5\frac{1}{2}$	..	..	..	..
	8	....	..	....	....	$6\frac{1}{2}$	1	..	..	..
	10	....	..	....	....	$7\frac{1}{2}$	..	..	..	..
	12	$\frac{5}{16}$	$\frac{15}{32}$	$2\frac{7}{8}$	$1\frac{7}{8}$	$7\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	16	....	..	....	....	$9\frac{1}{2}$	..	..	..	..
	20	....	..	....	....	12	$1\frac{1}{4}$	..	..	..
	24	....	..	....	....	13	..	..	..	..
36	4	$\frac{1}{4} +$	$\frac{3}{8}$	$2\frac{3}{8}$	$1\frac{5}{8}$	$4\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{8}$
	6	....	..	....	....	$5\frac{1}{2}$	..	..	..	..
	8	....	..	....	....	$6\frac{1}{2}$	..	..	..	..
	10	....	..	....	....	$7\frac{1}{2}$	..	..	..	..
	12	$\frac{5}{16}$	$\frac{15}{32}$	....	....	$7\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	16	....	..	$2\frac{9}{16}$	$1\frac{3}{8}$	$10\frac{1}{4}$	$1\frac{1}{4}$	..	..	..
	20	....	..	....	....	12	..	..	..	..
	24	....	..	....	....	$13\frac{1}{2}$	$1\frac{3}{8}$	1	$1\frac{1}{2}$	$\frac{1}{2}$
40	8	$\frac{1}{8}$	$\frac{15}{32}$	$2\frac{5}{8}$	1	$6\frac{3}{4}$	1	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{3}{8}$
	12	....	..	....	....	$7\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	..
	16	$\frac{11}{32}$	$\frac{1}{2}$	$2\frac{3}{4}$	$1\frac{1}{4}$	10	$1\frac{1}{4}$	..	..	..
	20	....	..	....	....	$11\frac{1}{2}$	$1\frac{3}{8}$	1	$1\frac{3}{4}$	$\frac{1}{2}$
	24	....	..	....	....	$15\frac{1}{4}$	$1\frac{1}{2}$	..	..	..
	24	....	..	....	....	15	..	..	..	..
44	8	$\frac{9}{32}$	$\frac{7}{16}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$6\frac{3}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$
	12	....	..	....	....	8	..	..	..	..
	16	$\frac{11}{32}$	$\frac{1}{2}$	3	$1\frac{5}{8}$	10	$1\frac{1}{4}$	..	..	..
	20	....	..	....	....	12	$1\frac{3}{8}$	1	$1\frac{1}{2}$	$\frac{1}{2}$
	24	....	..	$3\frac{1}{2}$	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
48	8	$\frac{9}{32} +$	$\frac{7}{16}$	$2\frac{1}{4}$	$1\frac{1}{4}$	$7\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$
	12	....	..	....	....	$8\frac{1}{2}$	$1\frac{1}{4}$	..	..	..
	16	$\frac{9}{8}$	$\frac{9}{16}$	$3\frac{1}{4}$	$1\frac{7}{8}$	10	$1\frac{3}{8}$	1	$1\frac{1}{4}$	$\frac{1}{2}$
	20	....	..	....	....	12	..	..	..	..
	24	....	..	....	....	15	$1\frac{1}{2}$	..	..	..
	24	....	..	....	....	15	..	..	..	..
54	12	$\frac{5}{16} +$	$\frac{15}{32}$	3	$1\frac{5}{8}$	$9\frac{1}{2}$	$1\frac{3}{8}$	1	$1\frac{1}{2}$	$\frac{1}{2}$
	16	....	..	....	....	$11\frac{1}{2}$	$1\frac{1}{2}$	..	..	..
	20	$\frac{13}{32}$	$\frac{19}{32}$	$3\frac{5}{8}$	$1\frac{3}{8}$	....	..	..	..	..
	24	....	..	....	....	15	$1\frac{1}{4}$	$1\frac{1}{4}$	2	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
60	12	$\frac{11}{32}$	$\frac{1}{2}$	$3\frac{5}{8}$	$1\frac{7}{8}$	10	$1\frac{3}{8}$	1	$1\frac{1}{4}$	$\frac{1}{2}$
	16	....	..	....	....	$11\frac{1}{2}$	$1\frac{1}{2}$	..	..	..
	20	$\frac{7}{16}$	$\frac{5}{8}$	$3\frac{13}{16}$	$1\frac{3}{4}$	$12\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	2	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
66	12	$\frac{11}{32}$	$\frac{1}{2}$	$3\frac{9}{8}$	$1\frac{9}{8}$	10	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{1}{2}$
	16	....	..	....	....	$11\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	2	..
	20	$\frac{1}{2}$	$\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{11}{8}$	$13\frac{1}{2}$	$1\frac{3}{4}$	..	..	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..
72	12	$\frac{3}{8}$	$\frac{9}{16}$	$3\frac{7}{8}$	$1\frac{11}{8}$	$10\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	2	$\frac{1}{2}$
	16	....	..	....	....	$12\frac{1}{2}$	$1\frac{1}{2}$	..	..	..
	20	$\frac{9}{16}$	$\frac{13}{16}$	$4\frac{3}{8}$	$2\frac{1}{8}$	$13\frac{1}{2}$	$1\frac{5}{8}$	..	..	..
	24	....	..	....	....	15	2	..	..	..
	24	....	..	....	....	15	..	..	..	..
	24	....	..	....	....	15	..	..	..	..

2048. Examples of Belt Pulleys.—Table 52 gives the dimensions of a set of cast-iron belt pulleys ranging from 6" to 72" in diameter, as made by a well-known manufac-

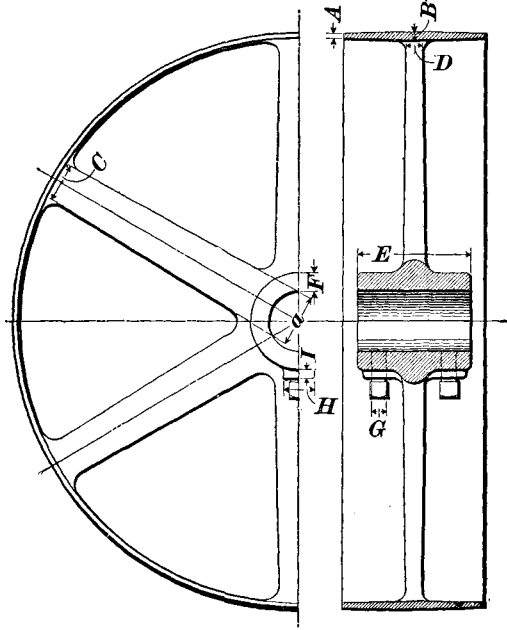


FIG. 720.

turing company. These pulleys are so designed that the number of patterns may be kept within reasonable limits, and at the same time have the dimensions correspond as nearly as possible with well-established rules.

The letters over the columns of dimensions given in the table correspond to the letters in Fig. 720.

In all cases the number of arms is 6, and the arms increase in size towards the hub with a taper of $\frac{1}{2}$ " per foot.

2049. Counterbalance.—Pulleys that run at high speeds must be carefully balanced, i. e., the center of gravity of the pulley must correspond with the center of the shaft, otherwise there will be a heavy stress on the shaft and bearings. Since it is seldom possible to make the pulley

exactly symmetrical, the difference in weight of the heavy side is compensated for by weights riveted to the inside of the rim on the light side.

ROPE BELTING.

2050. There is a growing tendency towards the substitution of hemp and cotton ropes for belting and line shaft-

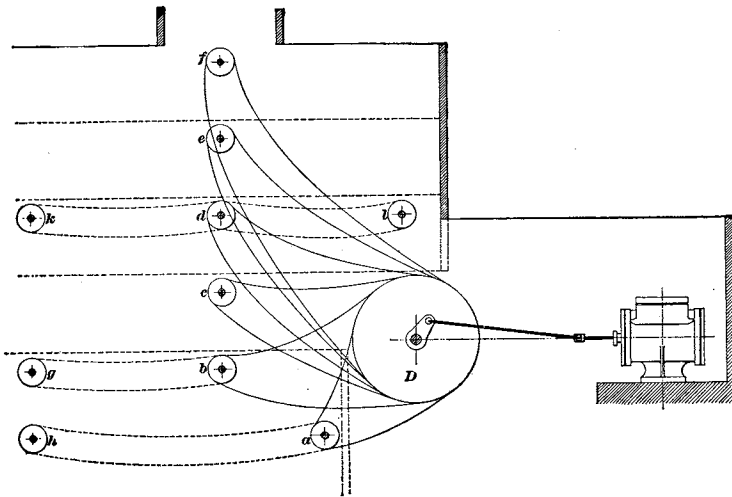


FIG. 721.

ing as a means of transmitting power in large factories and shops. The advantages claimed for the rope-driving system are :

1. Economy ; for a rope system is cheaper to install than either leather belting or shafting.
2. In the rope system there is less loss of power by slipping.
3. Flexibility ; that is, the ease with which the power is transmitted to any distance, and in any direction.

2051. There are two systems of rope transmission in common use. In the first, the transmission is effected by several parallel independent ropes which pass around the fly-wheel of the engine and the pulley or pulleys to be driven.

Each rope is made quite taut at first, but stretches until it slips, after which it is re-spliced. A good example of a rope transmission of this character is shown in outline in Fig. 721.

The fly-wheel *D* carries 35 parallel ropes which distribute power to the pulleys *a*, *b*, *c*, *d*, *e*, and *f*, located on the five floors of the mill. The ropes are distributed as follows : *a*, 4 ropes; *b* and *c*, 5 ropes each; *d*, *e*, and *f*, 7 ropes each. A secondary system of ropes drives the pulleys *g*, *h*, *k*, and *l*.

2052. In the second system of rope transmission, a single rope is carried around the pulley as many times as is

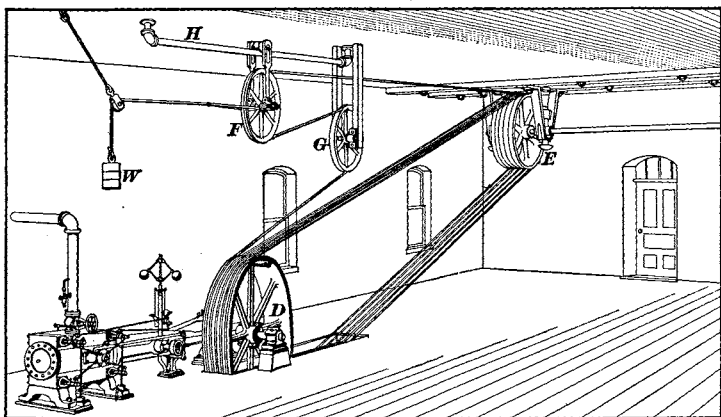


FIG. 722.

necessary to produce the required power, and the necessary tension is obtained by passing a loop of the rope around a weighted pulley. An example of this system is shown in Fig. 722.

The rope is wrapped continuously around the fly-wheel *D* and the driven pulley *E*. From the last groove of *E* the rope is led over the idlers *F* and *G*, which are set at such an angle as to lead it back to the first groove in *D*. The weight *W* is attached to the pulley *F* which is movable along the rod *H*. The movement of the pulley *F*, therefore, takes up the stretch of the rope, and keeps it always at the same tension. Rope pulleys may be attached to the shaft of the

pulley E , and the power received by E may thus be transmitted to any desired points.

The first of the above systems of transmission is used chiefly in Europe; the second, in the United States.

2053. Ropes.—The ropes used in rope transmission are either of hemp, manila, or cotton. Manila ropes are mostly used in this country. They are of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter.

The weight of ordinary manila, or cotton, rope is about $.3 D^2$ pounds per foot of length, where D represents the diameter of the rope in inches. Letting w = the weight per foot of length,

$$w = .3 D^2. \quad (280.)$$

The breaking strength of the rope varies from 7,000 to 12,000 lb. per sq. in. of cross-section. The average value may be taken as $7,000 D^2$, when D is the diameter of rope.

For a continuous transmission, it has been determined by experiment that the best results are obtained when the tension in the driving side of the rope is about $\frac{1}{35}$ of the breaking strength. That is,

$$T_1 = \text{tension in tight side} = \frac{7,000 D^2}{35} = 200 D^2.$$

2054. Power Transmitted by Ropes.—The ropes run in V-shaped grooves (see Fig. 724), and the coefficient of friction is, of course, greater than on a smooth surface. The coefficient for grooves with sides at an angle of 45° may be taken at from .25 to .33. The ratio $\frac{T_1}{T_2}$ will vary from $1\frac{1}{2}$ to 3, depending upon the arc of contact and coefficient of friction.

The horsepower that can be transmitted by a single rope running under favorable conditions is given by the formula

$$H = \frac{v D^2}{825} \left(200 - \frac{v^2}{107.2} \right). \quad (281.)$$

The horsepower transmitted by ropes of different diameters running at different velocities may be calculated from formula **281**, and plotted on cross-section paper. The

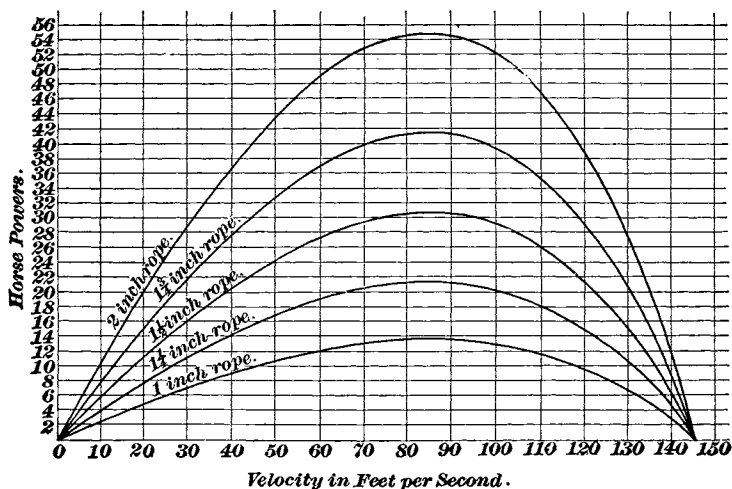


FIG. 723.

accompanying diagram (Fig. 723) shows the horsepowers transmitted by 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, and 2 inch ropes for various velocities. The horizontal distances represent velocities in feet per second, and the vertical ordinates the horsepower transmitted by a single rope.

The diagram shows that the maximum power is obtained at a speed of about 84 feet per second. For higher velocities, the centrifugal force becomes so great that the power is decreased, and when the speed reaches 145 feet per second, the centrifugal force just balances the tension, so that no power at all is transmitted. Consequently, a rope should not run faster than about 5,000 feet per minute, and it is preferable, on the score of durability, to limit the velocity to 3,500 feet per minute.

EXAMPLE.—A rope fly-wheel is 26 feet in diameter, and makes 55 revolutions per minute. The wheel is grooved for 35 turns of $1\frac{1}{4}$ -inch rope. What horsepower may be transmitted?

SOLUTION.—Velocity per second =

$$v = \frac{26 \times \pi \times 55}{60} = \frac{4,492}{60} = 74.9 \text{ feet.}$$

Then, from formula **281**,

$$H = \frac{v D^2}{825} \left(200 - \frac{v^2}{107.2} \right) = \frac{74.9 \times (1\frac{1}{2})^2}{825} \left(200 - \frac{(74.9)^2}{107.2} \right) = 30.16,$$

the horsepower transmitted by one rope or turn. Then, $30.16 \times 35 = 1,055.6 =$ horsepower transmitted by the 35 ropes. Ans.

Practically the same result may be obtained by referring to the diagram. It will be seen that for $1\frac{1}{2}$ -inch rope running 74.9 feet per second, the horsepower per rope is slightly over 30; hence, the total horsepower is $30 \times 35 = 1,050$, nearly.

EXAMPLE.—How many times should a $1\frac{3}{4}$ -inch rope be wrapped around a grooved wheel in order to transmit 400 horsepower, the speed being 3,500 feet per minute?

SOLUTION.—3,500 ft. per min. $= \frac{3,500}{60} = 58\frac{1}{3}$ ft. per sec. Referring to the diagram, a $1\frac{3}{4}$ -inch rope running at a speed of $58\frac{1}{3}$ ft. per sec. transmits $36\frac{1}{2}$ horsepower. Hence, the number of turns should be $\frac{400}{36\frac{1}{2}} = 11$, nearly. Ans.

2055. Pulleys for rope gearing differ from ordinary pulleys in having a grooved rim. The sides of the groove are inclined at an angle which may vary from 30° to 60° .

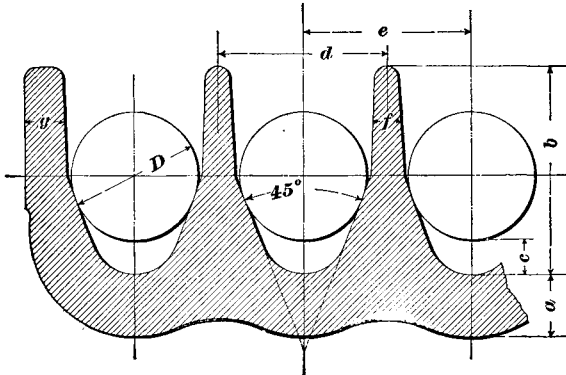


FIG. 724.

The weight of the rope wedges it into the angle of the groove, and, therefore, the more acute the angle the greater

is the coefficient of friction, and likewise the wear of the rope. The general practice, at present, is to make the angle between the sides 45° . The grooves are made circular at the bottom, and are polished or smoothed to avoid wearing the rope. A section of what is known as the English form of grooved rim is shown in Fig. 724. The following proportions may be used:

D = diameter of rope in inches.

$$a = \frac{1}{2} D. \quad e = \frac{4}{3} D.$$

$$b = 1\frac{5}{8} D. \quad f = \frac{1}{4} D.$$

$$c = \frac{1}{4} D. \quad g = f + \frac{1}{4}''.$$

$$d = \frac{4}{3} D.$$

A section of a grooved rim, in which the sides of the grooves are formed with circular arcs, is shown in Fig. 725.

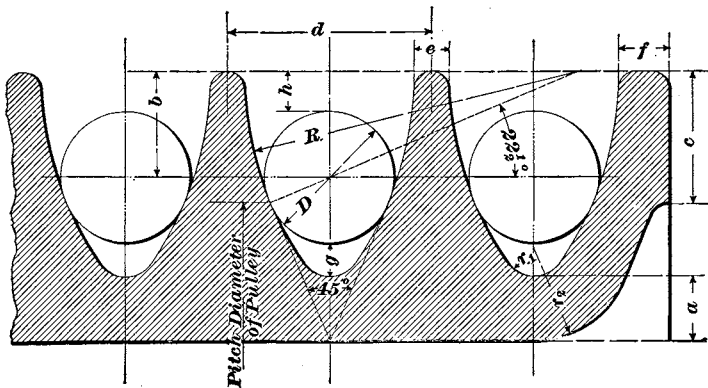


FIG. 725.

The proportions for this rim are as follows, using the diameter D of the rope as a unit:

$$a = \frac{1}{2} D. \quad e = \frac{1}{4} D + \frac{1}{16}''.$$

$$b = \frac{3}{4} D + \frac{1}{16}''.$$

$$f = \frac{1}{4} D + \frac{3}{16}''.$$

$$c = D. \quad g = \frac{1}{3} D.$$

$$d = 1.6 D. \quad h = \frac{1}{4} D + \frac{1}{16}''.$$

r_1 and r_2 are to be found by trial; they should be of such lengths as to make the curves drawn by them tangent to the required lines.

The long radius R is determined by drawing a line through the center of the rope at an angle of $22\frac{1}{2}^\circ$ with the horizontal, and producing it until it intersects a line drawn through the tops of the dividing ribs; then, with this point of intersection as a center, draw the curve forming the side of the groove tangent to the circumference of the rope.

The advantage claimed for this groove is that the rope will turn more freely in it, thus presenting new sets of fibers to the sides of the grooves, and increasing the life of the rope.

2056. Guide pulleys, idlers, and tension pulleys do not have V grooves, but the rope rests upon the bottom of a circular groove, as shown in Fig. 726.

2057. The diameter of a rope pulley should be at least 30 times the diameter of the rope. Good results are obtained when the diameters of pulleys and idlers on the driving side are 40 times, and those on the driven side 30 times the rope diameter. Idlers used simply to support a long span may have diameters as small as 18 rope diameters, without injuring the rope.

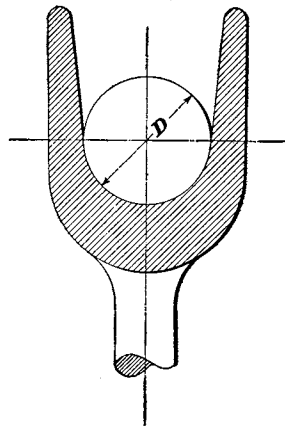


FIG. 726.

When possible, the lower side of the rope should be the driving side, for in that case the rope embraces a greater portion of the circumference of the pulley, and increases the arc of contact.

When the continuous system of rope transmission is used, the tension pulley should act on as large an amount of rope as possible. It is good practice to use a tension pulley and carriage for every 1,200 feet of rope, and have at least 10 per cent. of the rope subjected directly to the tension.

Aside from the grooved rim, rope pulleys are constructed the same as other pulleys. They may be cast solid, in halves

or in sections. The pulley grooves must be turned to exactly the same diameter; otherwise, the rope will be severely strained.

WIRE-ROPE GEARING.

2058. Telodynamic Transmission.—This name is applied to the method of transmitting power by means of wire ropes and pulleys. The method was introduced on the continent of Europe, in 1850, by C. F. Hirn, and has proven very successful and economical. Power may be transmitted great distances with very little loss.

The telodynamic transmission is very simple. It consists of driving and driven pulleys connected by a wire rope running at high velocity. When the distance is very great (sometimes several miles), relay pulleys are placed every 400 to 500 feet. The driving pulley then drives the first relay pulley, which in turn drives the second, and so on, there being a separate rope for each relay. A single rope, however, may be used over a distance of 1,000 to 2,000 feet by supporting it by guide pulleys, as shown in Fig. 727. The guide pulleys should be not more than 500 feet apart.

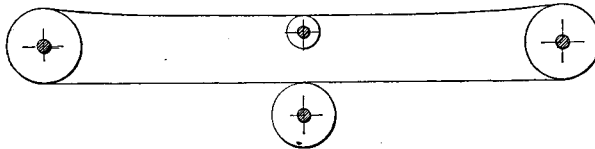


FIG. 727.

The diameter of the guide pulley in the driving side of the rope should be equal to that of the driving pulley, while the diameter of the pulley supporting the slack side may be half as great.

The pulleys are fixed to wood, iron, or masonry supports which are high enough to prevent the rope from dragging on the ground.

2059. The wire rope used for transmitting power is usually composed of 6 strands twisted around a hemp core. Each strand is composed of either 7 wires or 6 wires, and a

central hemp core. The number of strands, and wires to the strand, may be varied at pleasure.

Calling D the diameter of the rope, that is, the diameter of a ring that would just fit over the rope, and d the diameter of a single wire, we have for the ordinary rope of 42 wires,

$$D = 9\ d, \text{ or } d = \frac{D}{9}. \quad (282.)$$

The weight of wire rope per foot equals

$$w = 1.43\ D^2, \text{ nearly.} \quad (283.)$$

EXAMPLE.—What is the diameter of the wire composing a $\frac{5}{8}$ -inch wire rope containing 42 wires, and what is its weight per foot?

SOLUTION.— $d = \frac{D}{9} = \frac{\frac{5}{8}}{9} = .07''$, nearly, or about No. 13 Brown & Sharpe's wire gauge. Ans.

Weight per foot $= 1.43\ D^2 = 1.43 \times (\frac{5}{8})^2 = .56\ \text{lb.}$ Ans.

The total stress allowable in a rope of iron wires may be taken at about 25,000 lb. per sq. in.; the stress in ropes of steel wire may be taken at 28,000 lb. per sq. in.

In calculating the cross-section of a rope, the sum of the cross-sections of the individual wires must be taken; thus, if n is the number of wires in the rope, the cross-section is

$$\frac{\pi}{4} d^2 n, \text{ not } \frac{\pi}{4} D^2.$$

2060. Tensions in a Suspended Rope.—A perfectly flexible rope suspended between two points, as, for example, a wire rope suspended between two pulleys, hangs in a curve called the **catenary**. When, however, the deflection is not very great, as is usually the case in wire-rope transmission, the curve is very nearly a true parabola.

2061. In designing a wire-rope transmission, it is required to know the distance the rope will hang below the points of suspension, i. e., the **deflection** of the rope, and the tension in the rope at the pulleys.

In Fig. 728, let $A\ C\ B$ be a rope hanging from the points A and B , which are supposed to be at the same elevation;

then the tension at A or B is given by the formula

$$T = \frac{w a^2}{2 h} + w h, \quad (284.)$$

where w is the weight of the rope per foot of its length,

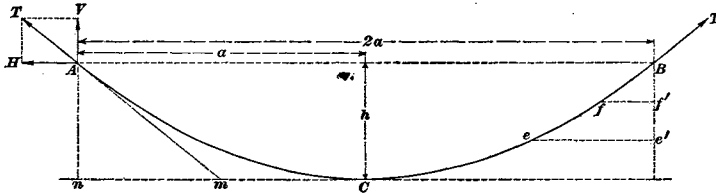


FIG. 728.

$a = \frac{1}{2}$ the distance in *feet* between the points of support, and h is the deflection in *feet* at the lowest point of the rope.

EXAMPLE.—The total distance between two rope pulleys is 400 ft., and the deflection at the center of the rope is 10 ft. Supposing the rope to weigh 1 lb. per ft., find the tension at the pulleys due to the weight of the rope.

SOLUTION.— $a = 400 \div 2 = 200$; $h = 10$; $w = 1$.

By formula **284**, we have

$$T = \frac{w a^2}{2 h} + w h = \frac{1 \times (200)^2}{20} + 1 \times 10 = 2,010 \text{ lb. Ans.}$$

2062. If we solve formula **284** for h , we obtain

$$h = \frac{T}{2w} - \sqrt{\frac{T^2}{4w^2} - \frac{a^2}{2}}. \quad (285.)$$

This formula may be used to find the deflection when the tension, weight of rope, and span are known.

2063. Stresses in a Wire Rope.—A wire rope when transmitting power is subjected to three different stresses:

1. The stress due to the direct longitudinal tension which depends upon the span, power transmitted, and weight of rope.

2. A stress caused by bending the wire around the convex portion of the pulley or sheave.

3. Stress due to centrifugal force.

The values of these stresses are expressed by the following formulas: The stress per square inch due to direct tension is

$$S_t = \frac{\frac{w a^2}{2h} + w h}{\frac{\pi}{4} d^2 n} = \frac{2 w (a^2 + 2 h^2)}{\pi d^2 n h}. \quad (286.)$$

The stress per square inch due to bending around the pulley equals

$$S_b = \frac{E_1 d}{2 R}, \quad (287.)$$

where E_1 is the coefficient of elasticity of the material composing the wire (see Art. 1352), d = diameter of wire composing the rope, and R = radius of pulley in inches.

The stress per square inch due to centrifugal force is

$$S_c = \frac{w v^2}{\frac{\pi}{4} g d^2 n} = \frac{4 w v^2}{\pi d^2 n g}, \quad (288.)$$

where v = velocity of rope in feet per second, and $g = 32.16$.

The total stress per square inch is the sum of these stresses, and is equal to

$$S = S_t + S_b + S_c = \frac{2 w (a^2 + 2 h^2)}{\pi d^2 n h} + \frac{E_1 d}{2 R} + \frac{4 w v^2}{\pi d^2 n g}. \quad (289.)$$

This total stress S should not exceed

25,000 lb. per sq. in. for wrought iron;

28,000 lb. per sq. in. for steel.

2064. Ratio of Tensions.—With long-rope transmissions the arc of contact does not vary much from 180° , and the coefficient of friction may be taken as about .22. With these conditions the tension T_1 on the driving side is about twice the tension T_2 on the slack side; i. e., $T_2 = \frac{1}{2} T_1$, therefore, the driving force $P = T_1 - T_2 = T_1 - \frac{1}{2} T_1 = \frac{1}{2} T_1 = T_2$.

The horsepower transmitted is

$$H = \frac{P v}{550} = \frac{P V}{33,000}.$$

One or two examples will serve to illustrate the use of the above equations and formulas.

EXAMPLE.—Power is transmitted by an iron wire rope containing 42 wires No. 15 B. & S. wire gauge, or .057 inch in diameter. The pulleys are 11 feet in diameter, and the rope runs at a speed of 4,800 feet per minute. The distance between pulleys is 400 feet. Find the horsepower transmitted, and the deflections of both tight and driving sides of rope.

SOLUTION.—The stress due to bending is

$$S_b = \frac{E_1 d}{2R}$$

For iron E_1 is about 25,000,000. Hence,

$$S_b = \frac{25,000,000 \times .057}{2 \times \frac{11 \times 12}{2}} = 10,795 \text{ lb. per sq. in.}$$

Diameter of rope is, by formula **282**,

$$D = 9d = 9 \times .057 = .513''.$$

Weight of rope per foot is, by formula **283**,

$$w = 1.43 D^2 = 1.43 \times .513^2 = .3764 \text{ lb.}$$

Stress due to centrifugal force is

$$S_c = \frac{4 w v^2}{\pi d^2 n g} = \frac{4 \times .3764 \times \left(\frac{4,800}{60}\right)^2}{3.1416 \times .057^2 \times 42 \times 32.16} = 699 \text{ lb. per sq. in.}$$

S_t can not be calculated by formula **286**, as the value of h is not known; but from formula **289**,

$$S_t = S - (S_b + S_c),$$

and since S must not exceed 25,000 for wrought iron,

$$S_t = 25,000 - (10,795 + 699) = 13,506 \text{ lb. per sq. in.}$$

$$T_1 = \text{maximum tension on driving side} = \frac{\pi}{4} d^2 n S_t =$$

$$.7854 \times .057^2 \times 42 \times 13,506 = 1,448 \text{ lb.}$$

$$T_2 = \frac{1}{2} T_1 = 724 \text{ lb.}; P = \text{driving force} = T_2 = 724 \text{ lb.}$$

$$H = \text{horsepower} = \frac{P V}{33,000} = \frac{724 \times 4,800}{33,000} = 105.3. \quad \text{Ans.}$$

For the deflection, we may use formula **285**,

$$h = \frac{T_1}{2w} - \sqrt{\frac{T_1^2}{4w^2} - \frac{a^2}{2}}.$$

The deflection of the driving side is, taking w as $\frac{8}{3}$,

$$h = \frac{1,448}{2 \times \frac{8}{3}} - \sqrt{\frac{1,448^2}{4 \times (\frac{8}{3})^2} - \frac{(200)^2}{2}} = 5 \text{ ft.} \quad \text{Ans.}$$

The deflection of the driven side is

$$h = \frac{724}{2 \times \frac{8}{3}} - \sqrt{\frac{724^2}{4 \times (\frac{8}{3})^2} - \frac{(200)^2}{2}} = 10.4 \text{ ft.} \quad \text{Ans.}$$

In order to solve the converse problem, that is, find the necessary size of a wire rope to safely transmit a given horsepower, some assumptions must be made. In the first place, the stress due to bending can not be found directly, since the diameter of the wire is unknown. We may, however, assume a ratio for $\frac{R}{d}$, and after finding the size of the wire required, the radius of the pulley is at once known. This ratio of $\frac{R}{d}$ varies from 600 to 1,400. When $\frac{R}{d} = 850$ for iron wire, the pulley diameter will be smaller than for any other ratio. The ratio should, however, be as great as the conditions will allow, for the larger the pulley for a given diameter of wire, the greater is the durability of the rope.

If the value of S_c , the stress due to the centrifugal force, be taken into account, it will complicate the solution very much; in fact, the only method of solution will be a cut-and-try method. As S_c is small in comparison with S_b or S_t for reasonable values of v , it may be neglected, and the diameter of the wire calculated as in the next example. If greater exactness is desired, substitute this value of d in formula 288; calculate the value of S_c , and then re-calculate the value of d .

EXAMPLE.—Required, to find the diameter of the wires in a steel wire rope transmitting 200 horsepower at a velocity of 5,100 feet per minute; also, required, the diameter of the pulley and rope. The rope is to contain 42 wires.

SOLUTION.—The driving force equals

$$P = \frac{33,000 H}{V} = \frac{33,000 \times 200}{5,100} = 1,294 \text{ lb.}$$

The tension on driving side equals

$$T_1 = 2P = 2 \times 1,294 = 2,588 \text{ lb.}$$

Assume the ratio $\frac{R}{d} = 900$; E_1 for steel = 30,000,000.

Then, the stress due to bending is

$$S_b = \frac{E_1 d}{2R} = \frac{30,000,000}{2 \times 900} = 16,667 \text{ lb. per sq. in.}$$

Hence, $S_t = 28,000 - 16,667 = 11,333 \text{ lb. per sq. in.}$

Cross-section of wires =

$$\frac{1}{4} \pi d^2 n = \frac{T_1}{S_t} = \frac{2,588}{11,833} = .2283 \text{ sq. in.}$$

$$d = \sqrt{\frac{.2283}{.7854 \times 42}} = .0832 \text{ in.}$$

The diameter of the rope is, therefore,

$$D = 9d = 9 \times .0832 = .7488, \text{ or say } \frac{3}{4} \text{ in.}$$

Assuming the diameter of rope to be $\frac{3}{4}$ " = .75", as found, the weight per foot is by formula **283**,

$$w = 1.43 D^2 = 1.43 \times .75^2 = .8044 \text{ lb.}$$

By formula **282**, $d = \frac{D}{9} = \frac{.75}{9} = .0833.$

Hence, by formula **288**,

$$S_o = \frac{4 \times .8044 \times \left(\frac{5,100}{60}\right)^2}{3.1416 \times .0833^2 \times 42 \times 32.16} = 790.$$

And, $S_t = 28,000 - (16,667 + 790) = 10,543 \text{ lb. per sq. in.}$

Cross-section of wires =

$$\frac{1}{4} \pi d^2 n = \frac{T_1}{S_t} = \frac{2,588}{10,543} = .2455 \text{ sq. in.,}$$

and

$$d = \sqrt{\frac{.2455}{.7854 \times 42}} = .0862. \text{ Ans.}$$

The diameter of the rope is, therefore,

$$.0862 \times 9 = .7758", \text{ say } \frac{3}{4}",$$

the same value as obtained when S_o was neglected. Ans.

Since $\frac{R}{d} = 900$, $R = 900 d = 900 \times .0862 = 77.58"$, and the diameter of the pulley = $2 \times 77.58 = 155" = 12 \text{ ft. } 11"$. Ans.

2065. Wire ropes are used also for hoisting and hauling loads in and about mines. The calculation of the size of a wire rope for any purpose is similar to that given above. If the rope is subjected to a straight pull, and is not bent around a sheave or drum, the cross-section may be found directly from the load and allowable safe stress; that is, cross-section = $\frac{\text{total load on rope}}{\text{safe stress per sq. in.}}$.

When the rope is bent around a pulley or drum, the stress due to bending, that is, $S_b = \frac{E_1 d}{2R}$, must be subtracted from the total safe stress.

Wire ropes used for hoisting are often made with 6 strands of 19 wires each, wound around a central hemp core, making in all $6 \times 19 = 114$ wires. This rope is more flexible than the regular transmission rope, and is, therefore, injured less in passing over small pulleys; but it will not stand as much wear when dragged over rough surfaces, as the wires of which it is composed are so much smaller.

2066. Wire-Rope Pulleys.—The pulleys, or sheaves, used in wire-rope transmission are made of cast iron with a groove lined with rubber, gutta-percha, leather, or other similar substance, on which the rope runs. The grooves are made so wide that the rope rests on the rounded bottom instead of being wedged against the sides, as in the case of hemp or cotton rope.

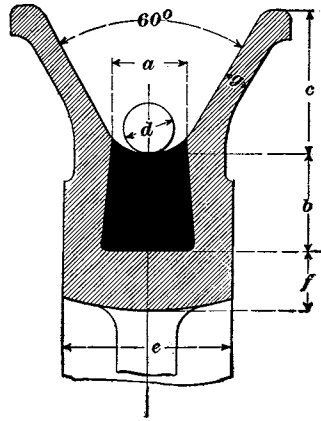


FIG. 729.

The proportions of the pulley rim are shown in Fig. 729.

They are as follows:

d = diameter of rope;

$$a = d + \frac{1}{4}''.$$

$$c = 2d + \frac{3}{4}''.$$

$$b = d + \frac{1}{2}''.$$

$$f = \frac{1}{2}d + \frac{3}{8}''.$$

$$e = 3d.$$

$$g = \frac{1}{4}d + \frac{1}{8}''.$$

The arms may be cross-shaped or oval; the latter form is preferable, as it offers less resistance to the air when the pulley is run at high speed. The size of the arms corresponds to those of belt pulleys transmitting the same force. For the number of arms Reuleaux gives the formula

$$n = 4 + \frac{R}{40D}, \quad (290.)$$

where R = radius of pulley in inches and D = diameter of

rope. The diameter of the pulley is fixed by the diameter of the rope and the number of wires in a strand. For a rope with seven wires to the strand, the diameter of the pulley should not be less than 150 times the diameter of the rope; and for a rope with 19 wires to the strand, the proportion should not be less than 90 to 1.

Table 53 gives the breaking strength and the power transmitted by various sizes of ropes, as determined by practical experience:

TABLE 53.**POWER TRANSMITTED BY WIRE ROPES (42 WIRES).**

Diameter of Ropes, Inches.	Diameter of Pulleys, Feet.	Revolutions per Minute.	Breaking Stress of Rope per Pound.	Horse-power Transmitted.	Velocity of Rope in Feet per Second.
$\frac{7}{16}$	5	100	4,260	8.6	26
$\frac{15}{32}$	6	100	5,660	13.4	31
$\frac{1}{2}$	7	100	8,200	21.1	36
$\frac{5}{8}$	8	100	11,600	27.5	42
$\frac{5}{8}$	8	120	11,600	33.0	50
$\frac{5}{8}$	9	100	11,600	51.9	47
$\frac{5}{8}$	9	120	11,600	62.2	56
$\frac{11}{16}$	10	100	15,200	73.0	52
$\frac{11}{16}$	10	120	15,200	87.6	62
$\frac{11}{16}$	10	140	15,200	102.2	73
$\frac{11}{16}$	12	100	15,200	116.7	63
$\frac{3}{4}$	12	120	17,600	148.9	75
$\frac{3}{4}$	12	140	17,600	173.7	87
$\frac{3}{4}$	14	100	17,600	185.0	73
$\frac{3}{4}$	14	120	17,600	222.0	87
$\frac{3}{4}$	15	120	17,600	300.0	94

NOTE.—The student may obtain much information concerning wire ropes from the trade catalogue of John A. Roebling's Sons Co., Trenton, N. J.

CHAINS.

2067. Chains may be used as simple fastenings or as belts for transmitting power. The ordinary, or open-link, and the stud-link round iron chains are shown in Fig. 730. The links are made from round iron bars which are cut off at the proper length, bent, and welded. The links should be made as small as possible, both on account of strength and flexibility. Ordinary chain proportions are shown on the figure. They are as follows:

$$\begin{aligned}
 & d = \text{diameter of iron;} \\
 & \text{For open link } \begin{cases} a = 4\frac{1}{2}d \text{ to } 5d; \\ b = 3\frac{1}{2}d. \end{cases} \\
 & \text{For stud link } \begin{cases} a = 5d \text{ to } 6d; \\ b = 3\frac{1}{2}d \text{ to } 3\frac{3}{4}d; \\ c = .6d; \\ e = .7d. \end{cases}
 \end{aligned}$$

Link chains which are used merely to support loads, as in suspension bridges, etc., have the links from 3 to 9 feet or more in length. As such chains do not belong properly to the subject of Machine Design, they will not be considered here.

2068. Strength of Chains.—The strength of a chain is less than that of the iron composing it, on account of the weld, and also because of the presence of bending action.

Formulas **130** and **131**, Art. **1421**, may be used to find the safe load in ordinary cases. For crane chains which require a large factor of safety, Towne gives the following as the safe load:

$$P = 3.3d^2 \text{ tons} = 6,600 d^2 \text{ lb.} \quad (291.)$$

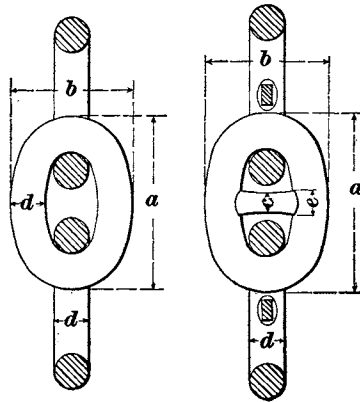


FIG. 730.

The *weight of chains* (open and stud link) may vary from $9 d^2$ to $9\frac{1}{2} d^2$ pounds per foot.

2069. Chain Drums.—When a chain must be coiled, as in the case of cranes and derricks, a grooved drum may be used. The groove passes spirally around the drum, and is just wide enough to receive the edge of a link of the chain. The drum may have a diameter of from $24 d$ to $30 d$ or more; the length should be such that the total amount of chain may be coiled on in one layer; because, if one layer is wound over another, the chain is injured.

Instead of a drum, a wheel or sheave with pockets may be used. Such a wheel requires less space than the drum, and injures the chain less. A form of chain wheel largely

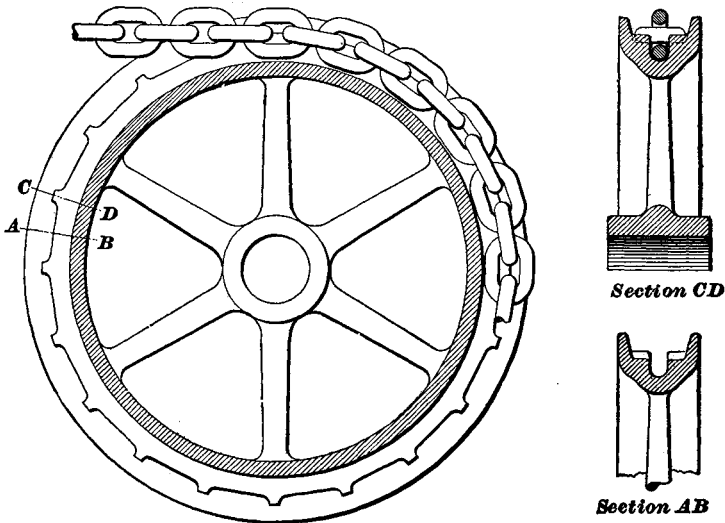


FIG. 731.

used for transmitting power, especially on cranes, chain blocks, etc., is shown in Fig. 731. The rim of the wheel is grooved for the links, and pockets are provided into which the links that lie parallel with the axis of the wheel rest.

The pitch of the pockets must, of course, be the same as the pitch of the links.

2070. Flat-link chains are used for driving machinery where very heavy resistances are to be overcome, as, for example, in wire-drawing machines, cranes, and dredging machines.

When the chain merely supports a load, it may have the form shown in Fig.

732. It consists of flat plates which are connected by pins. The pins are evidently in shear, and the plates are in direct tension. Since each of the two parallel plates carries one-half the load, it should have one-half the thickness of the single plate to which it is pinned.

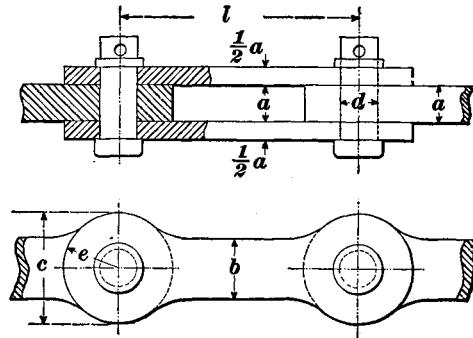


FIG. 732.

The links may be of any length desired, but the shortest convenient length is about $l = 3d$. The cross-section $= ab = \frac{P}{S_t}$, where P is the load and S_t the safe stress in tension. Taking both P and S_t in tons, we may assume $S_t = 5$ tons.

Then, $ab = .2P$.

The shearing section of a pin is $2 \times \frac{1}{4} \pi d^2 = \frac{1}{2} \pi d^2$. Therefore,

$$\frac{1}{2} \pi d^2 = \frac{P}{S_s}$$

where S_s = safe shearing stress.

Assuming $S_s = 4$ tons, we have

$$d = \sqrt{\frac{P}{2\pi}}$$

The following proportions may be used in ordinary cases:

$$b = \frac{4}{3} d. \quad c = \frac{8}{3} d. \quad e = \frac{11}{8} d.$$

When the links are short, the width b may be the same throughout. The pin connecting the plates may be riveted over or secured by a washer and split pin.

A flat-link chain may be used for transmitting powers somewhat after the fashion of a belt. The chain passes over wheels provided with teeth which engage with the links of the chain. Such a wheel is known as a **sprocket wheel**. Examples of chains used in this way are met with in agricultural machinery, bicycles, coal-mining machines, dredges, etc.

The flat-link gearing chain, Fig. 733, consists of two series of flat links which are kept some distance apart by the pins

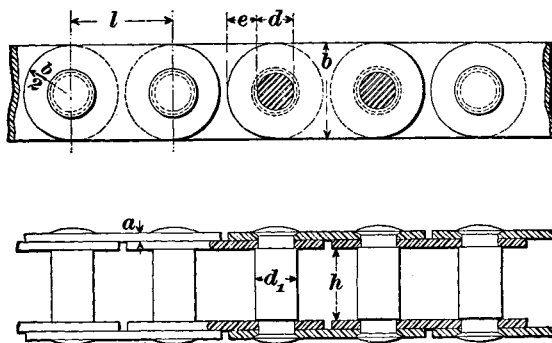


FIG. 733.

which connect them. These pins engage with the teeth of the sprocket wheel; they are enlarged between the series of plates so as to form a shoulder to prevent the plates from slipping, and also to give a greater wearing surface.

- Let n = number of plates on one side of chain;
 a and b = thickness and breadth of plates, respectively;
 d = diameter of ends of pin;
 d' = diameter of center of pin;
 h = length of enlarged part of pin;
 l = length of link between centers of pins;
 P = total load on chain in pounds.

All dimensions in inches.

Then, the following formulas and proportions are generally used:

$$\begin{aligned} n &= .13 \sqrt[3]{P}; & h &= 1.7 d + .5; \\ d &= .0115 \sqrt{\frac{P}{\sqrt{n}}}; & l &= 2.9 d; \\ b &= 2.5 d; & a &= \frac{85 d}{n + l}; \\ d' &= 1.2 d; & c &= .85 d. \end{aligned}$$

EXAMPLE.—Calculate the dimensions of a plate-link gearing chain for a working load of 8,000 lb.

SOLUTION.—Number of plates on one side =

$$\begin{aligned} n &= .13 \sqrt[3]{P} = .13 \sqrt[3]{8,000} = 2.6, \text{ say } 3; \\ d &= .0115 \sqrt{\frac{P}{\sqrt{n}}} = .0115 \sqrt{\frac{8,000}{\sqrt{3}}} = .78, \text{ say } \frac{3}{4}''; \\ d' &= 1.2 d = 1.2 \times \frac{3}{4} = .9'', \text{ say } \frac{23}{32}''; \\ b &= 2.5 d = 2.5 \times \frac{3}{4} = 1\frac{1}{8}''; \\ h &= 1.7 d + .5 = 1.7 \times \frac{3}{4} + .5 = 1.775''; \\ l &= 2.9 d = 2.9 \times \frac{3}{4} = 2.175''; \\ a &= \frac{.85 d}{n + l} = \frac{.85 \times \frac{3}{4}}{3 + 2.175} = .12'', \text{ say } \frac{1}{8}''; \\ c &= .85 d = .85 \times \frac{3}{4} = .64''. \end{aligned}$$

Various other forms of gearing chains are in common use. In designing machinery requiring the use of such chains it is customary to use some standard size made by a company engaged in the manufacture of chains.

It would be well for the student to send for the catalogue of some such company, and observe the proportions and sizes there adopted. Much good information may be obtained from the catalogue of The Link Belt Engineering Company, Chicago, Ill.

2071. Hooks.—Chains used on cranes and derricks must be provided with hooks for connecting to the load to be raised. The design of a crane hook must be made with care, since a break may cause loss of property and life.

A hook may be treated theoretically, as follows: The

maximum stress comes on the section $m n$ of the hook.

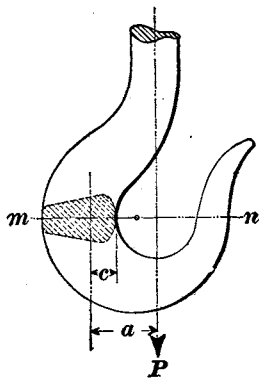


FIG. 734.

See Fig. 734. Let the center of gravity of this section be a distance a from the line of action of the load, and a distance c from the inside edge of the hook.

Let S_t = the stress in the section due to direct tension;

S_b = the stress due to bending;

A = area of section;

I = moment of inertia of section.

Then, for direct tension, $P = A S_t$, or $S_t = \frac{P}{A}$.

For bending, letting S_b = *safe* bending stress, the moment $= Pa = \frac{S_b I}{c}$ (see Art. 1398), or $S_b = \frac{Pac}{I}$.

Now, $S_b + S_t$, equals total stress, must not exceed a safe value, say about 12,000 lb., or 6 tons per sq. in. Then, if we take P in tons,

$$S_b + S_t = 6 \text{ tons} = P \left(\frac{1}{A} + \frac{ac}{I} \right).$$

Suppose, for example, we assume the section of the hook to be a rectangle, of length b and width $\frac{2}{3}b$, and let the distance a , Fig. 734, equal the length b of the section; what should be the dimensions of section for a load of 3 tons?

We have

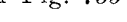
$$6 = P \left(\frac{1}{A} + \frac{ac}{I} \right) = 3 \left(\frac{1}{b \times \frac{2}{3}b} + \frac{b \times \frac{1}{2}b}{\frac{1}{12}b^3 \times \frac{2}{3}b} \right),$$

or $b^2 = \frac{21}{4}$.

$$\text{Hence, } b = \sqrt{\frac{21}{4}} = 2.29, \text{ say } 2\frac{5}{16}'';$$

$$\text{and } \frac{2}{3}b = 1.53, \text{ say } 1\frac{17}{32}''.$$

The proportions shown in Fig. 735 are those used by a large crane manufacturing company. They are based on the diameter of the iron rod of which the hook is made. This diameter may be obtained by the following formula:



The diagram shows a cross-section of a crane hook. It is a semi-circular shape with a central hole. The diameter of the iron rod is labeled 'd'. The distance from the center of the rod to the outer edge of the hook is labeled 'f'. The distance from the center of the rod to the inner edge of the hook is labeled 'a'.

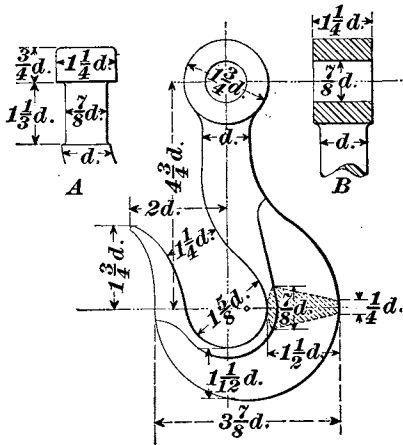


FIG. 735.

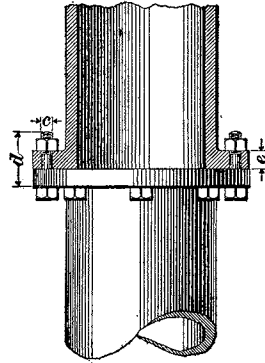
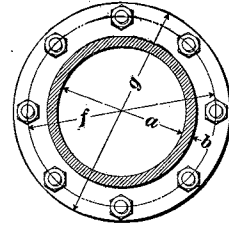


FIG. 736.

$d = \sqrt[4]{P}$, where P is the load in tons.

The hook may have an eye, as shown in the figure, or a neck for a swivel, as shown at *A*.

PIPE FLANGES.

2072. The ends of cast-iron pipes, elbows, etc., are often connected by means of flanges and bolts.

Fig. 736 shows the method of flanging and bolting the ends of two cast-iron pipes. The dimensions of the flanges for the various sizes of pipes are given in the following table:

TABLE 54.
STANDARD PIPE FLANGES.
n = number of bolts.

<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>n</i>	<i>e</i>	<i>f</i>	<i>g</i>
2.0	.409	$\frac{5}{8}$	2.0	4	$\frac{5}{8}$	4.75	6.0
2.5	.429	$\frac{5}{8}$	2.25	4	$1\frac{1}{16}$	5.25	7.0
3.0	.448	$\frac{5}{8}$	2.5	4	$\frac{3}{4}$	6.0	7.5
3.5	.466	$\frac{5}{8}$	2.5	4	$1\frac{3}{16}$	6.5	8.5
4.0	.486	$\frac{3}{4}$	2.75	4	$1\frac{5}{16}$	7.25	9.0
4.5	.498	$\frac{3}{4}$	3.0	8	$1\frac{5}{16}$	7.75	9.25
5	.525	$\frac{3}{4}$	3.0	8	$1\frac{5}{16}$	8.5	10.0
6	.563	$\frac{3}{4}$	3.0	8	1	9.625	11.0
7	.600	$\frac{3}{4}$	3.25	8	$1\frac{1}{16}$	10.75	12.5
8	.639	$\frac{3}{4}$	3.5	8	$1\frac{1}{8}$	11.75	13.5
9	.678	$\frac{3}{4}$	3.5	12	$1\frac{1}{8}$	13.0	15.0
10	.713	$1\frac{1}{8}$	3.625	12	$1\frac{3}{16}$	14.25	16.0
12	.790	$1\frac{1}{8}$	3.75	12	$1\frac{1}{4}$	16.5	19.0
14	.864	1	4.25	12	$1\frac{3}{8}$	18.75	21.0
15	.904	1	4.25	16	$1\frac{3}{8}$	20.0	22.25
16	.946	1	4.25	16	$1\frac{7}{16}$	21.25	23.5
18	1.020	$1\frac{1}{8}$	4.75	16	$1\frac{9}{16}$	22.75	25.0
20	1.090	$1\frac{1}{8}$	5.0	20	$1\frac{11}{16}$	25.0	27.5
22	1.180	$1\frac{1}{4}$	5.5	20	$1\frac{13}{16}$	27.25	29.5
24	1.250	$1\frac{1}{4}$	5.5	20	$1\frac{7}{8}$	29.5	32.0
26	1.300	$1\frac{1}{4}$	5.75	24	2	31.75	34.25
28	1.380	$1\frac{1}{4}$	6.0	28	$2\frac{1}{16}$	34.0	36.5
30	1.480	$1\frac{3}{8}$	6.25	28	$2\frac{1}{8}$	36.0	38.75
36	1.710	$1\frac{3}{8}$	6.5	32	$2\frac{3}{8}$	42.75	45.75
42	1.870	$1\frac{1}{2}$	7.25	36	$2\frac{5}{8}$	49.5	52.75
48	2.170	$1\frac{1}{2}$	7.75	44	$2\frac{3}{4}$	56.0	59.5

2073. The larger sizes of wrought-iron pipe, especially for high pressures, are best connected by means of flanges. Fig. 737 shows three styles of fastening these flanges to the pipe.

A is a cast-iron flange screwed to the end of the pipe by means of the standard pipe thread. It is much used, especially for sizes of pipe below 6".

B is a wrought-iron or steel flange which is screwed to the end of the pipe, and the end of the pipe is then riveted over as shown at *a*.

C is a forged or rolled steel flange that is used for large pipes and high pressures. The pipe is fastened to the flange

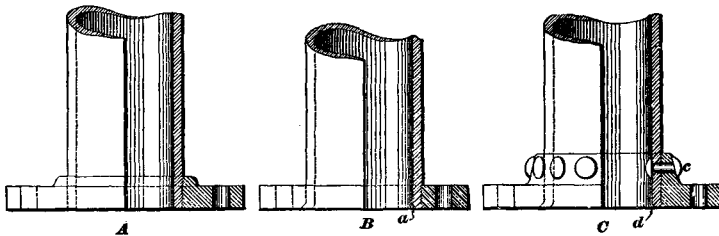


FIG. 737.

by rivets as shown at *c*, and the end is also calked or riveted over at *d* so as to form a tight joint.

The diameters of flanges and bolt circles, and number and sizes of bolts for wrought-iron pipe flanges, should be the same as given in Table 54; for, then, the flange for a pipe of a given size, whether cast or wrought iron, will fit any other pipe, valve, or fitting of the same size.

The thickness of the flanges may also be the same, although wrought-iron and steel flanges are usually made somewhat thinner.

2074. Gaskets.—In order to secure a tight joint, a thin strip of some soft material is placed between the flanges as shown in Fig. 738. The material most

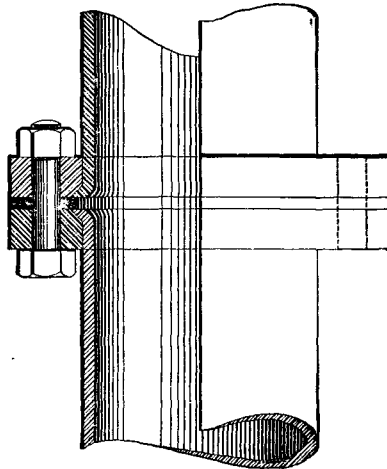


FIG. 738.

commonly used is either sheet rubber or paper, cut to the size of the flange.

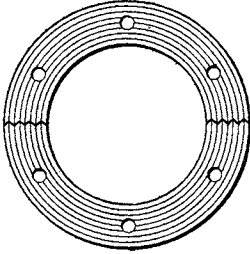


FIG. 739.

For steam pressures above 100 pounds per square inch, however, these materials are injured by the heat and often make trouble. To overcome these difficulties gaskets are sometimes made of lead or copper. Fig. 739 shows a gasket made of thin sheets of corrugated copper, as shown in the section.

MACHINE DESIGN.

(CONTINUED.)

STEAM ENGINE DESIGN.

PRELIMINARY DATA.

2075. The designer of an engine has for his preliminary data:

1. The type of engine desired; that is, simple or compound, horizontal or vertical, Corliss or marine, etc.
2. The horsepower to be developed.
3. Sometimes the boiler pressure.

He must determine:

1. Boiler pressure, if not already known.
2. Piston speed.
3. Point of cut-off.
4. Clearance.
5. Back pressure and compression.

For a simple engine, after the above data have been obtained, a theoretical indicator diagram may be drawn, and the mean effective pressure determined. Then the proportions of the cylinder can be calculated, and the design of the other parts readily follows. For a compound or triple expansion engine a more complicated process is necessary.

2076. The **boiler pressure** may be fixed beforehand if the engine is to have steam furnished by an existing boiler, or set of boilers, carrying a definite pressure. Theoretically, the boiler pressure should be made as high as the conditions will allow, since the thermal efficiency of the engine is

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increased by increasing the range of pressures. There is, however, a practical limit to the pressure to be employed, and the following are about the pressures used for the types of engines indicated:

Simple	70 to 120 lb.
Compound	100 to 150 lb.
Triple.....	150 to 200 lb., or higher.
Locomotive	140 to 210 lb.

For condensing engines the average boiler pressure for a given type will probably be from 15 to 30 pounds lower than given above.

The initial pressure in the engine cylinder will be less than the boiler pressure on account of loss caused by resistance to flow through the steam pipe and connections. Ordinarily the loss may be taken at about 8 per cent. of the boiler pressure.

2077. The **piston speed** for the various types of engines has already been discussed in Art. **1270**.

The tendency of modern engine builders is towards increased piston speed and higher steam pressures.

2078. The **point of cut-off** should, on the score of economy, usually occur early in the stroke. This is not possible in the case of simple slide-valve engines, but may be accomplished with engines fitted with Corliss valve gear or expansion valves. For ordinary simple engines, Mr. C. E. Emery gives the following formula for the most economical cut-off:

Let k = real cut-off;

e = number of expansions;

p_i = absolute initial pressure in lb. per sq. in.

$$\text{Then, } k = \frac{1}{e} = \frac{22}{22 + p_i} \quad (292.)$$

Formula **292** gives results rather too large for compound engines.

2079. The **clearance** may vary from $\frac{1}{2}$ to 3 per cent. in Corliss engines, and from 4 to 14 per cent. in high-speed engines.

The distance between the piston at end of stroke and the cylinder head, or the **piston clearance**, should be made as small as possible. On small stationary engines this distance may be $\frac{1}{4}$ inch, and it rarely exceeds $\frac{1}{2}$ inch on the largest marine engines. In some cases in actual practice, with a low-pressure cylinder 7 feet in diameter and a conical piston, this clearance is only $\frac{3}{8}$ inch.

2080. The **back pressure** should not exceed 16 or 17 lb. (absolute) in a well-designed non-condensing engine. For a condensing engine, the back pressure may be from 2 to 4 lb. per sq. in. The proper amount of compression can not be determined until the reciprocating parts are designed and their weight found. For slow-speed engines the compression is usually small. For high-speed engines the compression is usually large. For high-speed engines the pressure at the end of compression may be

$$p_o = \frac{p_i + 16}{2}, \quad (293.)$$

where p_i is the absolute initial pressure, and p_o is the absolute pressure at the end of compression.

2081. In order to show the general method of procedure in the design of an engine, we will take the following example:

Determine the data for a simple high-speed automatic non-condensing engine which is to develop 120 indicated horsepower.

For an engine of this type the boiler pressure may be taken at 85 pounds, gauge. The initial cylinder pressure will then be about $85 - .08 \times 85 = 78.2 = 78.2 + 14.7 = 92.9$, say 93 pounds, absolute. As the engine is to be non-condensing, we may take the back pressure as 17 pounds. Assume a clearance in this case of 6 per cent. The cut-off from formula **292** equals

$$k = \frac{22}{22 + 93} = .192, \text{ say } \frac{1}{5}.$$

By formula **293**, the steam is compressed to

$$\frac{93 + 16}{2} = 54\frac{1}{2} \text{ lb., absolute.}$$

We now have sufficient data to draw a theoretical diagram;

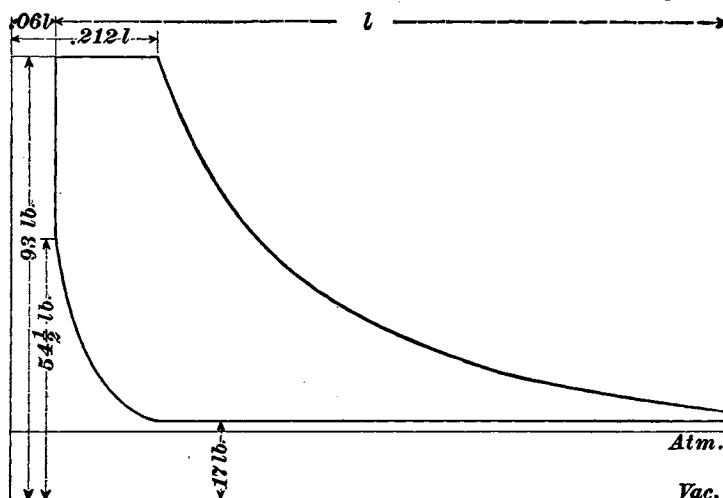


FIG. 740.

see Fig. 740. In drawing the diagram some convenient scale may be chosen for the pressures; say, 30 pounds per inch. Then, the height of the diagram above the vacuum line will be $93 \div 30 = 3.1$ in.

The length of the diagram is immaterial; assume for convenience that it is 4 in. Then, $l = 4$ in., and the clearance $= 4 \times .06 = .24$, say $\frac{1}{4}$ in. Now draw the diagram, assuming that both expansion and compression curves are equilateral hyperbolas (see Arts. **1161** and **1222**). By measurement or by calculation, the *mean effective pressure*, or the M. E. P., of the diagram, Fig. 740, is found to be 28.3 lb. per sq. in.

On account of cylinder condensation and other losses, the M. E. P. given by the theoretical card is never attained by the actual engine. To find the probable M. E. P. of the actual engine, the M. E. P. of the theoretical card must be multiplied by a factor, the magnitude of which depends upon

the style of engine. A good authority gives the following factors for the types of engines indicated:

Simple Engines.	Factor.
Special valve gear, engine jacketed.....	0.94.
Good ordinary valves, engine jacketed, large ports	0.90 to .92.
Ordinary valve gear, unjacketed.....	0.80 to .85.

In the present case, we will assume the factor to be .85; then, the probable M. E. P. is $28.3 \times .85 = 24$ lb. per sq. in. nearly.

In order to be a high-speed engine, the piston speed should be at least 600 feet per minute. Suppose 700 feet per minute is assumed; then, the area A of the cylinder equals

$$A = \frac{33,000 \times \text{horsepower}}{\text{M. E. P.} \times \text{piston speed}} = \frac{33,000 \times 120}{24 \times 700} = 235.7 \text{ sq. in.}$$

Then, diameter of cylinder = $d = 17\frac{1}{2}$ inches.

For convenience, take $d = 17$ in. Then, $A = 227$ sq. in., and the piston speed will be $\frac{33,000 \times 120}{24 \times 227} = 727$ ft. per min.

The length of the stroke may be made 24 inches; hence, the number of revolutions will be $\frac{727 \times 6}{24} = 182$ per minute.

The diameter of the low-pressure cylinder of a compound or triple-expansion engine may be found in the above manner by assuming that all the work is to be done in the low-pressure cylinder. In this case the factor by which to multiply the theoretical M. E. P. to obtain the probable M. E. P. is from .7 to .8 for a compound and .6 to .7 for a triple-expansion engine. The ratio of the volumes of the high, intermediate, and low-pressure cylinders being determined (see Art. 1306), the diameter of the high and intermediate cylinders may be found from that of the low-pressure cylinder.

CYLINDERS AND STEAM CHESTS.

2082. Fig. 741 is an example of a cylinder designed for a simple slide-valve engine. The front head A is cast solid with the cylinder. The method of fastening to the frame B is clearly shown.

The principal dimensions of this cylinder may be determined from the following proportions :

D = diameter of cylinder.

L = length of stroke + thickness of piston + twice the piston clearance.

C = length of stroke + distance from outer edge to outer edge of piston rings - $(.01 D + .125")$.

$a = 5.5 i$.

$b = 4.2 i$.

$c = i$.

$d = i$.

e' = the net area of a single cylinder head bolt whose nominal diameter is $e = \frac{A P}{4,000 n}$,

where A = the area of cylinder head in square inches;
 P = the steam pressure;
 n = the number of bolts.

The pitch of the bolts may be from 4.5 to 5.5 inches, but should never be more than $5 f$.

$f = 1.5 i$.

$g = .04 D + .125"$. Take the nearest nominal size pipe tap.

h = twice the outside diameter of drain pipe.

$i = .0003 P D + .375"$, where P is the steam pressure.
 If the steam pressure is less than 100 pounds make $P = 100$.

$j = .85 i$.

$k = 4 i$.

$l = .75 i$.

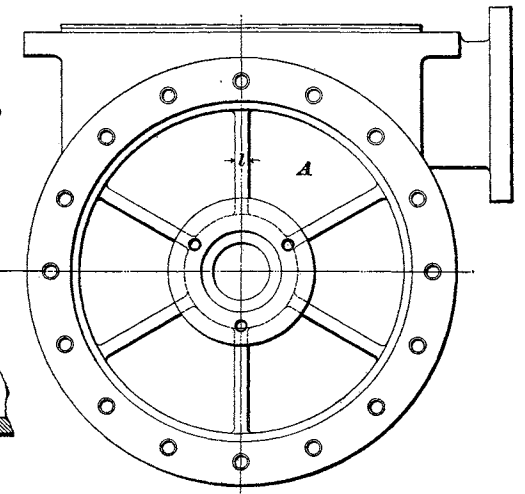
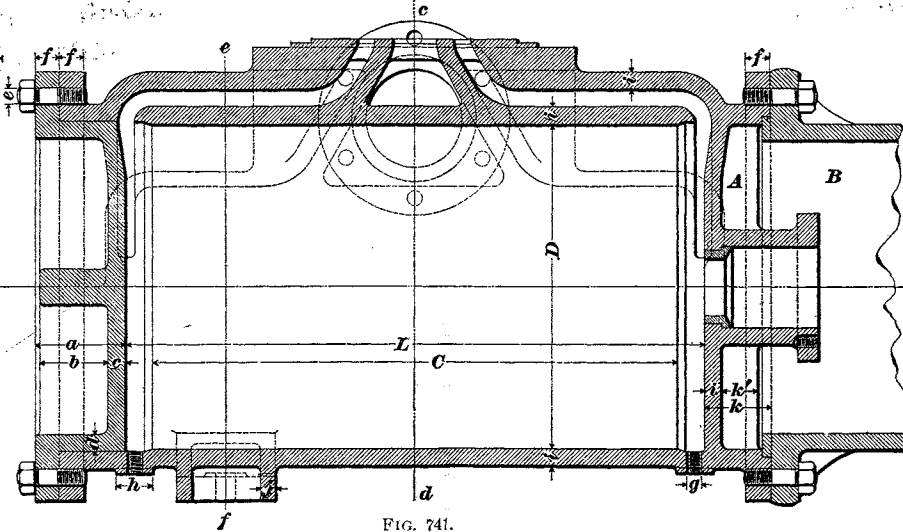
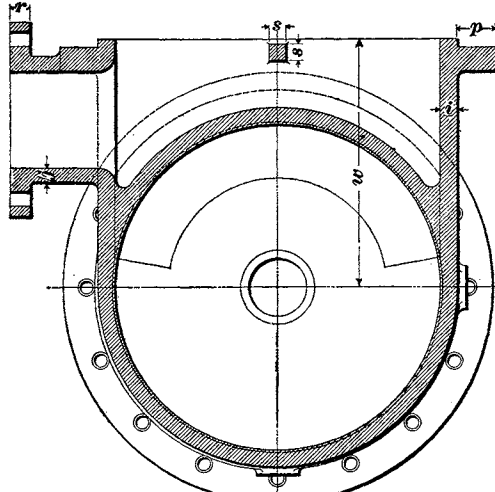
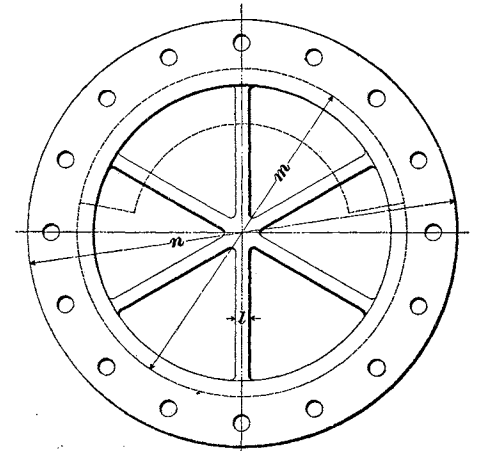
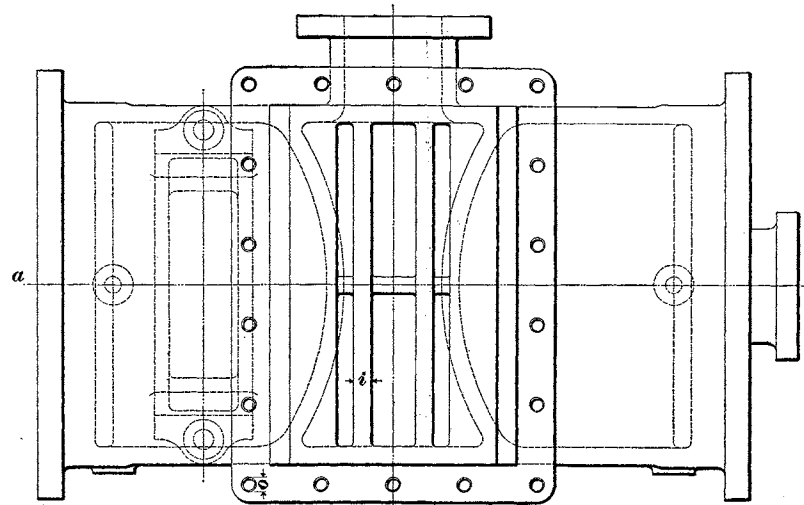
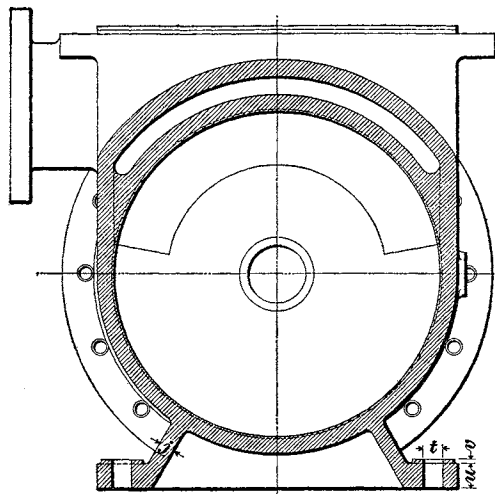
$m = 1.01 D + .125"$.

$n = m + 6 e$, never less. Here e is the nominal diameter of the bolt.

o = the nominal diameter of steam-chest bolts. The net area of a single steam-chest bolt = $\frac{A' P}{4,000 n'}$,

where A' = area of steam chest,
 n' = number of bolts in steam chest.

$p = 2.75 o$.



$$q = 1.5 r.$$

$$r = 1.25 i.$$

$s = i$. This is required only when the length of the port is greater than 12".

$t = 1.25 i$. When D is greater than 24" use 4 bolts in the standard and make $t = 1.1 i$.

$$u = 1.5 i.$$

$$v = .25", \text{ constant.}$$

2083. Steam Ports and Passages.—The dimensions of the *steam ports*, *exhaust ports*, and other steam passages, depend upon the velocity of the flow of steam. The ports and passages must be large enough to allow the steam to follow up the advancing piston without loss of pressure. The maximum allowable velocity of the steam in the passages, when they are short, is about 160 feet per second. But, with the ordinary ratio between the length of connecting-rod and length of crank, the average velocity is about $\frac{2}{3}$ of the maximum. Hence, the allowable average velocities are 100 to 125 feet per second for long and short passages, respectively.

Let l = length of port in inches;

b = breadth of port in inches;

A = area of cylinder;

S = average piston speed in feet per second;

v = average velocity of steam in feet per second.

Then, area of port $\times$ velocity of steam = area of piston $\times$ velocity of piston,

$$\text{or } lbv = AS,$$

$$\text{whence, } lb = \frac{AS}{v}. \quad (294.)$$

Take $v = 100$ for long indirect passages, and 125 for short direct passages.

The constant 100 may be used for v when designing plain slide-valve engines of the ordinary type which cut off late in the stroke, and 125 may be used for high-speed engines with early cut-off, and for the Corliss type.

The area of the exhaust port or ports may be from $1\frac{3}{8}$ to $2\frac{1}{2}$ times the area of a steam port.

The area of the cross-section of the steam pipe is approximately equal to the area of the steam port; likewise, the area of the exhaust pipe should be equal to that of the exhaust port.

The length l of the port may be $.6 D$ to $.9 D$ for slide-valve engines, and about $.9 D$ to D for the Corliss type.

The height w , Fig. 741, of the valve seat must be such that the area of the most contracted part of the exhaust port is not less than 75% of the area of the steam port.

2084. Fig. 742 shows a design for a cylinder having the steam chest cast solid with it. The front head in this

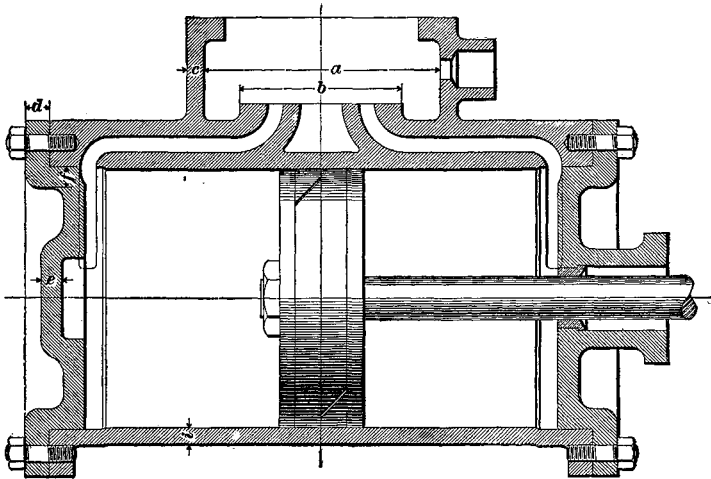


FIG. 742.

case is a separate casting fitted to the cylinder in the same manner as the back head. The heads, which are cast without ribs, are well suited for cylinders of small diameters. For larger diameters, the ribbed heads shown in Fig. 741 are better.

The following proportions apply to Fig. 742:

$$i = .0003 PD + .375''.$$

a = length of valve + travel of valve + twice the clearance between valve and steam chest at ends of valve travel.

b = the valve travel + length of valve $-\frac{1}{4}''$ to $\frac{1}{2}''$.

$$c = i.$$

$$d = 1.5 i.$$

$$e = 1.25 i.$$

$$f = 1.25 i.$$

All other dimensions are to be determined by the proportions given for Fig. 741.

2085. Fig. 743 is a steam chest for the cylinder shown

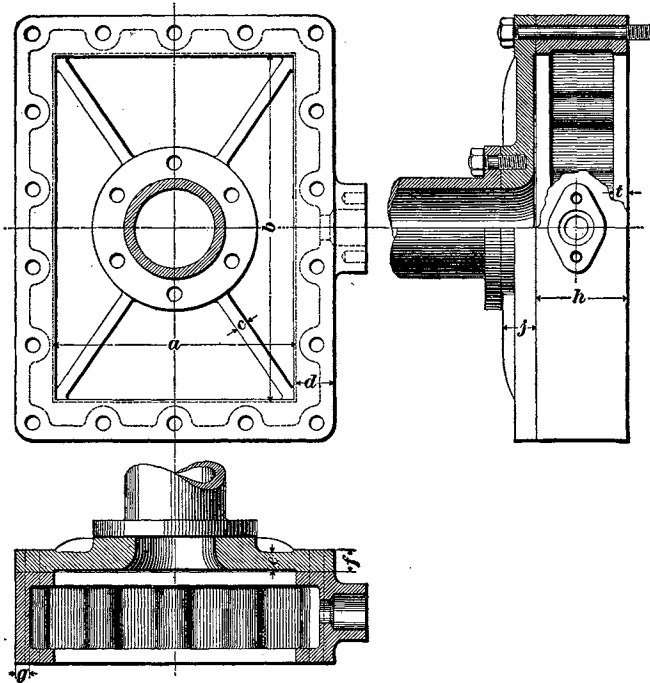


FIG. 743.

in Fig. 741. The principal dimensions are to be determined

by the following proportions, which are based upon the thickness i of the cylinder walls, and upon the travel and dimensions of the valve:

a = length of valve + travel of valve + twice the clearance between the valve and the steam chest at ends of valve travel.

b = breadth of valve + twice the clearance between one end of valve and steam chest.

$c = .75 i$.

$d = 2.75 o$, where o is the nominal diameter of the steam-chest bolts, as in Fig. 741.

$e = .04 \sqrt{A'} + .125''$ for all areas above 100 sq. in. A' = area of steam chest, outside measurement, in square inches.

$f = 1.3 e$.

$g = .85 i$.

h = height of valve + necessary clearance.

$j = 2.5 i$.

$t = .85 i$.

NOTE.—When the area of the steam-chest cover is less than 100 square inches, its thickness e may be equal to i . When the area of the steam-chest cover exceeds 600 square inches, the height of the ribs should be $3.5 i$, and their number should be increased.

2086. Fig. 744 shows a design for a steam-chest cover when the steam-pipe flange is on one side of the steam chest. Determine the thickness e by the same formula and rules as for the cover in Fig. 743. The other dimensions are found as follows:

$c = .75 e$.

$f = 1.3 e$.

$j = 2.6 e$.

$r = 6 e$.

p should never exceed the distance in inches given by the formula $\sqrt{\frac{40 e_1^2}{p_g}}$, where e_1 is the numerator of the fraction expressing the thickness of the cover in sixteenths of an inch, and p_g = gauge boiler pressure.

EXAMPLE.—Find the maximum pitch of the ribs for a cover $\frac{15}{16}$ " thick, subjected to a steam pressure of 160 pounds per square inch.

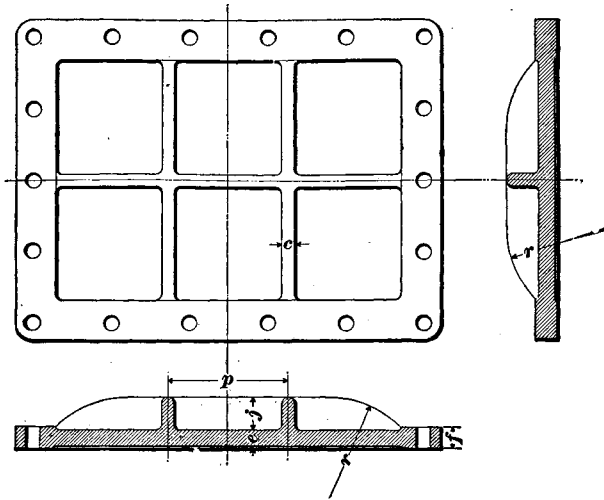


FIG. 744.

SOLUTION.—Substituting in the formula for p , we have

$$p = \sqrt{\frac{40 \times e_1^2}{p_g}} = \sqrt{\frac{40 \times 15^2}{160}} = 7.5 \text{ in. Ans.}$$

2087. Fig. 745 shows a Corliss engine cylinder which may be designed according to the following proportions:

D = diameter of cylinder.	$i = 1.8 e.$
$a = 1.21 D + 2 e + 1.25".$	$j = e.$
$b = .2 D + 1.125".$	$k = 1.2 e.$
$c = .048 D.$	$l = 1.7 x + 2" - 1.2 e,$ where
$c' = .079 D.$	x = diameter of piston
$d = .17 D.$	rod.
$e = .0003 PD + .375",$ if boiler	$l' = .32 D,$ about.
pressure is above 100	$m = .25 D.$
lb.; otherwise, $e =$	$n = .32 D.$
$.03 D + .375".$	$o = 1.25 e.$
$f = .82 e.$	$p = 1.3 e.$
$g = .9 e.$	$q = .25 D.$
$h = b + 2 (c + g).$	$q' = .32 D.$
$h' = h.$	$r = 1.2 e.$

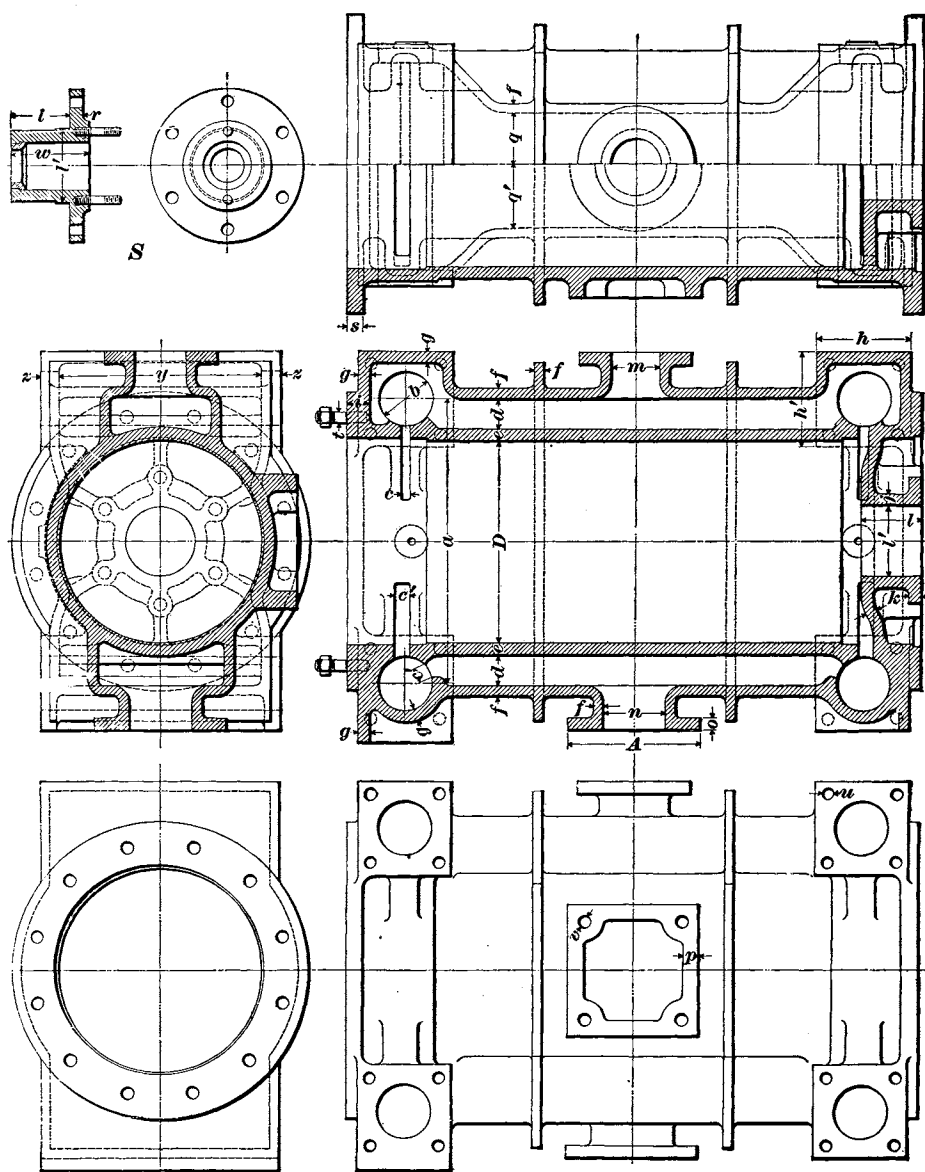


FIG. 745.

$$s = 1.5 e.$$

$$y = D.$$

$$t = (\text{see note}).$$

$$z = 1.5 e.$$

$u = e$, take nearest standard size bolt.

A is to be made according to Table 54, Art. **2072**.

$v = 1.2 e$, take nearest standard size bolt.

Bolts to be made according to the same table.

$w = 1.7 x + 2.25''$, where x = diameter of piston rod.

NOTE.—The bolts for cylinder heads are to be calculated from the formula given for cylinder-head bolts in connection with Fig. 741.

In this cylinder the stuffing-box S is a separate piece that is to be bolted to the cylinder head.

Fig. 746 shows a cylinder head that is suitable for cylin-

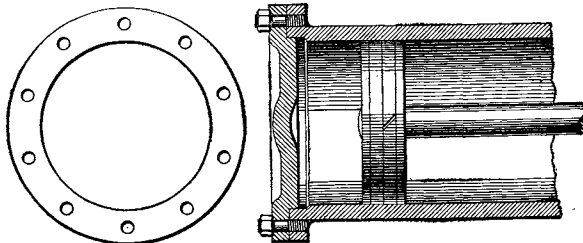


FIG. 746.

ders of small diameter. Its thickness may be the same as the thickness of the cylinder.

CRANK-SHAFTS.

2088. The general methods of computing the dimensions of crank-shafts, given in Arts. **1990** to **1992**, should be used for all important cases, since account is there taken of all the principal stresses.

Several instances have occurred where the shafts of large engines proved failures, because they were calculated from some simple approximate formula, and made too small. In one case a shaft 15 inches in diameter broke, causing great damage; it was found that had it been calculated by the methods given in the above-named articles, the shaft would have been $19\frac{1}{2}$ inches in diameter.

When a series of different sizes of engines of the same type are to be built, however, it may be assumed that they will run under about the same conditions. In such a case it is unnecessary to use the above general method of calculating the crank-shaft, and short empirical formulas may be deduced from the practice of the best makers.

For high-speed automatic short-stroke engines, the following formula corresponds with good practice:

$$d = .44 D + \frac{1}{2}'' , \quad (295.)$$

where d is the diameter of shaft and D = the diameter of cylinders.

For the Corliss type, in which the stroke is equal to or greater than twice the diameter,

$$d = .34 D + 2\frac{1}{2}'' , \quad (296.)$$

when D is equal to or greater than 16 inches. When D is less than 16 inches,

$$d = \frac{1}{2} D. \quad (297.)$$

A solid forged double crank is shown in Fig. 747. The crank, or cranks, are forged in the main shaft, as shown.

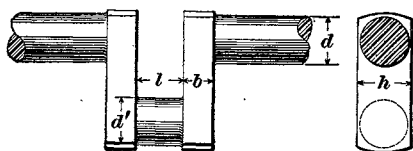


FIG. 747.

The following formula, given by Unwin, may be used to find the diameter of the shaft at journals:

$$d = 4.55 \sqrt[3]{\frac{H}{N}}, \quad (298.)$$

where H is the indicated horsepower, and N the revolutions per minute of shaft.

The proper cross-section $b h$ of the crank web may be obtained from the formula:

$$b h^2 = .9 d^3 \text{ to } d^3. \quad (299.)$$

Usually, $b = .6 d$ to $.8 d$; whence,

$$h = 1.05 d \text{ to } 1.3 d.$$

2089. Crank-Pins.—These are really end journals, and may be calculated by formulas **241** and **242**, Art. **1975**. There is, however, a growing tendency towards larger diameters and smaller ratios between length and diameter. Hence, in modern engine design, the pins are made much larger than mere strength would require.

The diameter of the crank-pin in marine engine practice (see Fig. 747) is made equal to or slightly greater than the diameter of the shaft journal. That is, in Fig. 747,

$$d' = d.$$

In this case the length of the pin subjected to pressure may be,

$$l = 1.1 d.$$

2090. Fig. 748 shows a style of crank much used on

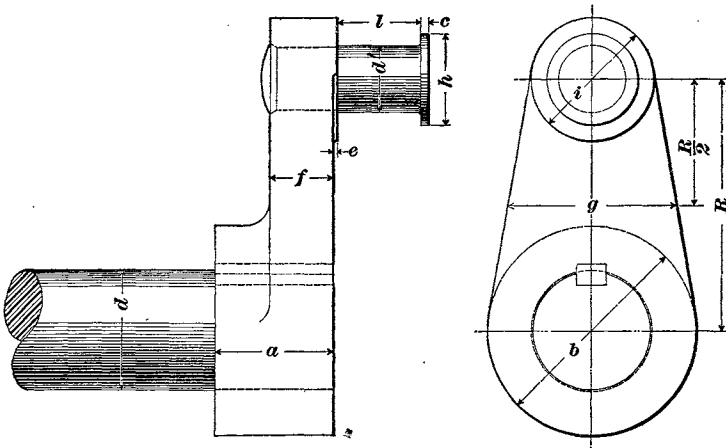


FIG. 748.

slow-speed engines, such as the Corliss type. The dimensions are to be computed by the following proportions:

D = diameter of engine cylinder.	$b = 1.75 d.$
d = diameter of crank-shaft	$c = .045 d + .0625''.$
$= .5 D,$	$d' = .28 D.$
$a = d.$	$e = .25''$, constant.
	$f = .375 g.$

g is found by drawing the lines tangent to i and b .
 $h = 1.35 d'$.
 $i = 1.125 d$.

$l = .26 D + .5''$ for cylinder diameters of 26" or less, and $l = d'$ for cylinder diameters greater than 26".

2091. Modern high-speed engines require counterweighting, and the crank usually takes the form of a disk, as shown in Fig. 749.

The disk is hollowed out, as shown, but a portion of the

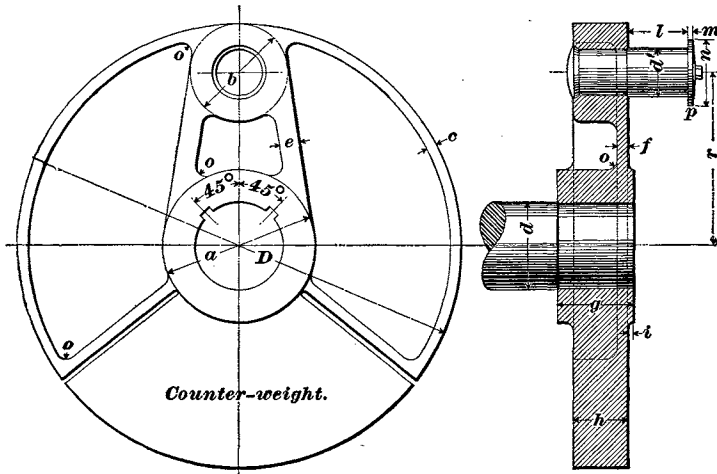


FIG. 749.

material is left in the side opposite the crank-pin, to form the counterweight which, by its centrifugal force, counteracts the centrifugal force resulting from the rotation of the crank-pin and rotating end of connecting-rod. The counterweight is a separate part of the disk proper, it being only cast to the hub a . It is thus made to allow for expansion and contraction of the casting in the larger crank disks. The width of the split is $\frac{3}{4}$ inch for engines of 48-inch stroke or less, and 1 inch for all larger sizes.

The following proportions represent the practice of good engine builders:

The unit is d , the diameter of the crank-shaft.

$$a = 1.75 d.$$

$$g = .875 d.$$

$$b = 1.125 d.$$

$$h = .625 d.$$

$$c = \frac{r}{24} + .5''.$$

$$l = .52 d + 1'' \text{ for cylinder diameters up to } 26'',$$

above that size make

$$d' = .56 d.$$

$$l = d'.$$

$$e = 2c.$$

$$f = c.$$

$$m = .045 d + .0625''.$$

i = should be given such a value that the connecting-rod will have about $\frac{1}{8}''$ clearance.

$$n = 1.35 d'.$$

$$o = c.$$

$$D = 2r + b.$$

NOTE.— p is a plate held to end of pin by tap bolt; o is the radius of all fillets except that of the boss z .

THE PISTON.

2092. Engine pistons are made in a great variety of forms. For small engines, that is, for cylinder diameters less than 8" or 10", the piston is often a solid disk of cast iron.

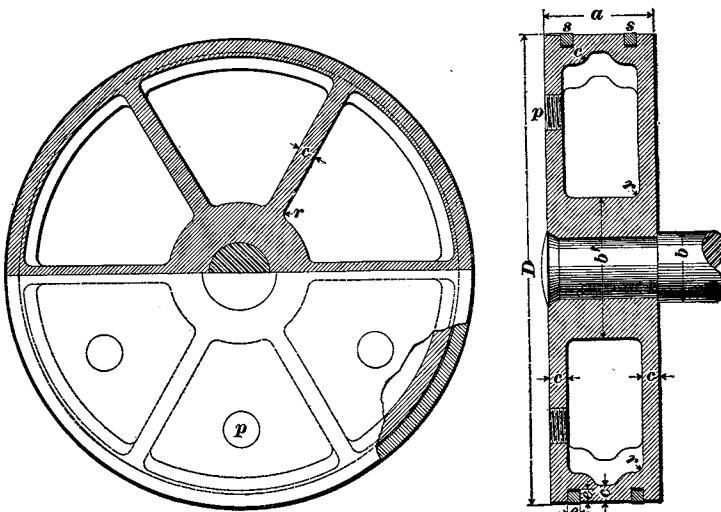


FIG. 750.

The Hollow Piston.—A form of piston that is much used for small engines is shown in Fig. 750. It consists

simply of a hollow circular disk of cast iron. The packing rings s, s are made of cast iron, and are split and sprung into place. Their elasticity causes them to press against the cylinder walls and thus prevent the leakage of steam.

The following proportions will give dimensions suitable for this piston:

D = diameter of cylinder in inches.

$a = .2 D + 1.5''$.

b = diameter of piston rod.

$b' = 2 b$.

$c = .18 \sqrt{2 D} - .1875''$.

$e = .75 c$.

$r = .5 c$.

p = core plug.

Number of ribs = $.08 (D + 34)$.

2093. The Built-Up Piston.—The piston shown in Fig. 751 is made in two parts; the main part A is called the **spider**; the **follower plate** B is bolted to it.

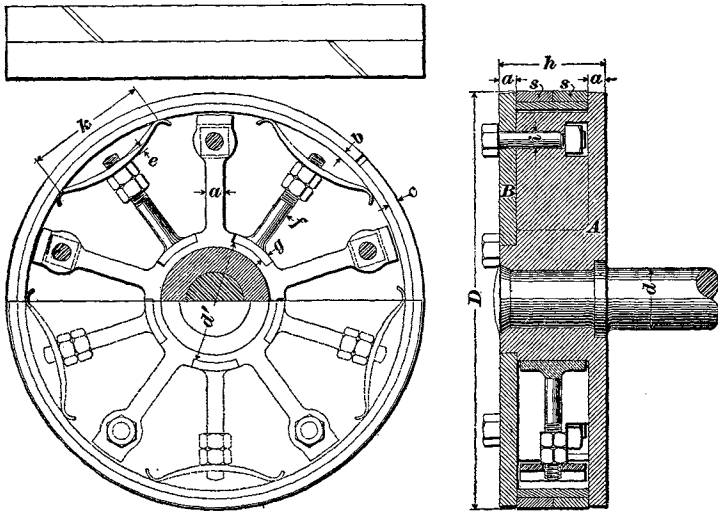


FIG. 751.

The spider is cast hollow, with radiating arms and lugs for the follower-plate bolts z . The split cast-iron **bull ring**

b is placed around the spider and is supported by the steel springs e , which are in turn supported by the brass studs f . The bull ring forms a support for the packing rings s, s .

The dimensions of this piston are given by the following proportions:

D = diameter of cylinder in inches.

$$a = .18 \sqrt{2D} - .1875''.$$

$$g = .5f.$$

$$b = .45a.$$

$$h = .2D + 1.5''.$$

$$c = .65a.$$

$$i = a - .125''.$$

d = diameter of piston rod.

$$k = \frac{1.4D}{n}.$$

$$d' = 2d.$$

$$e = \frac{.06D}{n}.$$

$$n = \text{number of ribs} = .08(D + 34).$$

$$f = a - .125''.$$

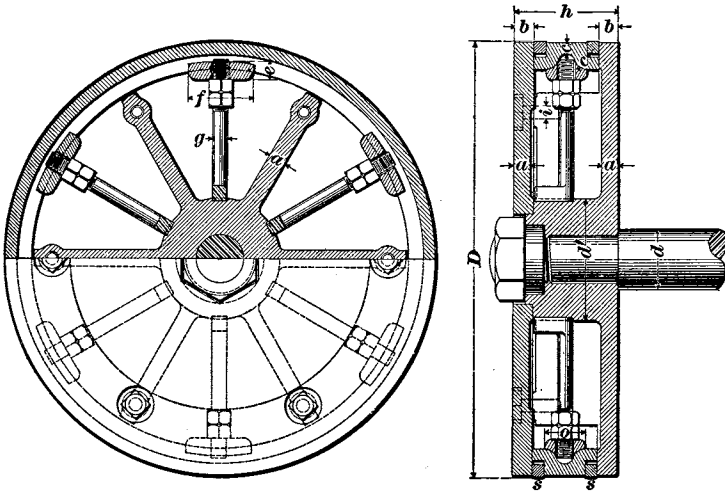


FIG. 752.

2094. Another form of built-up piston is shown in Fig. 752.

The proportions to be used for this piston are:

D = diameter of cylinder in inches.

$$a = .18 \sqrt{2D} - .1875''.$$

d = diameter of piston rod.

$$b = 1.25a.$$

$$d' = 2d.$$

$$c = .75a.$$

$$e = 1.25a.$$

$$f = 3.75 a.$$

$$o = 2.5 a.$$

$$g = a - .125".$$

$$n = \text{number of ribs} = .08 (D + 34).$$

$$h = .2 D + 1.5".$$

$$+ 34).$$

$$i = a - .125".$$

2095. The Solid Piston.—A form of piston much

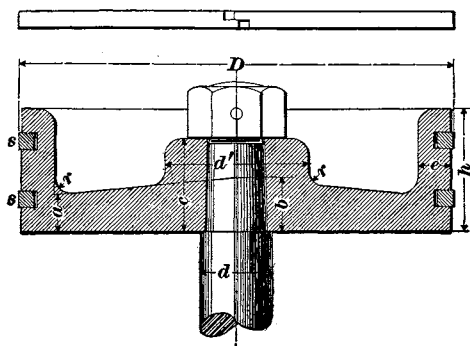


FIG. 753.

used in locomotive practice is shown in Fig. 753. It may be made of cast iron, but is usually a steel casting.

Suitable proportions for a cast-iron piston are:

D = diameter of cylinder in inches.

$$a = .08 D.$$

$$d' = 2 d.$$

$$b = .12 D.$$

$$e = 1.5 (.18 \sqrt{2 D} - .1875").$$

$$c = .15 D + 1.125".$$

$$h = .2 D + 1.5".$$

$$d = \text{diameter of piston rod. } r = .5 e.$$

If it is a steel casting, use the following proportions:

$$a = .05 D.$$

$$d' = 1.75 d.$$

$$b = .075 D.$$

$$e = 1.3 (.18 \sqrt{2 D} - .1875").$$

$$c = .15 D + 1.125".$$

$$h = .2 D + 1.5".$$

$$d = \text{diameter of piston rod. } r = .5 e.$$

Since the piston is solid, the rings must be cut and sprung to place. The form of the cylinder head is made to conform to the piston, so as to make the clearance small.

2096. Fig. 754 shows a steel-casting piston designed for the high-pressure cylinder of a marine engine. The dotted lines show how the cylinder head is made in order to fit closely around the piston. The conical form is given the piston in order to increase its strength.

The following proportions will give suitable dimensions for this piston for cylinders from 7" to 50" in diameter:

D = diameter of high-pressure cylinder in inches.

$a = .1 D + 1.5''$.

$b = \sqrt{20 D} - 7.5''$.

$c = .1 \sqrt{D}$.

d = diameter of piston rod.

$d' = 1.63 d$.

$e = .225 \sqrt{D} + .625''$.

$f = .1 \sqrt{D} + .25''$.

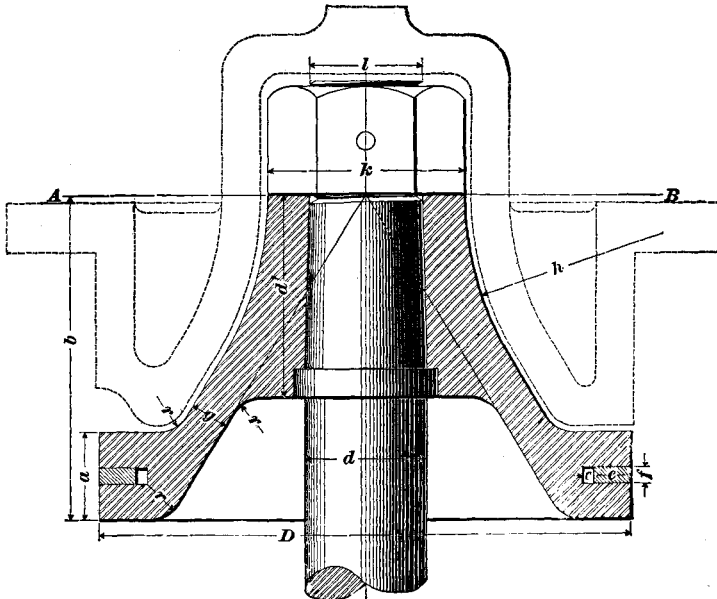


FIG. 754.

$g = .07 D$.

h is to be found by trial with the center on the line $A B$.

$k = 1.73 l + .1875''$.

l = diameter of threaded end of piston rod.

$r = \frac{a - f}{2}$.

A piston suitable for the intermediate and low-pressure cylinders of the engine for which the piston in Fig. 754 is designed is shown in Fig. 755. To compute the dimensions for this piston, take the dimensions $a, b, c, d, d', e, f, k, l$, and r , the same as for the high-pressure piston in Fig. 754. If the engine is compound, let D' represent the diameter of the low-pressure cylinder in inches, and make $s = .02 D'$.

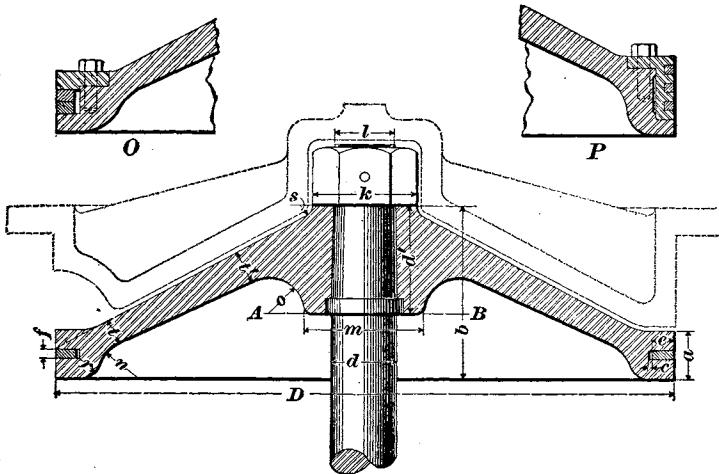


FIG. 755.

If a triple-expansion engine, let D' represent the diameter of the intermediate cylinder, and compute s as before, using the value found for both intermediate and low-pressure pistons. Make the remaining dimensions as follows:

$$m = 1.8 d.$$

n is to be found by trial with the center on the line representing the bottom edge of the piston.

o is to be found by trial with the center on the line AB .

$$\left. \begin{aligned} t &= .2 \sqrt{2 D_1} \\ t' &= .275 \sqrt{2 D_1} \end{aligned} \right\} \text{where } D_1 \text{ is the diameter of the cylinder for which the piston is made.}$$

At O and P , Fig. 755, are shown methods of attaching the packing rings to large pistons in such a way that the

rings may be removed for inspection or repairs without taking the piston out of the cylinder. This is a very important advantage in many cases, especially for marine work, where the pistons are often very heavy, and facilities for handling them poor.

PISTON PACKING.

2097. It is, of course, impossible to turn the piston to exactly fit the cylinder at all temperatures; therefore, the piston is made slightly smaller than the cylinder bore, and some form of packing is used to prevent the steam from leaking through between the piston and cylinder walls.

The simplest and about the best form of packing, particularly for small pistons, is a cast-iron ring shown in cross-section at *s, s*, Figs. 750 and 752. The rings are generally of uniform thickness. Many makers, however, prefer to make the thickness where the rings are cut about half the thickness at the opposite side.

The proportions used for the spring packing rings shown in Figs. 750 and 752 are as follows:

Thickness and depth of rings the same and equal to

$$.135 \sqrt{2D} - .14",$$

where D is the diameter of the cylinder.

At *A* and *C*, Fig. 756, the packing for the pistons shown in Figs. 754 and 755 is shown in detail. In addition to the dimensions given in connection with the pistons, the following proportions are to be used:

$$b = 3". \quad l = 9". \quad t = .0625".$$

Details of the packing shown in the section *O* of Fig. 755 are shown in Fig. 756 at *B* and *D*. The proportions applying here are:

$$b = 3". \quad t = .09375".$$

The length of the segments should be about 15", and two springs are placed behind each segment. The packing rings

shown in Fig. 756 are usually of cast iron, and the springs of steel.

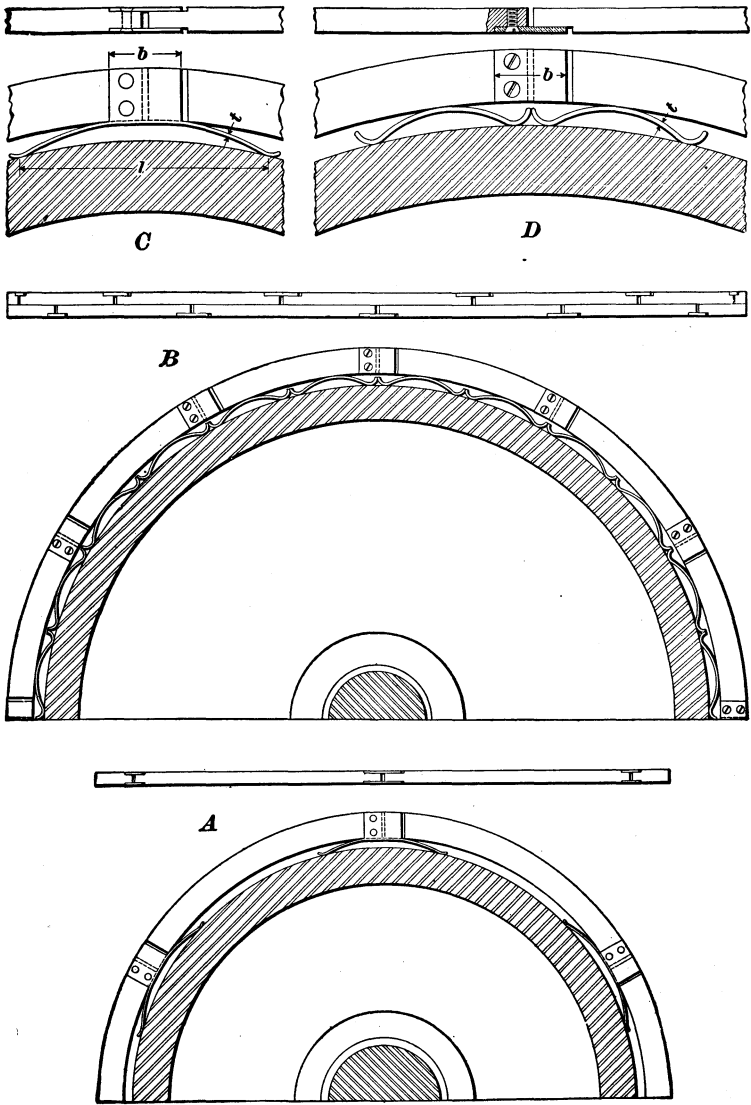


FIG. 756.

2098. Fig. 757 shows Tripp's patent piston packing. The rings S, S are made of cast iron, split so as to spring outwards against the cylinder walls. They are supported by an adjustable ring B , which is made with conical surfaces, and against which the packing rings bear. The pressure of the steam against the packing ring forces it against this conical surface, thus tending to open the ring out and make it press against the cylinder. The spiral springs t, t are for the purpose of holding the packing rings in place when they are not acted on by the steam pressure.

2099. Fig. 758 shows a style of ring packing much used for piston valves. A is a split or sectional cast-iron ring, which is forced out against the walls of the cylindrical valve

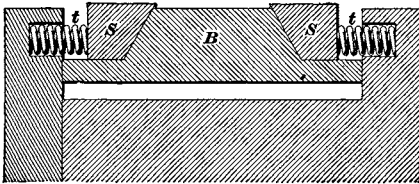


FIG. 757.

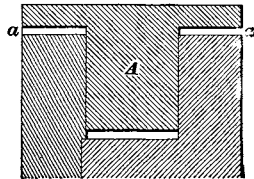


FIG. 758.

seat by the pressure of the steam in the spaces a, a between the overhanging parts of the ring and the main part of the piston or valve.

PISTON RODS.

2100. The piston rod is subjected alternately to tension and compression. If the rod is short in comparison to its diameter, it may be calculated as though simply subjected to tension or compression.

Let d = diameter of rod;

p = greatest pressure per square inch on piston;

D = diameter of cylinder;

l = length of rod;

S = safe crushing strength or tensile strength, whichever may be smaller.

Then, $\frac{1}{4} \pi d^2 S = \frac{1}{4} \pi D^2 p,$

or $d = D \sqrt{\frac{p}{S}}.$

For wrought iron the strength in compression is least, and a safe value for S is 3,600 pounds. For steel the safe strength in tension is least, and S may be taken at about 7,200 pounds. These values give a factor of safety of 10 to 12.

Substituting the value of S ,

$$\left. \begin{aligned} d &= .0167 D \sqrt{p} \quad (\text{wrought iron}); \\ d &= .0118 D \sqrt{p} \quad (\text{steel}). \end{aligned} \right\} \quad (300.)$$

2101. When the length of the piston rod is great in comparison with its diameter, it is liable to buckle, and must be treated as a long column. Therefore, formula **119**, Art. **1411**, may be used in such cases.

A simpler formula may, however, be obtained as follows:

Let P = maximum load on piston rod;

P_0 = load which will just cause the rod to begin to buckle;

k = factor of safety = 10.

The symbols l , d , D , etc., are the same as given above.

E = coefficient of elasticity of material of rod.

$$I = \text{moment of inertia of rod} = \frac{\pi d^4}{64}.$$

According to Weisbach,

$$P_0 = \left(\frac{\pi}{2l} \right)^2 E I.$$

$$\text{Then, } P_0 = 10 P = \left(\frac{\pi}{2l} \right)^2 E I = E \left(\frac{\pi}{2l} \right)^2 \frac{\pi d^4}{64}.$$

But

$$P = \frac{1}{4} \pi D^2 p;$$

$$\text{hence, } P_0 = \frac{10 \pi D^2 p}{4} = E \left(\frac{\pi}{2l} \right)^2 \times \left(\frac{\pi d^4}{64} \right),$$

or

$$d = \sqrt[4]{\frac{640 D^2 l^2 p}{\pi^2 E}}.$$

For wrought iron, take $E = 25,000,000$, and for steel = 30,000,000.

$$\left. \begin{aligned} \text{Then, } d &= .04 \sqrt[4]{D^2 l^2 p}, \text{ for wrought iron;} \\ \text{similarly, } d &= .038 \sqrt[4]{D^2 l^2 p}, \text{ for steel.} \end{aligned} \right\} \quad (301.)$$

2102. For some values of the ratio $\frac{l}{d}$, formulas **300** and **301** should give the same diameter of rod. To determine this ratio, we proceed as follows:

The first of the formulas **301** may be written as follows by squaring both members of the equation:

$$d^2 = .0016 D l \sqrt{p},$$

$$\text{or} \quad d = .0016 D \frac{l}{d} \sqrt{p}.$$

But, from formula **300** for wrought iron,

$$d = .0167 D \sqrt{p}.$$

$$\text{Hence,} \quad .0016 D \frac{l}{d} \sqrt{p} = .0167 D \sqrt{p},$$

$$\text{and} \quad \frac{l}{d} = \frac{.0167}{.0016} = 10\frac{1}{2}, \text{ nearly, for wrought-iron rod.}$$

$$\text{Similarly,} \quad \frac{l}{d} = \frac{.0118}{.038^2} = 8.2, \text{ for steel.}$$

The length l of the rod is known approximately as soon as the cylinder is designed. For calculation, the length should be taken between the points where the rod enters the piston and where it enters the cross-head.

To calculate the diameter of the rod, proceed as follows:

First find the diameter by formula **300**. If the rod is of wrought iron and the ratio $\frac{l}{d}$ (using the value of d just found) is less than $10\frac{1}{2}$, the value of d is correct. If the ratio $\frac{l}{d}$ exceeds $10\frac{1}{2}$, calculate d by formula **301**. The same process is applicable to a steel rod, except that the discriminating ratio is $\frac{l}{d} = 8.2$.

EXAMPLE.—Calculate the diameter of a wrought-iron piston rod 21 inches long, the diameter of the cylinder being 13 inches, and the steam pressure 90 lb.

SOLUTION.—By formula **300**,

$$d = .0167 D \sqrt{p} = .0167 \times 13 \times \sqrt{90} = 2\frac{1}{16}''.$$

Since $\frac{l}{d} = \frac{21}{2\frac{1}{16}}$ is less than $10\frac{1}{2}$, the value found is correct. **Ans.**

Supposing the rod to be of steel, the diameter would be from formula **300**,

$$d = .0118 D \sqrt[4]{p} = .0118 \times 13 \sqrt[4]{90} = 1.46 \text{ inches.}$$

But $\frac{l}{d} = \frac{21}{1.46}$ is greater than 8.2; hence, formula **301** must be used.

$$\begin{aligned} d &= .038 \sqrt[4]{D^2 l^2 p} \\ &= .038 \sqrt[4]{13^2 \times 21^2 \times 90} = 1.934 = 1\frac{15}{16}'' \quad \text{Ans.} \end{aligned}$$

APPROXIMATE FORMULAS FOR PISTON RODS.

2103. In many cases the length of the piston rod is about twice the cylinder diameter; that is, $l = 2 D$. Substitute this value of l in formula **301**, and take $p = 80$ lb.

Then, for wrought iron,

$$d = .04 \sqrt[4]{4 D^4 \times 80} = .169 D = \frac{D}{6}, \text{ nearly.}$$

For steel,

$$d = .038 \sqrt[4]{4 D^4 \times 80} = .161 D = \frac{4}{25} D.$$

Many engine builders thus make the diameter of the piston rod a certain fixed fraction of the cylinder diameter.

This fraction $\left(\frac{d}{D}\right)$ may be as small as $\frac{1}{10}$ in exceptional cases, and in a few instances it may be as large as $\frac{1}{5}$ or $\frac{2}{5}$. In the best modern practice, however, $\frac{d}{D}$ is about $\frac{1}{6}$ or $\frac{1}{4}$.

2104. Connection of Rod to Piston.—Modes of fastening the piston rod to the piston are shown in Figs. 750 to 755. The end of the rod is tapered and threaded to receive a nut, or it is riveted. The taper may vary in different cases from $\frac{1}{24}$ to $\frac{1}{4}$. The cross-section of the rod at root of threads should be such as to give a tensile strength of 5,000 lb. per sq. in. for wrought iron and 7,000 lb. for steel. Letting d_1 = diameter of rod at root of thread,

$$\frac{\pi}{4} d_1^3 \times 5,000 = \frac{\pi}{4} D^3 p \text{ for wrought iron;}$$

$$\frac{\pi}{4} d_1^3 \times 7,000 = \frac{\pi}{4} D^3 p \text{ for steel;}$$

$$\text{Or, } \left. \begin{aligned} d_1 &= .014 D \sqrt{p} \text{ for wrought iron;} \\ d_1 &= .012 D \sqrt{p} \text{ for steel.} \end{aligned} \right\} \quad (302.)$$

The rods with a collar forged on to bear against the piston are much to be preferred for heavy pressures. When the section of a rod is to be reduced it is important, especially for a steel rod, that a liberal fillet be provided, as shown in Fig. 751, so as to leave no sharp corners.

CONNECTING-RODS.

2105. The connecting-rod is subjected to various and severe stresses, the calculation of which is difficult and complicated, and the formulas derived from theoretical considerations are, therefore, somewhat unreliable.

The proportions for connecting-rods given below are based on the results of practical experience of standard engine builders. Fig. 759 shows a style of rod that gives excellent results in stationary work. The cross-head end is forged solid, and cut out for the brasses, which are made without top and bottom flanges on one side, so that they can be slipped into the rod. The brasses are held in place and adjusted by the steel wedge w_1 and the adjusting screws S_1 . The brasses on the cross-head end of connecting-rods are seldom babbitted, as experience shows that it gives unsatisfactory results.

The crank end of the rod is made fork-shaped, so that the brasses can be put on to the crank-pin and then slipped into the rod from the end. If the wrist-pin can not be removed from the cross-head, such a construction must also be used for the cross-head end of the rod. The bolt B , which is turned and fitted in a reamed hole, holds the brasses, which are adjusted by a steel wedge and screws, in the same manner as for the cross-head end. The crank-pin brasses are babbitted, as shown.

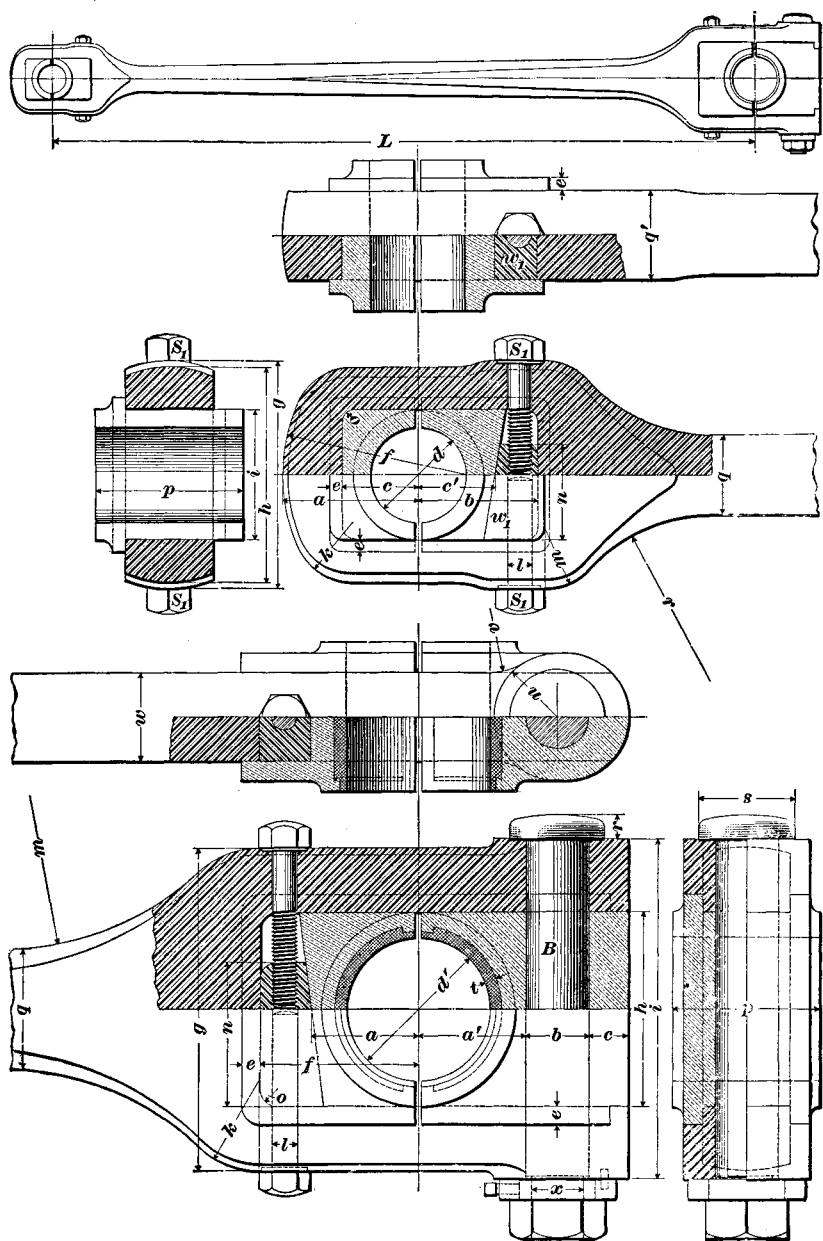


FIG. 759.

The dimensions of this rod are to be made according to the following proportions, which are suitable for a rod of either steel or wrought iron:

For the wrist-pin (cross-head pin) end:

D = diameter of cylinder in inches.

$$d = .2 D = \text{diameter of wrist-pin.} \quad l = .035 D + .25''.$$

$$m = .625 d.$$

$$a = 1.42 d.$$

$$n = d.$$

$$b = 1.125 d + .375''.$$

$$o = .125 d.$$

$$c = .75 d + .125''.$$

$$p = .26 D + .5'' \text{ for cylinders up to } 26'' \text{ in diameter,}$$

$$c' = .75 d + .125''.$$

and $p = .28 D$ for cylinders above $26''$ in diameter.

$$e = .125 d.$$

$$f = 1.92 d.$$

$$g = 2.375 d.$$

$$q = .155 D + .0625''.$$

$$h = 2.25 d.$$

$$q' = .17 D + .0625''.$$

$$i = 1.35 d.$$

$$k = .625 d.$$

$$r = 1.75 d.$$

Taper of adjusting wedges = $1\frac{1}{2}''$ per foot.

For the crank-pin end:

D = diameter of cylinder in inches.

$$d' = .28 D = \text{diameter of crank-pin.} \quad p = .26 D + .5'' \text{ for cylinders up to } 26'' \text{ in diameter,}$$

$$a = .75 d'.$$

and $p = .28 D$ for cylinders above $26''$ in diameter.

$$a' = .75 d'.$$

$$b = .1 D + .4375''.$$

$$c = .625 b.$$

$$q = (.155 D + .0625) \sqrt{\frac{L}{S}}, \text{ in}$$

$$e = .125 d'.$$

which L = length of connecting-rod and S = length of stroke.

$$f = d' + .5''.$$

$$g = 2.25 d'.$$

$$h = 1.35 d'.$$

$$i = 2.375 d'.$$

$$r = .375 b.$$

$$k = .625 d'.$$

$$s = 1.5 b.$$

$$l = .035 D + .25''.$$

$$t = .02 D + .0625''.$$

$$m = 2 d'.$$

$$u = b.$$

$$n = d'.$$

$$v = b.$$

$$o = .125 d'.$$

$$w = .17 D + .0625''.$$

$$x = .8 b.$$

For dimensions of the nut and locking collar, see Art. 1946.

Taper of adjusting wedge, $1\frac{1}{2}''$ per foot.

2106. In Fig. 760 is shown a **strap end** connecting-rod. The straps c_1 and c_2 are fastened to the ends of the rods by means of the gibs a_1 and a_2 and the cotters b_1 and b_2 . The cotters are held in place by the set-screws s_1 and s_2 . Small steel blocks, shown between the ends of the set-screws and the cotters, are used to prevent injury of the cotter by the set-screws.

The rod, cotters, gibs, and straps may be made of either wrought iron or steel. The crank-pin brasses are shown babbitted, and wrist-pin brasses without babbitt. The brasses are adjusted by means of the cotters, which draw the straps farther on to the rod when they are driven in.

The dimensions for the rod shown in Fig. 760 are given by the following proportions:

For wrist-pin end,

D = diameter of cylinder.

d = $.2D$ = diameter of wrist-pin.

n = $.155 D + .0625''$.

$x = \frac{\pi}{4} n^2$ = a factor for use in finding proportions below.

a = $.75 d + .125''$.

a' = $.75 d + .125''$.

b = $\sqrt{2.5 x}$.

c = $.25 b$.

e = $.125 d$.

f = $.26 D + .5''$ for cylinders up to $26''$ in diameter, and f = $.28 D$ for cylinders above $26''$ in diameter.

g = $1.3 n$.

$$h = \frac{.5 x}{g - c}.$$

$$i = \frac{.32 x}{h}.$$

$$k = \frac{x}{1.8 d}.$$

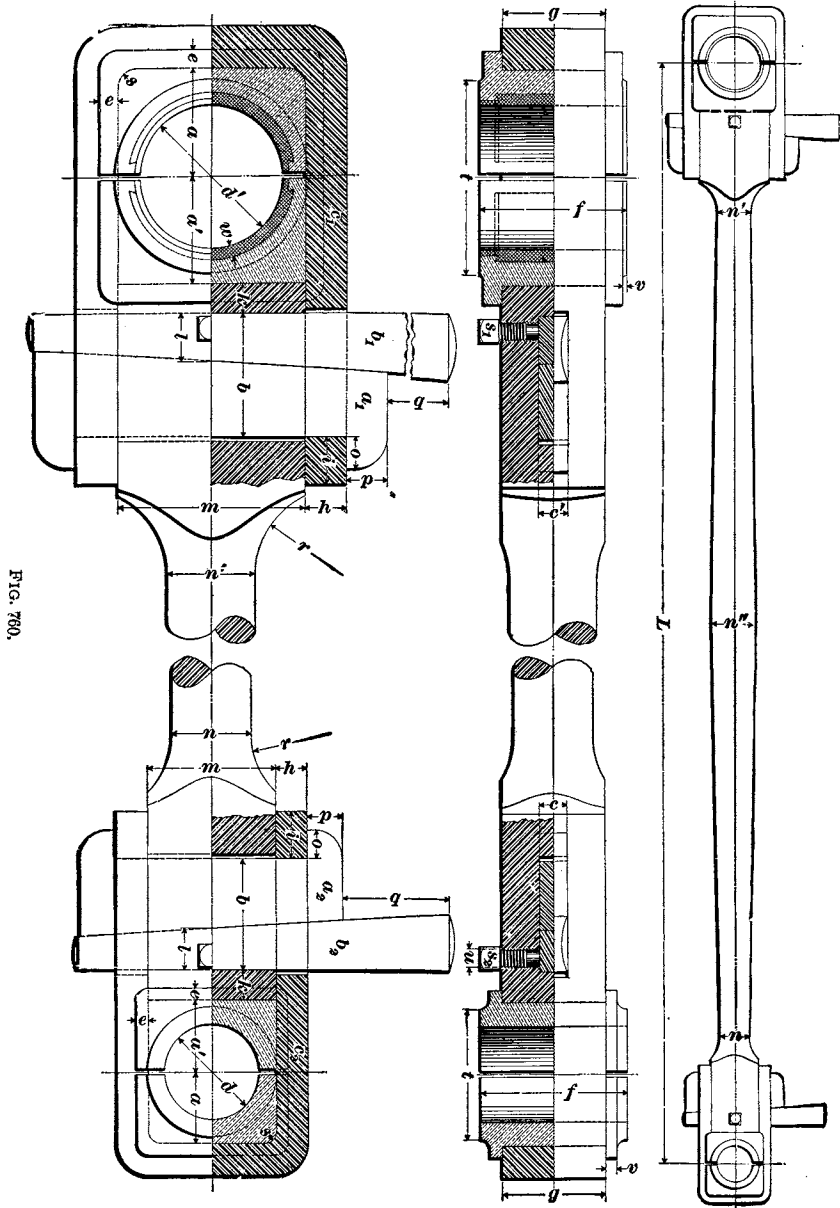
$$l = .375 b.$$

m = $1.35 d$ for wrist-pins up to $3.5''$ in diameter, and m = $1.48 n$ for pins above $3.5''$ in diameter.

$$o = .25 b.$$

$$p = .33 b.$$

q = $1.125 d$ for wrist-pins up to $3.5''$ in diameter, and q = $4''$, constant, for pins above $3.5''$ in diameter.



$$r = n.$$

$$u = .02 D + .25''.$$

$$s = .125 d.$$

$$v = .125 d.$$

$$t = 1.35 d.$$

The taper of the cotter is $\frac{3}{4}''$ per foot.

Proportions for the crank-pin end:

D = diameter of cylinder in inches.

$$d' = .28 D = \text{diameter of crank-pin.} \quad i = \frac{.32 x'}{h}.$$

$$n' = 1.1 n. \quad (n = .155 D + .0625'') \quad k = \frac{x}{1.8 d} = \text{same as wrist-pin end.}$$

$$x' = \frac{\pi}{4} n'^2 = \text{a factor used below.} \quad l = .375 b.$$

$$a = .75 d'.$$

$$m = 1.3 d'.$$

$$a' = .75 d'.$$

$$o = .25 b.$$

$$b = \sqrt{2.5 x'}.$$

$$p = .33 b.$$

$$c' = .25 b.$$

$$q = \text{same values as for wrist-pin end.}$$

$$e = .125 d'.$$

$$r = 1.1 n.$$

$$f = .26 D \text{ for cylinder diameters up to } 26'', \text{ and}$$

$$s = .125 d'.$$

$$f = .28 D \text{ for cylinders above } 26'' \text{ in diameter.}$$

$$t = 1.35 d'.$$

$$v = .125'' \text{ (constant).}$$

$$w = .02 D + .0625''.$$

$$g = 1.3 n = \text{same as wrist-pin end.}$$

$$n'' = n \left(\sqrt{\frac{L}{S}} - .22'' \right), \text{ where}$$

L = length of rod and
 S = stroke, both in inches.

$$h = \frac{.5 x'}{g - c'}.$$

Taper of cotter, $\frac{3}{4}''$ per foot.

2107. Fig. 761 shows a connecting-rod with **marine ends**. For marine engines, and in some cases for stationary engines, the cross-head end is forked as shown. For most stationary work, however, the cross-head end is not forked, and a solid, or strap, end is often used with a marine crank-pin end. The brasses are held to the ends of the rod, which are forged T shaped, by turned bolts. These bolts pass through steel or wrought-iron caps and the brasses. Liners are fitted between the two parts of each brass, and when

the brasses become worn the liners are taken out and either filed or planed down, thus allowing the brasses to be tightened. The crank-pin brasses are babbitted, and the brass is chipped out between the babbitt blocks, so that there will be bearing only on the babbitt. This is common practice in marine work, but is seldom done in stationary work.

The liners in the crank-pin end are secured by small pins p_1 , which pass through the liner and project into the holes h_1 , shown in the view of the brass given at A . B is a view of one of the wrist-pin brasses. The rod and caps are usually made of steel, although wrought iron may be used.

The dimensions for the rod shown in Fig. 761 are to be determined by the following proportions:

$a = \sqrt{.0004 AP}$, where A = area of piston and P = the boiler pressure.

$a' = a \left(\sqrt{\frac{L}{S}} - .05'' \right)$, where L = length of rod and S = stroke.

$b = 1.3 d$.

$b' = .6 a$.

$b'' = .5 a'$.

$c = .7 a$.

$c' = .7 a$.

d = diameter of cross-pin.

$d' = 1.1 d$.

$e = .25 d$.

$f = .35 c$.

$g = 1.4 c$.

h = area of bolts at bottom of thread = $.00008 AP$ for steel and $.0001 AP$ for wrought iron, where A = area of cylinder and P = boiler pressure.

$i = 1.5 h$.

$j = h$.

$h' = .875 h$.

$h'' = h$.

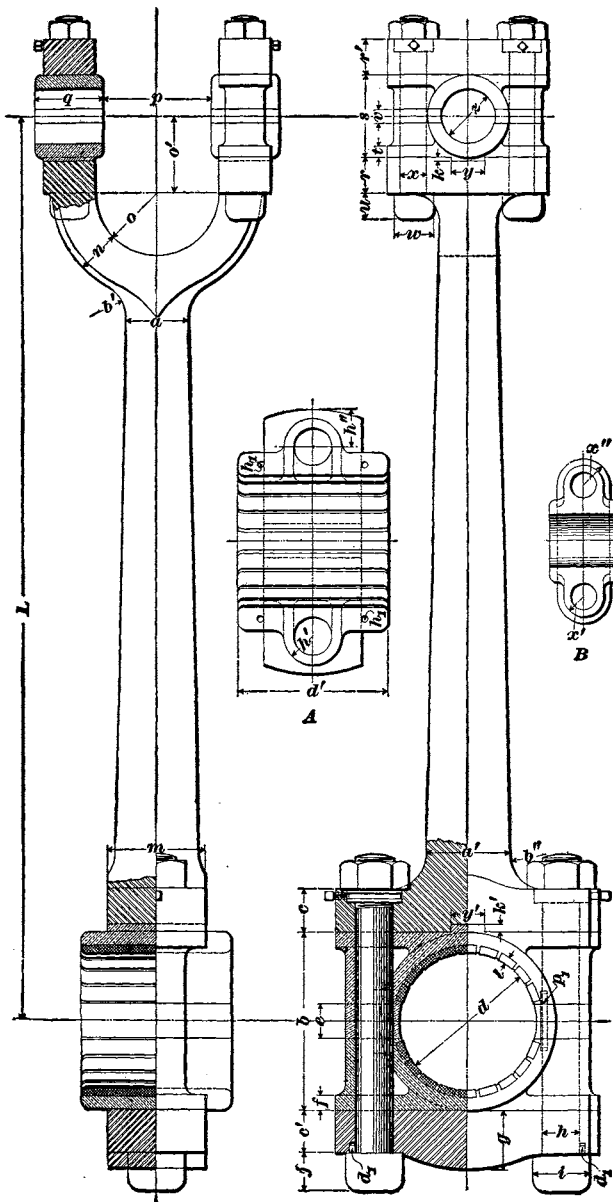


FIG. 761.

$$k = .05 z + .0625''.$$

$$l = .05 d + .0625''.$$

$$k' = l.$$

$$m = 1.1 a'.$$

$$n = .7 a.$$

$$o = .5 p + .5 (q - 2 x).$$

$$o' = .6 a + .675 z.$$

p to fit cross-head, i. e., $2 B + .25''$, where B = diameter of piston rod.

q = length of wrist-pin as made for cross-head.

$$r = .6 a.$$

$$r' = .6 a.$$

$$s = 1.35 z.$$

$$t = .35 r.$$

$$u = x.$$

$$v = .25 z.$$

$$w = 1.5 x.$$

$x = .00004 AP$ for steel, and $.00005 AP$ for wrought iron.

$$y = .25 d.$$

$$y' = .25 d.$$

z = diameter of wrist-pin as made for cross-head, Fig. 763.

$$x' = .875 x.$$

$$x'' = x.$$

NOTE.— x and h should be taken as the diameter of the nearest larger size of bolt, and the diameter of that bolt should be used as the unit where proportions are given in terms of x or h .

This rod may be used with the cross-head shown in Fig. 763. If the rod is used for a compound or triple-expansion engine, design it for the cylinder that does the most work, and make the rods alike for all cylinders. The same rule applies to the cross-head.

Proportions for locknuts to be made as shown in Art. 1946. The dowel-pins d_1 are used to keep the bolt from turning with the nut.

The distance between the bolts should be such that the brass will be about $\frac{1}{4}$ inch thick at the thinnest part between the bolt and the pin.

CROSS-HEADS.

2108. The **cross-head pin** is a simple neck journal supported at the ends and loaded at the middle. It may, therefore, be designed by the rules given under the head of journals.

Cross-heads are made in a great variety of forms, some of the most important of which, together with proportions for their design, are given below. Fig. 762 shows a cross-head much used on Corliss and similar engines. It is composed of a cast-iron box with a boss for the piston rod, and bosses for the wrist-pin. The wrist-pin is steel or wrought iron, with the ends turned tapering so as to fit snugly into the cross-head. It is held by a nut and washer, and has a projecting part y which is drilled for an oil cup. Holes are drilled into the pin, as shown by the dotted lines, for the purpose of leading oil to the connecting-rod brasses.

Boss gibs g_1 are fitted to the cross-head on tapered ways, and these gibs can be adjusted by means of the bolts t_1 . The gibs shown on the cross-head have cylindrical bearing surfaces, but a gib is shown at A with the bearing surface V shaped. The guides are made either cylindrical or V shaped, to correspond to the gibs.

The following proportions give dimensions for designing the cross-head shown in Fig. 762:

D = diameter of cylinder.

d = diameter of piston rod.

a must be found by making a scale drawing of the connecting-rod in its extreme position. Care must be taken that the rod will clear the gibs, and also the guides, for all positions.

$c = 2.125 d$.

$d' = 2 d$.

$d'' = 2.125 d$.

$e = .01 D + .5'$.

$e' = e$.

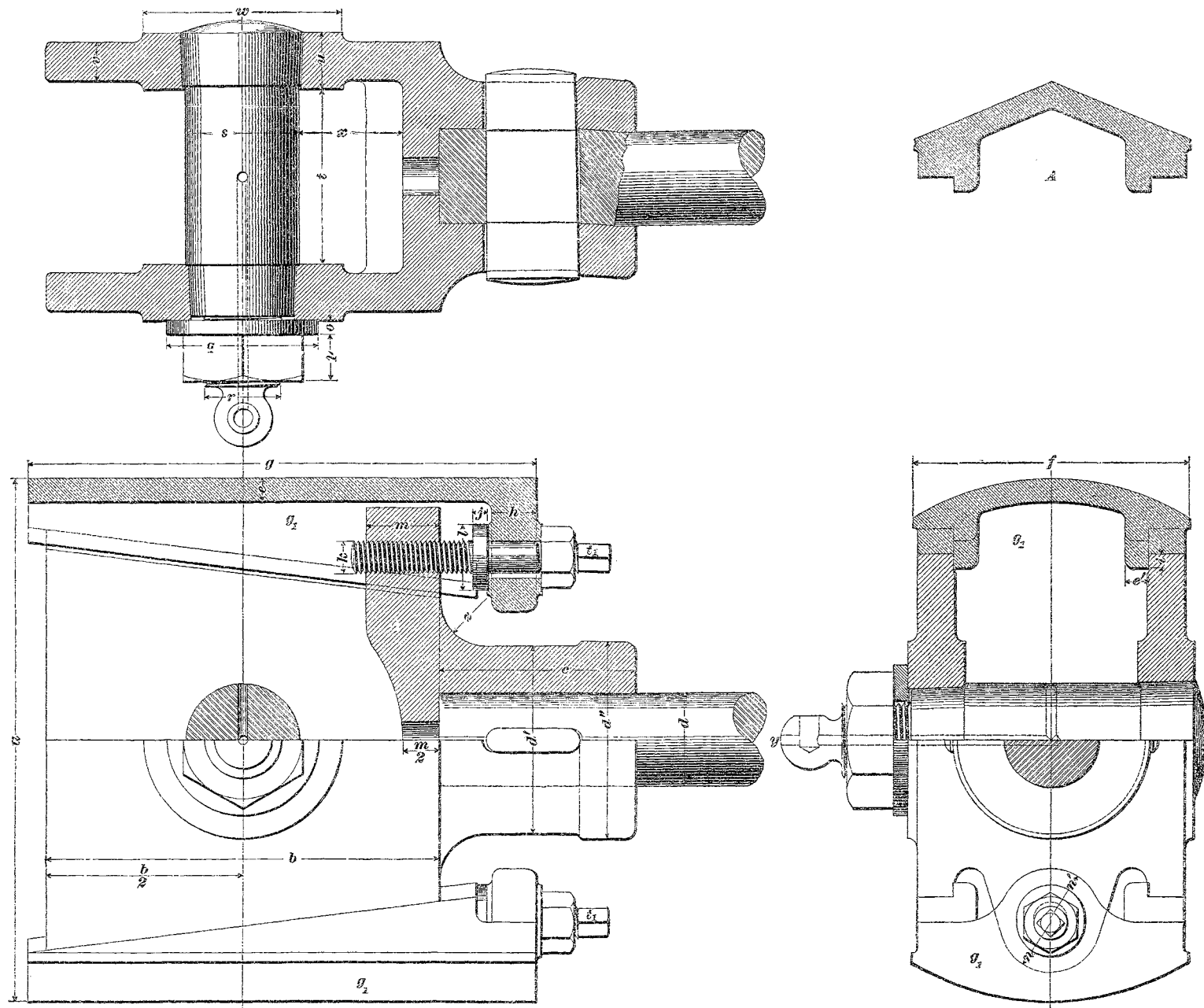


FIG. 702.

$f = .357 D + 1.625''$ for cylinders up to 26" in diameter,
and $f = .376 D + 1''$ for cylinders larger than 26"
in diameter.

$g = 3 s + .225 D + 1.375''$.

$h = .04 D + .5625''$.

$i = .6 e$.

$j = .015 D + .125''$.

$k = .04 D + .3125''$.

$l = .08 D + .625''$.

$m = .12 D + .125''$.

$n = .06 D + 5''$.

$n' = n$.

$o = .19 r$.

$p = .625 r$.

$q = 2.125 r$.

$r = .66 s$.

$s = .2 D$.

$t = .26 D + .5''$ for cylinders up to 26" in diameter,
and $t = .28 D$ for cylinders above 26" in diame-
ter.

$u = .05 D + .625''$.

$v = .043 D + .3125''$.

$w = 1.75 s$.

$x = s$.

y = plug for oil hole.

$z = .5 d$.

Taper of gibs 1.5" per foot.

For cylinders above 20" in diameter the gibs should be ribbed.

This cross-head is designed to be used with a solid-end connecting-rod; see Fig. 759.

2109. Fig. 763 shows a style of cross-head used mostly for marine work. The wrist-pin is in two parts a_1, a_1 , forged solid with the block b_1 , which is of either wrought iron or steel. This cross-head requires a forked-end connecting-rod similar to that shown in Fig. 761. The bearing surfaces are composed of two cast-iron shoes fastened to the block by

bolts. These shoes are babbitted, the babbitt being dovetailed into and raised a little above the surface of the iron.

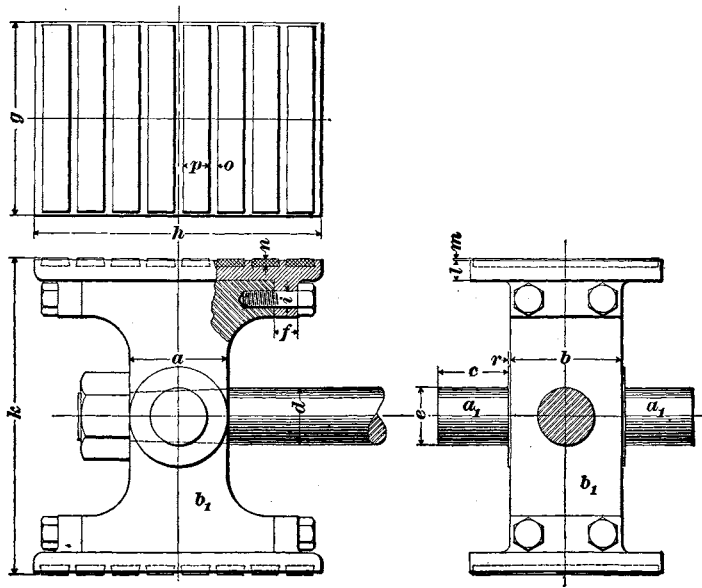


FIG. 763.

so that no wear will come directly on the iron. The piston rod is tapered in the block and fastened with a nut.

The dimensions of this cross-head are based on the following proportions:

D = diameter of cylinder.

d = diameter of piston rod.

$a = 1.75 d$.

$b = 2 d$.

$c = \sqrt{.0005 A P}$.

$e = .8 \sqrt{.0005 A P}$.

A = area of piston in square inches.

P = boiler pressure in pounds per sq. in.

$f = .05 D + .5"$.

$g = .66 \sqrt{\frac{.035 A P C}{L}}$.

$$h = \sqrt{\frac{.035 A P C}{L}}$$

C = length of crank in inches.

L = length of connecting-rod in inches.

$i = \frac{3}{4}"$ for $D = 15"$ or less; $\frac{7}{8}"$ for $D =$ from $15"$ to $20"$;
 $1"$ for $D =$ from $20"$ to $25"$, and $1\frac{1}{4}"$ for D above
 $25"$.

k must be such that the connecting-rod will clear cross-head and guides.

$l = .05 D + .25"$.

$m = .125"$, constant.

$n = .016 D = .1875"$.

$o = .5"$, about.

$p = 1.75"$, about.

$r = .125"$, constant.

2110. Fig. 764 shows a modification of the marine

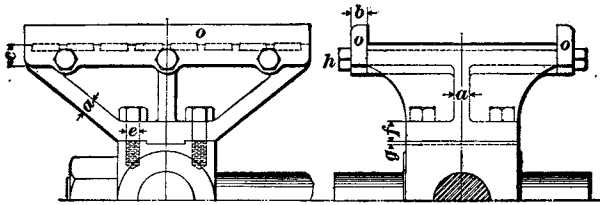


FIG. 764.

cross-head, in which the cast-iron shoe forms a much larger proportion, and is provided with guiding strips o , o .

The proportions that apply to this form are;

$$a = .03 D + .5"$$

$$b = .03 D + .5"$$

$$c = .05 D + .5"$$

$$e = \frac{7}{8}" \text{ up to } D = 20"; 1" \text{ up to } D = 25", \text{ and } 1\frac{1}{4}" \text{ for } D \text{ above } 25".$$

$$f = .05 D + .5"$$

$$g = .02 D.$$

$$h = \frac{3}{4}" \text{ for } D = 20" \text{ or less; } \frac{7}{8}" \text{ for } D = 20" \text{ to } 25", \text{ and } 1" \text{ for } D \text{ above } 25" \text{ in diameter. Space bolts } h \text{ not more than } 7" \text{ between centers.}$$

The other dimensions of this style of cross-head may be obtained from the proportions given for Fig. 763.

The shoes for the cross-heads, Figs. 763 and 764, are adjusted by placing liners behind them.

2111. Fig. 765 is an example of a cross-head that is much used on box-bed engines. The main part *A* is of cast

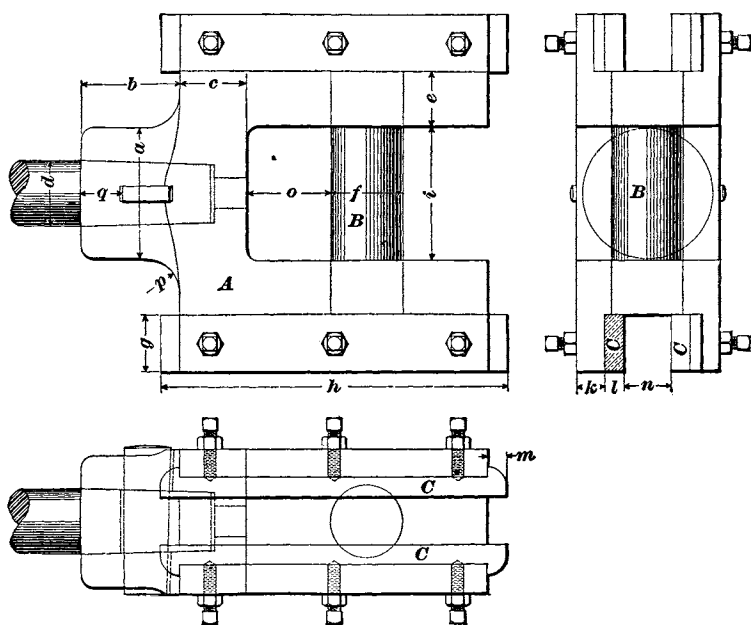


FIG. 765.

iron, with a boss for the end of the piston rod, which is secured by means of a cotter. The wrist-pin *B* is either wrought iron or steel, forced into the cross-head. Brass or bronze gibs *C* that are adjustable by means of the set-screws furnish the surfaces that bear on the guides.

Proportions for the cotter are to be taken from Art. 1968, and the other proportions are as follows:

D = diameter of cylinder.	C = length of crank in inches.
d = diameter of piston rod.	
$a = 2d$.	L = length of connecting-rod in inches.
$b = 1.5d$.	
$c = d$.	$i = .26D + .5$.
$e = .75f$.	$k = .075D$.
$f = .2D$.	$l = \frac{h}{18}$.
$g = \frac{h}{6}$.	$m = l$.
$h = \sqrt{\frac{PAC}{16.5L}}$.	n = thickness of guides.
P = boiler pressure.	o = space required to clear connecting-rod.
A = area of piston in square inches.	$p = .5d$.
	$q = .75d$.

Set-screws may be $\frac{3}{8}$ " for cylinders up to 8" in diameter; $\frac{7}{16}$ " for cylinders from 8" to 12" diameter, and $\frac{1}{2}$ " for all sizes above. Use two set-screws for cylinders up to 8" in diameter, and three for larger cylinders. The above proportions are suitable for cylinders up to 16" in diameter.

VALVES, VALVE STEMS, ECCENTRIC-RODS.

2112. The motion of the slide valve has been fully described under the subjects of Steam and Steam Engines, and Applied Mechanics. Hence, it is only necessary here to give the proportions of the various parts. Two sections of a slide valve are shown in Fig. 766.

First, take the design of the valve seat. The width b and length l of steam port are obtained from formula **294**, Art.

2083. The width of the bridges c , c between the ports is usually made equal to the thickness of the cylinder walls. The width of the exhaust port is, as before stated, from $1\frac{3}{4}$ to $2\frac{1}{2}$ times the width of the steam port. In any given case the exhaust port must be wide enough so that when the valve is at the end of its travel (see Fig. 249, Art. **1238**,) the width of the portion of exhaust port remaining open is at least equal to the width of the steam port.

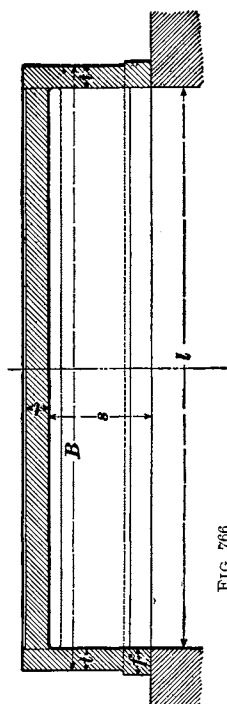


FIG. 766.

Let a = width of exhaust port;

b = width of steam port;

c = width of bridge;

k = half of travel of valve.

Then, in order that the above condition may be fulfilled, a should be equal to or greater than $b + k + i - c$.

Let i = inside lap;

o = outside lap.

Then, in Fig. 766, $h = a + 2(c - i)$.

$$e = b + i + o.$$

$$L = h + 2e = a + 2c + 2b + 2o.$$

$$B = l + 2t.$$

When the valve at the end of its travel just opens the steam port fully,

$$k = b + o.$$

The height s of the hollow underneath the valve must be sufficient to allow a free exhaust. For low piston speeds, s may be made equal to or slightly greater than the width b of the steam port; that is, $s = b$. More often, $s = \frac{3}{4}a$ to a , where a is the width of the exhaust port.

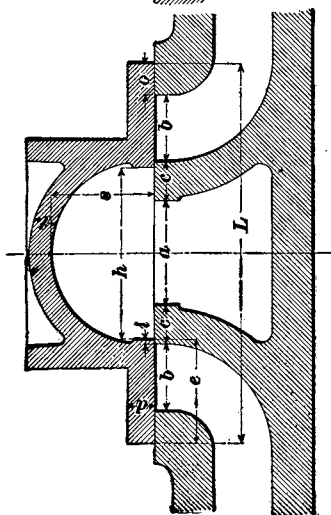
Also, d may be $1.2t$,

and f may be $1.1t$.

The thickness t of the metal of the valve equals

$t = .03D + .25"$ (cast iron),
where D is the cylinder diameter in inches.

The lead, lap, valve travel, etc., are readily determined from the valve diagram; see Arts. 1621, etc.



These quantities, in addition to the proportions given above, furnish sufficient data to design a plain slide valve. The above proportions and formulas may be readily applied to the design of more complicated forms of slide valves, such as the Allen valve, double-ported valve, piston valve, etc.

2113. The **valve stem** must be designed to move the valve under the most unfavorable conditions that may occur in practice; hence, we may assume that the valve is unbalanced, for, even if balanced, the joint may leak.

Further, the valve may run dry upon the seat, thus increasing the coefficient of friction.

Let L = length of valve; (See Fig. 766.)

B = breadth of valve;

f = coefficient of friction;

p = pressure on back of valve which may be taken as the boiler pressure;

d = diameter of valve stem.

Then, the load which the valve stem must move equals $f p B L$ pounds.

Under the most unfavorable circumstances f should not exceed $\frac{1}{5}$, or .20 (when the valve is properly lubricated, $f = \frac{1}{20}$ to $\frac{1}{16}$). For designing purposes, assume $f = \frac{1}{4}$, or .25. Then, the load on the valve stem is

$$\frac{p B L}{4} \text{ pounds.}$$

The valve stem is really a long column alternately in tension and compression; but, since under all ordinary circumstances, the load is very much less than given above, it will be safe to treat it simply as a rod in tension, and use a low value for the safe stress, S .

We then have

$$\frac{p B L}{4} = \frac{\pi d^3}{4} S,$$

or

$$d = \sqrt[3]{\frac{p B L}{\pi S}}.$$

The following proportions will give the proper dimensions:

$$a = \sqrt{\frac{.21 b d^2}{h}}.$$

b = dimension to fit valve.

$$c = .375 d.$$

d = diameter of valve stem in inches.

$$e = .5 d.$$

$$f = .75 a.$$

$$g = .5 d.$$

h = dimension to fit valve.

2115. Two other methods are shown in Fig. 768. At

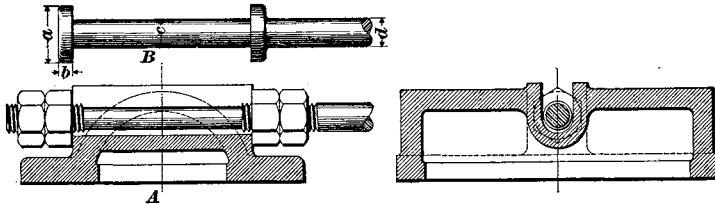


FIG. 768.

B the valve stem is forged with two collars, and at A the end of the stem is threaded for two sets of nuts.

This allows the valve to adjust itself more or less, and thus prevents the stuffing-box from wearing. The arrangement at B also furnishes a means for setting the valve so as to get the proper location over the ports.

The proportions for the valve-stem fastening shown in Fig. 768 are:

$$c = d.$$

$$b = .5 d.$$

$$a = 2 d.$$

$$d = \text{diameter of valve stem.}$$

The outer end of the valve stem may terminate in some form of cross-head running in guides (see Fig. 299, Art. 1308), or it may be jointed to a rocker-shaft, as shown in Fig. 242, Art. 1226.

2116. Eccentric-rods may be rectangular or circular in cross-section. Quite often the rod is tapered, being largest where it joins the eccentric strap. It is a common practice to make the area of the smallest section of the rod equal to

about .8 the area of cross-section of valve stem, the latter being calculated from formula **303**.

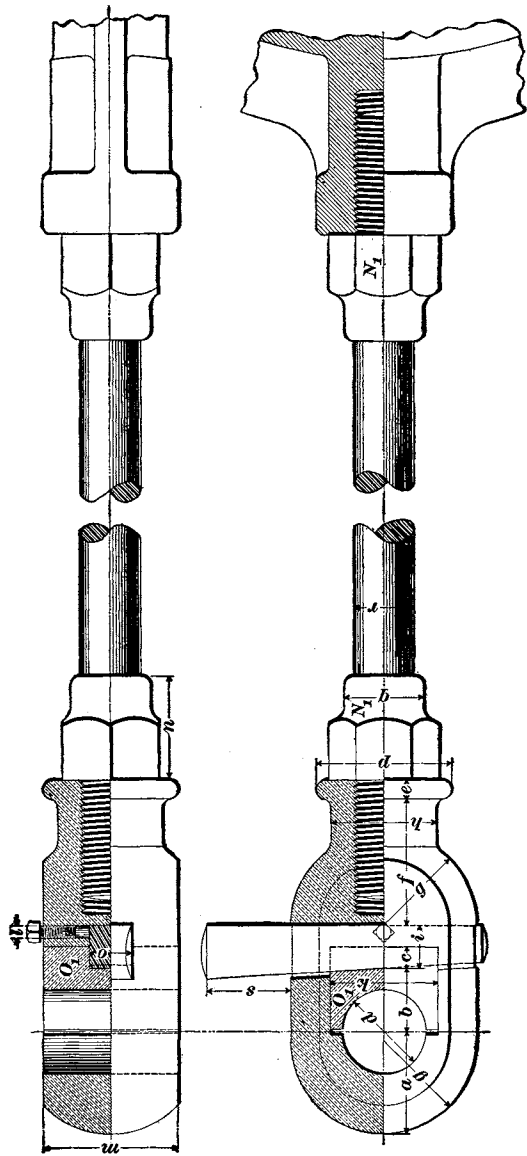


FIG. 769.

The area at the large end may then be made about $\frac{1}{3}$ larger than the area at the small end.

The end of the eccentric-rod that joins the valve stem is often forked, as shown in Fig. 642, Art. 1955. In such cases the proportions given on the figure may be used.

Fig. 769 shows an eccentric-rod with right and left threaded ends, one of which is attached to the eccentric strap, and the other to a brass bearing for connecting to the valve-rod pin or rocker-arm pin. The threaded ends of the rod furnish means for adjusting the valve, and the locknuts N_1, N_2 prevent the rod from turning after the valve is properly set.

The brass has a loose piece O_1 which is adjustable by means of the cotter, thus furnishing means of taking up wear.

The following proportions will give the dimensions for this rod and its brass:

D = Diameter of valve stem.

$d = 1.77 D.$	$k = 1.3 d.$
$a = 1.2 d.$	$l = .25 D,$ but never less
$b = .75 d.$	than $.25''.$
$c = .25 d.$	$m = 1.6 d.$
$e = .3 r.$	$n = 1.75 r.$
$f = 1.75 d.$	$q = 1.3 r.$
$g = 1.1 d.$	r to be designed as a long
$h = 1.75 r.$	column.
$i = .25 d + .25 D + .1875'',$	$s = d.$
but never less than	
$.25 d + .4375''.$	

Taper of cotter = $\frac{3}{4}''$ per foot.

2117. Fig. 770 shows an eccentric-rod with a modification of the marine end for the valve-stem pin bearing. The rod passes through a boss on the eccentric strap, and is fastened by the two nuts. This construction admits of adjusting the valve when necessary. The bearing for the valve-stem pin is composed of two brass seats that are held in place by a wrought-iron cap, and the stud bolts; liners

are placed between the end of the rod and the cap; the brasses may be adjusted by filing.

The proportions for this rod, and of the boss for fastening it to the eccentric strap, are as follows:

D = diameter of valve stem.

$d = 1.77 D.$

$j = d.$

$a = d + f + .375''.$

$k = 1.6 d.$

$b = 1.25 d.$

l = diameter of eccentric-rod at eccentric end.

$c = 1.5 d.$

$m = 2.1 l.$

$e = 1.5 d + .1875''.$

f = area at root of thread $n = .75 D.$

$= .38 D^2.$

$o = 3 l.$

$g = .5 i.$

$p = 1.5 D.$

$h = 1.5 d.$

$s = .125 d.$

$i = 3.5 f + d + .375''.$

Determine the diameter of the rod by treating it as a long column.

ECCENTRIC SHEAVES AND STRAPS.

2118. Fig. 771 shows a design for an eccentric, with a cast-iron sheave and a steel strap, that is especially adapted for vertical engines. The sheave is made in two parts, so that it can be readily put on or removed from the shaft without disturbing fly-wheels or bearings. In some cases this is necessary, owing to the construction of the shaft, which will not permit an eccentric to be slipped into place over the end. The end of the eccentric-rod is forged T shaped, and fastened to the strap by tap bolts.

The two halves of the strap are held apart by liners, which permit of adjustment for wear. Split pins are put through the holes in the ends of the bolts n to keep the nuts from turning off.

The following proportions give the necessary dimensions for this eccentric:

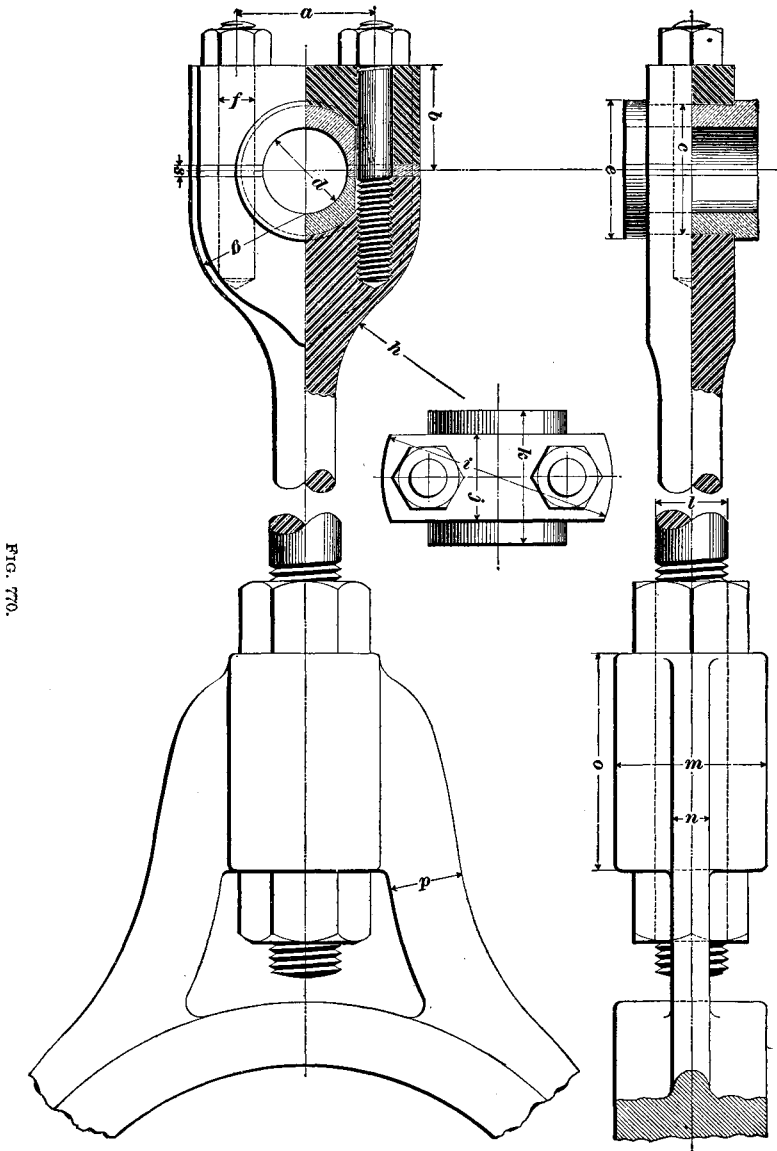
D = diameter of valve stem.

d = diameter of shaft.

$b = 2.5 n$ at least, but never

$a = d + 2k + 2f$, never less.

less than w .



$$b' = b + .5 c.$$

$$c = .6 D + .375".$$

$$e = .25 c.$$

$$f = .7 D + .5", \text{ unless more is required to allow nuts to be placed on stud } m.$$

$$g = .6 D + .375".$$

$$k = \text{eccentricity.}$$

$$l = .75 \text{ of diameter of bolt } m.$$

$$\text{Area of bolt } m \text{ at root of thread} = .38 D^2; \text{ use nearest standard size of bolt.}$$

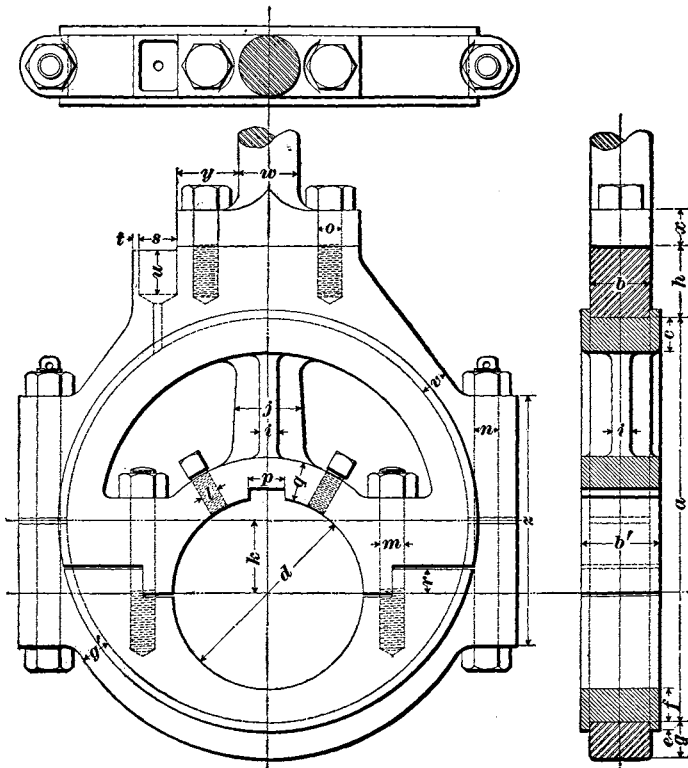


FIG. 771.

$$g' = .5 D + .25".$$

$$h = 3 o.$$

$$i = .5 c.$$

$$j = 2 c.$$

$$n = \text{diameter of bolt } m.$$

$$o = \text{diameter of bolt } m.$$

$$p = .7 D + .5".$$

$$q = .7 D + .5".$$

$$r = .125 d.$$

$$s = D.$$

$$t = .25", \text{ constant.}$$

$$u = 1.25 D.$$

$$v = .5 D + .25".$$

w = diameter of eccentric-rod.

$$x = .6 w.$$

$$y = 2.5 o.$$

z is to be found by laying out. The bolt n should clear the eccentric sheave by $\frac{1}{4}"$ on all sizes up to $D = 1\frac{1}{2}"$; $\frac{3}{8}"$ for sizes of D from $1\frac{1}{2}"$ to $2"$, and $\frac{1}{2}"$ for all sizes above $D = 2"$.

2119. In Fig. 772 the eccentric sheave and strap are both made of cast iron. The eccentric sheave is cast solid,

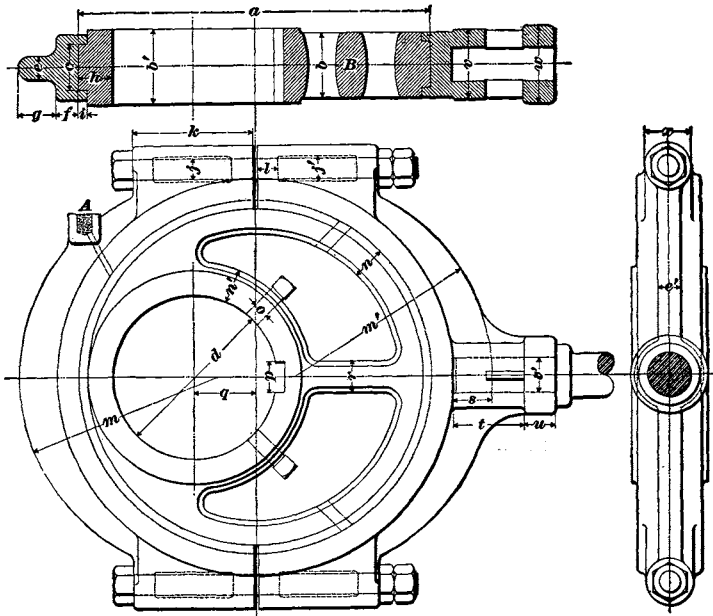


FIG. 772.

and must, therefore, be slipped over the end of the shaft. The eccentric-rod is held in a boss on the strap by means of a cotter.

It will be seen that in this case the strap is grooved for the sheave, while in Fig. 771 the groove is in the sheave. The construction which places the groove in the strap has the advantage of retaining the oil better.

For eccentrics used with valve stems $\frac{1}{2}$ " in diameter or less the holes for bolts j are not to be cored.

A = boss for oil cup.

B = cross-section of rib r .

The proportions are as follows:

D = diameter of valve stem.

d = diameter of shaft.

$l = j$.

$a = d + 2q + 2h$.

$m = \frac{d + 2q + 2h + 2f}{2}$.

$b = 2D + .125$ ".

$b' = 2.25D + .125$ ".

$m' = m$.

$c = 1.5D$.

$n = D + .125$ ".

$e = .75D$.

$n' = D + .125$ ".

$e' = .75D$.

$o = .75j$.

$f = .7D$.

$p = D$.

$g = 1.25D$.

q = eccentricity.

$h = D + .125$ ".

$r = D$.

$i = .25D + .0625$ ".

$s = 1.25D$.

j = area of bolt at root of thread = $.38 D^2$; use the nearest standard size bolt.

$t = 2.25D + 1.25$ ".

$u = D$.

$v = 2.25D$.

$v' = 1.125D$.

$j' = j + .1875$ ".

$w = 2.5D$.

$k = 4D$.

$x = 2.25j$.

STUFFING-BOXES.

2120. A stuffing-box of the ordinary form is shown in

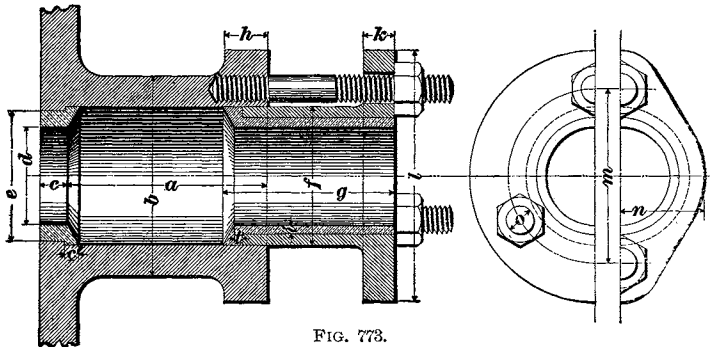


FIG. 773.

Fig. 773. The gland may be made of brass, of cast iron lined with brass, or simply of cast iron.

The brass lining, however, injures the rod less than the harder iron. The gland is usually held in place by two stud bolts, but for large rods the gland is sometimes made circular instead of oval, and fastened by three or more studs.

The proportions used for a gland of the form shown are:

d = diameter of rod.

$a = 1.6d + 1.5''$.

$b = 1.75d + 1.125''$.

$c = .1d + .75''$.

$c' = .5c$.

$e = 1.25d + .375''$.

$f = 1.25d + .625''$.

$g = 1.5d + 1''$.

$h = .3d + .5''$.

$i = .04d + .1875''$.

$k = .25d + .25''$.

$l = 2.25d + 1.75''$.

$m = 1.6d + 1.25''$.

$n = .75d + .375''$.

$o = .25d + .25''$ for two bolts.

$= .2d + .25''$ for three bolts.

$= .05d + 1.0625''$ for four bolts.

$t = i$.

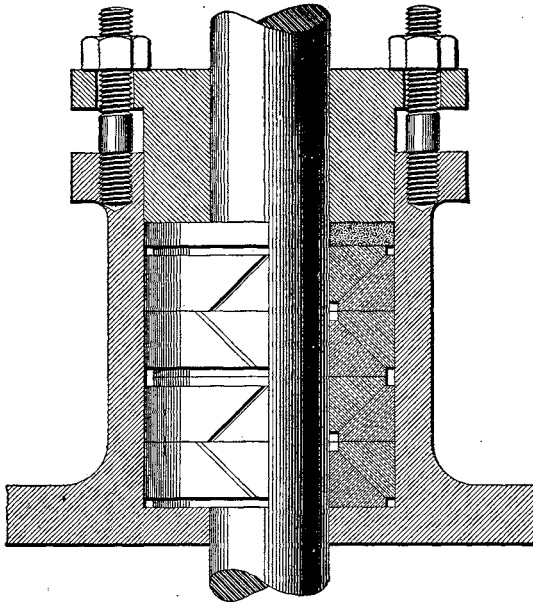


FIG. 774.

Use two bolts for glands on rods up to 3.5 inches in diameter; above that size make gland round, and use three bolts

for rods up to 5.5" in diameter, and four bolts for all larger sizes.

2121. For very high steam pressures various styles of metallic piston and packing are used. One of the best of these is Katzenstine's, shown in Fig. 774.

The construction of the stuffing-box and gland for this packing is very similar to the form shown in Fig. 773, but the packing is made up of rings of brass or similar anti-friction metal. These rings are made in two or more segments, depending on the size of the rod; by reason of their conical shape, the pressure of the gland forces the inner ones against the rod, while the outer ones are pressed against the sides of the stuffing-box. A rubber or fibrous ring placed between the gland and the first ring serves as a cushion to make the packing slightly elastic.

2122. A stuffing-box of the form shown in Fig. 775 is

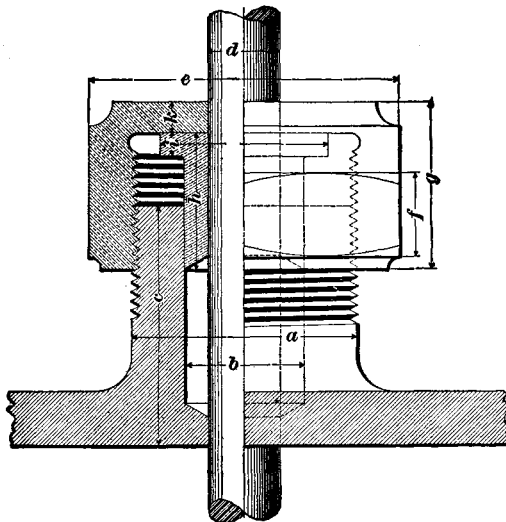


FIG. 775.

generally used for small work, such as the spindles of valves, etc. The outside of the stuffing-box is threaded to receive a hexagonal nut which fits over the gland. As the nut is

screwed down, the gland is pressed downwards and compresses the packing.

The proportions used are:

d = diameter of rod.

$a = 2.5 d + .5''$.

$g = 2 d + .25''$.

$b = 1.5 d + .125''$.

$h = 1.5 d + .25''$.

$c = 3 d + .25''$.

$i = .25 d + .0625''$.

$e = 3.5 d + .625''$.

$k = .5 d$.

$f = d + .125''$.

This design may be used for rods up to $1\frac{1}{4}''$ diameter.

Make the number of threads per inch the same as for a bolt whose diameter is equal to the diameter of the rod.

ENGINE FLY-WHEELS.

2123. Fly-wheels are subjected to a variety of complicated stresses. It is therefore difficult to base the design upon theory alone, and reliance must be placed upon empirical rules representing successful practice.

First, consider a fly-wheel which is intended merely to equalize the turning moment, and which does not carry a driving belt. The weight of the rim for any given case may be found from formula **107**, Art. **1328**. Then, knowing the diameter of the wheel, it is easy to find the required cross-section.

Let W = required weight of rim in pounds;

D = mean diameter of rim in inches ;

w = weight of material per cubic inch;

A = area of cross-section in square inches.

Then,

$$W = \pi D A w,$$

or

$$A = \frac{W}{\pi D w}.$$

For example, assume in the problem given in Art. **1328** that the fly-wheel is 12 feet in diameter; since the rim is required to weigh 5,288 pounds, the cross-section of the rim must be

$$A = \frac{W}{\pi D w} = \frac{5,288}{3.1416 \times 144 \times .261} = 44.7 \text{ sq. in.}$$

Fly-wheels of this type usually have rims of rectangular section, the depth being from 1.1 to 1.4 times the breadth.

The usual form of the rims is shown in Fig. 776. The only precaution necessary in designing such a rim is to limit the

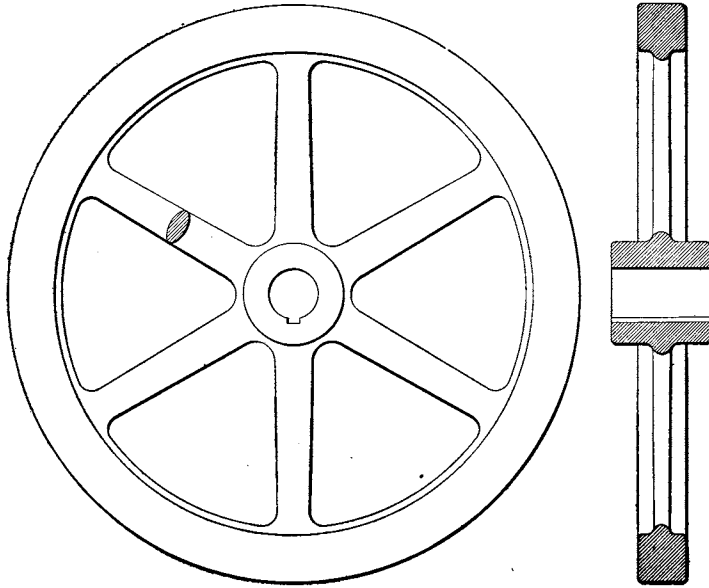


FIG. 776.

velocity to a safe value. The maximum allowable rim speed is usually taken at a mile per minute = 88 feet per second. Occasionally this may run as high as 100 feet per second.

The arm of a fly-wheel is subjected to the following straining forces:

1. The centrifugal force due to the rim.

2. A transverse pull at certain points of the stroke; for example, when the crank effort is less than the resistance, the rim is retarded (see Art. **1327**) and gives up energy to help turn the shaft. This energy must be transmitted through the arms.

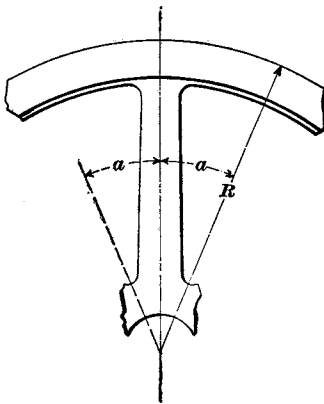


FIG. 777.

3. If the fly-wheel carries a belt, the belt pull is, of course, transmitted through the arms.

Suppose the wheel to be made in sections, each section containing one arm.

Let W_1 = weight of one section of rim;

W_2 = weight of one arm;

R = outer radius of wheel in feet;

r = outer radius of wheel in inches;

v = velocity of rim in feet per second;

w = angular velocity;

h = distance in feet from center of wheel to center of gravity of section of rim;

n = number of arms;

α = half the angle subtended by section of rim (see Fig. 777).

The centrifugal force due to one section of the rim is

$$F = \frac{W_1 h w^2}{g}.$$

According to Weisbach,

$$h = \frac{R n \sin \alpha}{\pi}, \text{ very nearly.}$$

Also, $w = \frac{v}{R}.$

Substituting these values of h and W , the centrifugal force of the section of the rim is

$$\frac{W_1 h w^2}{g} = \frac{W_1 n v^2 \sin \alpha}{\pi g R} \text{ pounds.}$$

The center of gravity of the arm may be taken as $\frac{1}{2} R$ from the center, and the velocity of this center of gravity is, therefore, $\frac{1}{2} v$. Consequently, the centrifugal force due to the arm is

$$\frac{W_2 (\frac{1}{2} v)^2}{g \times \frac{1}{2} R} = \frac{W_2 v^2}{2 g R}.$$

To these stresses must be added the weights of the section and arm, as they exert a pull when hanging vertically downwards. The direct tension on each arm is, therefore,

$$T = \frac{W_1 n v^2 \sin a}{\pi g R} + \frac{W_2 v^2}{2 g R} + W_1 + W_2. \quad (a)$$

NOTE.—The general formula for centrifugal force is $F = \frac{m v^2}{R}$, when m = the mass of the revolving body, v = the velocity of the center of gravity in feet per second, and R = radius to center of gravity in feet. This may be easily changed to correspond with formula 19, Art. 903, as follows:

$$m = \frac{W}{g}; \quad N = \frac{60 v}{2 \pi R}, \text{ or } v = \frac{2 \pi R N}{60}.$$

Substituting in the above formula,

$$\frac{W}{g R} \times \left(\frac{2 \pi R N}{60} \right)^2 = .00034 W R N^2.$$

The term **angular velocity** is applied to the result obtained by dividing the circumferential velocity by the radius; hence, $w = \frac{v}{R}$.

Therefore, if h = radius to center of gravity in feet,

$$F = \frac{m v^2}{h} = \frac{m v^2}{h} \times \frac{h}{h} = m h \frac{v^2}{h^3} = m h \left(\frac{v}{h} \right)^2 = m h w^2 = \frac{W h w^2}{g}.$$

To take account of the second of the straining actions above mentioned, we may proceed as follows:

From a crank-effort diagram, such as is shown in Fig. 315, Art. 1327, the greatest difference between the crank effort and the constant resistance may be found. For example, in Fig. 315, this difference is represented by the ordinate $A M$ or $B N$. *Multiply this pressure, expressed in pounds, by the area of the cylinder and by the diameter of the fly-wheel (in feet), and divide by the stroke in feet. This will give the equivalent pull at the ends of the arms. Call it P_1 . Then, the bending moment on one arm is*

$$\frac{P_1 r}{n} \text{ inch-pounds.}$$

In a similar manner, if the fly-wheel is belted, the pull of the belt is found from the formula

$$P_2 = \frac{63,025 H}{r n} \text{ (see formula 231, Art. 1963),}$$

and the moment on each arm is

$$\frac{P_2 r}{n} \text{ inch-pounds. Let } P_1 + P_2 = P_0.$$

Then, in accordance with formula 116, Art. 1398,

$$\frac{P_2 r}{n} + \frac{P_1 r}{n} = \frac{(P_2 + P_1) r}{n} = \frac{P_0 r}{n} = \frac{S_4 I}{c}, \quad (b)$$

where S_4 = safe transverse strength, and I = moment of inertia, etc.

Let A = area of cross-section of arm.

Then, the stress on the arm due to direct tension is, from equation (a),

$$S_1 = \frac{T}{A},$$

from equation (b),
$$S_4 = \frac{P_0 r c}{n I}.$$

$S_1 + S_4$ must not exceed a safe value, k .

$$\text{Adding,} \quad S_1 + S_4 = \frac{T}{A} + \frac{P_0 r c}{n I} = k. \quad (304.)$$

This formula may be used for finding the arm dimensions of a wheel cast in sections. If, however, the rim is cast solid, the centrifugal force developed is chiefly borne by the rim itself, and the expression $\frac{T}{A}$ may be dropped. In this case,

$$k = \frac{P_0 r c}{n I},$$

$$\text{or} \quad \frac{I}{c} = \frac{P_0 r}{n}. \quad (305.)$$

The value of $\frac{I}{c}$ for the desired section may be found from the Table of Moments of Inertia.

An example will best show the application of formula **304**. Take a fly-wheel 18 feet in diameter, with 8 arms. The wheel is in sections. The cross-section of the rim is 60 square inches. There is no belt, but the stress induced by acceleration of the rim is 9,000 pounds at the rim; that is, $P_1 = 9,000$ pounds. The rim runs at a speed of 70 feet per second. It is required to design the arms, which are to be rectangular in cross-section.

Each section contains $\frac{1}{8}$ of the rim, and, therefore, it weighs $\frac{3.1416 \times 18 \times 12 \times 60 \times .261}{8} = 1,328$ lb. (approximately). For the present leave the arm out of consideration.

Then, the direct tension on the arm due to centrifugal force is, from equation (a),

$$T = \frac{W_1 n v^2 \sin \alpha}{\pi g R} + W_1 = \frac{1,328 \times 8 \times 70^2 \times \sin 22\frac{1}{2}^\circ}{\pi \times 32.16 \times 9} + 1,328 = 23,236 \text{ lb.}$$

Using a safe stress of 3,000 lb. per sq. in., the cross-section of the arm must be, to withstand this tension,

$$\frac{23,236}{3,000} = 7\frac{3}{4} \text{ sq. in.}$$

In reality, this cross-section must be largely increased to provide for the bending force at the ends of the arms. Assume that the final section may be double that given above, or $2 \times 7\frac{3}{4} = 15\frac{1}{2}$ sq. in. Then, the weight of the arm is

$$15\frac{1}{2} \times 108 \times .261 = 437 \text{ lb.} = W_2,$$

and
$$\frac{W_2 v^2}{2 g R} + W_2 = \frac{437 \times 70^2}{64.32 \times 9} + 437 = 4,136 \text{ lb.}$$

Then,
$$T = 23,236 + 4,136 = 27,372 \text{ lb.}$$

For the stress k , take 3,000 lb. per sq. in.

From formula **304**,

$$\frac{T}{A} + \frac{P_0 r c}{n I} = k, \text{ or } \frac{27,372}{A} + \frac{9,000 \times 108}{8} \frac{c}{I} = 3,000.$$

From the Table of Moments of Inertia,

$$A = b d, \text{ and } \frac{c}{I} = \frac{6}{b d^3}.$$

Let $b = .4 d$; then, $A = .4 d^2$, and $\frac{c}{I} = \frac{15}{d^3}$.

$$\text{Hence, } \frac{27,372}{.4 d^2} + \frac{9,000 \times 108 \times 15}{8 d^3} = 3,000;$$

$$\text{or } \frac{68,430}{d^2} + \frac{1,822,500}{d^3} = 3,000.$$

It will be found that a value of $d = 9\frac{1}{2}$ inches, nearly, satisfies the equation. Hence, take $d = 9\frac{1}{2}"$ and $b = 9.5 \times .4 = 3.8 = 3\frac{3}{4}"$.

The area of the cross-section from these dimensions might now be used to give more accurately the centrifugal force of the arm. It would make little difference in the final result, however.

2124. Construction of Fly-Wheels.—Fly-wheels of small diameter are usually cast solid; the arms are of oval cross-section, and the wheel has the general appearance of a belt pulley with a heavy rectangular rim (see Fig. 776).

A heavy fly-wheel with oval arms is shown in Fig. 778. This wheel is built in four sections, with two arms to each section, and in addition the hub is formed of two separate rings that are bolted and keyed to the segments forming the inner ends of each pair of arms. The segments of the rim are joined by means of steel or wrought-iron rings R which are shrunk on to bosses formed by recesses cast in the rim. Besides these rings, bolts B pass through lugs on the inner surface of the rim. In order that the wheel may be amply strong, the net section of the bolt and two rings must be sufficient to withstand the action of centrifugal force tending to separate the rim through the section which they join. The bolts and keys joining the inner ends of

the arms to the hub are in double shear, and must be calculated to withstand the centrifugal force due to the arms and rim plus the force necessary to retard or accelerate the rim.

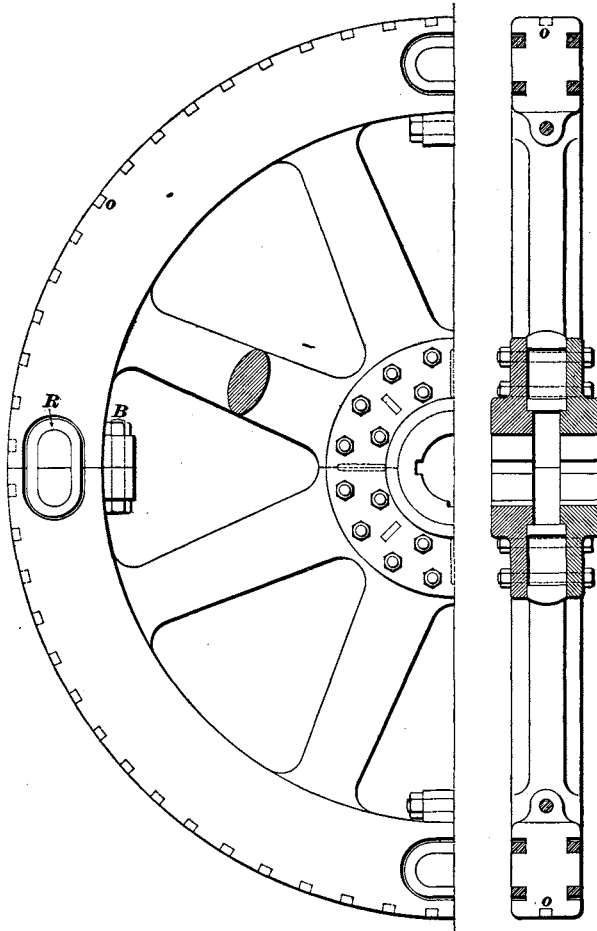


FIG. 778.

2125. Fig. 779 shows a fly-wheel with the face of the rim turned to serve as a belt pulley. The arms are oval in

section and cast hollow, thus giving them increased stiffness for a given weight. The rim is also given a channel-shaped section, which increases its ability to withstand the bending

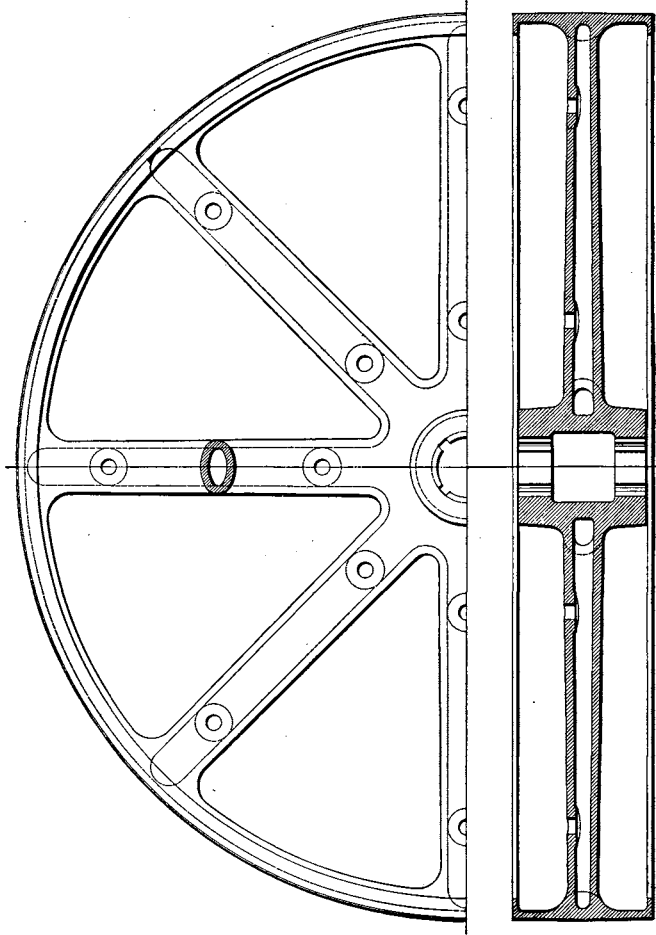


FIG. 779.

stresses produced by centrifugal force in the sections between the arms.

2126. Fig. 780 is a fly-wheel of large diameter, with the face of the rim turned for a belt. This wheel has ten

arms, and the rim is cast in ten segments that are bolted together by means of flanges on the inner surface. The

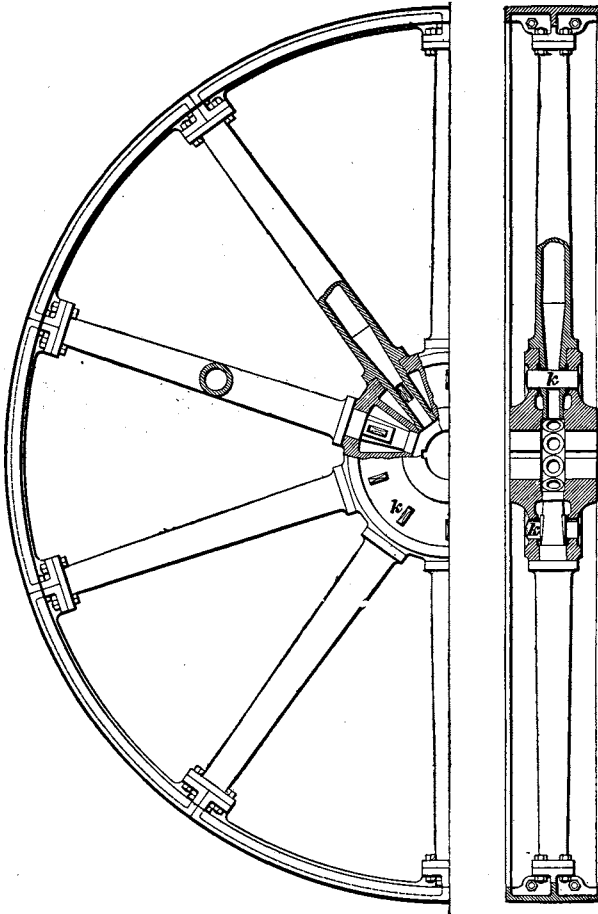


FIG. 780.

segments of the rim are also bolted to the ends of the arms by means of flanges cast on the rim and arms.

The arms are circular in section, and cast hollow. Their inner ends are turned to fit recesses bored in the hub, and held in the hub by steel or wrought-iron keys *k*.

2127. Another method of fastening the arms to the hub is shown in Fig. 781. Here the ends of the arms are cast with flanges, and they also have a circular boss turned on them which fits into a recess bored in the hub. Bolts

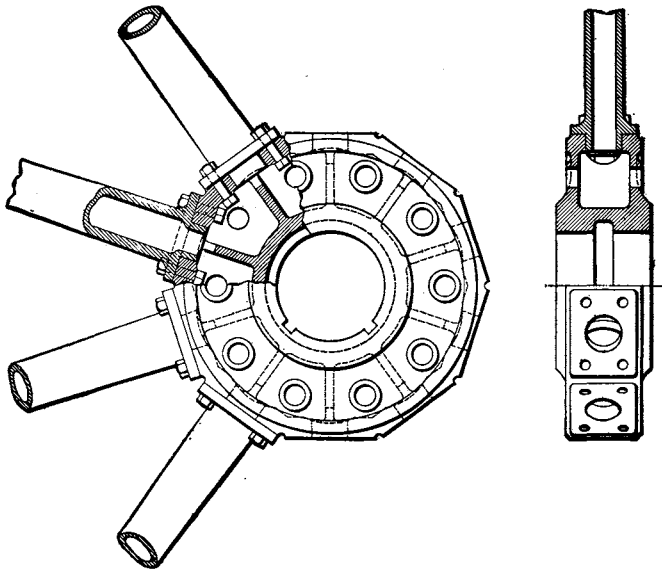


FIG. 781.

pass through the flanges in the ends of the arms and in the face of the hub, thus holding the arms securely in place.

2128. Fig. 782 is an example of a fly-wheel cast in halves. The sections of the rim are joined by means of steel or wrought-iron bars *B*, inserted in holes cast in the ends of the rims. These bars are fastened to the rim by keys *K* that pass through holes fitted for that purpose. The arms are oval in section, and cast solid. The hub is

provided with bosses through which four bolts are passed, thus joining the two parts of the hub securely. The holes *o* cored in the rim of the fly-wheels, shown in Figs. 778 and

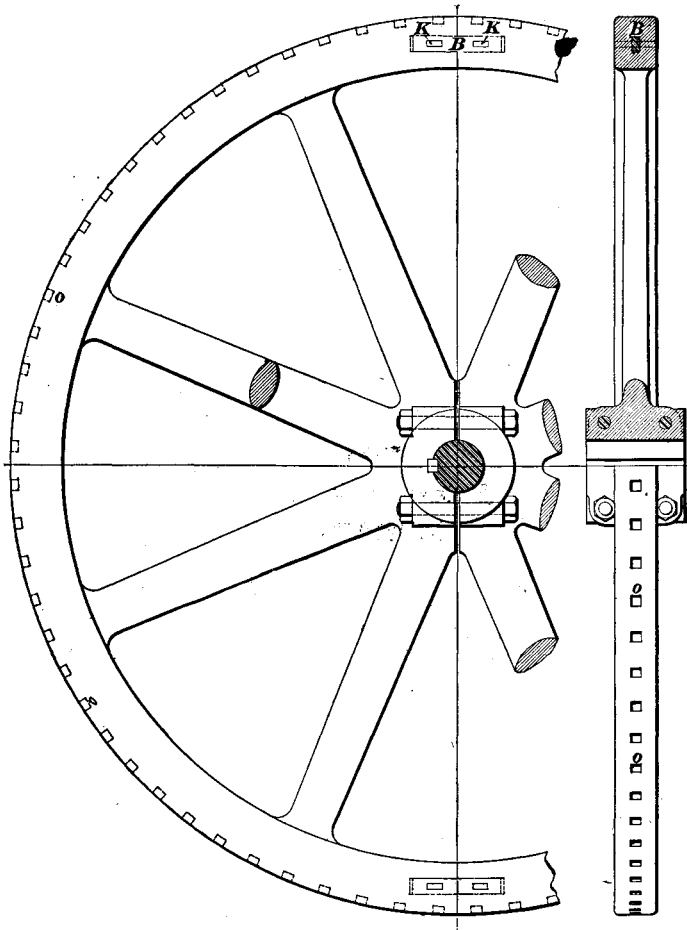


FIG. 782.

782, are for the purpose of inserting the end of a bar when it is required to turn the engine, either to get the crank off from the center in starting, or for any other purpose.

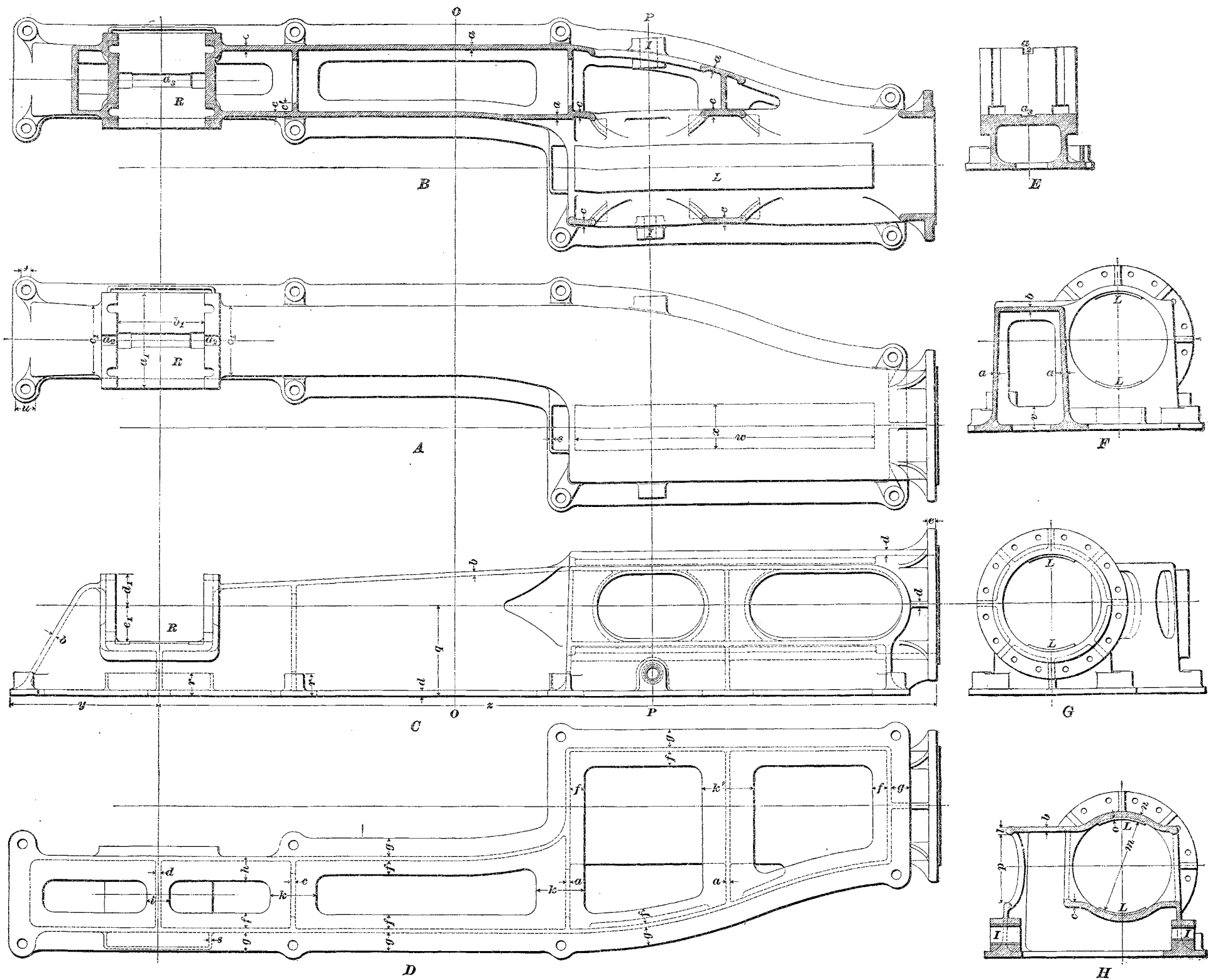


FIG. 788.

ENGINE FRAMES, OR BEDS.

2129. The **frame**, or **bed**, of an engine is the main structure to which the other parts are attached. It provides the necessary stiffness and rigidity, and, on account of its mass, absorbs more or less of the vibration due to the movement of the reciprocating parts.

Engine beds are made in a great variety of forms, each type of engine having its peculiar type of bed.

Fig. 783 shows a substantial style of engine bed for horizontal engines. *A* is a top view; *B* a horizontal section on the center line looking towards the bottom; *C* a front side view, and *D* a view of the bottom. *E* is a cross-section through the center line of the main bearing; *F* a cross-section on the line *OO*; *G* an end view, and *H* a cross-section through the guides on the line *PP*. The guides *L, L* are cast solid with the bed, and bored out to form the bearing surface for the cross-head, which is of the form shown in Fig. 762. *I, I* are bosses which form bearings for the rocker-arm shaft. These bearings are provided with brass or babbitt bushings. The main bearing, which is separate from the frame, rests in the opening *R*.

Proportions for designing this bed are based on the diameter of the cylinder, the length of stroke, dimensions of cross-head, and length of connecting-rod, as follows:

D = diameter of cylinder.

a = $.027 D + .1875''$.

l = $2 a$.

b = $1.1 a$.

m = the distance required to

c = $1.25 a$.

clear the connecting-

c' = $2.5 a$.

rod.

d = $1.5 a$.

n = $2 a$.

e = $2.25 a$.

o = $.5 a$.

f = $4 a$.

p = $.75 m$.

g = $4.75 a$, but never less than *u*.

q = $.8 D$ to D .

h = $6.5 a$.

r = $6 a$.

i = $6 a$.

s = $.5 a$.

k = $12 a$.

t = $.06 D + .5''$ (use the nearest standard size of bolt).

k' = $13.5 a$.

u = $2.1 t$.

$$\begin{array}{ll}
 v = 6.5 a. & x = \text{same width as cross-head.} \\
 w = \text{length of stroke} + & \text{length of rubbing surface of cross-head} \\
 & - (.01 D + .1875"). \quad y = \text{about } 1.3 D. \text{ In all cases the crank must clear the bosses and nuts for the foundation bolts.}
 \end{array}$$

The length z must be such that the hub of the cross-head will clear the stuffing-box bolts when at the end of the stroke. Its value approximately = length of crank + length of connecting-rod + distance from center of cross-head pin to end of cross-head hub + clearance between cross-head hub and stuffing-box bolts + the distance which the stuffing-box bolts project into the frame. This distance z is best determined by laying out the various parts to scale.

The dimensions for the seat for the main bearing are;

d' = diameter of crank-shaft journal.

$$\begin{array}{ll}
 a_1 = 1.75 d'. & d_1 = .5 d' + 1.25". \\
 b_1 = 1.65 d' - .5". & e_1 = .66 d'. \\
 c_1 = .62 D.
 \end{array}$$

The bearing for the frame shown in Fig. 783 is shown in detail in Fig. 784.

Proportions for designing this bearing are:

d' = diameter of journal.

D = diameter of cylinder.

$$\begin{array}{ll}
 a = d' + 1". & g = .1 d' + .5625". \\
 a' = .2 d' + 2". & g' = .1 d' + 1". \\
 b = .5 d' + 1". & h = .85 d'. \\
 b' = .12 d' + 1.25". & i = .1 d' + .25". \\
 c = .66 d'. & i' = .2 d' + .5". \\
 c' = .06 d' + .625". & j = .1 d' + .25". \\
 c_1 = .62 D. & k = .5 d' + 1.25". \\
 e = 1.65 d' - .5". & l = .375", \text{ constant.} \\
 e' = 1.22 d'. & l' = .1 d' + .375". \\
 f = .25 d' + .375". & m = .175 d' + .3125". \\
 f' = 1.35 d'. & n = .25 d' + .25".
 \end{array}$$

$n' = .1 d' + .375''$.	$t = .11 d'$.
$n'' = .2 d' + .5''$.	$t' = .02 d' + .25''$.
$o = .625''$, constant.	$u = .04 d' + .125''$; use near-
$o' = .375''$, constant.	est standard size
$p = .3 d' + .5''$.	bolt.
$p' = .15 d' + .375''$.	$v = .15 d' + .375''$.
$q = .02 d' + .5''$.	$w = 1.2 d'$.
$q' = .02 d' + .25''$.	$w' = 1.75 d'$.
$r = .1 d'$.	$x = 2.5''$, constant.
$r' = .15 d'$.	$y = .3 d' + .75''$.
$s = .9 d'$.	$z = .2 d' + .5''$.

It will be seen that this bearing has four seats, including the cap, which is lined with babbitt so as to form the top seat. The two side seats are adjustable by means of the wedges W , which are moved by the bolts B . The bearing is held to the engine bed by the T-head bolts O , O , which fit into slots cast in the bed for this purpose. The side and bottom seats are of brass, with babbitt linings. A is a top view of the cap, A_1 a side view of the cap, and A_2 a section of the cap on the center line. Lugs a_1 , usually of wrought iron, fit in slots a_2 , Fig. 783, to prevent end motion of the cap. C is an inside, or top, view of the bottom seat. It has lugs b_1 which fit into the slots c_1 of the wedges W (see view D_1 , which is a half-section through the bearing on the line $P P$, with the wedge in place). D_2 is a half-section of the bearing on the center line. The bottom seat has a lug a_4 (see section D_2) that fits in a corresponding slot in the bed. This slot is shown at a_3 in section D_1 ; also at a_3 , Fig. 783.

2130. Fig. 785 is an example of a frame for a vertical engine, as made by a well-known builder. The dimensions for this frame are given in Table 55, for various sizes of cylinders:

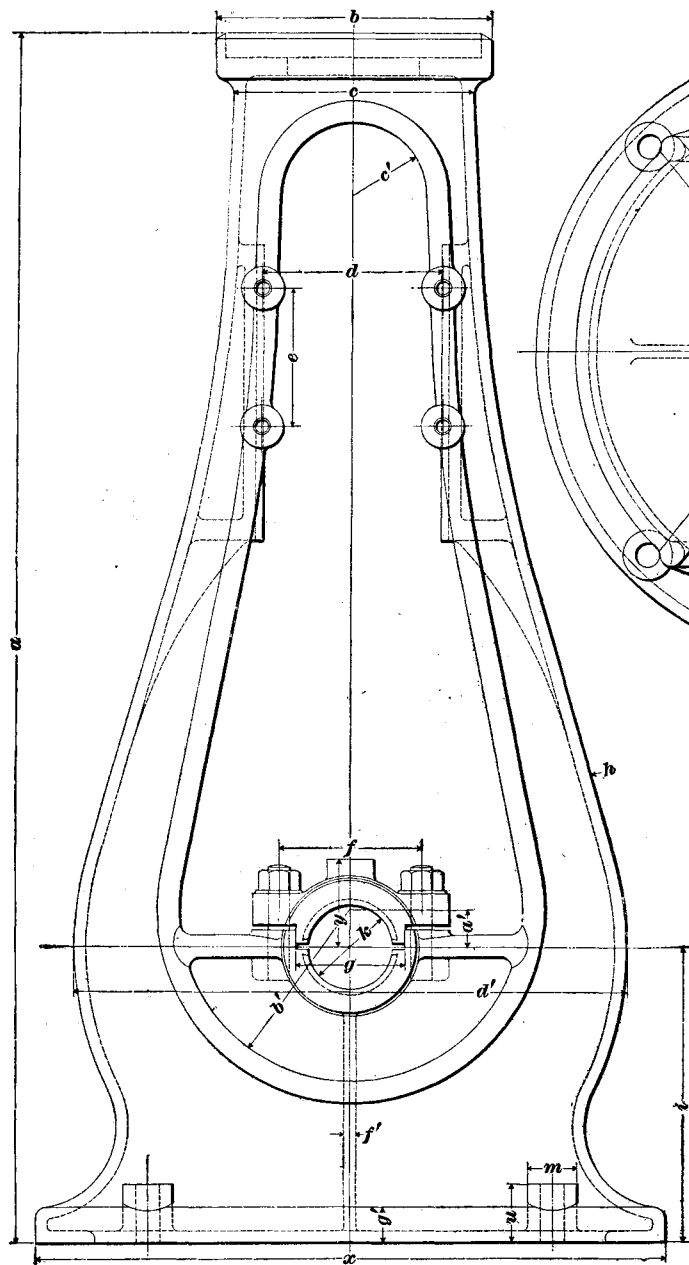


FIG. 785.

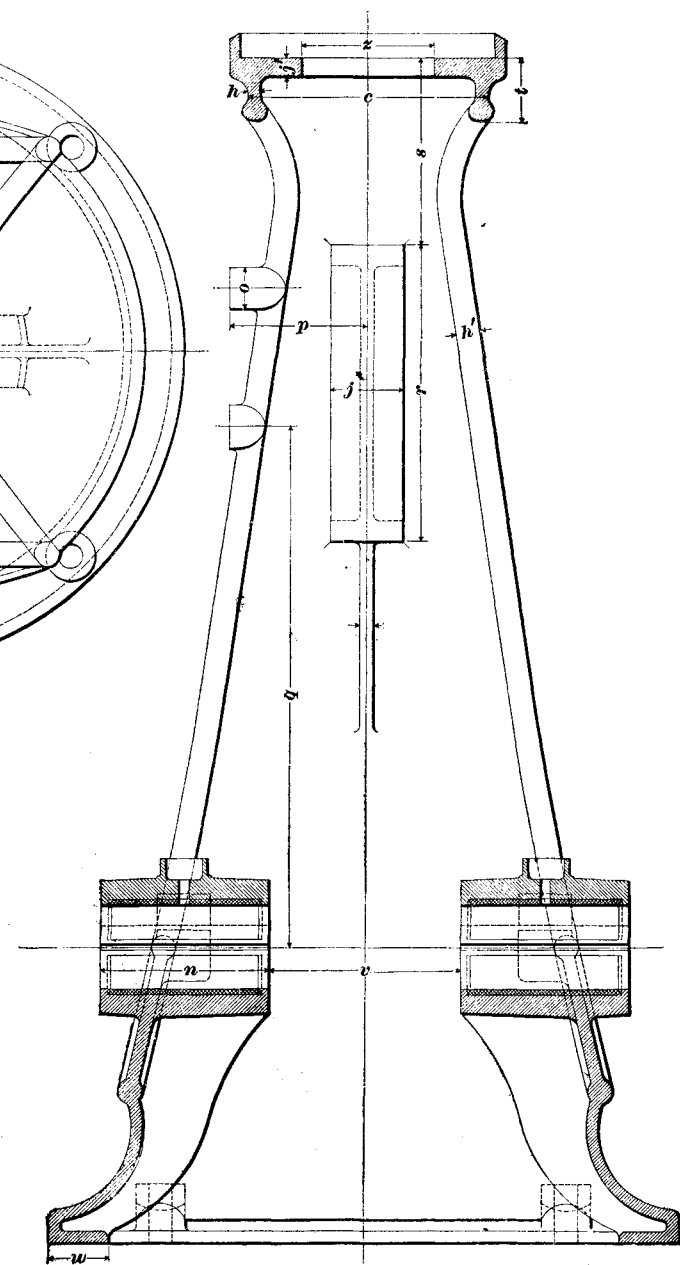


TABLE 55.

Size.	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>	<i>j</i>	<i>k</i>	<i>l</i>	<i>m</i>	<i>n</i>	<i>o</i>	<i>p</i>	<i>q</i>	<i>r</i>	<i>s</i>	<i>t</i>	<i>u</i>	<i>v</i>	<i>w</i>	<i>x</i>	<i>y</i>	<i>z</i>
3" × 5".....	28½	6⅞	6	3⅜	3½	3⅝	2¼	½	6½	1½	1¼	4½	1½	3⅝	1	3½	12⅝	7¼	21⅞	1½	1⅝	3⅝	½	12½	2	3⅝
4" × 6".....	34¼	7⅞	7¼	5¼	4½	4½	3	⅝	7¼	1½	2	5	1½	4⅞	1½	3⅞	13⅝	9⅝	4¼	2⅝	1⅝	4⅞	⅝	15	2¼	4½
5½" × 7".....	40¼	9½	8	6	5½	5	3⅝	⅝	10	2½	2½	6	1¼	51⅞	1½	4⅝	15½	10½	4¼	2¼	2⅝	4⅞	1	18	3½	4⅝
7" × 9".....	50¼	11½	10	7½	5¾	6¼	4	¾	12⅝	2½	2½	7½	2	5⅝	1¼	5	21⅝	12½	7½	3¼	3	6¼	2½	26¼	4¼	5½
9" × 12".....	61¼	14¼	12½	9	7¼	9	6¾	⅝	13¾	3½	3½	9½	2	5½	2	5¾	30⅞	17½	7½	4¼	3½	11	3¼	26½	6	7½

Size.	<i>a'</i>	<i>b'</i>	<i>c'</i>	<i>d'</i>	<i>e'</i>	<i>f'</i>	<i>g'</i>	<i>h'</i>	<i>i'</i>	<i>j'</i>
3" × 5".....	11⅞	4	2⅞	11½	⅝	⅝	1	½	⅝	½
4" × 6".....	1⅞	4⅞	2½	13½	⅝	½	1⅞	¾	½	¾
5½" × 7".....	1	5¼	2⅞	15¼	¾	½	1¼	¾	½	¾
7" × 9".....	2⅞	7⅞	31⅞	23	⅞	1⅞	1	⅞	1	1
9" × 12".....	¾	7⅞	4⅞	23½	⅞	1¼	1½	⅞	1½	1½

e' = size of foundation bolt.
 For 9" × 12" engine a disk-center crank is used.

EXAMPLES OF ENGINE PROPORTIONS.

2131. It has been previously stated that when a standard line of engines is to be manufactured, the rules and formulas for the design of the various parts need not be applied to each individual engine. It is found that under the conditions in which engines are to work a certain ratio may be assumed to exist between the sizes of the parts. For example, a certain line of engines work uniformly at a steam pressure of 75 lb., and the length of the piston rod bears a fixed relation to the length of stroke. Under these circumstances, the diameter of the piston rod may be a fixed fraction of the diameter of the cylinder for all sizes, and it is only necessary, therefore, to multiply the cylinder diameter by this fraction to find the diameter of the piston rod.

In the following tables are given the proportions of a standard line of Corliss engines made by a leading manufacturer. They will serve to illustrate the use of fixed proportions in designing, and will also furnish valuable examples of good, modern practice.

TABLE 56.

Diameter of Cylinder, Inches.	Stroke, Inches.	Revolutions per Minute.	Piston Speed in Feet per Minute.	Diameter of Shaft Journal.
10	24	90	360	5
12	24	90	360	5½
14	30	80	400	7
16	30	80	400	7½
16	36	70	420	8
18	36	70	420	8½
20	36	70	420	9
16	42	65	455	8¼
18	42	65	455	8¾
20	42	65	455	9¼
20	48	60	480	9½
22	48	60	480	10
24	48	60	480	10

TABLE 56—(Continued).

Diameter of Cylinder, Inches.	Stroke, Inches.	Revolutions per Minute.	Piston Speed in Feet per Minute.	Diameter of Shaft Journal.
22	54	60	540	$10\frac{1}{4}$
24	54	60	540	$10\frac{3}{4}$
26	54	60	540	$11\frac{1}{4}$
24	60	60	600	11
26	60	60	600	$11\frac{1}{2}$
28	60	60	600	12
30	60	60	600	$12\frac{1}{2}$
32	60	60	600	13
34	60	60	600	$13\frac{1}{2}$
36	60	60	600	14

TABLE 57.

Diam- eter of Cylin- der.	Diam. and Length of Crank- Pin.	Diameter and Length of Cross- Head Pin.	Diam- eter of Valve Stem.	Depth of Piston.	Diam- eter of Piston Rod.	Width of Crank Disk.	Clear- ance of Piston.
10	$2\frac{1}{2}$	$1\frac{5}{8} \times 2\frac{1}{2}$	$\frac{7}{8}$	4	$1\frac{5}{8}$	$2\frac{1}{2}$	$\frac{1}{4}$
12	3	2×3	1	$4\frac{1}{2}$	2	3	$\frac{1}{4}$
14	$3\frac{1}{2}$	$2\frac{3}{8} \times 3\frac{1}{2}$	$1\frac{1}{8}$	5	$2\frac{1}{4}$	$3\frac{1}{2}$	$\frac{1}{4}$
16	4	$2\frac{5}{8} \times 4$	$1\frac{1}{4}$	$5\frac{1}{2}$	$2\frac{1}{2}$	4	$\frac{1}{4}$
18	$4\frac{1}{2}$	$3 \times 4\frac{1}{2}$	$1\frac{3}{8}$	6	$2\frac{3}{8}$	$4\frac{1}{2}$	$\frac{1}{4}$
20	5	$3\frac{3}{8} \times 5$	$1\frac{1}{2}$	$6\frac{1}{2}$	$3\frac{1}{4}$	5	$\frac{1}{4}$
22	$5\frac{1}{2}$	$3\frac{5}{8} \times 5\frac{1}{2}$	$1\frac{1}{2}$	7	$3\frac{1}{2}$	$5\frac{1}{2}$	$\frac{5}{16}$
24	6	4×6	$1\frac{5}{8}$	$7\frac{1}{2}$	$3\frac{3}{8}$	6	$\frac{5}{16}$
26	$6\frac{1}{2}$	$4\frac{1}{4} \times 6\frac{1}{2}$	$1\frac{3}{4}$	$7\frac{3}{4}$	$4\frac{1}{8}$	$6\frac{1}{2}$	$\frac{5}{16}$
28	7	$4\frac{5}{8} \times 7$	$1\frac{3}{4}$	$8\frac{1}{4}$	$4\frac{1}{2}$	7	$\frac{5}{16}$
30	$7\frac{1}{2}$	$5 \times 7\frac{1}{2}$	$1\frac{7}{8}$	$8\frac{1}{2}$	$4\frac{3}{8}$	$7\frac{1}{2}$	$\frac{5}{16}$
32	8	$5\frac{1}{4} \times 8$	$1\frac{7}{8}$	$8\frac{1}{2}$	$5\frac{1}{8}$	8	$\frac{5}{16}$
34	$8\frac{1}{2}$	$5\frac{5}{8} \times 8\frac{1}{2}$	2	$8\frac{3}{4}$	$5\frac{1}{2}$	$8\frac{1}{2}$	$\frac{3}{8}$
36	9	$5\frac{7}{8} \times 9$	2	9	$5\frac{3}{4}$	9	$\frac{3}{8}$

TABLE 58.

Diameter of Cylinder.	Steam Inlet Area, sq. in.	Exhaust Area, sq. in.	Diameter of Valve.	Inlet Ports.	Exhaust Ports.	Width of Steam Chest.	Width of Exhaust Chest.	Depth of Steam and Exhaust Chests.	Diameter of Steam Pipe.	Diameter of Ex- haust Pipe.
10	4.71	7.85	$3\frac{1}{8}$	$\frac{1}{2} \times 10$	$\frac{1}{8} \times 10$	5	$6\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{2}$	$3\frac{1}{2}$
12	6.79	11.31	$3\frac{1}{2}$	$\frac{5}{16} \times 12$	$\frac{1}{8} \times 12$	6	$7\frac{1}{2}$	2	3	4
14	9.23	15.39	$3\frac{7}{8}$	$\frac{11}{16} \times 14$	$\frac{1}{8} \times 14$	7	9	$2\frac{1}{4}$	$3\frac{1}{2}$	$4\frac{1}{2}$
16	12.00	20.00	$4\frac{1}{4}$	$\frac{3}{4} \times 16$	$\frac{1}{4} \times 16$	8	10	$2\frac{1}{2}$	4	5
18	15.27	25.44	$4\frac{5}{8}$	$\frac{7}{8} \times 17$	$\frac{1}{2} \times 17$	9	$11\frac{1}{2}$	$2\frac{3}{4}$	$4\frac{1}{2}$	6
20	18.85	31.42	5	1×19	$\frac{11}{16} \times 19$	10	$12\frac{1}{2}$	3	5	$6\frac{1}{2}$
22	22.80	38.00	$5\frac{3}{8}$	$1\frac{1}{8} \times 20\frac{1}{8}$	$\frac{1}{8} \times 20\frac{1}{8}$	11	$14\frac{1}{2}$	$3\frac{1}{4}$	$5\frac{1}{2}$	7
24	27.14	45.24	$5\frac{3}{4}$	$1\frac{3}{16} \times 22\frac{1}{8}$	$2 \times 22\frac{1}{8}$	12	15	$3\frac{1}{2}$	6	$7\frac{1}{2}$
26	31.85	53.09	$6\frac{1}{8}$	$1\frac{5}{16} \times 24\frac{1}{4}$	$2\frac{1}{8} \times 24\frac{1}{4}$	13	$16\frac{1}{2}$	$3\frac{3}{4}$	$6\frac{1}{2}$	$8\frac{1}{2}$
28	36.95	61.58	$6\frac{1}{2}$	$1\frac{7}{16} \times 25\frac{1}{2}$	$2\frac{1}{2} \times 25\frac{1}{2}$	14	$17\frac{1}{2}$	4	7	9
30	42.41	70.69	7	$1\frac{9}{16} \times 27\frac{1}{2}$	$2\frac{3}{8} \times 27\frac{1}{2}$	15	19	$4\frac{1}{2}$	$7\frac{1}{2}$	$9\frac{1}{2}$
32	48.26	80.43	$7\frac{1}{2}$	$1\frac{5}{8} \times 29\frac{1}{4}$	$2\frac{3}{4} \times 29\frac{1}{4}$	16	20	5	8	$10\frac{1}{2}$
34	54.48	90.79	8	$1\frac{3}{4} \times 31\frac{1}{4}$	$2\frac{5}{8} \times 31\frac{1}{4}$	17	$21\frac{1}{2}$	$5\frac{1}{2}$	$8\frac{1}{2}$	11
36	61.07	101.79	$8\frac{1}{2}$	$1\frac{7}{8} \times 33$	$3\frac{1}{8} \times 33$	18	$22\frac{1}{2}$	6	9	$11\frac{1}{2}$

TABLE 59.

Diameter of Cylinder.	Thickness of Cylinder.	Thickness of Chests.	Thickness of Valve Chamber.	Bearing of Valves.
10	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
12	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{16}$
14	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$
16	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{4}$
18	1	$1\frac{3}{16}$	1	$1\frac{3}{8}$
20	$1\frac{1}{16}$	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{1}{2}$
22	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{1}{8}$	$1\frac{5}{8}$
24	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{3}{4}$
26	$1\frac{1}{4}$	1	$1\frac{3}{16}$	$1\frac{7}{8}$
28	$1\frac{1}{4}$	1	$1\frac{1}{4}$	2
30	$1\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$2\frac{1}{8}$
32	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$2\frac{1}{4}$
34	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$2\frac{3}{8}$
36	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$2\frac{1}{2}$

An inspection of the above tables shows that the following rules are used in designing the above line of engines:

Let D = diameter of cylinder.

Then, diameter of shaft = $.34 D + 2\frac{1}{2}"$, nearly. A more exact but less simple formula is

diameter of shaft = $.26 \sqrt{DL} + 2\frac{1}{2}"$, where L is the stroke.

Diameter of crank-pin = $\frac{D}{4}$.

Length of crank-pin = $\frac{D}{4}$.

Length of cross-head pin = $\frac{D}{4}$.

Diameter of cross-head pin = diameter of crank-pin $\times 0.65$.

Diameter of steel valve stem = $.19 \sqrt[3]{D^2}$.

$$\begin{aligned}\text{Depth of piston} &= \frac{D}{4} + 1\frac{1}{2}" \text{ for } D \text{ less than 24 inches;} \\ &= \frac{D}{8} + 4\frac{1}{2}" \text{ for } D \text{ greater than 24 inches.}\end{aligned}$$

$$\text{Diameter of piston rod} = .16 D.$$

$$\text{Width of crank disk} = \frac{D}{4}.$$

$$\text{Area of steam port} = .06 \times \text{area of cylinder.}$$

$$\text{Area of exhaust port} = .1 \times \text{area of cylinder.}$$

$$\text{Diameter of valve} = \frac{3 D}{16} + 1\frac{1}{4}."$$

$$\text{Width of steam chest} = \frac{D}{2}.$$

$$\text{Width of exhaust chest} = .63 D.$$

$$\text{Depth of steam and exhaust chests}$$

$$= \frac{D}{8} + \frac{1}{2}" \text{ for } D \text{ less than 28 in. ;}$$

$$= \frac{D}{4} - 3" \text{ for } D \text{ greater than 28 in.}$$

$$\text{Diameter of steam pipe} = \frac{D}{4}.$$

$$\text{Diameter of exhaust pipe} = 0.31 D.$$

$$\text{Thickness of cylinder} = .028 D + \frac{1}{8}."$$

$$\text{Thickness of chests} = \text{thickness of cylinder} \times 0.8.$$

$$\text{Thickness of valve chamber}$$

$$= \text{thickness of chest} + \frac{1}{8}" \text{ for } D = 10 \text{ to } 16 \text{ in. ;}$$

$$= \text{thickness of chest} + \frac{3}{16}" \text{ for } D = 18 \text{ to } 26 \text{ in.}$$

$$= \text{thickness of chest} + \frac{1}{4}" \text{ for } D = 28 \text{ to } 36 \text{ in.}$$

$$\text{Bearing of valve} = \text{diameter of valve} \times 0.3.$$

DYNAMOS AND MOTORS.

INTRODUCTION.

2132. **Electricity** is the name given to the cause of all electrical phenomena, the word being derived from a Greek word meaning *amber*, that substance having been observed by the Greeks to possess peculiar properties which we now understand to be due to electricity.

Although electrical science has advanced sufficiently far to recognize the fact that the exact nature of electricity is unknown, yet recent research tends to demonstrate that all electrical phenomena are due to a peculiar strain or stress of a medium called *ether*; that when in this condition the *ether* possesses *potential energy* or *capacity for doing work*, as is manifested by attractions and repulsions, by chemical decomposition, and by luminous, heating, and various other effects.

In all probability, electricity is not a form of matter, for it possesses only one physical property in common with material substances, namely, **indestructibility**; it does not possess *weight*, *extension*, or any of the other physical properties of matter.

Electrical science is founded upon the effects produced by the action of certain forces upon matter, and all knowledge of the science is deduced from these effects. The study of the fundamental principles of electricity is an analysis of a series of experiments and the classification of the results in each particular case under general laws and rules. It is not necessary to keep in mind any hypothesis of the exact nature of electricity; its effects, and the laws which govern them,

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are quite similar to those of well-known mechanical and natural phenomena, and will be best understood by comparison. The two most essential features, therefore, in acquiring a knowledge of the electrical science are, first, to learn how to develop electrical action, and, second, to determine the effects produced by it.

2133. The number of processes for developing electrical action is almost innumerable, but the most important can be classified under one of the following general heads:

- (a) By the contact of dissimilar substances.
- (b) By chemical action.
- (c) By the application of heat.
- (d) By magnetic induction.

2134. The presence of electricity, also, can be detected in many different ways; under certain conditions it will

(a) Cause attractions and repulsions of light particles of matter, such as feathers, pith, gold-leaf, pieces of paper, etc.

(b) Decompose certain forms of matter into their various elements and cause other chemical changes.

(c) Produce motion in a freely suspended magnetic needle, such as the needle of a compass.

(d) Violently agitate the nervous system of all animals, causing a **shock**.

(e) Heat the substances through which it acts.

These are the principal effects produced by the action of electricity; others of less importance will appear from time to time during the study of the different branches of the science.

2135. Electricity may either appear to reside upon the surface of bodies as a **charge**, under *high pressure* or *tension*, or flow through their substance as a **current**, under comparatively *low pressure* or *tension*.

That branch of the science which treats of charges upon the surface of bodies is termed **electrostatics**, and the charges are said to be **static charges** of electricity.

Electrodynamics is that branch which treats of the action of *electric currents*.

STATIC CHARGES.

2136. When a glass rod or a piece of amber is rubbed with silk or fur, the parts rubbed will have the property of attracting light particles of matter, such as pieces of silk, wool, feathers, gold-leaf, pith, etc., which, after momentary contact, are again repelled. These attractions and repulsions are caused by a static charge of electricity residing upon the surface of those bodies. A body in this condition is said to be **electrified**.

A better experiment for demonstrating this action is to suspend a small pith-ball by a silk thread from a support or bracket, as shown in Fig. 786. If a *static charge* of electricity be developed on a *glass rod*, by rubbing it with *silk*, and the rod be brought near the pith-ball, the ball will be attracted to the rod, but, after momentary contact, will be repelled. By this contact the ball receives a charge of the same nature as that on the glass rod, and as long as the two bodies retain their charges, mutual repulsion will take place whenever they are brought near each other. If a stick of *sealing-wax*, electrified by being rubbed with fur, is approached to another pith-ball, the same results will be produced, i. e., the ball will fly towards the sealing-wax, and after contact will be repelled. But the charges

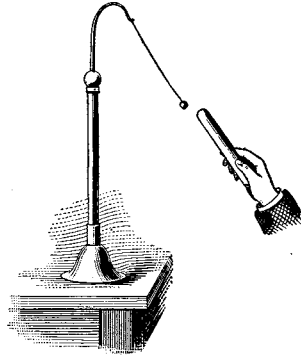


FIG. 786.

respectively developed in these two cases are not in the same condition. For, if, after the pith-ball in the first case had been touched with the *glass rod* and repelled, the electrified *sealing-wax* be brought in the vicinity, *attraction* would take place between the ball and the sealing-wax. Conversely, if the pith-ball be charged with the electrified sealing-wax, it will be repelled by the wax and attracted by the glass rod.

An electric charge developed upon *glass* by rubbing it

with silk has been termed, for convenience, a **positive (+) charge**; and that developed on resinous bodies, by rubbing with flannel or fur, a **negative (—) charge**.

Neither a positive nor a negative charge is produced alone, for there is always an equal quantity of both charges produced; one charge appearing on the body rubbed, and an equal amount of the opposite charge upon the rubber.

The intensity of the charge developed by rubbing the two substances together is independent of the actual amount of friction which takes place between the bodies. For, in order to obtain the highest possible degree of electrification, it is only necessary to bring every portion of one surface into intimate contact with every particle or every portion of the other; when this is done, no extra amount of rubbing can develop any greater charge upon either substance.

2137. From the foregoing experiments are derived the following laws :

When two dissimilar substances are placed in contact, one of them always assumes the positive and the other the negative condition, although the amount may sometimes be so small as to render its detection very difficult.

Electrified bodies with similar charges are mutually repellent, while electrified bodies with dissimilar charges are mutually attractive.

2138. In the following list, called the **electric series**, the substances are arranged in such order that each receives a *positive* charge when rubbed or placed in contact with any of the bodies following it, and a *negative* charge when rubbed with any of those which precede it :

- | | | |
|--------------|--------------|-------------------|
| 1. Fur. | 6. Cotton. | 11. Sealing-wax. |
| 2. Flannel. | 7. Silk. | 12. Resins. |
| 3. Ivory. | 8. The body. | 13. Sulphur. |
| 4. Crystals. | 9. Wood. | 14. Gutta-percha. |
| 5. Glass. | 10. Metals. | 15. Gun-cotton. |

For example, *glass*, when rubbed with *fur*, receives a *negative* charge; but when rubbed with *silk*, it receives a *positive* charge.

CONDUCTORS AND NON-CONDUCTORS.

2139. Only that part of a dry glass rod which has been rubbed will be electrified; the other parts will produce neither repulsion nor attraction when brought near a suspended pith-ball. The same is true of a piece of sealing-wax or resin. These bodies do not readily *conduct* electricity; that is, they *oppose* or *resist* the passage of electricity through them. Therefore, it can only reside as a *charge* upon that part of their surface where it is developed. Experiments show that when a metal receives a charge at any point, the electricity immediately passes or flows through its substance to all parts. Metals, therefore, are said to be **good conductors** of electricity. Bodies have accordingly been divided into two classes, i. e., **non-conductors**, or **insulators**, or those bodies which offer a very high **resistance** to the passage of electricity; and **conductors**, or those bodies which offer a comparatively low resistance to its passage. This distinction is not absolute, for all bodies conduct electricity to some extent, while there is no known substance which does not offer some resistance to the flow of electricity.

In giving the following list and dividing the different substances into two classes, it should be understood that it is done only as a guide for the student. Between these two classes are many substances which might be included in either list, and no hard or fast line can be drawn.

Silver,	}	CONDUCTORS.
Copper,		
Other metals,		
Charcoal,		
Ordinary water,		
The body.		
Paper,	}	NON-CONDUCTORS
Oils,		
Porcelain,		OR
Wood,		INSULATORS.

Silk,	}	NON-CONDUCTORS OR INSULATORS.
Resins,		
Gutta-percha,		
Shellac,		
Ebonite,		
Paraffine,		
Glass,		
Dry air, etc.		

ELECTRODYNAMICS.

2140. In dealing with *electric currents*, the word **potential** will be substituted for the general and vague phrase, *electrical condition*.

The term *potential*, as used in electrical science, is analogous with *pressure*, in gases; *head*, in liquids; and *temperature*, in heat.

When an electrified body, *positively* charged, is connected to the earth by a conductor, electricity is said to flow *from* the body *to* the earth; and, conversely, when an electrified body, *negatively* charged, is connected to the earth in a similar manner, electricity is said to flow *from* the earth *to* that body. This is called the **direction of flow** of an electric current. That which determines the *direction of flow* is the relative *electrical potential* or *pressure* of the two charges in regard to the earth.

It is impossible to say with certainty in which direction electricity really flows, or, in other words, to declare which of two points has the higher and which the lower electrical potential, or pressure. All that can be said with certainty is that, when there is a *difference of electrical potential*, or *pressure*, electricity tends to flow *from* the point of higher, *to* that of the lower, *potential*, or *pressure*.

For convenience, it has been arbitrarily assumed and conventionally adopted that that electrical condition called *positive* is at a higher potential or pressure than that called *negative*; and that electricity tends to flow *from* a *positively* *to* a *negatively* electrified body.

The zero or normal level of water is taken as that of the

surface of the sea, and the normal pressure of air and gases as that of the atmosphere at the sea-level; similarly, there is a *zero potential*, or *pressure, of electricity* in the earth itself. The earth may be regarded as a reservoir of electricity of infinite quantity, and its potential, or pressure, may therefore be taken as zero.

The electrical condition called *positive* is assumed to be at a higher potential or pressure than the earth; and that called *negative* is assumed to be at a lower potential or pressure than the earth.

2141. It must be understood that electricity is a *condition of matter*, and not matter itself, for it possesses neither *weight* nor *dimensions*. Consequently, the statement that electricity is *flowing* through a conductor must not be taken too literally; it must not be supposed that any material substance, such as a liquid, is actually passing through the conductor in the same sense as water flows through a pipe. The statement that electricity is flowing through a conductor is only another way of expressing the fact that the conductor and the space surrounding it are in different conditions than usual and that they possess unusual properties. The action of electricity, however, is quite similar in many respects to the flow of liquids, and the study of electric currents is much simplified by the analogy.

2142. In order to produce what is called an electric current, *it is first necessary to cause a difference of electrical potential between two bodies or between two parts of the same body.*

It was stated that when two dissimilar substances are simply placed in contact, one always assumes the positive and the other the negative condition; or, in other words, *a difference of electrical potential is developed between the two bodies.*

Placing a piece of copper and zinc in contact will develop a difference of electrical potential which can easily be detected. The same results will follow if the plates are slightly separated from each other and placed in a vessel

containing saline or acidulated water, leaving a small portion of one end of each plate exposed. The exposed ends of the zinc and copper are now electrified to different degrees, or, in other words, there is a *difference of electrical potential* between them, one plate being at a higher potential than the other.

When the exposed ends are connected by any conducting material, the potential between the plates tends to *equalize*, and a momentary rush or discharge of electricity passes between the exposed ends through the conductor, and also between the submerged ends through the liquid. During its passage through the liquid, the electricity causes certain chemical changes to take place; these chemical changes cause in their turn a fresh *difference of potential* between the plates, which is followed immediately by another equalizing discharge, and that by a further difference, and so on. These changes follow one another with great rapidity; so rapid, in fact, that it is impossible to distinguish them apart, and they appear absolutely *continuous*. The equalizing flow which is constantly taking place from one plate to the other is known as a **continuous current** of electricity. Consequently, an electric current becomes continuous when the difference of potential is constantly maintained.

By the use of a very delicate instrument, the submerged end of the copper is found to be electrified with a *negative* charge, while the submerged end of the zinc is electrified with a *positive* charge. The direction of the current, therefore, will be *from the submerged end of the zinc through the liquid to the submerged end of the copper; and from the exposed end of the copper to the exposed end of the zinc.*

2143. A **simple voltaic or galvanic cell**, Fig. 787, is an apparatus for developing a continuous current of electricity. It consists, essentially, of a vessel containing saline or acidulated water in which are submerged two plates of dissimilar metals, or one metal and a metalloid (as, for instance, carbon).

Electrolyte is the name given to the liquid, which, as it transmits the current, is decomposed by it.

The two dissimilar metals, when spoken of separately, are called **voltaic** or **galvanic elements**; and, when taken collectively, are known as a **voltaic couple**.

A **voltaic** or **galvanic battery** is a number of simple cells properly joined together.

Electrodes or **poles** of a cell or battery are metallic terminals or connectors attached to the exposed ends of the plates, and are used to connect the cell or battery to any exterior conductor, or to another cell or battery.

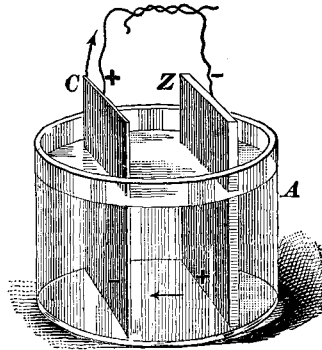


FIG. 787.

It should be remembered that the polarity of the submerged ends of the plates is always of opposite sign to that of their electrodes. For example, in the case of the zinc and copper couple, the electrode fastened to the zinc would be spoken of as the *negative* electrode of the cell; while the zinc itself would be the *positive* element of the cell—its submerged end being *positive*.

In any voltaic or galvanic couple, the element which is acted upon by the electrolyte will always be the *positive* element, and its electrode the *negative* electrode of the cell.

2144. The following list of voltaic elements composes what is called the **electromotive series**:

- | | | |
|-------------|---------------|---------------|
| 1. Zinc. | 5. Iron. | 9. Copper. |
| 2. Cadmium. | 6. Nickel. | 10. Silver. |
| 3. Tin. | 7. Bismuth. | 11. Gold. |
| 4. Lead. | 8. Antimony. | 12. Platinum. |
| | 13. Graphite. | |

Any two of these metals form a *voltaic couple* and produce a difference of potential when submerged in saline or acidulated water, the one standing first on the list being the *positive* element or plate, and the other the *negative*. For ex-

ample, if *nickel* and *graphite* are used, the *nickel* will be acted upon by the liquid and will form the *positive* element; but if *nickel* and *zinc* are used, the *zinc* will be acted upon by the liquid, and hence will be the *positive* element.

The difference of potential will be greater in proportion to the distance between the positions of the two substances in the list. For example, the difference of potential developed between *zinc* and *graphite* is much greater than that developed between *zinc* and *nickel*; in fact, the difference of potential developed between zinc and graphite is equal to the difference of potential developed between zinc and nickel *plus* that developed between nickel and graphite.

Electricity flowing as a *current* differs from *static charges* in three important degrees—namely, (1) its *potential* is much lower, (2) its *actual quantity* is greater, and (3) it is *continuous*.

A substance charged from a strong voltaic battery possesses the property of attracting light substances only in the slightest degree; in fact, the attractions can only be detected with the most delicate instruments. The *potential* of a current of electricity is comparatively so small that a voltaic battery composed of a large number of cells is not sufficient to produce a spark more than one or two hundredths of an inch long in air, whereas a small, rapidly moving leather belt will sometimes produce static sparks of more than an inch in length. The length of the spark affords a means of estimating potentials, a high potential being capable of producing a longer spark than a low potential, but the length of spark gives us no means of estimating the **current strength** or quantity of electricity flowing. The *actual quantity* of electricity is measured by the amount of water it will decompose. Gauged by this standard, the quantity of electricity produced by a voltaic cell no larger than a thimble would be found greater than that from a large, rapidly moving belt, giving static sparks several inches in length.

2145. There are three different methods of connecting or grouping the cells in a voltaic battery: *In series; in parallel, or multiple-arc; in multiple-series.*

Cells are connected **in series** when the positive electrode of the first cell is connected to the negative electrode of the second, and the positive electrode of the second is connected to the negative electrode of the third, and so on, as shown in the diagram, Fig. 788. In this we have adopted the usual signs for representing a cell, the short broad line representing the positive electrode of the cell and the long narrow line the negative electrode. In this method of connecting or grouping of cells, when the negative electrode of the first

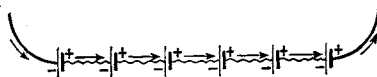


FIG. 788.

cell is connected to the positive electrode of the last by some exterior conductor the total current produced will flow successively through each cell. This method of grouping is used when there is available a large number of *low* potential cells and a *high* potential is desired, as in long telegraph lines or other *high* resistance circuit.

2146. Cells are connected in **parallel** or **multiple-arc** when the positive electrodes of all the cells are connected to one main positive conductor and all the negative electrodes are connected to one main negative conductor, as

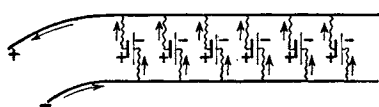


FIG. 789.

shown by the diagram, Fig. 789. In parallel or multiple-arc grouping, only a part of the total current flowing in

main conductors will pass through each cell. This method of grouping is used when it is desired to obtain a strong current from a number of cells (when the external resistance is *low*), as in electro-plating.

2147. Cells are connected in **multiple-series** by arranging them in several groups, each group being composed of several cells connected in series, and then connecting all the groups together in parallel or multiple-

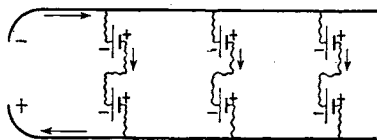


FIG. 790.

arc, as shown in the diagram, Fig. 790. This method is

used where both a higher potential and a stronger current are required than any one cell of the group will give.

CIRCUITS.

2148. A **circuit** is a path composed of a conductor, or of several conductors joined together, through which an electric current flows from a given point around the conducting path back again to its starting point.

A circuit is **broken**, or **open**, when its conducting elements are disconnected in such manner as to prevent the current from flowing.

A circuit is **closed**, or **complete**, when its conducting elements are so connected as to allow the current to flow.

A circuit in which the earth, or ground, forms part of the conducting path is called an **earth**, or a **grounded**, circuit.

The **external** circuit is that part of a circuit which is outside, or external to, the electric source.

The **internal** circuit is that part of a circuit which is included within the electric source.

In the case of the simple voltaic cell, the *internal circuit* consists of the two metallic plates, or elements, and the electrolyte; an *external circuit* would be a wire or any conductor connecting the free ends of the electrodes.

2149. Conductors are said to be connected in **series** when they are so joined together as to allow the current

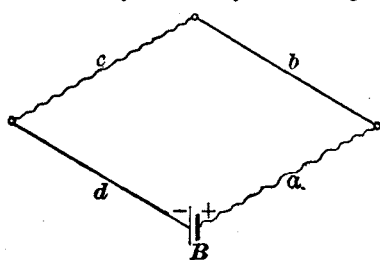


FIG. 791.

to pass consecutively through each. For example, Fig. 791 represents a *closed* circuit consisting of a simple voltaic cell *B*, and four conductors *a*, *b*, *c*, and *d*, connected *in series*.

A circuit which is divided into two or more branches, each branch transmitting part of the main current, is a **derived**, or **shunt**, **circuit**, and the separate branches are said to be connected in **parallel**, or **multiple-arc**. An example of a *derived* circuit of two

branches in *parallel* is shown in Fig. 792. The main current flows first through the conductor *a*, then divides between the branches *c* and *b*, and finally uniting and completing the circuit through the conductor *d*; the two branches *c* and *b* being the conductors, which are connected in *parallel*, or *multiple-arc*. The way the current divides, and how the amount which will flow through the branches *b* and *c* is determined, will be treated of later:

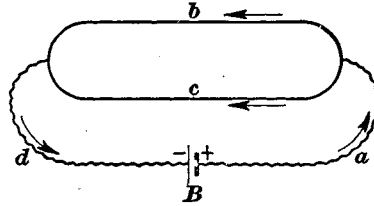


FIG. 792.

MAGNETISM.

2150. Magnets are substances which have the property of attracting pieces of iron or steel, and the term **magnetism** is applied to the cause of this attraction. *Magnetism* exists in a natural state in an ore of iron, which is known in chemistry as *magnetic oxide of iron*, or *magnetite*. This magnetic ore was first found by the ancients in *Magnesia*, a city in Asia Minor; hence, substances possessing this property have been called magnets.

It was also discovered that when a small bar of this ore is suspended in a horizontal position by a thread, it has the property of pointing in a north and south direction. From this fact the name **lodestone** — *leading-stone* — was given to the ore.

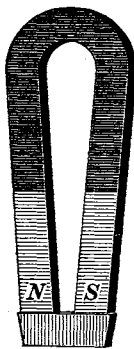


FIG. 793.

When a bar or needle of hardened steel is rubbed with a piece of lodestone, it acquires magnetic properties similar to those of the lodestone, without the latter losing any of its own force. Such bars are called **artificial magnets**.

Artificial magnets which retain their magnetism for a long time are called **permanent magnets**.

The common form of artificial or permanent magnet, Fig. 793, is a bar of steel bent into the shape of a

horseshoe and then hardened and magnetized. A piece of soft iron, called an **armature**, or a **keeper**, is placed across the two free ends, which helps to prevent the steel from losing its magnetism.

2151. If a bar magnet is dipped into iron filings, the filings are attracted towards the two ends, and adhere there in tufts; while towards the center of the bar, half way between the two ends, there is no such tendency. See Fig. 794. That part of the magnet, where there is no

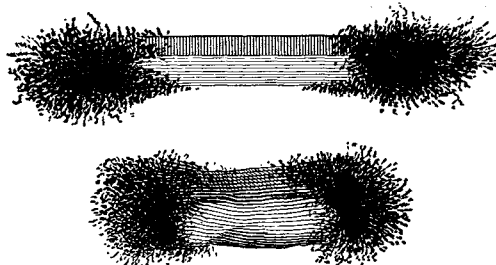


FIG. 794.

apparent magnetic attraction, is called the **neutral line**; and the parts around the two ends, where the attraction is greatest, are called **poles**. An imaginary line drawn through the center of the magnet, from end to end, connecting the two poles together, is the **axis of magnetism**.

A **compass** consists of a magnetized steel needle, Fig. 795, resting upon a fine point so as to turn freely in a horizontal plane.

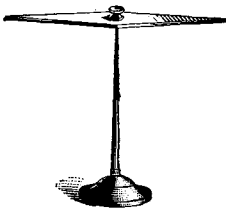


FIG. 795.

When not in the vicinity of other magnets, or magnetized iron, the needle will always come to rest with one end pointing towards the north, and the other towards the south. The end pointing northward is the **north-seeking pole**, or, simply, the *north pole*, and the opposite end is the **south-seeking** or *south pole*. This *polarity* applies as well to all magnets.

If the *north pole* of one magnet is brought near the *south pole* of another magnet, attraction takes place; but if two

north poles or two south poles are brought together, they repel each other. In general, *like magnetic poles repel one another; unlike poles attract one another.*

The earth is a great magnet whose magnetic poles coincide nearly, but not quite, with the true geographical north and south poles. A freely suspended magnet, therefore, will always point in an approximately north and south direction.

It is impossible to produce a magnet with only one pole. If a long bar magnet is broken into any number of parts, each part will still be a magnet and have two poles, a north and a south one.

2152. Magnetic substances are those substances which, although not in themselves magnets, that is, not possessing poles and neutral lines, are, nevertheless, capable of being attracted by a magnet. In addition to iron and its alloys, the following elements are magnetic substances: *Nickel, cobalt, manganese, oxygen, cerium, and chromium.* These, however, possess magnetic properties in a very inferior degree compared with iron and its alloys. All other known substances are called **non-magnetic substances.**

2153. The space surrounding a magnet, in which any magnetic substance will be attracted or repelled, is called its **magnetic field**, or simply its **field**. Magnetic attractions and repulsions are assumed to act in a definite direction, and along imaginary lines called **lines of magnetic force**, or simply **lines of force**, and every magnetic field is assumed to be traversed by such *lines of force*—in fact, to exist by virtue of them. Their position in any plane may be shown by placing a sheet of paper over a magnet, and sprinkling fine iron filings over the paper. In the case of a bar magnet lying on its side, the iron filings will arrange themselves in curved lines extending from the north to the south pole, as shown in

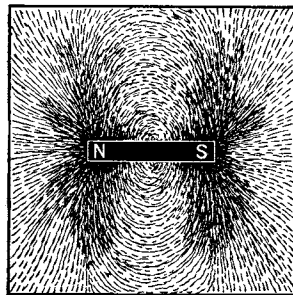


FIG. 796.

Fig. 796. A view of the magnetic field looking towards either pole of a bar magnet would exhibit merely radial lines, as shown by the filings in Fig. 797.

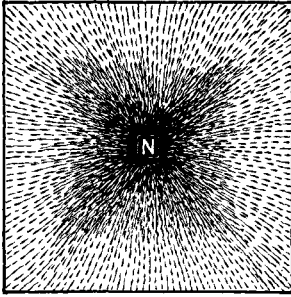


FIG. 797.

Every line of force is assumed to pass out from the north pole, make a complete circuit through the surrounding medium and into the south pole; thence, through the magnet, to the north pole again, as shown in Fig. 798.

This is called the *direction of the lines of force*, and the path which they take is called the *magnetic circuit*.

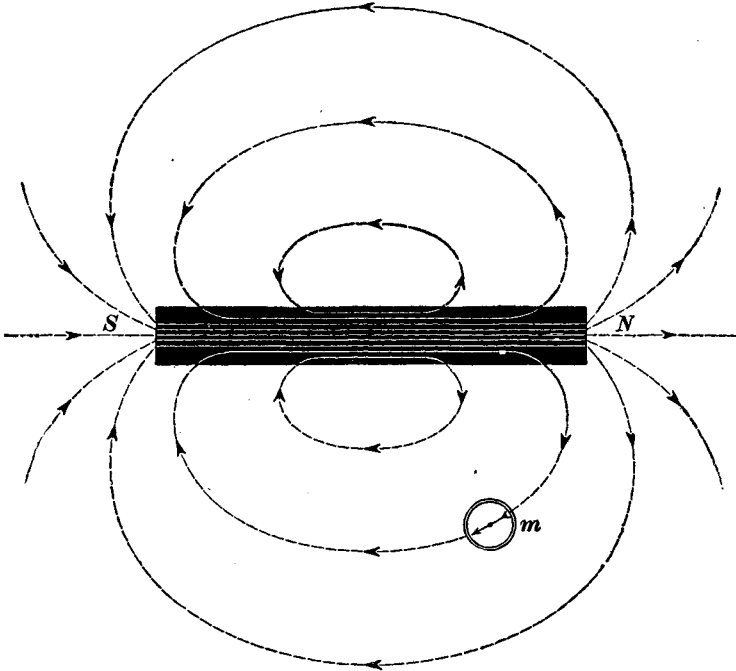


FIG. 798.

2154. The *direction of the lines of force* in any magnetic field can be traced by a small, freely suspended magnetic

needle, or a small compass such as indicated by *m* in Fig. 798. The north pole of the needle will always point in the direction of the line of force, the length of the needle lying either parallel or tangent to the lines of force at that point. If the needle be moved bodily in the direction towards which the north pole points, its center or pivot will describe a path coinciding with the direction of the lines of force in that part of the magnetic field.

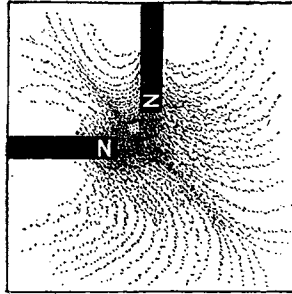


FIG. 799.

NOTE.—In all diagrams, the *direction of the lines of force* will be represented by arrow-heads upon dotted lines.

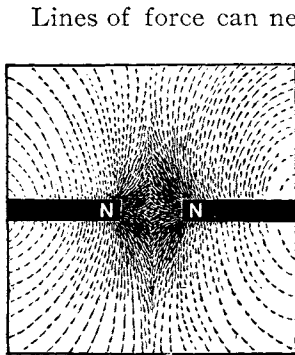


FIG. 800.

Lines of force can never intersect each other; when two opposing magnetic fields are brought together, as indicated by the iron filings in Fig. 799 and Fig. 800, the lines of force from each will be crowded and distorted from their original direction until they coincide in direction with those opposing, and form a resultant field in which the direction of the lines of force will depend upon the relative strengths of the two opposing negative fields. The resulting poles thus formed are called **consequent poles**.

In every magnetic field there are certain stresses which produce a *tension* along the lines of force and a *pressure* across them; that is, they tend to *shorten* themselves from end to end, and *repel* one another as they lie side by side.

2155. When a magnetic substance is brought into a magnetic field, the lines of force in that vicinity crowd together and all tend to pass through the substance. If the substance is free to move on an axis (but not bodily) towards the magnet pole, it will always come to rest with its greatest extent or length in the direction of the lines of force

The body will then become a magnet, its south pole being situated where the lines of force enter it, and its north pole where they pass out. The production of magnetism in a magnetic substance in this manner is called **magnetic induction**. The production of artificial magnetism in a hardened steel needle or bar by contact with lodestone is one case of magnetic induction.

The **amount** or **quantity of magnetism** is expressed by the total number of lines of force contained in a magnetic circuit.

Magnetic density is the number of lines of force passing through a unit area measured perpendicularly to their direction.

ELECTROMAGNETISM.

2156. If a conductor be placed parallel to the magnetic axis of a compass needle, and a current passed through the

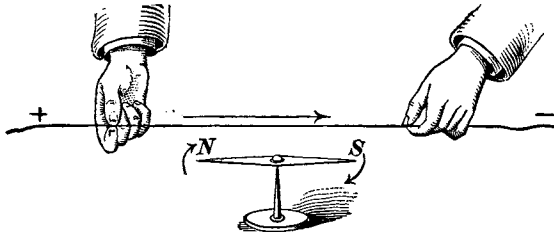


FIG. 801.

conductor in either direction, the needle will tend to place itself at right angles to the conductor, as shown by arrows in Fig. 801; or, in general, an electric current and a magnet exert mutual force upon each other. From the definition given in Art. **2153**, the space surrounding the conductor is a *magnetic field*. If the conductor is threaded up through a piece of cardboard, and iron filings are sprinkled on the cardboard, they will arrange themselves in concentric circles around the

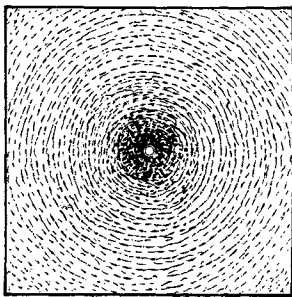


FIG. 802.

conductor, as represented in Fig. 802. This effect will be observed throughout the entire length of the conductor, and is caused entirely by the current. In fact, every conductor conveying a current of electricity can be imagined as completely surrounded by a sort of magnetic *whirl*, the magnetic density decreasing as the distance from the current increases. See Fig. 803.

2157. If the current in a horizontal conductor is flowing *towards* the *north*, and a compass is placed *under* the conductor, Fig. 804, the north pole of the needle will be deflected towards the *west*; by placing the compass *over* the wire, Fig. 805, the north pole of the needle will be deflected towards the *east*. By reversing the direction of the current in the conductor, the needle will point in the opposite direction in each case, respectively.

If the conductor is placed *over* the needle, and then bent back *under* it, forming a loop as shown in Fig. 806, the tendency of the current in both top and bottom portions of the wire is to deflect the north pole of the needle in the same direction.

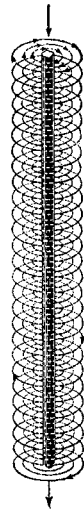


FIG. 803.

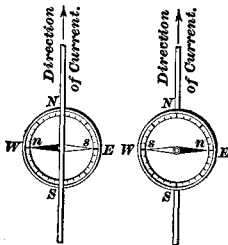


FIG. 804.

FIG. 805.

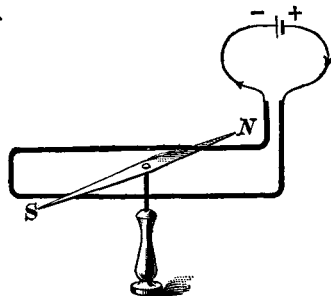


FIG. 806.

From these experiments, knowing the direction of current in the conductor, the following rule is deduced for the direction of the lines of force around the conductor:

Rule.—*If the current is flowing in the conductor away from the observer, then the direction of the lines of force will be around the conductor in the direction of the hands of a watch.*

The direction of the lines of force around a conductor is indicated in Fig. 807, where the current is assumed to be flowing downwards, that is, piercing the paper.

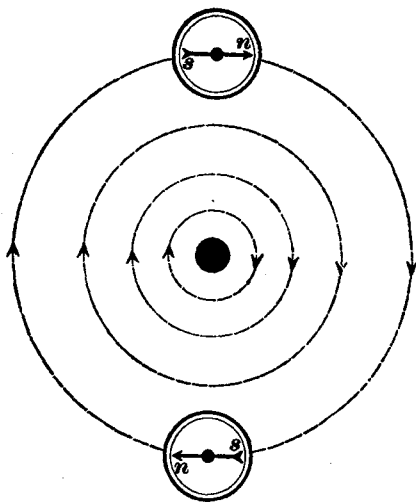


FIG. 807.

2158. Two parallel conductors, both transmitting currents of electricity, are either mutually attractive or repellent, depending upon the relative direction of their currents. If the currents are flowing in the *same* direction in both conductors, as represented in Fig. 808, the

lines of force will tend to surround both conductors and contract, thus *attracting* the conductors. If, however, the

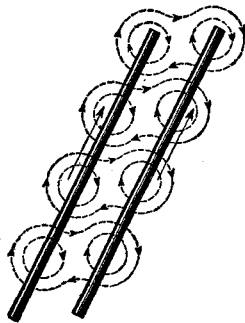


FIG. 808.

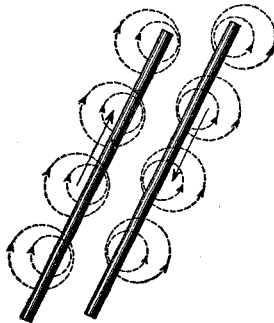


FIG. 809.

currents are flowing in opposite directions, as in Fig. 809, the lines of force lying between the conductors will have the same direction and, therefore, *repel* the conductors.

2159. If the conductor carrying the current is bent into the form of a loop, as in Fig. 810, then all the lines of

force around the conductor will thread through the loop in the same direction. By bending the conductor into a long

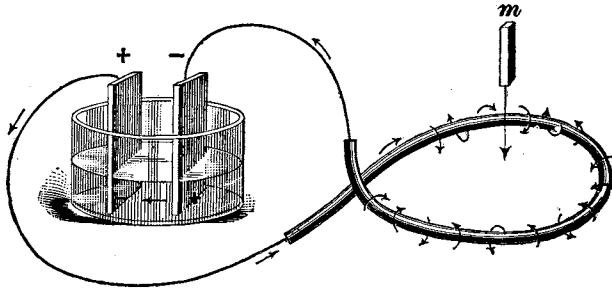


FIG. 810.

helix of several loops, the lines of force around each loop will coincide with those around the adjacent loops, forming several long lines of force which thread through the entire helix, entering at one end and passing out at the other. The same conditions now exist in the helix as exist in a bar magnet, i. e., the lines of force *pass out* from one end and *enter* the other. In fact, the helix possesses a *north* and a *south pole*, a *neutral line*, and all the properties of attraction and repulsion of a magnet. If it is suspended in a horizontal position and free to turn, it will come to rest pointing in a north and south direction.

A helix made in this manner, around which a current of electricity is circulating, is called a **solenoid**.

2160. The **polarity** of a solenoid, that is, the direction of the lines of force which thread through it, depends upon the direction in which the conductor is coiled, and the direction of the current in the conductor.

To determine the polarity of a solenoid, knowing the direction of the current:

Rule.—*In looking at the end of the helix, if it is so wound that the current circulates around the helix in the direction of the hands of a watch, that end will be a south pole; if in the other direction, it will be a north pole.*

Fig. 811 represents a conductor coiled in a right-handed

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helix. If the current starts to flow from the end where the observer stands, that end will be a south pole and the observer will be looking through the helix in the direction of the lines of force.

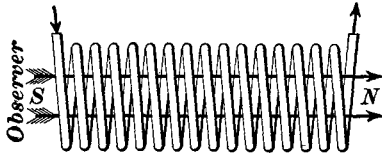


FIG. 811.

The polarity of a solenoid can be changed by reversing the direction of the current in the conductor.

2161. In Art. **2155** it was stated that when a magnetic substance is brought into a magnetic field, the lines of force in that field crowd together, and all try to pass through that substance; in fact, they will alter their circular shape, and extend a considerable distance from their original position, in order to pass through it. A magnetic substance, therefore, offers a better path for the lines of force than air or other non-magnetic substances.

The facility afforded by any substance to the passage through it of lines of force is called **magnetic permeability**, or, simply, **permeability**.

The *permeability* of all non-magnetic substances, such as air, copper, wood, etc., is taken as 1 or unity. The permeability of soft iron may be as high as 2,000 times that of air. If, therefore, a piece of soft iron be inserted into the magnetic circuit of a solenoid, the number of lines of force will be greatly increased, and the iron will become highly magnetized.

2162. A magnet produced by inserting a magnetic substance into the magnetic circuit of a solenoid is an **electro-magnet**, and the magnetic substance around which the current circulates is called the **core**. See Fig. 812. The solenoid is generally termed the **magnetizing coil**.

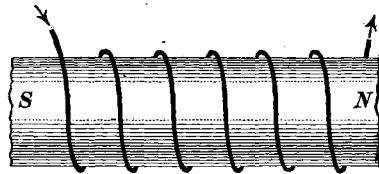


FIG. 812.

In the ordinary form of electro-magnet, the magnetizing

coil consists of a large number of turns of *insulated* wire—that is, wire covered with a layer or coating of some non-conducting or insulating material, usually silk or cotton; otherwise, the current would take a shorter and easier circuit from one coil to the adjacent one, or from the first to the last coil through the iron core without circulating around the magnet.

The simplest form of an electro-magnet is the bar magnet. As usually constructed, it consists of a straight bar of iron or steel *B*, fitted into a *spool* or *bobbin* made of hard vulcanized rubber or some other inflexible insulating material. The magnetizing coil of fine insulated copper wire *w* is wound in layers in the bobbin as shown by the cross-section in Fig. 813.

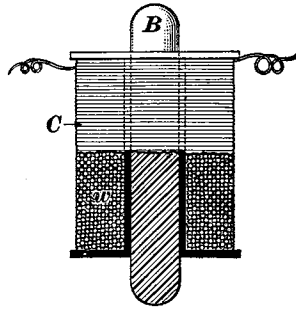


FIG. 813.

The rule for determining the polarity of a solenoid, Art. 2160, is the same for an electro-magnet. It makes no difference whether the wire is wound in one layer or in any number of layers, or whether it is wound towards one end and then wound back again over the previous layer towards the other end; so long as the current circulates continually in the same direction around the core, the polarity of the magnet will remain unchanged.

2163. The most convenient form of electro-magnet for a great variety of uses is the *horseshoe* or **U-shaped** electro-magnet, Fig. 815. It consists of a bar of iron bent into the shape of a horseshoe with straight ends and provided with two magnetizing coils, one on each end of the magnet. The two ends which are surrounded by the coils are the *cores* of the magnet, and the arc-shaped piece of iron joining them together is known as the **yoke** of the magnet. The ordinary **U-shaped** electro-magnet is made in three parts—namely, two iron cores wound with the magnetizing coils, and

a straight bar of iron joining the two cores together for a yoke, as shown in Fig. 814. In looking at the free ends of the two cores, Fig. 815, the current should circulate around

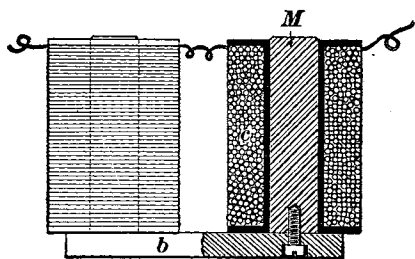


FIG. 814.

one core in an opposite direction to that around the other. If the current circulates around both cores in the same direction, the lines of force produced in the two cores, respectively, oppose one another, forming two like

poles at their free ends and a *consequent pole* in the yoke. The total number of lines of force produced by both coils will be greatly diminished, and the magnet will exhibit only a small amount of magnetic attraction.

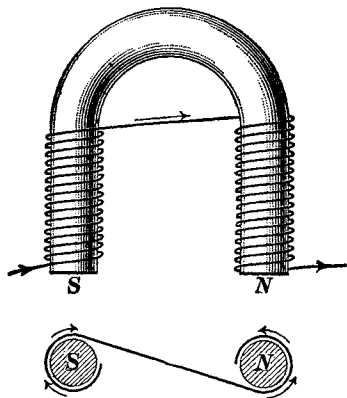


FIG. 815.

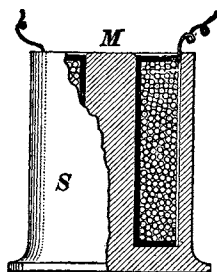


FIG. 816.

Another common form of electro-magnet is known as the **iron-clad** electro-magnet. In its simplest form, Fig. 816, it contains only one magnetizing coil and one core. The core is fastened to a disk-shaped iron yoke, and the magnetic circuit is completed through an iron shell which rises up from the yoke and completely surrounds and protects the coil.

ELECTRICAL UNITS.

2164. The three principal units used in practical measurements of a current of electricity are :

*The **ampere**, or the practical unit denoting the rate of flow of an electric current, or the strength of an electric current.*

*The **ohm**, or the practical unit of resistance.*

*The **volt**, or the practical unit of electrical potential or pressure.*

Electromotive force, written E. M. F., or simply E, is the *total generated difference of potential* in any electric source or in any circuit. For example, the total difference of potential developed between the plates of a simple voltaic cell would be the *electromotive force* of that cell.

Ordinarily, the term *electromotive force* is used to express any difference of potential—that is, the electromotive force is the difference of potential between two points.

The relation of these three practical units will be better understood by the analogy of the flow of water through a pipe. The force which causes the water to flow through the pipe is due to the *head* or *pressure*; that which *resists* the flow is the friction of the water against the inside of the pipe, and the amount would vary with circumstances. The *rate of flow*, or the *current*, may be expressed in *gallons per minute*, and is a ratio between the head or pressure and the resistance caused by the friction of the water against the inside of the pipe. For, as the pressure or head *increases*, the rate of flow or current *increases* in proportion; as the resistance *increases*, the current *diminishes*.

In the case of electricity flowing through a conductor, the *electromotive force* or *potential* corresponds to the pressure or head of water, and the resistance which a conductor offers to the flow of electricity, to the friction of the water against the pipe. The *strength of an electric current*, or the *rate of flow of electricity*, is also a ratio—a ratio between the electromotive force and the resistance of the conductor through which the current is flowing. This ratio as applied

to electricity was first discovered by Dr. G. S. Ohm, and has since been called **Ohm's law**.

2165. Ohm's Law.—*The strength of an electric current in any circuit is directly proportional to the electromotive force developed in that circuit and inversely proportional to the resistance of the circuit; i. e., it is equal to electromotive force divided by the resistance.*

Ohm's law is usually expressed algebraically, thus:

$$\text{Strength of current} = \frac{\text{electromotive force}}{\text{resistance}}.$$

If the electromotive force (E) is expressed in *volts* and the resistance (R) in *ohms*, the formula will give the strength of current (C) directly in *amperes*; thus, $C = \frac{E}{R}$.

Before giving examples of the application of Ohm's law, the value and significance of each unit will be treated upon separately.

2166. The Ampere, or the Unit Strength of Current.—The strength of an electric current can be described as a *quantity* of electricity flowing continuously every second, or, in other words, it is the rate of flow of electricity, just as the current expressed in *gallons per minute* is the *rate of flow* of liquids. When one unit quantity of electricity is flowing continuously every second, then the rate of flow, or the strength of current, is *one ampere*; if two unit quantities are flowing continuously every second, then the strength of current is *two amperes*, and so on. It makes no difference in the number of amperes whether the current flows for a long period or for only a fraction of a second; if the quantity of electricity that would flow in one second is the same in both cases, then the strength of the current *in amperes* is the same.

Electricity possesses neither *weight* nor *extension*, and therefore an electric current can not be measured by the usual methods adopted for measuring liquids and gases. In liquids, the strength of the current is determined by

measuring or weighing the actual quantity of the liquid which has passed between two points in a certain time and dividing the result by that time. The strength of an electric current, on the contrary, is determined directly by the effect it produces, and the actual quantity of electricity which has passed between two points in a certain time is afterwards calculated by multiplying the strength of the current by the time.

2167. The principal effects produced by an electric current are given in Art. **2134**; of these, the one most generally used for measuring is the action of the current upon a magnetic needle, as shown in Art. **2156**. The instrument commonly used in laboratory practice for measuring and detecting small currents of electricity is called the **galvanometer**.

The action of the galvanometer is based upon the principle given in Art. **2156**, where a magnetic needle, freely suspended in the center of a looped or coiled conductor, is deflected by a current of electricity passing around the coil or loop. In ordinary practice, the needle is suspended either upon a pivot projecting into an agate cup fixed in the needle, or by a fiber suspension, as shown by *F* in Fig. 817. In the simpler forms of galvanometers, the magnetic needle itself swings over a dial graduated in degrees; in other forms, a light index needle is rigidly attached to the magnetic needle and swings over a similar dial, as indicated by *I* in Fig. 817; and in the more sensitive galvanometers, Fig. 818, a small reflecting mirror is attached to the fiber suspension and reflects a beam of light upon a horizontal scale situated several inches from the galvanometer.

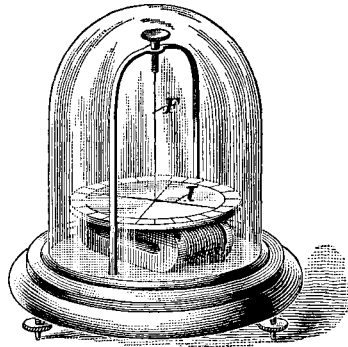


FIG. 817.

In any of these galvanometers, when no current is flowing in the coils, the needle should point in a direction

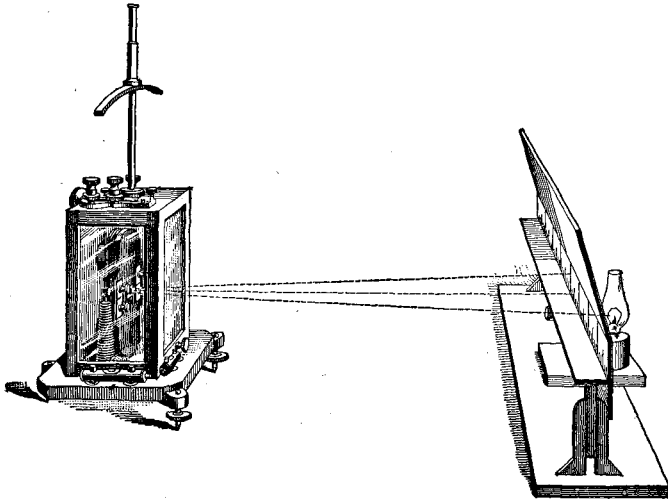


FIG. 818.

parallel to the length of the coil, Fig. 819. The measuring of currents by most galvanometers depends upon the magnetic needle being held in this position by the magnetic attraction of the earth's magnetism or the attraction of some adjacent magnet. When a current of electricity passes around the coil, its tendency is to deflect the magnetic needle at right angles to its original position, as explained in Art. **2156**, while the tendency of the earth's

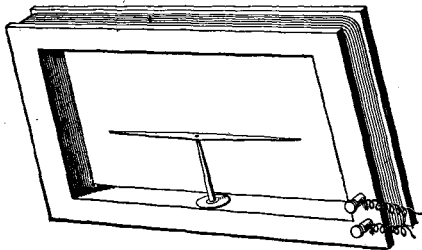


FIG. 819.

magnetism is to oppose the movement. The couple thereby produced will cause the needle to be deflected a certain number of degrees from its original position, depending upon the relative strengths of the two

magnetic fields. The stronger the current in the coil, the greater the deflection. With a galvanometer of standard

dimensions and a magnetic field of known strength, such as the earth's magnetism at a convenient place on its surface, a strength of current can be conventionally adopted as a unit which will produce a certain deflection; all other galvanometers can be calibrated from this standard, and their dials graduated to read the strength of current directly, in the conventional unit adopted.

2168. Commercial and portable instruments are devised for measuring the strength of current directly in *amperes*, and are called **ampere meters**, or simply *ammeters*. The action of the current flowing through the coils in these instruments causes small magnetic needles or other coils of wire to act against either the tension of springs or against gravitational forces. The majority of ammeters are provided with an index needle which travels over a scale or dial graduated in divisions, each division representing one ampere, or fractions or multiples of one ampere.

Fig. 820 shows the general form of a standard Weston ammeter used for commercial testing purposes. The strength of the current flowing in a circuit can be measured directly in amperes by opening the circuit at any convenient place and connecting the two ends thus formed to the binding post *p* and *p'*. The direction of the current in the circuit should be determined beforehand, so that it passes *into* the instrument by the binding post marked with the positive (+) sign; otherwise, the index needle will be deflected off the scale in the wrong direction, which is liable to damage the instrument and cause error in reading when the current passes through in the proper direction.

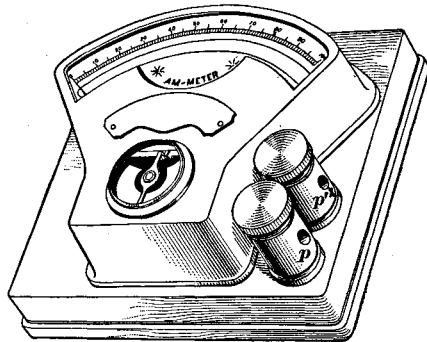


FIG. 820.

2169. The Ohm, or the Unit of Resistance.—In Art. **2139** it was stated that the resistance varied in different substances—that is, one substance offers a higher resistance to a current of electricity than another. Electrical resistance, therefore, can be defined as a property of matter, varying with different substances, and in virtue of which such matter opposes or resists the passage of electricity.

The resistance which all substances offer to the passage of an electric current is one of the most important quantities in electrical measurements. In the first place, it is that which determines the strength of an electric current in any circuit in which a difference of potential is constantly maintained, as shown by Ohm's law; and in the second place, the unit of resistance, the *ohm*, is the only unit in electrical measurements for which a material standard can be adopted, other quantities being measured by the effect they produce. The basis of any system of physical measurements is generally some material standard conventionally adopted as a unit, physical measurements in each system being made by comparison with the unit of that system.

The unit of electrical resistance now universally adopted is called the **international ohm**. One international ohm is the resistance offered by a column of pure mercury 106.3 centimeters in length and 1 square millimeter in sectional area at 32° F., or the temperature of melting ice. The dimensions of the column expressed in inches are as follows: length, 41.85 inches; sectional area, .00155 square inch. Hereafter the word "international" will be omitted and simply the word "ohm" used; the *international ohm*, however, as defined above, will always be implied, unless otherwise stated.

2170. If a given conductor offers a resistance of 2 ohms to a current of 1 ampere, it offers the same amount, no more nor less, to a current of 10 amperes. Hence, *the resistance of a given conductor at equal temperatures is always constant, irrespective of the strength of current flowing through it or the electromotive force of the current.*

2171. If the length of a conductor be doubled, its resistance will be doubled; that is, the resistance of a given conductor increases as the length of the conductor increases, the resistance being directly proportional to the length of the conductor.

When it is required to find the resistance of a conductor of which the length is varied and other conditions remain unchanged, the following formula may be used:

$$r_2 = \frac{r_1 l_2}{l_1}. \quad (306.)$$

In this formula

r_1 = the original resistance;

r_2 = the required or changed resistance;

l_1 = the original length;

l_2 = the changed length.

As in all examples of proportion, the two lengths must be reduced to the same unit.

By this formula we see that *the resistance of a conductor after its length is changed is equal to the original resistance multiplied by the changed length, and the product divided by the original length.*

EXAMPLE.—Find the resistance of 1 mile of copper wire, if the resistance of 10 feet of the same wire be .013 ohm.

SOLUTION.— $r_1 = .013$ ohm; $l_1 = 10$ feet; $l_2 = 1$ mile = 5,280 feet. Then, by formula **306**, the required resistance $r_2 = \frac{.013 \times 5,280}{10} = 6.864$ ohms. Ans.

2172. If the sectional area of a conductor is doubled and other conditions remain unchanged, the resistance will be halved. We may, then, obtain the value of the resistance of a conductor for any change in sectional area by the following formula:

$$r_2 = \frac{r_1 a_1}{a_2}, \quad (307.)$$

in which r_1 = the original resistance of the conductor;

r_2 = the changed resistance;

a_1 = the original sectional area;

a_2 = the changed sectional area.

From the relations here expressed, it will be seen that the resistance varies inversely as the sectional area—that is, *the resistance of a given conductor diminishes as its sectional area increases.*

The resistance of a conductor is independent of the *shape* of its cross-section. For example, this shape may be circular, square, rectangular, or irregular; if the sectional area be the same in all cases, the resistances will be the same, other conditions being similar.

EXAMPLE.—The resistance of a conductor whose sectional area is .025 sq. in. is .32 ohm; what would be the resistance of the conductor if its sectional area were increased to .125 sq. in. and other conditions remain unchanged?

SOLUTION.— $r_1 = .32$ ohm; $a_1 = .025$ sq. in., and $a_2 = .125$ sq. in. Then, by formula 307, the required resistance $r_2 = \frac{r_1 a_1}{a_2} = \frac{.32 \times .025}{.125} = .064$ ohm. Ans.

EXAMPLE.—The sectional area of a certain conductor is .01 sq. in. and its resistance is 1 ohm; if its sectional area be decreased to .001 sq. in. and other conditions remain unchanged, what will be the resistance?

SOLUTION.— $r_1 = 1$ ohm; $a_1 = .01$ sq. in., and $a_2 = .001$ sq. in. By formula 307, the resistance $r_2 = \frac{1 \times .01}{.001} = 10$ ohms. Ans.

2173. When comparing resistances of round copper wires, the following formula is used:

$$r_2 = \frac{r_1 D^2}{d^2}, \quad (308.)$$

in which r_1 = the original or known resistance;
 r_2 = the required resistance;
 D = the original diameter;
 d = the changed diameter.

This formula is based on the rule that, since the sectional area of a round conductor is proportional to the square of its diameter (sectional area = diameter² $\times$.7854), *the resistance of a round conductor is inversely proportional to the square of its diameter.*

EXAMPLE.—The resistance of a round copper wire .2 in. in diameter is 45 ohms; from this calculate the resistance of a round copper wire .3 in. in diameter, other conditions remaining the same in both cases.

SOLUTION.—In this example, $r_1 = 45$ ohms; $D = .2$ inch, and $d = .3$ inch. Hence, by formula **308**, the required resistance

$$r_2 = \frac{45 \times .2^2}{.3^2} = \frac{45 \times .04}{.09} = 20 \text{ ohms. Ans.}$$

EXAMPLE.—If the resistance of a round German silver wire $\frac{1}{8}$ in. in diameter is 12.6 ohms, what is the resistance of a round German silver wire $\frac{1}{16}$ in. in diameter, other conditions being equal in the two cases?

SOLUTION.—In this example, $r_1 = 12.6$ ohms; $D = \frac{1}{8} = .125$ inch, and $d = \frac{1}{16} = .0625$ inch. Hence, by formula **308**,

$$r_2 = \frac{12.6 \times .125^2}{.0625^2} = 50.4 \text{ ohms. Ans.}$$

2174. The resistance of two or more conductors connected in *series* (Art. **2145**) is equal to the sum of their separate resistances. For example, if four conductors having separate resistances of 8, 12, 22, and 34 ohms, respectively, are connected in series, their total or joint resistance would be $8 + 12 + 22 + 34 = 76$ ohms.

2175. The **microhm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly small resistances, and is equal to *one millionth* ($\frac{1}{1,000,000}$) of an *ohm*. Hence, to express the resistance in *microhms*, multiply the resistance in *ohms* by 1,000,000; and, conversely, to express the resistance in ohms, divide the resistance in microhms by 1,000,000. For example, .75 ohm = $.75 \times 1,000,000 = 750,000$ microhms; or, $750,000$ microhms = $750,000 \div 1,000,000 = .75$ ohm.

2176. The **megohm** is a unit of resistance, devised to facilitate calculations and measurements of exceedingly large resistances, and is equal to 1,000,000 ohms. Therefore, to express the resistance in *megohms*, divide the resistance in ohms by 1,000,000; and, conversely, to express the resistance in ohms, multiply the resistance in megohms by 1,000,000. For example, $850,000$ ohms = $\frac{850,000}{1,000,000} = .85$ megohm; or, $.85$ megohm = $.85 \times 1,000,000 = 850,000$ ohms.

The megohm is used chiefly to measure the resistance of bad conductors and insulators.

2177. In order to compare the resistances of different substances, the dimensions of the pieces to be measured must be equal; for, by changing its dimensions, a good conductor may be made to offer the same resistance as an inferior one. Under like conditions, annealed silver offers the least resistance of all known substances. Soft, annealed copper comes next on the list, and then follow all other metals and conductors.

The resistance of a given conductor, however, is not always constant; it changes with the temperature of the conductor. In all metals, the resistance *increases* as the temperature rises; in liquids and carbons, the resistance *decreases* as the temperature rises. The amount of variations in the resistance caused by a change in temperature for one degree is called the **temperature coefficient**. The temperature coefficients for the common metals are given in Table 60 for degrees Fahrenheit. These coefficients, however, only hold true for a limited change of temperature, and should not be used with extreme changes. The rules given below, making use of these coefficients, are not absolutely accurate, but nearly enough so for practical purposes.

To find the resistance of a conductor after its temperature has risen, knowing its original resistance and the number of degrees rise, other conditions remaining unchanged:

Let r_1 = the original resistance ;

r_2 = the resistance after a change in temperature ;

k = the temperature coefficient ;

t = rise or fall in temperature, degrees Fahrenheit.

Then, for a *rise* in temperature,

$$r_2 = r_1 (1 + t k). \quad (309.)$$

That is, *the resistance of a conductor after its temperature has risen may be obtained by multiplying the original resistance by one plus the product of the number of degrees rise and the temperature coefficient.*

EXAMPLE.—The resistance of a piece of copper wire at 32° F. is 40 ohms; determine its resistance when its temperature is 52° F.

SOLUTION.— $R = 40$ ohms;
 $k = .002155$ (from Table 60);
 $t = 52 - 32 = 20$ degrees.

By formula **309**, the required resistance $r_2 = r_1 (1 + t k) = 40 (1 + 20 \times .002155) = 40 \times 1.0431 = 41.724$ ohms. Ans.

2178. To find the resistance of a conductor after its temperature has fallen, knowing its original resistance and the number of degrees fall, other conditions remaining unchanged:

For a *fall* in temperature, $r_2 = \frac{r_1}{1 + t k}$. **(310.)**

That is, *the resistance of a conductor after its temperature has fallen may be obtained by dividing the original resistance by one plus the product of the number of degrees fall and the temperature coefficient.*

EXAMPLE.—The original resistance of a piece of German silver wire is 16 ohms; find its resistance after its temperature has fallen 22° F.

SOLUTION.— $R = 16$ ohms;
 $k = .000244$ (from Table 60);
 $t = 22^\circ$ F.

By formula **310**, the required resistance

$$r_2 = \frac{r_1}{1 + t k} = \frac{16}{1 + 22 \times .000244} = \frac{16}{1.005368} = 15.9145 \text{ ohms. Ans.}$$

2179. Specific resistance is the term given to the resistance of substances of unit length and unit sectional area at some standard temperature. In what follows, the specific resistance of a substance is the resistance of a piece of that substance one inch in length and one square inch in sectional area at 32° F.—that is, at the temperature of melting ice; this may also be expressed as the resistance of a cube of that substance taken between two opposing faces.

A list of the common metals is given in Table 60, in the order of their relative resistances, beginning with silver as offering the least resistance. The first column of figures gives the *specific resistance* in microhms of 1 cubic inch of the corresponding metal at 32° F. By applying formula **306**, the resistance of any conductor of known dimensions

which is made of one of the metals in the table can be determined. The second column of figures gives the relative resistance of the different metals compared with silver.

TABLE 60.

Name of Metal.	Resistance, Microhms per Cu. In.	Relative Resistance.	Temperature Coefficient.
Silver, annealed.....	.5921	1.	.002094
Copper, annealed....	.6292	1.063	.002155
Silver, hard-drawn...	.6433	1.086	.002094
Copper, hard-drawn..	.6433	1.086	.002155
Gold, annealed.....	.8102	1.369	.002028
Gold, hard-drawn....	.8247	1.393	.002028
Aluminum, annealed.	1.1470	1.935	
Zinc, pressed.....	2.215	3.741	.002028
Platinum, annealed..	3.565	6.022	
Iron, annealed.....	3.825	6.460	
Nickel, annealed....	4.907	8.285	
Tin, pressed.....	5.202	8.784	.002028
Lead, pressed.....	7.728	13.05	.002150
German silver.....	8.240	13.92	.000244
Antimony, pressed...	13.98	23.60	.002161
Mercury.....	37.15	62.73	.000400
Bismuth, pressed....	51.65	87.23	.001967

For example, the resistance of mercury is 62.73 times the resistance of silver, or the resistance of iron is 6.46 times the resistance of silver, and so on.

EXAMPLE.—Find the resistance in ohms of a round column of mercury 70" high and .05" in diameter. Ans. 1.3244 ohms.

EXAMPLE.—Find the resistance in ohms of 1 mile of square iron wire (annealed) .1" on a side. Ans. 24.2352 ohms.

2180. In a simple voltaic cell the *internal* resistance—that is, the resistance of the two plates and the electrolyte—is of great importance, for it determines the maximum strength of current that can possibly be obtained from the

cell. In the common forms of cells, the internal resistance may be excessively large, owing to the resistance of the electrolyte, the specific resistance of ordinary liquids used as electrolytes being from 1 to 20 million times that of the common metals. In liquids, as in all conductors, the resistance increases as the length of the circuit increases, and diminishes as its sectional area increases. Hence, the internal resistance of a simple voltaic cell is reduced by decreasing the distance between the plates or elements and by increasing their active surfaces. The internal resistance of the ordinary forms of cells varies from about .2 to 20 ohms.

2181. For practical and commercial testing, the standard column of mercury, representing the resistance of one ohm, has been replaced by a coil of wire, usually a platinum-silver alloy. The coil is carefully calibrated to offer a resistance of exactly one ohm at some convenient temperature, and is enclosed in metallic case, the connections to the two ends of the coils being made by two heavy terminals of copper wire passing up through the hard rubber cover. Such coils are known as *standard ohm coils*. The commercial form of standard ohm coils is shown in Fig. 821.

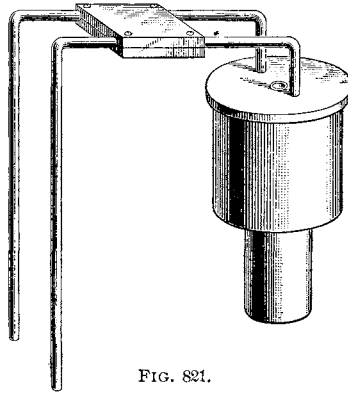


FIG. 821.

2182. An apparatus called a **resistance box** or **rheostat** is largely used for reducing or controlling the strength of currents in various circuits. Such rheostats are connected directly in *series* or *shunt* with the circuit, and are termed *dead resistances*. The resistance in these rheostats is usually made adjustable—that is, the amount of resistance which they offer may be varied at the will of the operator by the use of a sliding contact, or by removable plugs. Rheostats in which the amount of resistance is varied by

sliding contacts are used mostly where accuracy is of less importance and where the currents are comparatively large.

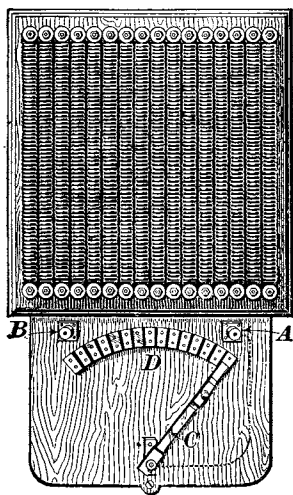


FIG. 822.

Fig. 822 shows a typical form of sliding-contact rheostat. In this particular rheostat, the coils of resistance wire are connected to a row of contact-pieces *D*, as shown in the diagram, Fig. 823. The current enters the rheostat through the terminal *A*, passes through the movable arm *C*, and then through all the resistance coils between the contact-piece on which the arm rests and the terminal *B*. When the arm rests upon the first contact-piece, as shown by the full lines in this

diagram, all of the resistance is said to be *in circuit*—that is, the current passes through all the coils. By moving the arm to the left towards the terminal *B*, as shown by the dotted lines, the coils connected to the contact-pieces which have been passed over by the arm are said to be *cut out* of circuit, and the current only passes through the remaining coils.

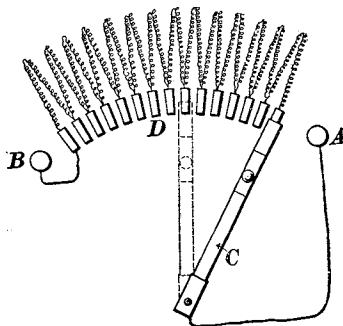


FIG. 823.

2183. Rheostats in which the resistance is adjusted by means of removable plugs are employed in laboratory practice, where small currents are used and where great accuracy is required. The resistance coils in these rheostats are enclosed in a wooden box, and the actual resistance of each coil is carefully determined. A resistance box offering 10,000 ohms resistance is shown in Fig. 824, the separate coils

offering resistances from one ohm up to 5,000 ohms. The operation of adjusting the resistance by means of the remov-

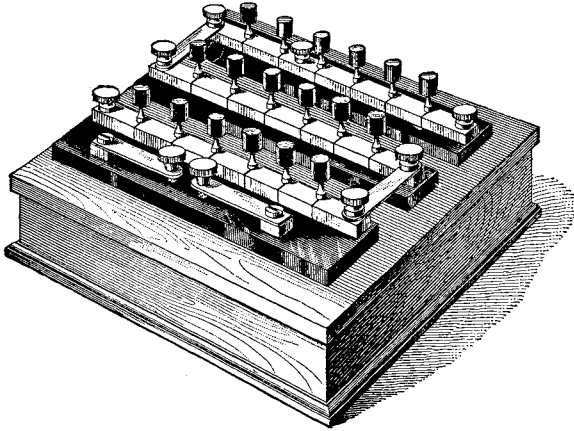


FIG. 824.

able plugs can be seen from the diagram in Fig. 825. The contact-pieces *a*, *b*, *c*, etc., are arranged side by side on the top of the case and are separated from each other by a small

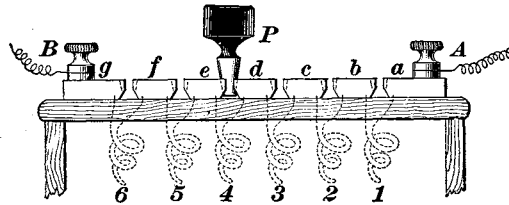


FIG. 825.

air space. The ends of each contact-piece are provided with a tapered recess in such a manner as to allow a metallic plug to be inserted between them and thereby connect the two together electrically. The current passes into the rheostat by the terminal *A*, and when all the plugs are removed flows consecutively through all the coils 1, 2, 3, 4, 5, and 6 to the terminal *B*. The total resistance of the rheostat can be lowered by inserting the plug *P* between the contact-pieces; this operation *short-circuits*, or *cuts out*, the particular coil connected to the two contact-pieces, or, in

other words, the current, instead of flowing through the coils, passes directly from one contact-piece to the other through the metallic plug.

2184. Electrical resistance may be measured by an apparatus called a **Wheatstone's bridge**. A bridge when completed ready for taking measurements consists of three main parts: (1) an adjustable resistance box containing a number of coils, the exact resistance of each coil being known; (2) a galvanometer for detecting small currents, and (3) a battery of several cells. The coils of the resistance box are divided into three groups, two of which are called **proportional** or **balance arms**, and the third is known as the **adjustable arm**. Each proportional arm is composed of three and sometimes four coils of 1, 10, 100, and 1,000 ohms resistance, respectively. The adjustable arm contains a large number of coils ranging from .1 ohm up to 10,000 ohms.

The operation of the bridge depends upon the principle of the relative difference of potential between two points in a divided circuit of two branches. The electrical connections of the bridge are shown in the diagram, Fig. 826. *M*

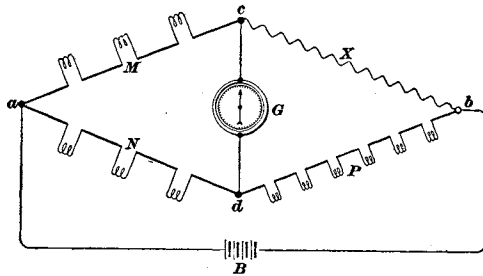


FIG. 826.

represents the resistance of one of the balance arms, which will be termed for convenience the *upper* balance arm; *N* represents the resistance of the other balance arm which will be termed the *lower* balance arm; *P* represents the resistance of the adjustable arm, and *X* represents an unknown resistance, the value of which is to be determined. One terminal of the detecting galvanometer *G* is connected at *c*—the junction of the upper balance arm and the unknown

resistance; the other terminal is connected at d —the junction of the lower balance arm and the adjustable arm. One pole of the battery is connected at a —the junction of the two balance arms; the other pole at b —the junction of the adjustable resistance and the unknown resistance. The current from the battery divides at b , part of it flowing through resistances X and M , and the rest through P and N . When the resistances M , N , P , and X fulfil the proportion $\frac{M}{N} = \frac{X}{P}$, then the two points c and d will have the same potential, and no current will flow through the galvanometer G . Since the resistances of M , N , and P are known, the resistance of X will be given by the fundamental equation $X = \frac{M}{N} \times P$ when the arms are so adjusted as to cause no deflection of the galvanometer. For example, suppose that the two ends of a copper wire are connected to the terminals b and c , and after adjusting the resistance in the arms so that the galvanometer shows no deflection, the resistances of the different arms read as follows: $M = 1$ ohm; $N = 100$ ohms, and $P = 112$ ohms. Then, substituting these values in the fundamental equation, gives

$$X = \frac{M}{N} \times P = \frac{1}{100} \times 112 = 1.12 \text{ ohms.}$$

2185. The actual various forms of resistance boxes used with the bridges differ widely from the diagram, but all are based upon this same principle and fundamental equation. A common pattern of resistance box for this purpose is constructed similar to the adjustable rheostat, as previously described, where the adjustments are made with removable plugs. Ordinarily the contact-pieces are arranged in the shape of a letter S, and the galvanometer and battery circuits are connected as shown in Fig. 827. The position of the two balance arms and the adjustable arm can be readily seen by comparing the connections of the battery and galvanometer circuits with those in the original diagram. K and K' represent keys for opening the circuits when the plugs are withdrawn or inserted in varying the resistance, or

when the bridge is not in use. In this particular case, the 1,000-ohm plug in the upper balance arm is supposed to be

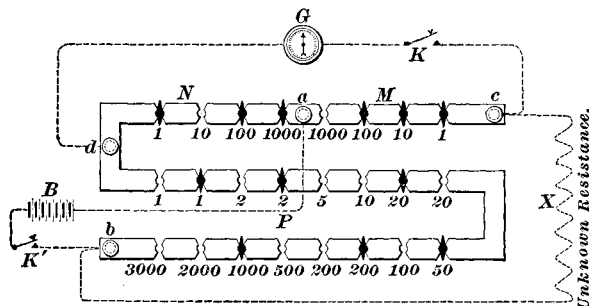


FIG. 827.

drawn, and, therefore, $M = 1,000$ ohms. In the lower balance arm the 10-ohm plug is supposed to be drawn, and therefore, $N = 10$ ohms. In the adjustable arm the following plugs are supposed to be drawn: 1, 2, 5, 10, 20, 100, 200, 500, 2,000, and 3,000 ohms; therefore, the resistance P is the sum of these resistances, or 5,838 ohms. If, under these conditions, there is no deflection of the galvanometer when the two keys, K and K' , are pressed and both circuits are closed, the resistance of X will be 583,800 ohms; for substituting the values of M , N , and P in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{1000}{10} \times 5838 = 583,800$ ohms.

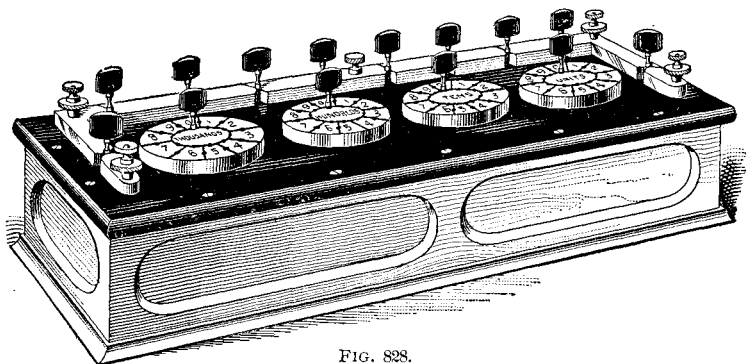


FIG. 828.

Fig. 828 shows a special pattern of resistance box for a Wheatstone's bridge, in which the coils of the adjustable arm

are arranged in the form of four dials. This pattern is known as the *dial* pattern, and is widely used in making resistance measurements.

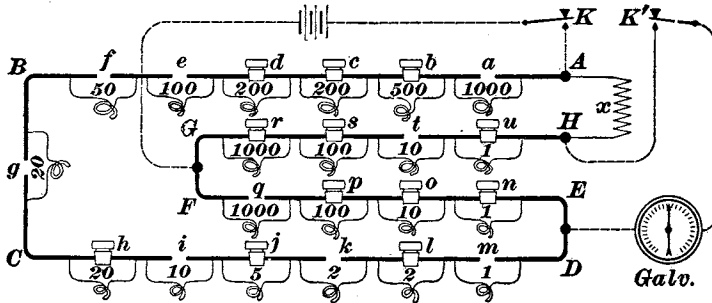


FIG. 829.

EXAMPLE.—The diagram in Fig. 829 represents a particular type of Wheatstone's bridge to which a battery and galvanometer are properly connected for measuring unknown resistances. An unknown resistance x is connected to the terminals A and H ; when the plugs $a, e, f, g, i, k, m, q,$ and t are drawn, and when both the contact keys K and K' are pressed, the galvanometer shows no deflection. Determine the resistance of x .

SOLUTION.—From the connections of the galvanometer and battery circuits, it will be seen that the resistance coils in line GH represent the upper balance arm M of the bridge; that the coils in the line EF represent the lower balance arm N , and that the coils in the lines AB and CD represent the adjustable arm P . From the fundamental equation of the Wheatstone's bridge, x (the unknown resistance) = $\frac{M}{N} \times P$. In this particular case, the plug t in the upper arm is drawn, hence, $M = 10$ ohms; in the lower arm q is drawn, hence, $N = 1,000$ ohms, and in the adjustable arm, the plugs $a, e, f, g, i, k,$ and m are drawn, hence, $P = 1000 + 100 + 50 + 20 + 10 + 2 + 1 = 1183$ ohms. Substituting these values in the fundamental equation, gives $x = \frac{M}{N} \times P = \frac{10}{1000} \times 1183 = 11.83$ ohms. Ans.

2186. The Volt, or the Practical Unit of Electromotive Force.—In mechanics, pressures of all kinds are measured by the *effects* they produce; similarly, in electrotechnics, *potential* is measured by the effect it produces.

It has been shown that electrical potential will cause an electric current to flow against the resistance of a conductor; and also how the units of resistance and current are obtained. It follows that a *unit potential* would be that electromotive force which would maintain a current of unit strength in a circuit whose resistance is unity. By definition, therefore, the *volt*, or *the practical unit of potential*, is that electromotive force which will maintain a current of *one ampere* in a circuit whose resistance is *one ohm*. With a known resistance in ohms and a known strength of current in amperes, the electromotive force in volts is determined by Ohm's law, Art. **2165**, for, by transposing, $E = CR$.

This method of determining the potential of a circuit can be readily shown by the following illustration: Suppose, for example, it is desired to determine the electromotive force in volts required to drive a current of 2 amperes through a certain copper wire. In the first place, the resistance of the copper wire is found by Wheatstone's bridge as previously described. For convenience, it is assumed that its resistance is found to be 1.2 ohms. Then the electromotive force E required to drive 2 amperes through the wire will be 2.4 volts, for, by substituting, $E = CR = 2 \times 1.2 = 2.4$ volts.

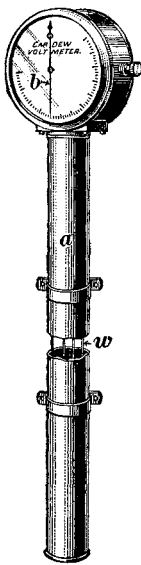
The maximum difference of potential developed by any single voltaic couple placed in any electrolyte is about 2.25 volts; in the common forms of cells, the difference of potential developed averages from .75 to 1.75 volts.

2187. When several cells are connected in *series*, the total electromotive force developed will be equal to the sum of the electromotive forces developed by the separate cells; or, if the cells are composed of the same voltaic elements, the total electromotive force developed will be equal to the electromotive force of one cell, multiplied by the number of cells in series. For example, a battery is composed of 12 cells connected in series, and the electromotive force in each cell is 1.5 volts; the total electromotive force of the battery is $1.5 \times 12 = 18$ volts.

Connecting cells in *parallel* or *multiple-arc* does not increase the electromotive force of a battery; the electromotive force will always be equal to the electromotive force of one cell, no matter how many cells are connected to the main conductors, provided, of course, that all cells develop equal electromotive forces.

2188. Measuring instruments called **voltmeters** have been devised for indicating electromotive forces and differences of potential directly in volts. Principal among these are the *Cardew* and *Weston* voltmeters.

The **Cardew** voltmeter, Fig. 830, depends for its operation upon the linear expansion of a metallic wire when heated



by an electric current. The expansion wire *w* is enclosed in a long cylindrical case *a*, and is attached in such a way that its expansion causes a small grooved wheel, on the axis of the index needle, to revolve in one direction when the wire expands or lengthens, and in the opposite direction when the wire contracts or shortens. The movements of this wheel cause the index *b* to move over the scale. Since the resistance is nearly constant, the current that will flow is proportional to the E. M. F.; the greater the E. M. F. the more will the wire be expanded, and the greater will be the consequent deflection. The resistance of the wire, however, is so large as to permit only a weak current to pass through it when the needle is deflected over the entire scale. A Cardew voltmeter which indicates up to 100 volts has a

resistance of about 500 ohms. The circular scale is divided into small divisions, each representing one volt, or fractions, or multiples of one volt.

2189. The **Weston** voltmeter is based upon the same principles as the Weston ammeter and in appearance, Fig. 831, is quite similar. Its internal resistance, as in all voltmeters is exceedingly large; the resistance of a Weston

voltmeter for indicating up to 150 volts is about 19,000 ohms; while the resistance of a Weston ammeter, measuring strengths of currents up to 15 amperes, is only .0022 ohm. It will be seen that, owing to the great resistance, the current passing through a

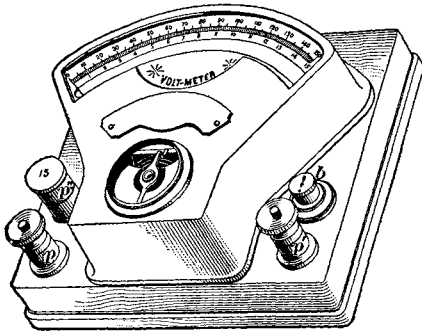


FIG. 831.

current passing through a voltmeter is exceedingly small. For example, in the instrument described above, when indicating 150 volts, the current, by Ohm's law, is only $150 \div 19,000 = .0079$ ampere. All voltmeters are provided with at least two terminals, or binding posts,

such as p and p' , Fig. 831. Connections are made by two separate conductors, called *voltmeter leads*, from these binding posts to two points between which the difference of potential, or the electromotive force, is to be measured. The Weston voltmeters usually have a third binding post p'' , which, when used with p' , corresponds with a second graduated scale situated directly under the main scale, one division of the upper scale having the value of two lower divisions. The majority of voltmeters are also provided with a contact button b , which, when pressed, closes the circuit and allows the index needle to be deflected by the current. When the pressure upon the button is relaxed, the circuit is opened, and the index needle returns to the zero mark.

2190. The methods of connecting voltmeters and ammeters for measuring electromotive forces and currents of various circuits should be thoroughly understood. Suppose, for example, that the terminals of a battery composed of 4 cells connected in series are connected

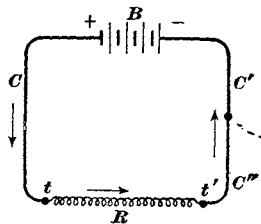


FIG. 832.

to an unknown resistance, and it is desired to know the strength of current flowing through the circuit, and also the difference of potential required to drive that current through the unknown resistance when the only instruments available are an ammeter and a voltmeter. In Fig. 832, let B represent the battery and R the unknown resistance; C , C' , and C'' are three large conductors for making necessary connections. With the connections as shown, there is practically a continuous current flowing through the closed circuit, that is, from the battery through the conductors and the unknown resistance.

FIG. 833.

The first step is to determine the strength of this current by the use of an ammeter. Assuming that the battery is constant, that is, that the electromotive force developed in it does not vary, then, so long as the resistance of the circuit is not altered, the strength of the current will remain unchanged and *will be the same in all parts of the circuit*. Hence, if an ammeter be inserted in any part of the circuit, as between C' and C'' , Fig. 833, it will measure the total strength of current flowing through the entire circuit. As has been stated, the internal resistance of the ammeter is so small that its insertion makes no appreciable change in the total resistance of the circuit, and, therefore, does not to any extent affect the current flowing. For convenience, assume that the strength of the current flowing in the circuit is found to be 1.2 amperes. The next operation is to find the electromotive force required to drive a current of 1.2 amperes through the resistance R ; or, in other words, to find the difference of potential between the terminals t and t' , when a current of 1.2 amperes is flowing in the circuit. This is accomplished by connecting the two terminals t and t' , Fig. 834, of the unknown resistance R , to the two binding posts p and p' of the voltmeter $V.M.$ by two voltmeter leads l and l' . Any small wires of reasonable length can be used for voltmeter leads, as the current

they transmit is exceedingly weak owing to the extremely high resistance of the voltmeter. After pressing the

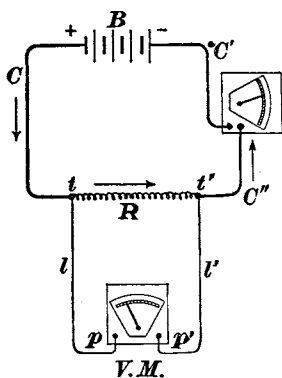


FIG. 834.

contact-button, assume the needle indicates a potential of 6 volts; this, then, is the electromotive force required to force a current of 1.2 amperes through the unknown resistance R ; or, in other words, the difference of potential between the terminals t and t' is 6 volts. From these readings of the current and voltage, and by the application of Ohm's law, the resistance R of the circuit between t and t' can be determined. By algebra, Ohm's law

can be transposed from the equation $C = \frac{E}{R}$ to $R = \frac{E}{C}$ and be equally true; this signifies that the resistance R of any conductor, or circuit, is equal to the electromotive force, or the difference of potential E in volts, divided by the strength of current C in amperes, flowing through that circuit or conductor. In the previous case, it has been found that it requires an electromotive force of 6 volts to drive a current of 1.2 amperes through the resistance R ; hence, from Ohm's law $R = \frac{E}{C} = \frac{6}{1.2} = 5$ ohms.

APPLICATIONS OF OHM'S LAW.

TO CLOSED CIRCUITS.

2191. The following facts are to be carefully noted regarding the application of Ohm's law to closed circuits:

The strength of current (C) is the same in all parts of a closed circuit, except in the cases of derived circuits, where the sum of the currents in the separate branches is always equal to the current in the main or undivided circuit.

The resistance (R) is the resistance of the internal circuit plus the resistance of the external circuit.

The electromotive force (E) in a closed circuit is the total generated difference of potential in that circuit.

2192. The following formula may be used to determine the strength of current in amperes flowing in a closed circuit when the electromotive force and the total resistance are known:

$$C = \frac{E}{R}, \quad (311.)$$

where C = current in amperes;

E = electromotive force in volts;

R = resistance in ohms.

That is to say, *the strength of current in amperes is found by dividing the electromotive force in volts by the total resistance in ohms.*

EXAMPLE.—The two electrodes of a simple voltaic cell are connected by a conductor whose resistance is 1.6 ohms. If the internal resistance of the cell is 5 ohms and the total electromotive force developed is 1.75 volts, what is the strength of current flowing in the circuit?

SOLUTION.—Let r_i = the internal resistance and r_e = the resistance of the copper wire. Then $R = r_i + r_e = 1.6 + 5 = 6.6$ ohms, the total resistance of the circuit. Then, by formula **311**, the current,

$$C = \frac{E}{R} = \frac{1.75}{6.6} = .265 \text{ ampere. Ans.}$$

2193. The following formula may be used to find the total resistance in ohms of a closed circuit when the electromotive force and the strength of current are known:

$$R = \frac{E}{C}, \quad (312.)$$

the letters having the same significance as in formula **311**. By formula **312** it will be seen that *the resistance in ohms of a closed circuit is found by dividing the electromotive force in volts by the current in amperes.*

EXAMPLE.—The total electromotive force developed in a closed circuit is 1.8 volts and the strength of the current flowing is .6 ampere; find the resistance in ohms.

SOLUTION.—By formula **312**, the resistance

$$R = \frac{E}{C} = \frac{1.8}{.6} = 3 \text{ ohms. Ans.}$$

2194. The following formula may be used to find the total electromotive force in volts developed in a closed circuit, when the strength of current and the total resistance are known:

$$E = C R. \quad (313.)$$

The letters have the same meaning as in formulas **311** and **312**. We find here that *the electromotive force in volts developed in a closed circuit is obtained by multiplying together the current in amperes and the resistance in ohms.*

EXAMPLE.—The internal resistance of a closed circuit is 2 ohms and the external resistance is 3 ohms; if the current flowing is .4 ampere, what is the electromotive force developed?

SOLUTION.—Let r_i = the internal resistance and r_e = the external resistance. Then $R = r_i + r_e = 2 + 3 = 5$ ohms. By formula **313**, the electromotive force $E = CR = .4 \times 5 = 2.0$ volts. Ans.

TO DROP OR LOSS OF POTENTIAL.

2195. Referring again to water flowing in a pipe, though the *quantity* of water which passes is the same at any cross-section of the pipe, the *pressure per square inch* is not the same. Even in the case of a horizontal pipe of the same diameter throughout, the water when flowing suffers a *loss* of head or pressure. It is this difference of pressure that causes the water to flow between two points against the friction of the pipe.

This is precisely similar to a current of electricity flowing through a conductor. Though the *quantity of electricity* that flows is equal at all cross-sections, the electromotive force is by no means the same at all points along the conductor. It suffers a loss or drop of electrical potential in the direction in which the current is flowing, and it is this difference of electrical potential that causes the electricity to flow against the resistance of the conductor. *Ohm's law* not only gives the strength of the current in a closed circuit, but also the *difference of potential* in volts along that circuit. The difference of potential (E') in volts between any two points along a circuit is equal to the product of the

strength of the current (C) in amperes and the resistance (R') in ohms of that part of the circuit between those two points, or $E' = C R'$, which is an example of the use of formula **313**. E' also represents the *loss* or *drop* of potential in volts between the two points. If any two of these quantities are known, the third can be readily found; for, by transposing, $C = \frac{E'}{R'}$ and $R' = \frac{E'}{C}$, as already given in formulas **311** and **312**.

EXAMPLE.—Fig. 835 represents part of a circuit in which a current of 3 amperes is flowing. The re-

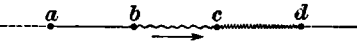


FIG. 835.

sistance from a to b is 1.5 ohms; from b to c is 2.3 ohms, and from c to d is 3.6 ohms. Find the difference of potential between a and b , b and c , c and d , and a and d .

SOLUTION.—Since, by formula **313**, $E' = C R'$, then, the difference of potential between a and $b = 3 \times 1.5 = 4.5$ volts.

“ “ “ “ “ b and $c = 3 \times 2.3 = 6.9$ “

“ “ “ “ “ c and $d = 3 \times 3.6 = 10.8$ “

“ “ “ “ “ a and $d = 4.5 + 6.9 + 10.8 =$

22.2 volts; or, in other words, the *loss* or *drop* of potential caused by a current of 3 amperes flowing between a and d is 22.2 volts.

2196. In a great many cases it is desirable to have the current flow from the source a long distance to some electrical receptive device and return without causing an excessive drop or loss of potential in the conductors leading to and from the two places. In such circuits, the greater part of the total generated electromotive force is expended in the receptive device itself, and only a small fraction of it is lost in the rest of the circuit. Under these conditions, it is customary to decide upon a certain *drop* or *loss of potential* beforehand, and from that and the current calculate the resistance of the two conductors.

EXAMPLE.—It is desired to transmit a current of 5 amperes to an electrical device situated 500 feet from the source; the total generated E. M. F. is 120 volts, and only $\frac{1}{10}$ of this potential is to be lost in the conductors leading to and from the receptive device. (*a*) Find the resistance of the two conductors, and (*b*) the resistance per foot of the conductors, assuming each to be 500 feet long.

SOLUTION.—(a) $\frac{1}{10}$ of 120 volts = 12 volts, which represents the *drop* or *loss* of potential on the two conductors. Let $E' = 12$ volts; $C = 5$ amperes, and $R' =$ the total resistance of the two conductors.

Then, by formula **312**, $R' = \frac{E'}{C} = \frac{12}{5} = 2.4$ ohms. Ans.

(b) The resistance per foot of the conductor is found by formula **306**. In this case $r_1 = 2.4$ ohms; $l_1 = 1,000$ feet; $l_2 = 1$ foot. Then the resistance per foot

$$r_2 = \frac{2.4 \times 1}{1,000} = .0024 \text{ ohm. Ans.}$$

TO VOLTAIC CELLS.

2197. The difference of potential between the two electrodes of a simple voltaic cell when no current is flowing—that is, when the circuit is open—is always equal to the total electromotive force developed within the cell; but when a current is flowing—that is, when the circuit is *closed*—a certain amount of potential is expended in forcing the current through the internal resistance of the cell itself. Hence, the difference of potential between the two electrodes when the circuit is closed is always smaller than when the circuit is open. This difference of potential between the two electrodes when the circuit is closed is sometimes called the *available* or *external* electromotive force, to distinguish it from the *internal* or *total generated* electromotive force.

2198. To find the available electromotive force of a cell, let $E =$ the total generated E. M. F.;

$E' =$ available E. M. F. when the circuit is closed;

$C =$ the current flowing when the circuit is closed;

$r_i =$ the internal resistance of the cell.

Then, the drop or loss of potential in the cell $= Cr_i$, and the available electromotive force

$$E' = E - Cr_i. \quad (314.)$$

The available electromotive force of a cell is equal to the difference between the total generated electromotive force and the potential expended in forcing the current through the internal resistance of the cell when the circuit is closed. From Ohm's law, this loss or drop of potential in the cell itself is equal

to the product of the internal resistance in ohms and the strength of the current in amperes flowing through the circuit.

EXAMPLE.—In a voltaic cell, the total generated E. M. F. is 2.2 volts, and the internal resistance is .8 ohm. If a current of 1.2 amperes flows through the cell when the circuit is closed, what is the available E. M. F., or, in other words, the difference of potential between the two electrodes?

SOLUTION.—Let E' = the available E. M. F.; E = the total generated electromotive force; C = the current in amperes, and r_i = the internal resistance.

Then, by formula 314,

$$E' = E - Cr_i = 2.2 - (1.2 \times .8) = 1.24 \text{ volts. Ans.}$$

TO DERIVED CIRCUITS.

2199. In treating upon derived circuits, only that part of the circuit will be considered which is divided into branches and each branch transmitting part of the total current; the rest of the circuit is assumed to be closed through some electric source, as, for instance, a voltaic battery.

Before applying Ohm's law to derived circuits, the word *conductivity* should be thoroughly understood. Conductivity can be defined as the facility with which a body transmits electricity, and is the opposite of resistance. For example, copper is of low resistance and high conductivity; mercury is of high resistance and low conductivity. In other words, conductivity is the inverse or reciprocal of resistance. There is no established unit of conductivity; it is used merely as a convenience in calculations. For example, if the resistance of a circuit is 2 ohms, its conductivity is represented by $\frac{1}{2}$; if the resistance is increased to 4 ohms, the conductivity would only be one-half as much as in the former case and would be represented by $\frac{1}{4}$.

The **conductivity** of any conductor is, therefore, unity divided by the *resistance* of that conductor; and, conversely, the resistance of any conductor is unity divided by its conductivity.

2200. Fig. 836 represents a derived circuit of 2 branches.

Let r_1 and r_2 = the separate resistances of the two branches, respectively; c_1 and c_2 = the separate currents in each branch, respectively, and C = the sum of the currents in the

two branches—that is, the current in the main or undivided branch. Then, $c_1 + c_2 = C$, and $C - c_2 = c_1$.

When the current flows from a to b , if the resistances r_1 and r_2 are equal, the current will divide equally between

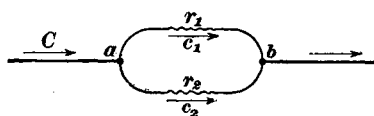


FIG. 836.

the two branches; thus, if a current of 2 amperes is flowing in the main circuit, one ampere will flow through each branch.

When the resistances of the two branches are unequal, the current will divide between them in inverse proportion to their respective resistances. In Fig. 836, the resistances of the two branches are r_1 and r_2 . Therefore, $c_1 : c_2 :: r_2 : r_1$.

By algebra, this proportion gives the two following formulas:

$$\text{For the first branch, } c_1 = \frac{C r_2}{r_1 + r_2}. \quad (315.)$$

That is, of two branches in parallel, dividing from a main circuit, the current in the first branch is equal to the current in the main multiplied by the resistance of the second branch, and the product divided by the sum of the resistances of the two branches.

$$\text{For the second branch, } c_2 = \frac{C r_1}{r_1 + r_2}. \quad (316.)$$

Of two branches in parallel, dividing from a main circuit, the current in the second branch is equal to the current in the main multiplied by the resistance of the first branch, and the product divided by the sum of the resistances of the two branches.

EXAMPLE.—Suppose the resistance r_1 of the first branch is 2 ohms, and the resistance r_2 of the second branch is 3 ohms, find the separate currents c_1 and c_2 in the two branches, respectively, when the current C in the main or undivided branch is 60 amperes.

SOLUTION.— $r_1 = 2$ ohms, $r_2 = 3$ ohms, and $C = 60$ amperes. To find the current c_1 in the first branch, substitute these values in formula **315**, which will give $c_1 = \frac{C r_2}{r_1 + r_2} = \frac{60 \times 3}{2 + 3} = \frac{180}{5} = 36$ amperes. Ans.

To find the current c_2 , in the second branch, substitute these values in formula **316**, which will give

$$c_2 = \frac{C r_1}{r_1 + r_2} = \frac{60 \times 2}{2 + 3} = \frac{120}{5} = 24 \text{ amperes. Ans.}$$

2201. It is clear that two conductors in parallel will conduct an electric current more readily than one alone; that is, their *joint conductivity* is greater than either of their separate conductivities taken alone. This being the case, their resistances must follow the inverse law—viz., the joint resistance of two conductors in parallel must be *less* than either of their separate resistances taken alone.

Rule.—*If the separate resistances of two conductors are equal, their joint resistance when connected in parallel is one-half of the resistance of either conductor.*

For example, take two conductors, the separate resistance of each being 2 ohms, and connect them in parallel; their joint resistance will then be one-half their separate resistance, or 1 ohm.

2202. When the separate resistances of two conductors in parallel are unequal, the determination of their joint resistance when connected in parallel involves some calculation.

In Fig. 836, the conductivities of the branches are $\frac{1}{r_1}$ and $\frac{1}{r_2}$, respectively. Hence, their joint conductivity when connected in parallel is $\frac{1}{r_1} + \frac{1}{r_2} = \frac{r_2 + r_1}{r_1 r_2}$; now, since the resistance of any conductor is the reciprocal of its conductivity, then the *joint resistance* of the two branches in parallel is the reciprocal of their joint conductivity; or, $1 \div \frac{r_2 + r_1}{r_1 r_2} = \frac{r_1 r_2}{r_2 + r_1}$. Hence, joint resistance $R'' = \frac{r_1 r_2}{r_1 + r_2}$. **(317.)**

That is, *the joint resistance of two conductors connected in parallel is equal to the product of their separate resistances divided by the sum of their separate resistances.*

EXAMPLE.—In Fig. 836, given $r_1 = 2$ ohms and $r_2 = 3$ ohms; find their joint resistance in parallel.

SOLUTION.—From formula **317**, their joint resistance $R'' = \frac{r_1 r_2}{r_1 + r_2}$
 $= \frac{2 \times 3}{2 + 3} = \frac{6}{5} = 1\frac{1}{5}$ ohms. Ans.

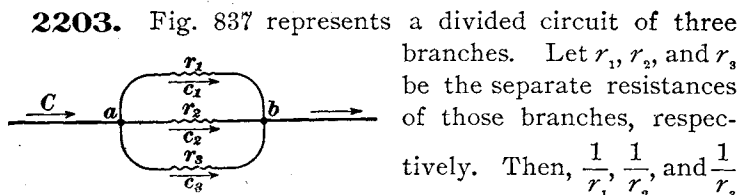


FIG. 837.

represent the separate conductivities of the three branches, respectively. Their joint conductivity $= \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}$. Since the joint resistance is the reciprocal of their joint conductivity, then it is equal to

$$1 \div \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3} = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}.$$

Hence, the joint resistance of three branches in parallel,

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}. \quad (318.)$$

That is, *the joint resistance of three or more conductors connected in parallel is equal to the reciprocal of their joint conductivity.*

EXAMPLE.—In Fig. 837, given, $r_1 = 5$ ohms; $r_2 = 10$ ohms, and $r_3 = 20$ ohms; find their joint resistance from a to b .

SOLUTION.—By formula **318**, their joint resistance,

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2} = \frac{5 \times 10 \times 20}{10 \times 20 + 5 \times 20 + 5 \times 10} = \frac{1000}{350} = \frac{20}{7} \\ = 2\frac{6}{7} \text{ ohms. Ans.}$$

2204. In a derived circuit of any number of branches, the difference of potential between where the branches divide and where they unite is equal to the product of the sum of the currents in the separate branches and their joint resistance in parallel, as will be apparent from consideration of Ohm's law, Art. **2165**.

For example, if the currents in the three branches, Fig. 837, are 16, 8, and 4 amperes, respectively, and the joint resistance from a to b is $2\frac{6}{7}$ ohms, then the difference of potential between a and $b = (16 + 8 + 4) \times 2\frac{6}{7} = 28 \times \frac{20}{7} = 80$ volts.

2205. The separate currents in the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate resistance of each branch.

For example, in Fig. 837, assume that the separate resistances of the three branches are, respectively, 5, 10, and 20 ohms, and that the difference of potential between *a* and *b* is 80 volts. Then, the current in the first branch is $\frac{80}{5} = 16$ amperes; in the second, $\frac{80}{10} = 8$ amperes, and in the third $\frac{80}{20} = 4$ amperes.

2206. The separate resistance of the branches of a derived circuit can be determined by finding the difference of potential between where the branches divide and where they unite, and dividing the result by the separate currents in each branch.

For example, in Fig. 837, assume the difference of potential between *a* and *b* to be 80 volts, and the currents in the separate branches to be 16, 8, and 4 amperes, respectively; then, the resistance of the first branch is $\frac{80}{16} = 5$ ohms; of the second, $\frac{80}{8} = 10$ ohms, and of the third, $\frac{80}{4} = 20$ ohms.

EXAMPLE.—Fig. 838 represents a closed circuit, part of which, from *a* to *b*, forms a derived, or shunt, circuit of three separate branches *A*, *B*, and *C*, in parallel; r_1 , r_2 , and r_3 represent the separate resistance of the branches, respectively, from *a* to *b*; and R' represents the resistance of the rest of the closed circuit from *b* to *a* in the direction in which the current is supposed to be flowing, including the internal resistance of the battery *K*. Let $r_1 = 2$ ohms; $r_2 = 3.2$ ohms; $r_3 = 4.4$ ohms, and $R' = .8$ ohm.

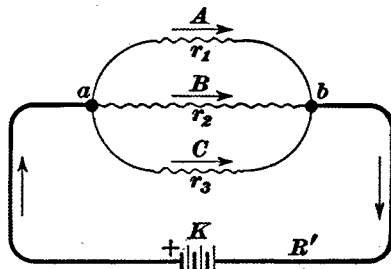


FIG. 838.

If a current of 2 amperes is flowing in the main, or undivided, circuit, find the total electromotive force developed in the battery *K*.

SOLUTION.—From the application of Ohm's law to closed circuits, formula **313**, $E = C R$, where E is the total electromotive force developed within the electric source, C the strength of current flowing, and R the total resistance of the circuit through which the current passes. In this particular problem, the total resistance of the closed circuit, will be the *joint* resistance of the three branches in parallel, plus the resistance R' , of the rest of the circuit. Hence, first find the joint resistance of the three branches A , B , and C , in parallel from a to b . By formula **318**, the joint resistance of three conductors, in parallel, is $\frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$, where r_1 , r_2 , and r_3 represent the separate resistances of the three conductors. Substituting, gives

$$\frac{2 \times 3.2 \times 4.4}{3.2 \times 4.4 + 2 \times 4.4 + 2 \times 3.2} = \frac{28.16}{14.08 + 8.8 + 6.4} = \frac{28.16}{29.28} = .9617 \text{ ohm,}$$

the joint resistance of the three branches A , B , and C , in parallel from a to b . The total resistance of the closed circuit is, therefore, $.9617 + .8 = 1.7617$ ohms, and $E = C \times R = 2 \times 1.7617 = 3.5234$ volts. Ans.

ELECTRICAL QUANTITY.

2207. The rate of flow of liquids is expressed in units of quantity per second, or minute; and similarly, the strength of an electric current can be defined as a quantity of electricity flowing per second. The practical unit of *electrical quantity* is called the **coulomb**.

The coulomb is such a quantity of electricity as would pass in one second through a circuit in which the strength of current is one ampere.

As stated in Art. **2166**, the *quantity* of electricity is calculated from the strength of current; it can not be actually measured. For example, suppose the strength of current in a closed circuit to be 10 amperes, as measured by an ammeter; if such a current flows for only one second, the quantity of electricity which has passed around the circuit is 10 coulombs; but if the current flows for 2 seconds, the quantity of electricity would be 20 coulombs.

Hence, to calculate the quantity of electricity which has passed in a circuit in a certain time when the strength of the current in amperes is known:

Let Q = the quantity of electricity in coulombs C , the strength of current in amperes, and t the time in seconds.

$$\text{Then, } Q = C t. \quad (319.)$$

If any two of these quantities are known, the third can be readily found. By transposition, $C = \frac{Q}{t}$ and $t = \frac{Q}{C}$.

Therefore, to obtain the quantity of current which has passed through a circuit in a given time, *multiply the strength of current in amperes by the time in seconds.*

EXAMPLE.—Find the quantity of electricity, in coulombs, that flows around in a closed circuit in $1\frac{1}{2}$ hours, when the strength of current is 12 amperes.

SOLUTION.—Reducing the time to seconds gives $1.5 \times 60 \times 60 = 5,400$ seconds; hence, $t = 5,400$ seconds and $C = 12$ amperes. Then, from the formula **319**, $Q = C t = 12 \times 5,400 = 64,800$ coulombs. Ans.

ELECTRICAL WORK.

2208. When an electric current flows from a higher to a lower potential, *electrical energy* is expended, and *work* is done by the current. The principle of the *conservation of energy* teaches that energy can never be destroyed; it follows, therefore, that if energy has to be expended in forcing a quantity of electricity against a certain amount of resistance, the equivalent of that energy must be transformed into some other form. This other form is usually *heat*; that is, when a quantity of electricity flows against the resistance of a conductor, a certain amount of *electrical energy* is transformed into *heat energy*.

The actual amount of heat developed is an exact equivalent of the *work done* in overcoming the resistance of the conductor, and varies directly as that resistance. For example, take two wires, the resistance of one being twice that of the other, and send currents of equal strengths through each. The amount of heat developed in the wire of higher resistance will be twice that developed in the wire offering the lower resistance.

The unit used to express the amount of mechanical work done is known as the *foot-pound*. The work done, in raising any mass through any height, is found by multiplying the weight of the body lifted by the vertical height through which it is raised; similarly, the practical unit of *electrical*

work is that amount accomplished when a unit quantity of electricity, *one coulomb*, flows between a potential of *one volt*.

The unit of electrical work is, therefore, the *volt-coulomb*, and is called the **joule**.

1 *joule* = .7373 foot-pound.

2209. By means of the following formulas, we may find directly the amount of electrical work accomplished in *joules* during a given time in any circuit:

Let J = electrical work in joules;

C = current in amperes;

t = time in seconds during which the current flows;

E = potential, or E. M. F., of circuit;

R = resistance of circuit.

When the current and electromotive force are known,

$$J = C E t. \quad (320.)$$

When the current and resistance are known,

$$J = C^2 R t. \quad (321.)$$

When the resistance and electromotive force are known,

$$J = \frac{E^2 t}{R}. \quad (322.)$$

To determine, therefore, the electrical work done in a given time, *multiply the quantity of electricity, in coulombs, which has passed in the circuit during that time, by the loss or drop of potential as measured directly, or as computed from the values of the current and resistance.*

EXAMPLE.—Find the amount of work done in joules when a current of 15 amperes flows for $\frac{1}{2}$ an hour, against a resistance of 2 ohms.

SOLUTION.—Reducing the time to seconds, gives $30 \times 60 = 1,800$ seconds = t . The current = $C = 15$ amperes, and the resistance = 2 ohms = R . Then, by formula **321**, the electrical work done

$$J = 15 \times 15 \times 2 \times 1,800 = 810,000 \text{ joules. Ans.}$$

2210. When the work in joules is known, the work in foot-pounds

$$F-P = .7373 J. \quad (323.)$$

That is, *the equivalent work done in foot-pounds is obtained by multiplying the number of joules by .7373.*

EXAMPLE.—Express the work done in foot-pounds in a circuit when a current of 8 amperes flows for 2 hours between a potential of 10 volts.

SOLUTION.—Reducing the time to seconds gives $2 \times 60 \times 60 = 7,200$ seconds = t . The current = 8 amperes = C , and the electromotive force = 10 volts = E . Then, by formula **320**, the electrical work done = $J = 8 \times 10 \times 7,200 = 576,000$ joules. Expressed in foot-pounds, this will be, by formula **323**,

$$F \cdot P = .7373 \times 576,000 = 424,684.8 \text{ foot-pounds. Ans.}$$

ELECTRICAL POWER.

2211. Power, or *rate of doing work*, is found by dividing the amount of work done by the time required to do it. In mechanics, the unit of power is called the **horsepower**; in electrotechnics, the unit of power is the **watt**. It is found by dividing the amount of electrical work done by the time required to do it.

Let E = the electromotive force in volts; Q , the quantity of electricity in coulombs; C , the current in amperes, and W , the power in watts.

By formula **320**, the amount of electrical work, $J = CEt$. Then,

$$W = \frac{CEt}{t} = CE. \quad (324.)$$

The power in watts is equal to the strength of current in amperes, multiplied by the electromotive force in volts.

EXAMPLE.—What is the power in watts developed in a closed circuit in which a current of 12 amperes is flowing, between a difference of potential of 25 volts?

SOLUTION.— $E = 25$ volts and $C = 12$ amperes. Hence, by formula **324**,

$$W = CE = 12 \times 25 = 300 \text{ watts. Ans.}$$

By taking into consideration the resistance of the circuit, the equation for determining the power in watts may be expressed in two other ways:

By derivation from formula **321**,

$$W = \frac{C^2 R t}{t} = C^2 R. \quad (325.)$$

That is, *the power in watts is equal to the strength of current in amperes squared, multiplied by the resistance in ohms.*

EXAMPLE.—Find the power in watts in a closed circuit in which a current of 30 amperes is flowing against a resistance of 3 ohms.

SOLUTION.— $C = 30$ and $R = 3$. Hence, by formula **325**,

$$W = C^2 R = 30^2 \times 3 = 2,700 \text{ watts. Ans.}$$

By derivation from formula **322**,

$$W = \frac{E^2 t}{R t} = \frac{E^2}{R}. \quad (326.)$$

That is, *the power in watts is the quotient arising from dividing the electromotive force in volts, squared, by the resistance in ohms.*

EXAMPLE.—The drop of potential in a closed circuit when a current is flowing is 20 volts and the resistance is 10 ohms; what is the power in watts expended?

SOLUTION.— $E = 20$ volts and $R = 10$ ohms. Hence, by formula **326**,

$$W = \frac{E^2}{R} = \frac{20^2}{10} = 40 \text{ watts. Ans.}$$

2212. One watt equals $\frac{1}{746}$ of a horsepower; or, one horsepower equals 746 watts.

If $H.P. =$ horsepower

$$H.P. = \frac{W}{746}. \quad (327.)$$

That is, *to express the rate of doing electrical work in horsepower units, find the number of watts and divide the result by 746.*

The horsepower may also be expressed by three other equations, by expressing the watts in terms of electromotive force, current, and resistance, as obtained from formulas **324**, **325**, **326**, viz.:

$$H.P. = \frac{EC}{746}; \quad H.P. = \frac{C^2 R}{746}, \text{ and } H.P. = \frac{E^2}{746R}.$$

EXAMPLE.—Given, current = 50 amperes and electromotive force = 250 volts; express the power directly in horsepower units.

SOLUTION.— $E = 250$ volts; $C = 50$ amperes; hence, $H.P. = \frac{EC}{746} = \frac{250 \times 50}{746} = 16.756 \text{ horsepower. Ans.}$

EXAMPLE.—Given, strength of current = 25 amperes and resistance = 14.92 ohms; express the power directly in horsepower units.

SOLUTION.— $C = 25$ amperes; $R = 14.92$ ohms; hence,

$$H.P. = \frac{C^2 R}{746} = \frac{25^2 \times 14.92}{746} = 12.5 \text{ horsepower. Ans.}$$

EXAMPLE.—Given, electromotive force = 110 volts and resistance = 4 ohms; express the power directly in horsepower units.

SOLUTION.— $E = 110$ volts; $R = 4$ ohms; hence, $H.P. = \frac{E^2}{746R} = \frac{110^2}{746 \times 4} = 4.055 \text{ horsepower. Ans.}$

2213. To express the power in watts when the horsepower is known, use the following formula:

$$W = H.P. \times 746. \quad (328.)$$

That is to say, *the power in watts is found by multiplying the horsepower by 746.*

EXAMPLE.—Express the equivalent of 4.35 horsepower in watts.

SOLUTION.— $H.P. = 4.35$; by formula **328**, the electrical power $W = 4.35 \times 746 = 3,245.1$ watts. Ans.

DYNAMOS AND MOTORS.

(CONTINUED.)

ELECTROMAGNETIC INDUCTION.

2214. It has been shown that an electric current circulating around a coiled conductor produces lines of force which thread through the coil, entering at one end and leaving at the other. So long as the current in the coil remains at a constant strength, the lines of force have direction and position only; unless influenced by some exterior magnetic substance, they do not increase or diminish in number, or change their position relatively to the coil. Fig. 839 represents such a coil around which a current is flowing from the battery *B*. Suppose the battery is disconnected from

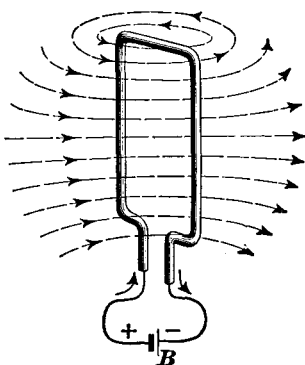


FIG. 839.

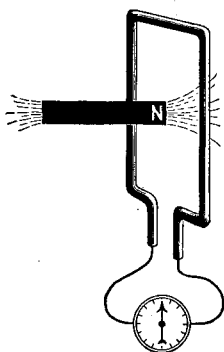


FIG. 840.

the coil and a galvanometer for detecting small currents is inserted in its place. A magnetic pole suddenly thrown into the coil, as represented in Fig. 840, will cause a deflection of the galvanometer needle; the needle, however, will return to its original position as soon as the magnet comes to rest. Withdrawing the magnet from the coil also causes a deflection of the needle, but in the opposite direction. In the first case, a momentary current is induced in the circuit, as shown by the deflection of the galvanometer needle while the magnet is being inserted into

the coil; this current immediately subsides when the magnet ceases to move. In the second case, the same effects are produced, with the exception that the current induced in the coil flows in an opposite direction to that in the first case.

These induced currents are caused by a change in the number of lines of force which pass through the coil. In passing into or out of the coil, the lines of force from the magnet set up an E. M. F. in that portion of the conductor in which the number of lines of force is changing, and this E. M. F. tends to send a current through the circuit.

2215. In the place of a small magnetic pole, imagine the coil to be suddenly inserted into a large uniform magnetic field where

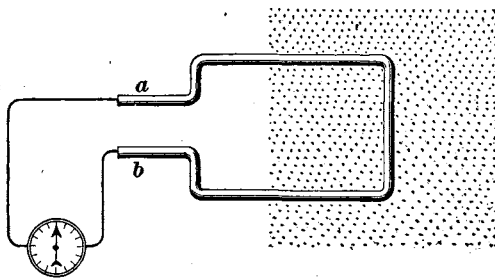


FIG. 841.

all the lines of force are parallel to one another. The diagram, Fig. 841, represents a cross-sectional view of such a field. The dots

represent the ends of the lines of force; their direction is assumed to be downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south magnetic pole. As the coil enters the magnetic field with its plane at right angles to the lines of force, a current will be induced in the coil and the galvanometer needle will be deflected; this induced current is produced by a change in the number of lines of force which pass through the coil, as in the previous case. Withdrawing the coil from the magnetic field will also induce a current in the circuit, but it will deflect the galvanometer needle in an opposite direction, showing that the current in the circuit is reversed.

If the coiled conductor be straightened out, forming one

long conductor, and then moved across the magnetic field at right angles to the lines of force, as represented in Fig. 842, a current will be generated in the circuit. The current, however, immediately subsides when the motion ceases, no matter whether the conductor is in the magnetic field or otherwise. Should the conductor be moved in the magnetic field, with its length parallel to the lines of force, as in Fig. 843, no current will be generated in the circuit. From these two experiments the following principle is deduced:

When a conductor is moved across a magnetic field so that it cuts the lines of force, an E. M. F. is generated which tends to send a current through that conductor.

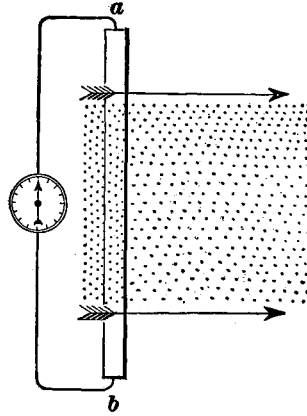


FIG. 842.

2216. In reality, currents generated in a conductor *cutting* lines of force, and those *induced* in a coiled conductor by a change in number of lines of force which pass through the coil, are due to the same movement. For every conductor conveying an electric current forms a closed coil, and every line of force is a complete magnetic circuit by itself.

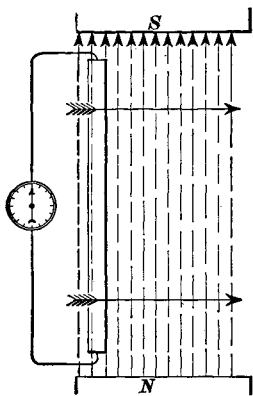


FIG. 843.

Consequently, when any part of a closed coil is cutting lines of force, the lines of force are passing through the coil in a definite direction and changing at the same rate as the cutting. For example, in Fig. 844, the heavy loop *C C* represents a closed coil, and the light loop *L F* represents four lines of force. When the two closed loops are brought together, the closed coil is cut at

one place *a* by four lines of force, and, at the same time, the number of lines of force passing through the closed coil increases from nothing to four. In calculations, however,

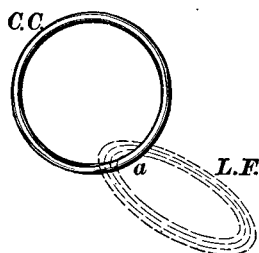


FIG. 844.

it is convenient to make a distinction between the two cases: in the one case, to consider that the current is *generated* by a conductor of a certain length *cutting* lines of force at right angles; and in the other, to consider that the current in a closed coil is *induced* by a *change* in the number of lines of force passing through the coil.

In these explanations, it must not be forgotten that an electric current is the result of a difference of potential or electromotive force. Consequently, it is not actually a current that is generated in the moving wire, but an electromotive force; for, in all of the previous experiments in which currents are induced or generated in a conductor by the lines of force, if the circuit is opened at any point, no current will flow, but the electromotive force still exists.

2217. There are three methods of producing an electromotive force by induction in a coiled conductor; namely, by *electro-magnetic induction*, by *self-induction*, and by *mutual induction*.

In **electro-magnetic induction**, the change in the number of lines of force which pass through the coil is due to some relative movement between the coil and a magnetic field; as, for example, by thrusting a magnet into the coil or withdrawing it; or, again, by suddenly inserting the coil into a magnetic field with its plane at right angles to the lines of force.

2218. In **self-induction**, the change in the number of lines of force is caused by sudden changes in a current which is already flowing through the coil itself, and is supplied from some exterior source. This exterior current produces a magnetic field in the coil, and so long as the

strength of the current remains constant, there is no change in the number of lines of force which pass through the coil. But if the strength of the current is suddenly increased, a change in the number of lines of force occurs; the change in turn *induces* an electromotive force in the conductor, which *opposes* the original current in the coil and tends to keep the current from rising. Its action is similar to that which would take place if some extra resistance were suddenly inserted into the circuit at the instant the strength of the current is increased. The original current eventually reaches its maximum strength in the coil as determined by Ohm's law, but its rise is not instantaneous; it is retarded to a certain extent by this induced electromotive force. If, on the contrary, the strength of the original current is suddenly allowed to decrease, another change is produced in the lines of force which pass through the coil; this new change induces an electromotive force in the coil which acts in the *same* direction as that of the original current and tends to keep it from falling. As in the previous case, however, the original current will eventually drop to its minimum strength, as determined by Ohm's law, but it will fall gradually, and a fraction of a second will elapse before it becomes constant. In short, the current flowing through a coiled conductor acts as if possessing *inertia*; any sudden change in the strength of the current produces a corresponding electromotive force which opposes that change and tends to keep the current at a constant strength.

2219. In mutual induction, two separate coiled conductors, one conveying a current of electricity, are placed near each other, so that the magnetic circuit produced by the one in which the current flows is enclosed by the other, as shown in Fig. 845, where the current circulates around the coil *P* when the circuit is closed at key *b*. The coil *P* is called

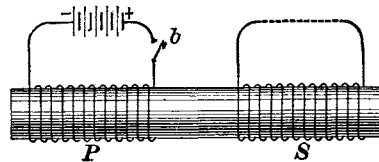


FIG. 845.

the **primary** or **exciting coil**; the other coil S is the **secondary coil**.

Any sudden change in the strength of the current circulating around the primary coil, as, for instance, breaking the circuit at b , produces a corresponding change in the number of lines of force in the magnetic circuit which passes through both coils; and, hence, an electromotive force is induced in the secondary coil. If the primary circuit is completed at b , and the current tends to rise in that coil, the electromotive force induced in the secondary coil causes a current to circulate around in it in the *opposite* direction to the current in the primary coil. If, on the contrary, the circuit at b is suddenly opened and the current in the primary decreases, the induced electromotive force in the secondary causes a current to circulate around in it in the *same* direction as the current in the primary coil.

2220. The direction of an induced current in a coil depends upon the direction of the lines of force in the coil, and whether their number is increasing or diminishing. If these two facts are known, the direction in which the current circulates around the coil is determined by the following rule :

Rule.—*If the effect of the action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in the direction of the movement of the hands of a watch as viewed by a person looking along the magnetic field in the direction of the lines of force ; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around in the opposite direction.*

For example, in the diagram, Fig. 841, when the coil is inserted into the magnetic field, thereby *increasing* the number of lines of force which pass through the coil, the current circulates from b around the coil to a , and thence, through the galvanometer, to b again; when the coil is withdrawn and the number of lines *diminishes*, the current circulates in the opposite direction; that is, from a around the coil to b ,

and thence, through the galvanometer, to *a* again. That end of the coiled conductor *from* which the current flows *to* the external circuit, as from *a* through the galvanometer, in the first case, is the *positive* pole or terminal of the coil; in the second case, *b* is the *positive* pole or terminal.

2221. Referring to the straight conductor in which a current is generated by moving it across a magnetic field at right angles to the lines of force, the direction of the current in the conductor depends upon the relation of the direction of the lines of force to that of the moving conductor. The conductor must necessarily be moved across the magnetic field at some angle to the lines of force, and the current generated in the conductor will tend to flow at right angles to the lines of force and at right angles to the direction in which the conductor is moving. In Fig. 842, if the conductor is moved from left to right across the lines of force, the current generated in it will tend to flow upwards through the conductor; that is, from *b* to *a* through the conductor, then from *a* to *b* through the galvanometer. If the conductor is moved in the opposite direction, that is, from right to left, the current in the conductor will tend to flow in a reversed direction; that is, from *a* to *b* through the conductor and from *b* to *a* through the galvanometer. A convenient method for remembering the direction of a current generated in a straight conductor, when the conductor is moved in a magnetic field at right angles to the lines of force, is as follows:

Rule.—Place thumb, forefinger, and middle finger of the right hand so that each will be perpendicular to the other two; if the forefinger points in the direction of the lines of force, and the thumb points in the direction towards which the conductor is moving, then the middle finger will point in the direction towards which the current generated in the conductor tends to flow.

For example, in Fig. 846, if a vertical conductor be moved across the front of the north pole *N* of the magnet in the direction towards which the thumb points, the current

generated in the conductor will flow downwards; that is,

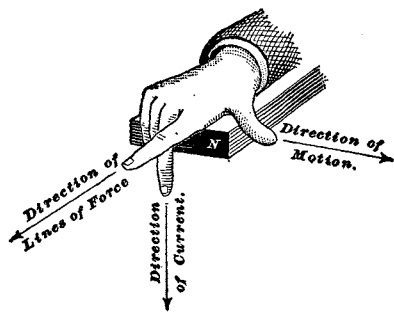


FIG. 846.

in the direction towards which the middle finger is pointing.

The summary of these electromagnetic induction experiments can be stated as follows: *Electromotive forces are generated in a conductor moving in a magnetic field at right angles to the direction of*

the lines of force, or are induced in a coiled conductor when a change occurs in the number of lines of force which pass through the coil.

PHYSICAL THEORY OF THE DYNAMO.

2222. In Fig. 847, a rectangular coil of copper wire is placed in the center of a uniform field with its plane lying perpendicular to the lines of force; in this position, the coil encloses the greatest number of lines of force. A voltmeter *V. M.* for measuring small E. M. F.'s, is connected to the two ends of the coil, as shown in the diagram. The circuit in the voltmeter is kept closed, and any E. M. F. generated in the conductor will be indicated by the deflection of the index needle. So long as the coil remains at rest in the magnetic field no E. M. F. is generated; but imagine the coil to be rotated on an axis in its own plane, such as represented by the broken line *m n* in

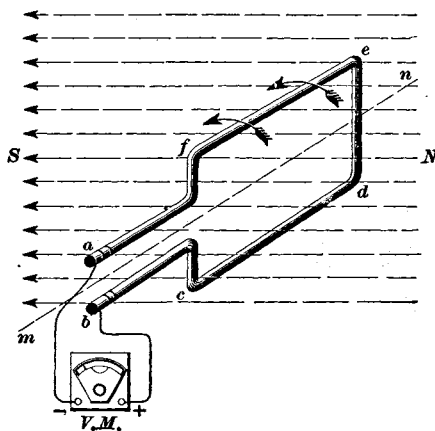


FIG. 847.

the direction indicated by the curved arrows. As the coil starts to rotate, its sides cd and ef begin to cut the lines of force at right angles, thus generating an E. M. F. in each side. From the rule stated in Art. **2221**, the E. M. F. generated in the upper side tends to cause a current to flow from f to e ; and in the lower side, the current tends to flow from d to c . Hence, the E. M. F.'s generated in the two coils are added together, and the total E. M. F. generated by the coil is indicated by the V. M. between a and b , the end b forming the *positive* terminal of the coil. If the coil is rotated at a uniform angular velocity, that is, if the speed of rotation is constant throughout each revolution, the deflection of the voltmeter becomes greater as the coil revolves from its vertical position until it passes through one-quarter of a revolution and reaches a position where its plane lies parallel to the lines of force.

2223. The diagram, Fig. 848, represents an end view of the coil in two positions: position 1, as shown by the dotted lines, represents the coil standing vertically at the moment of starting, and position 2, as shown by the full lines, represents the coil lying horizontally after passing through one-quarter of a revolution. The deflection of the needle, if read at frequent intervals during this quarter of a revolution, gradually increases, beginning at zero in position 1, and reaching a maximum at position 2. The gradual rise of the E. M. F. in the circuit, while the coil is revolving from between the positions 1 and 2, can be graphically shown by means of cross-section paper, Fig. 849. The horizontal divisions represent equal intervals of time, and the sum of the divisions

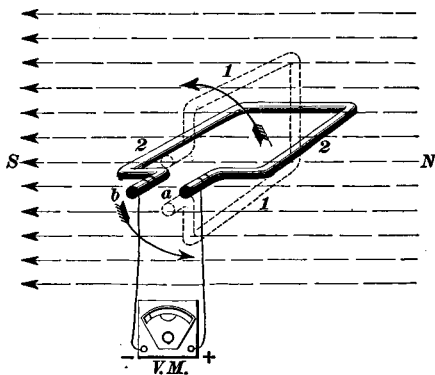


FIG. 848.

allly increases, beginning at zero in position 1, and reaching a maximum at position 2. The gradual rise of the E. M. F. in the circuit, while the coil is revolving from between the positions 1 and 2, can be graphically shown by means of cross-section paper, Fig. 849. The horizontal divisions represent equal intervals of time, and the sum of the divisions

between *A* and *B* is the total time occupied by the coil in revolving one quarter of a revolution; the vertical divisions

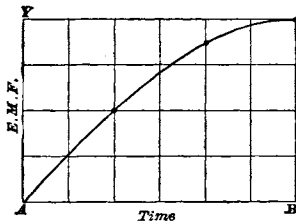


FIG. 849.

represent E. M. F., and the sum of the divisions between *A* and *Y* is the total E. M. F. that is being generated in the coil when it is passing through position 2. The vertical distances between the line *A B* and the curved line represent the E. M. F. which is being generated in the coil at every instant during its rotation between positions 1 and 2. For example, let each vertical division represent 2.5 volts; then, the distance between *A* and *Y* represents 10 volts. When the coil has revolved one-third of the distance between positions 1 and 2, Fig. 848, it has consumed one-third of the time; hence, at this instant the E. M. F. that is being generated in the coil is represented by the number of divisions between the line *A B* and the curved line, at one-third the distance towards *B*, which equals two divisions; or, $2 \times 2.5 = 5$ volts. When the coil travels two-thirds the distance between positions 1 and 2, the E. M. F. that is being generated at that instant is represented by the number of divisions between the line *A B* and the curved line at two-thirds the distance towards *B*, which equals about 3.48 divisions, or $3.48 \times 2.5 = 8.7$ volts

2224. After the coil passes through position 2, the E. M. F. that is being generated begins to diminish, and by the time the coil has revolved one-half of a revolution and is once more in a vertical position, the E. M. F. falls to zero again. The E. M. F. that is being generated at every instant during one-half of a revolution can be shown by a continuation of the curve on cross-section paper, Fig. 850. The sum of the divisions between *A* and *C* represent the total time occupied by the coil in rotating one-half of a revolution. It will be seen that the maximum E. M. F. that is being generated at any instant is at position 2, Fig. 848,

which corresponds with B , Fig. 850. In this position the plane of the coil lies parallel to the lines of force, and its

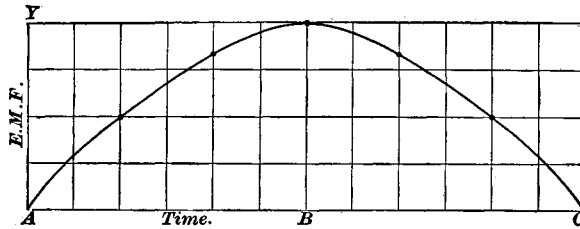


FIG. 850.

sides $c d$ and $e f$, Fig. 847, are cutting the lines of force at exactly right angles. The sides of the coil at the moment of passing through this position are cutting more lines of force for equal intervals of time than in any other position during the first half of a revolution.

From this fact the following principle is deduced: *That the E. M. F. generated in a moving conductor cutting lines of force at right angles is directly proportional to the rate of cutting.* Supposing, for example, that a magnetic field contains 100,000 lines of force, and that a conductor is moved across the field at right angles in such manner as to cut every line of force. If the time occupied by the conductor in passing across the field is one second, then the rate of cutting is 100,000 lines per second; or, if it occupied two seconds, the rate of cutting is 50,000 lines per second, and so on. The E. M. F. generated in the former case is twice as great as that generated in the latter. The method for determining the number of lines of force in a magnetic field will be described later.

2225. Fig. 851 shows the coil after being rotated one-half of a revolution. As soon as the coil starts on the last half of the revolution, its sides $c d$ and $e f$ begin to cut a few lines of force at right angles, and, consequently, an E. M. F. is generated in each side. The E. M. F., however, tends to cause a current to flow in the coil in an opposite direction to that which would flow during the first half of the revolution. For, by applying the rule in

Art. 2221, the E. M. F. generated in the sides tends to cause a current to flow from c to d , and from e to f ; the

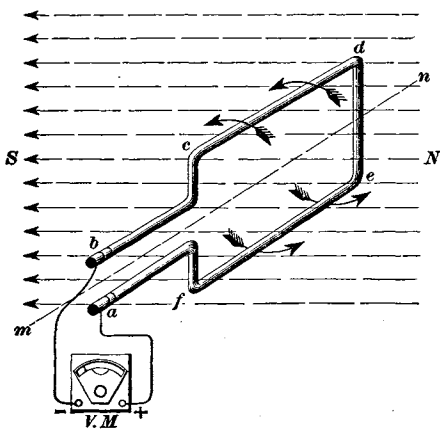


FIG. 851.

end a of the coil, which in the first half of the revolution was the negative terminal of the coil, now forms the positive terminal. Hence, in order to allow the current to enter the positive binding-post of the voltmeter, the connections must be reversed.

The E. M. F. which is generated as the coil is rotated through

the last half of the revolution gradually rises as in the first half, reaching a maximum height when the plane of the coil lies parallel to the lines of force, and afterwards falling to zero again as the coil reaches a vertical position.

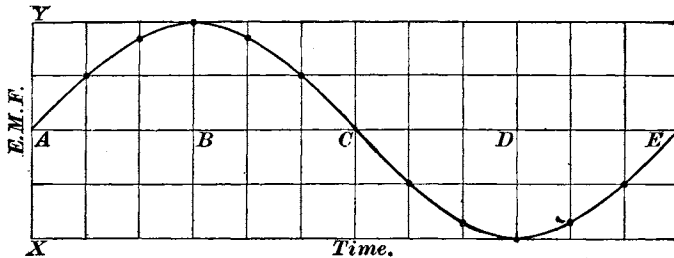


FIG. 852.

In Fig. 852, the E. M. F. that is generated in the coil at every instant during one complete revolution is graphically shown by the use of the cross-section paper. The sum of the divisions between A and E represents the time occupied by the coil in making one complete revolution; the divisions between A and Y represent the E. M. F. which tends to send a current in one direction through the coil as in the first half of the revolution, and the divisions between A and X repre-

sent the E. M. F. which tends to send a current through the coil in an opposite direction as in the last half of the revolution. The divisions between the curved line and the line AE , or **base line**, give the E. M. F. that is being generated in the coil at any instant during the revolution, and the direction in which the E. M. F. tends to act depends upon whether this E. M. F. falls above or below the base line AE . For convenience, let the direction in which the E. M. F. tends to act in the first half of the revolution be called **positive** (+) **direction**, and in the last half **negative** (−) **direction**. For example, the E. M. F. that is generated in the coil when it has revolved three-quarters of a revolution is represented by the distance between D and the curved line, which, in this case, is two divisions; and, since these divisions are below the base line, the direction in which this E. M. F. tends to act is negative.

2226. In Fig. 853, a dead resistance R_e and an ammeter $A. M.$ are connected in series with the coil. The resistance

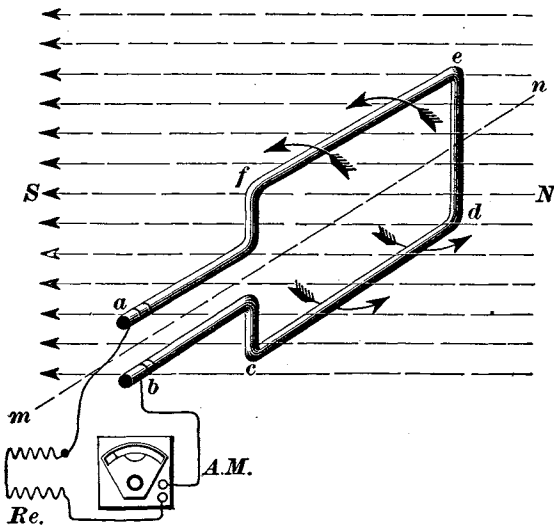


FIG. 853.

of the entire circuit, including the coil and ammeter, is comparatively small; hence, any E. M. F. generated in the coil

causes a corresponding current to flow through the circuit, and its strength is indicated by the ammeter *A. M.* When the coil begins to revolve, a feeble E. M. F. is generated in it as previously described. This E. M. F. causes a corresponding current to flow through the circuit in a positive direction; as the E. M. F. becomes larger, the strength of current in the circuit becomes greater, and *vice versa*. After the coil is rotated one-half of a revolution, and the direction in which the E. M. F. tends to act becomes negative, the direction of the current in the circuit is also reversed. If there is no self-induction to retard the rise and fall of the current in the circuit, as explained in Art. 2218, the strength of the current in the circuit at any instant is exactly proportional to the E. M. F. that is being generated in the coil at that moment; for, according to Ohm's law, the strength of current in any circuit is equal to the E. M. F. generated in that circuit, divided by its resistance. The rising and falling and also the reversing of the current in all parts of the circuit for each revolution, therefore, can be represented graphically on cross-section paper in the same manner as previously described for the E. M. F. Fig. 854 represents

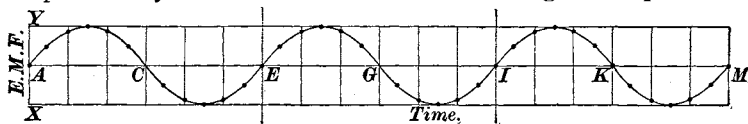


FIG. 854.

the rising, falling, and reversing of the current in the circuit for three complete and consecutive revolutions of the coil; the divisions between *A* and *E*, *E* and *I*, and *I* and *M* represent the time of each revolution, respectively. The divisions between the base line *A M* and the curved line above the base line represent the strength of current in the circuit when the direction of flow is positive, and those below represent the strength of current when the direction of flow is negative. Revolving the coil, therefore, at a constant speed generates a current in the circuit, which, in every complete revolution, rises gradually to a maximum strength and falls to zero in one direction, then is reversed,

and the same effect is produced in the opposite direction. In other words, the current in the circuit *alternates* from one direction to the opposite direction in each revolution.

An electric current of this character flowing through a circuit is termed an **alternating current**.

2227. The next step is to demonstrate the principle of changing, or *commuting*, this alternating current into a

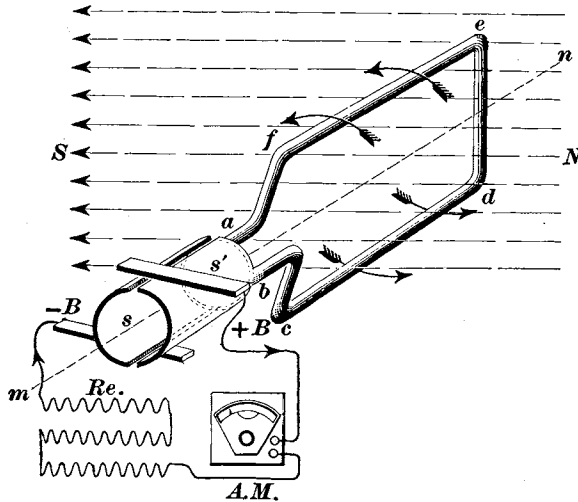


FIG. 855.

direct current. In Fig. 855, the two ends of the coil are fastened to two halves *s* and *s'* of a metallic tube. These halves are called **segments**, and in this case are separated by a small air space, the rigidity of the coil holding them apart. The combination of the two segments, or, in fact, any number of segments held together in this position, is called the **commutator**. Two copper strips *+B* and *-B*, called **brushes**, press against the segments, and are held in a horizontal position while the coil is rotated. The brushes rub, or *brush*, against the segments and make electrical contact only.

When the coil is in a vertical position, as represented in the figure, both brushes rest against both segments; but, as soon as the coil starts on the first half of a revolution in the

direction indicated by the arrows, the brush $-B$ leaves segment s' , and rubs only against segment s ; brush $+B$ leaves segment s , and rubs only against segment s' . As previously described, the electromotive force that is generated in the coil during the first half of a revolution causes a current to flow from a through the coil to b , and from b through the external circuit to a again, making b the positive end of the coil. Hence, in this case, $+B$ is the positive brush, and the current in the external circuit flows in the direction indicated by the arrow-heads. As the coil starts on the last half of a revolution, the direction of the current in the coil changes, and a becomes the positive end of the coil. But the current in the external circuit continues to flow in the same direction as in the first half of the revolution, and $+B$ remains the positive brush. For, at the beginning of the second half of a revolution, when end a of the coil becomes positive, $-B$ leaves segment s and makes contact with s' ; and $+B$ leaves s' and makes contact with s . Hence, the current in the external circuit, during a complete revolution, flows from the positive brush $+B$ through the resistance R_e and the ammeter $A. M.$ to the negative brush $-B$; that is, the current in the external circuit flows continually in the same direction, while the current in the coil itself flows in two directions during every revolution. But the strength of the current in the external circuit is by no means constant; it rises from zero to a maximum strength, and falls again to zero twice in every revolution, but in always the same direction. The effect is graphically shown in Fig. 856

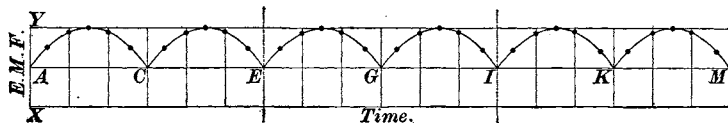


FIG. 856.

by the use of cross-section paper, where the divisions between A and E , E and I , and I and M represent the time occupied by the coil in rotating each revolution, respectively, and the vertical divisions between the base line $A-M$ and the curved line represent the strength of the current in the

external circuit at every instant during the three revolutions. The effect is produced continually in the external circuit if the coil is rotated at a constant speed. These impulses in the strength of the current give it the name of **pulsating current**.

2228. In Fig. 857, two separate coils are placed in a magnetic field at right angles to each other. Four metallic segments s , s' , s'' , and s''' are cut from a cylindrical ring to

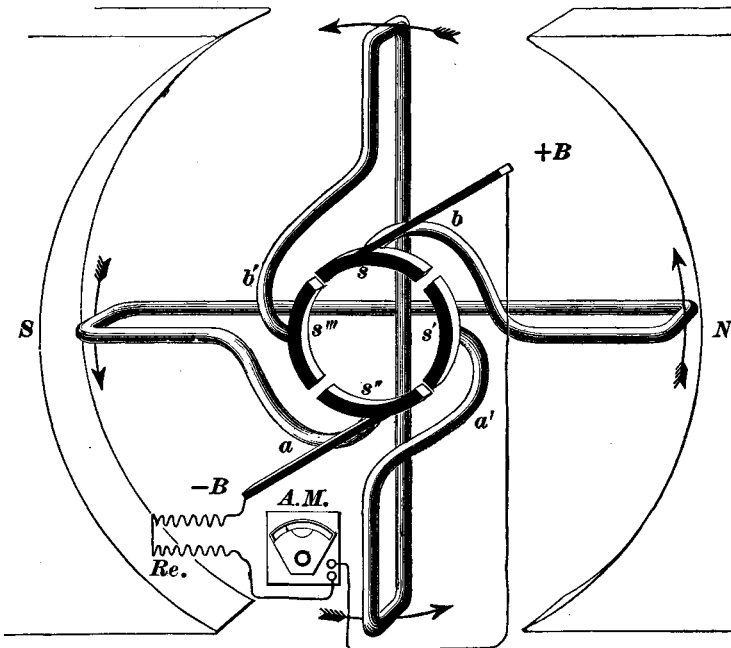


FIG. 857.

form the commutator, and are separated from one another by small air spaces; the two ends of each coil are connected to two opposite segments in such manner that an imaginary diameter connecting the two segments together would lie at right angles to the plane of their coil, as shown in the figure. Two metallic brushes $+B$ and $-B$ rub against the commutator, touching the two segments diametrically opposite to each other. A line drawn through the center of the commutator,

connecting the contact ends of the two brushes, should lie at right angles to the direction of the lines of force in the magnetic field in which the coils are rotated. As the two coils and commutator are rotated in the direction indicated by the arrows, the two brushes rub against the segments consecutively and always make contact with the two opposite ones. The brushes are connected to an external circuit consisting of the ammeter A , M , and the resistance R_c . At the position of the coils in the figure, the brushes are rubbing against the segments s and s'' , which are connected to the ends of the horizontal coil. From previous experiments, it will be seen that at this position the horizontal coil is generating a maximum E. M. F., which tends to send a current from a through the coil to b ; hence, the current is flowing in the external circuit from $+B$ to $-B$. After the coils and commutator are rotated one-eighth of a revolution from this position, and the E. M. F. in the coil begins to fall, the brush $+B$ passes from segment s to segment s' , and brush $-B$ passes from s'' to s''' . The E. M. F. that is being generated in the vertical coil when the brushes pass to segments s' and s''' is nearly maximum. Consequently, the strength of the current which has been flowing in the external circuit from the other coil does not decrease to zero; it only diminishes a small amount before the segments of the next coil make contact with the brushes, when it begins to increase again. It will be seen that during one complete revolution of the moving parts, the brushes passed over four segments; that the direction of the current produced is *from* the coils *to* brush $+B$, and *into* them *from* brush $-B$. These actions produce a *direct* current in the external circuit which flows continually in the same direction, but whose strength fluctuates, or changes, regularly four times in every revolution.

By resorting again to the cross-section paper, the fluctuations of the current in the exterior circuit can be graphically shown. In Fig. 858, the divisions between the base line AM represent the strength of current in the external circuit for three complete revolutions. So long as the speed

of rotation is uniform, the current decreases to a little less than three-quarters of its maximum strength; providing, of

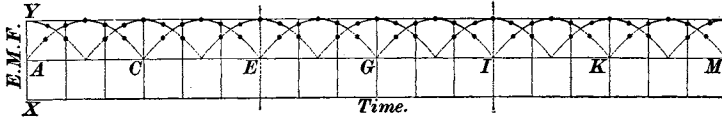


FIG. 858.

course, the resistance of the external circuit is not altered; the dotted curved lines indicate how the strength of the current would fall to zero if only one of the coils were used.

The strength of such currents can be made more uniform and the pulsations less noticeable by using several coils connected to the segments of a commutator, the planes of the coils being placed at equal angles from each other.

2229. In Art. **2161**, it is stated that the *permeability* of iron is much greater than that of air; or, in other words, if a piece of iron were inserted in a magnetic field, the number of lines of force in the field would be greatly increased. Hence, if the coils are wound around a cylindrical drum of iron, as shown in Fig. 859, the number of lines of force passing through the coils is increased, and the E. M. F. that is generated is greater, since, Art. **2224**, the E. M. F. is proportional to the rate of cutting of the lines of force. The coils are entirely insulated from the iron core by some non-conducting material, such as cloth, mica, or paper; otherwise, they would be short-circuited on the core; that is, the current would flow through the iron instead of passing into the external circuit. The other conditions remain unchanged; i. e., the lines of force have the same direction as in the previous cases, and remain in one position while the coils are revolved. The core should not be made of one solid mass of iron; for, if such were the case, the core, when rotated, would act as a

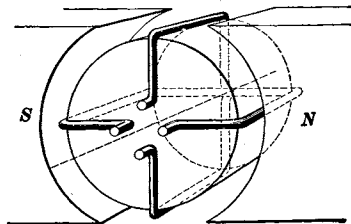


FIG. 859.

large closed conductor, cutting lines of force at right angles. The E. M. F. generated in the core would cause **local**, or **eddy**, currents to flow through the iron itself, heating it and uselessly dissipating a large amount of energy. An idea of how these eddy currents would circulate in a solid iron

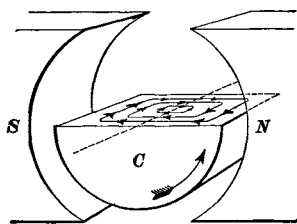


FIG. 860.

core can be formed from Fig. 860. *C* represents the solid iron core, the top half of which is cut away. The curved lines and arrow-heads show the direction in which the eddy currents would flow if the core was rotated in the direction indicated by the large arrow. To

overcome this difficulty, the core is made of a large number of round, thin iron plates, or disks, each disk being insulated from the adjacent ones by some non-conducting material, such as tissue paper, insulating japan, or simply by the oxide formed on the surface of the disk during the process of its manufacture. The disks should be fastened together in such a manner that, when rotated in a magnetic field, their flat surfaces are parallel to the direction of the lines of force and to the direction of rotation, as shown by Fig. 861. Dividing the core into disks in no way diminishes the magnetic permeability of the iron, and for all practical purposes, it prevents the eddy currents from flowing.

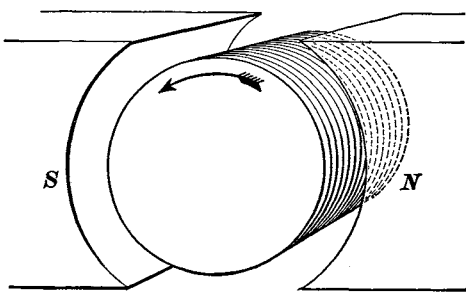


FIG. 861.

2230. An iron core inserted between the poles of a magnet not only increases the total number of lines of force from the magnet, but attracts nearly all the stray lines of force from the surrounding air; that is, the lines of force prefer to complete their circuit through iron rather than through air or other non-magnetic substances. For exam-

ple, in Fig. 862, an iron ring R is placed between the poles N and S of a magnet; the lines of force pass out from the north

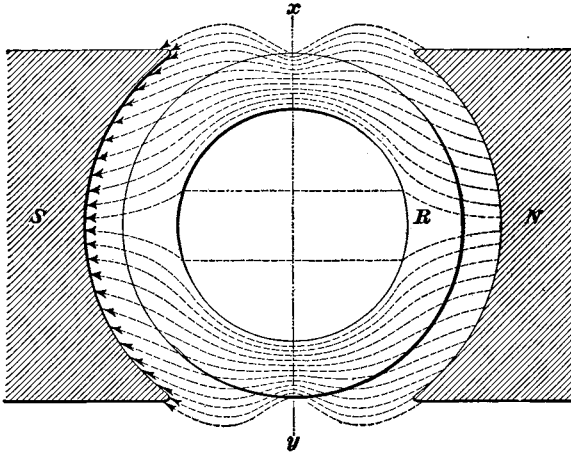


FIG. 862.

pole N and enter the iron ring. When passing across the air gap, they are uniformly distributed, but after entering the ring, they crowd together and remain in the iron as long as possible. If the total number of the lines of force is large in comparison with the cross-sectional area of the iron ring on xy , a few will pass through the air in the inside of the ring, as shown in the cut; but in most cases the number of such stray lines is not large enough to be considered. Consequently, in Fig. 863, if a loop of insulated wire $abcd$ is wound around the iron ring, and the ring and loop are rotated on a central axis mn like the rim of a fly-wheel, only that part of the loop from a to b is cutting lines of force at right angles; the rest of the loop, from b to c and from c to d , is inactive in relation to the lines of force. From the rule given in Art. 2221, it will be seen that the E. M. F. generated in the side ab of the loop tends to send a current from b to a during the first half of the revolution from yy' to xx' ; and in the opposite direction during the last half.

2231. No current will flow from the loop through the external circuit when the ring is made of some non-magnetic

substance, as will be understood from the following explanation: Imagine the iron ring to be moved from the field without disturbing the loop; then, imagine the loop to be rotated around the axis mn in precisely the same path as before. The lines of force in the field are now uniformly distributed, and as the loop moves the part between c and d will cut the lines of force at approximately the same rate as the part between a and b . But the electromotive forces

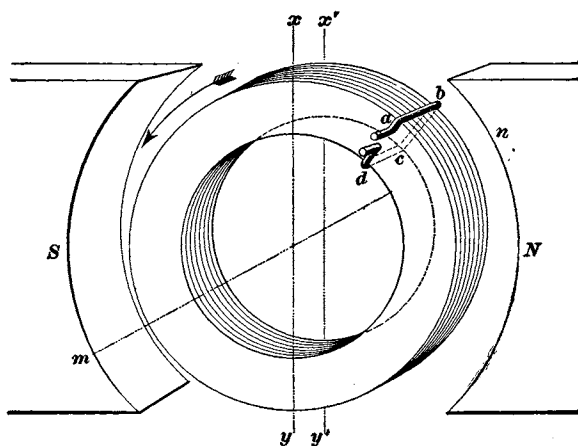


FIG. 863.

generated in the two parts tend to oppose each other; that is, the E. M. F. generated between a and b tends to act away from b , and that generated between c and d tends to act away from c . Hence, there is no difference of potential between the ends a and d , and no current will flow through an external circuit.

After replacing the iron ring again, suppose the insulated wire to be wound around it several times, as represented in Fig. 864, and the ends of the coil connected to two metallic segments S' and S'' . By applying the rule in Art. 2221, it will be seen that the electromotive forces generated in the separate turns at a , b , and c are added together; that is, the difference of potential between the brushes $+B$ and $-B$ is the sum of the electromotive forces generated

in the separate turns. The current obtained from such a coil is *pulsating*, and is similar to that described in Art. **2227**.

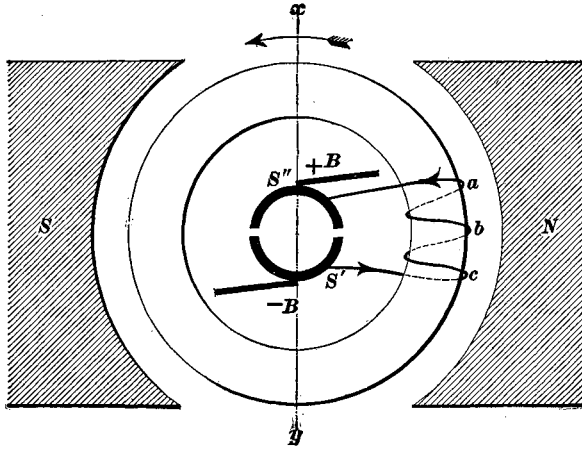


FIG. 864.

For all practical purposes, the total E. M. F. generated by such a coil is directly proportional to the number of turns. For example, if a coil of one turn generates two volts at a certain position and angular velocity, then a coil of 4 turns will generate 8 volts under the same conditions, and so on. But the turns in each coil must be approximately close together. For, if the coil is wound over a large portion of the ring, some of the turns, at one position of the coil, will be cutting the lines of force as they pass out from the north pole, while other turns will be cutting the lines of force as they enter the south pole, the electromotive forces generated in the two cases being opposed to each other. This action will be readily understood by winding the entire core with one large coil of several turns and connecting the two ends of the coil together, as represented in Fig. 865. At the instant the ring and coils reach the position shown in the figure, the E. M. F. generated in the separate turns tends to act in the direction indicated by the arrowheads upon the winding. No current can flow around the coil, because the electromotive forces generated in the two halves act towards each other at a' , and away from each other at b' .

2232. It is possible, however, to obtain a continuous current from the coil by the addition of a commutator with several segments, as will presently be seen. If the ends of a voltmeter are touched to a' and i' during the instant the coil occupies the position in Fig. 865, a difference of potential between the two points will be indicated, a' being the positive point and i' the negative. Hence, if these two points are connected to an external circuit, a current will flow through it from a' to i' , while the coil is at the position shown in the figure. As soon, however, as the coil is rotated about one-sixteenth of a revolution, the difference of potential between a' and i' will begin to fall, and the greatest difference will now be found between p' and h' . About another sixteenth of a revolution will bring the greatest difference of potential between o' and g' , and so on. In short, as the coil is rotated, the greatest difference

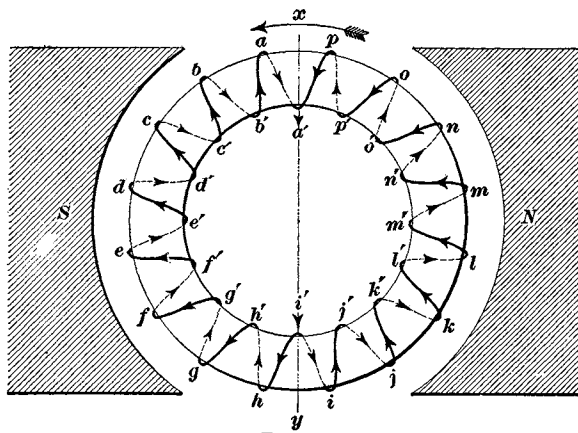


FIG. 865.

of potential will always be found between any two turns situated diametrically opposite one another when they pass through the vertical diameter xy . The next operation is to provide some means to utilize this difference of potential between each pair of turns as they arrive in a vertical position. This is accomplished by connecting each turn to a separate segment of a commutator by a small conductor, and allowing two brushes to rub against the commutator at two

points diametrically opposite each other on the vertical diameter $x y$, Fig. 866. From an examination of the figure, it will be seen that the two halves of the coil are connected in parallel or multiple; that is, the current divides at i' , one-half passing through the turns i, j, k, l , etc., and the other

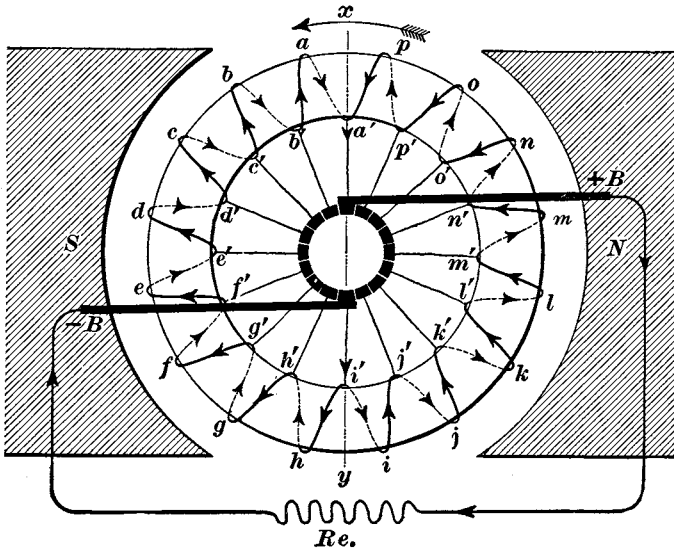


FIG. 866.

through h, g, f, e , etc., to a' , where it again unites. The maximum E. M. F. that is obtained from the coil is equal, therefore, to the E. M. F. generated in one-half of the coil. This statement will be better understood by comparing the coil to a battery of voltaic cells connected in multiple-series. For example, in Fig. 867, the separate cells from a to h , inclusive, correspond to the separate turns on one-half of the coil; and the cells from i to p correspond to the turns on the other half. From Art. 2187, the total E. M. F. of the above battery is equal to the E. M. F. of either of the two sets

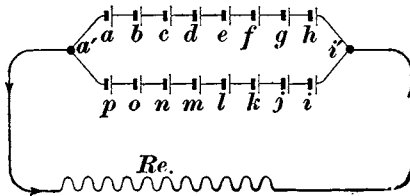


Fig. 867.

which are connected in parallel; and the total E. M. F. of either of the two sets is the product of the E. M. F. of 1 cell and the number of cells which are connected in series, as from a to h , inclusive.

If a comparatively large number of turns and segments is used, the current flowing from $+B$ through the external circuit to $-B$ will be practically continuous, that is, non-pulsating; the fluctuations caused by the brushes when passing from one segment to another are extremely minute, and produce no appreciable change in the strength of the current in the external circuit.

2233. A conductor wound upon a core in this manner is termed a **closed-coil winding**, since all the turns are connected together in one *continuous*, or *closed*, coil, and the current is obtained from it by tapping into each turn or set of turns. In the case where the turns or sets of turns are separate and distinct from each other and their ends are connected to opposite segments of a commutator, as in Figs. 857 and 864, the winding is termed an **open-coil** winding.

2234. A *closed-coil winding* can be applied to a cylindrical drum core as described in Art. **2229**, and a continuous non-pulsating current obtained from the brushes, as in the case of the ring core. The method of winding is somewhat similar to that of the ring, and each turn or set of turns is tapped into and connected to the segment of a commutator by a separate lead, as will be seen from the diagram, Fig. 868. The conductor is started at any convenient place on the core, as, for example, at a , and wound across the face of the drum to the rear end; then, wound nearly diametrically across the end, and from there along the face of the core to the front end at a' . From a' , the conductor is wound across the front end to a point somewhat in advance, or behind the original starting point a , as, for example, to b ; from b , it makes another complete turn in like manner, which is followed by a third, and so on, until the last turn is connected to the first by joining the two ends of the coil together at a . A separate lead L is tapped into the

conductor at every complete turn where it is wound across the front end of the core and connected to the separate segments

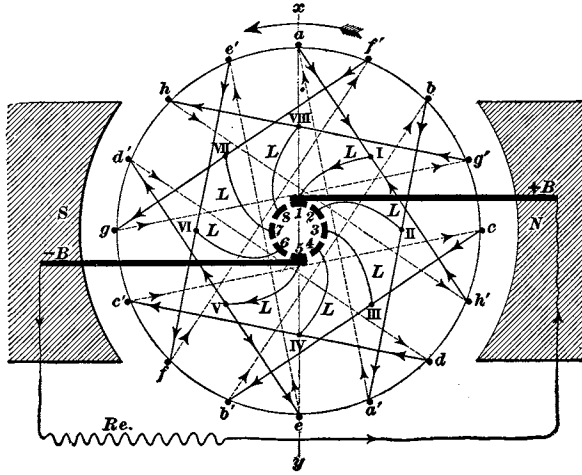


FIG. 868.

of a commutator. From an examination of the diagram, it will be seen that only a part of the wires on the face of the drum are cutting the lines of force as they enter and pass out of the core at any one instant during a revolution. At the position represented, the wires e' , a , f' and b' , e , a' are the inactive ones, so far as the lines of force are concerned; but they still perform the important function of completing the circuit for the current. The parts of the core where the wires are not cutting the lines of force as the core is rotated are called the **neutral spaces**; and the two opposite parts of the commutator to which the coils are connected are called the **neutral points** of the commutator. Each individual wire becomes inactive twice during every revolution and passes through two neutral spaces; but this fact does not change the positions of the neutral spaces—they lie on an imaginary diameter approximately perpendicular to the lines of force. This same effect takes place in the commutator, i. e., each segment passes through two neutral points during one complete revolution, but the neutral points remain in a fixed position relative to the neutral spaces of

the core. The neutral segments of the commutator, at any instant during a revolution, are those segments which are connected to the wires passing through the two neutral spaces at that instant. The neutral points, however, can be shifted to different points around the commutator by changing the leads from the coil to the segments. For example, in Fig. 868, the two neutral points lie opposite each other on the commutator along the vertical diameter xy . But if the lead from I is connected to segment No. 7, instead of No. 1, and the lead from II to segment No. 8, and so on around the commutator, then the two neutral points will lie opposite each other on the commutator along a horizontal diameter, and, in order to collect any current from the commutator, the brushes $+B$ and $-B$ must be shifted around a quarter of a revolution to these new neutral points.

The current flowing through the winding divides at one neutral space and flows through the coil in opposite directions, uniting again at the other neutral space as indicated by the arrow-heads. According to the rule given in Art. **2221**, the current in all the active wires in front of the north pole flows along the periphery of the core towards the observer; that in the wires in front of the south pole flows away from the observer.

2235. The next step is to determine the magnitude of the E. M. F. in volts generated in a closed coil. As previously stated, the E. M. F. generated in a conductor cutting lines of force at right angles is proportional to the *rate of cutting*. Consider the case of a single conductor moving across a magnetic field in which the total number of lines of force is known; the rate of cutting is equal to the total number of lines of force cut by the conductor, divided by the time required to cut them. This may be expressed in the form of an equation, thus, $\text{rate of cutting} = \frac{N}{t}$; when N is the total number of lines cut and t is the time required to cut them. By definition, *one volt* is that E. M. F. generated in a

conductor when it is cutting lines of force at the rate of one hundred million (100,000,000) per second. Hence, $E = \frac{N}{10^8 t}$, where E is the E. M. F. in volts, and t the time in seconds, since $100,000,000 = 10^8$.

For example, suppose a magnetic field contains 4,500,000 lines of force, and a conductor cuts the total number in the same direction in 1.5 seconds. The E. M. F. that is being generated in the conductor is equal to .03 volt, since $E = \frac{N}{10^8 t} =$

$$\frac{4,500,000}{100,000,000 \times 1.5} = .03 \text{ volt.}$$

When two or more conductors are cutting lines of force at equal rates, the E. M. F. obtained by connecting them in series is equal to the E. M. F. developed by one conductor, multiplied by the number of conductors. Consequently, if

S is the number of conductors in series, then $E = \frac{NS}{10^8 t}$,

where E is the total E. M. F. in volts that can be obtained from S conductors cutting N lines in t seconds. For example, if 8 conductors are moved across the magnetic field containing 4,500,000 lines of force in 1.5 seconds, and they are connected in series, then $E = \frac{NS}{10^8 t} = \frac{4,500,000 \times 8}{100,000,000 \times 1.5} = .24 \text{ volt.}$

Next, imagine these eight conductors to be moved across the magnetic field in the same direction at the rate of 30 times per second for 1.5 seconds; then, the number of lines cut in one second is $4,500,000 \times 30 = 135,000,000$, and the total number of lines cut in 1.5 seconds is, therefore, $135,000,000 \times 1.5 = 202,500,000$. Hence, $E = \frac{(Nn t)S}{10^8 t} =$

$$\frac{202,500,000 \times 8}{100,000,000 \times 1.5} = 10.8 \text{ volts;}$$

here n = the number of times per second that one conductor cuts the lines of force.

But, in general, the E. M. F. that is obtained from several conductors connected in series moving continually across

the same magnetic field at a constant number of times per second is independent of the length of time the operation is continued. For, in the above equation, $E = \frac{(Nn t)S}{10^8 t}$, the two t 's cancel one another, leaving the equation, $E = \frac{NSn}{10^8}$.

In the above example, for instance, so long as the eight conductors are moved across the magnetic field at the rate of 30 times per second, the E. M. F. that is being generated in them is always 10.8 volts, no matter whether the operation is continued for 1.5 seconds or for one hour. The time of 1.5 seconds was used merely to demonstrate the principle.

2236. The equation $E = \frac{NSn}{10^8}$ can now be applied with some modifications to the closed coil conductor wound upon either the ring or drum core. The ring core, Fig. 866, will first be considered. In the equation, E is the maximum E. M. F. in volts that is obtained from the brushes $+B$ and $-B$, when the core is revolved; N is the total number of lines of force passing from the north pole through the core to the south pole. Each wire, therefore, on the periphery of the core cuts the total number of lines twice during every revolution; or, in other words, each outside wire cuts $2N$ lines of force per revolution. S is the number of outside wires on the periphery through which the current flows in *series*, and n is the number of complete revolutions per second of the core. Therefore, the maximum E. M. F. in volts that is obtained from the brushes is found by the formula,

$$E = \frac{2NSn}{10^8}. \quad (329.)$$

That is to say, *the E. M. F. obtained from a number of conductors connected in series and moved across a magnetic field is equal to twice the number of lines of force multiplied by the number of conductors in series and by the revolutions per second of the core, divided by 100,000,000.* For example, assume the total number of lines N passing from the north

pole through the core to be 3,000,000, or $N = 3,000,000$. In the diagram, Fig. 866, there are 8 outside wires in series, or $S = 8$. If the core is rotated at 2,100 revolutions per minute, $n = \frac{2,100}{60} = 35$ revolutions per second. Substi-

tuting the values in the formula gives $E = \frac{2NSn}{10^8} = \frac{2 \times 3,000,000 \times 8 \times 35}{100,000,000} = 16.8$ volts, or the difference of

potential between the brushes $+B$ and $-B$, on open circuit. The difference of potential between the brushes when the external circuit is closed is somewhat smaller than when no current is flowing; because, as in the case of the voltaic cell, a part of the total E. M. F. developed is required to overcome the internal resistance of the coil itself.

The formula $E = \frac{2NSn}{10^8}$ holds equally true for the drum core, Fig. 868. In both cases, the number of outside wires through which the current flows in *series* is equal to one-half the total number of outside wires. Hence, by using the same magnetic field and rotating the cores at equal speeds, the E. M. F. generated in both cases will be equal.

2237. The foregoing articles demonstrate the elementary principles and physical theory of a **dynamo**. A *dynamo*, therefore, is a machine for converting mechanical energy into electrical energy by electromagnetic induction. It has three essential features, viz.: (1) a magnetic field; (2) a conductor, or several conductors, called an **armature**, in which the electromotive force is generated by some movement relative to the lines of force in the magnetic field, and (3) a *commutator*, or a *collector*, from which the current is collected by two or more conducting brushes.

In all dynamos, the magnetic field is produced either by a permanent magnet or by an electro-magnet, and they are classified accordingly; for present purposes, however, it is sufficient to consider only the uniform magnetic field lying between the poles of some large magnet. In the

preceding article, the armature core and commutator were assumed to be fastened rigidly to a shaft and the shaft supported by suitable bearings in such a position that the core would rotate in the magnetic field with its axis of rotation at right angles to the lines of force. The shaft with core and commutator was assumed to be rotated by some exterior mechanical power. The armature conductors were wound directly upon the core and rotated with it. If it were not for mechanical considerations, however, only the armature conductors would need to be rotated; the core could remain stationary.

ARMATURE REACTIONS.

2238. When the current is flowing through the armature conductors, it produces several effects upon the magnetic field; and the field, in return, reacts upon the current. These effects will be considered before describing the typical forms of dynamos.

Consider the case of a single conductor in which a current is flowing from a voltaic battery, or a continuous-current dynamo, and a magnet. It has been shown that a magnet and a conductor conveying an electric current exert a mutual force upon each other; or, in other words, each tends to produce motion in the other. In the case of a compass placed over or under a conductor conveying a current, if the magnetic needle be held rigidly and the conductor be allowed to swing freely in a horizontal plane, it would tend to place itself at right angles to the length of the needle. In general, *when a conductor conveying an electric current is placed in a magnetic field, the conductor will tend to move in a definite direction and with a certain force, depending upon the strength and direction of the current, and upon the direction and density of the lines of force in that field.*

Imagine that a conductor conveying an electric current is placed across a uniform magnetic field, and that it lies in a position at right angles to the lines of force. For example, the diagram in Fig. 869 represents a cross-sectional view of

a uniform magnetic field, the dots representing the ends of the lines of force and the heavy line a conductor conveying a current. The direction of the lines of force is assumed to be downwards, that is, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south magnetic pole. The lines of force along the conductor from the top to the bottom of the magnetic field act upon the current in the conductor with equal intensities, and all tend to move the conductor in the same direction. This action, if the magnetic field is uniform, is similar to that of a uniformly distributed load upon a beam tending to move or bend it.

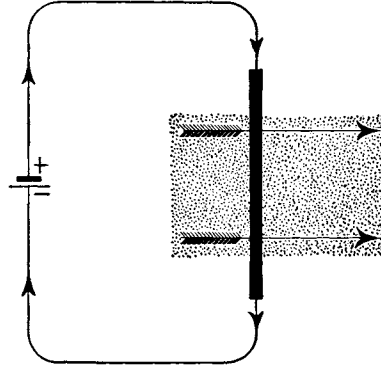


FIG. 869.

The motion imparted to the conductor is perpendicular to the lines of force, and also perpendicular to the flow of current in the conductor. To fulfil these conditions, therefore, the conductor in Fig. 869 must tend to move bodily either to the right or left across the field; in which of these two directions it moves depends upon the relative direction of the lines of force with the direction of the current in the conductor. In this case, if the direction of the lines is downwards, piercing the paper, and the current flows *from* the top *to* the bottom of the diagram, as indicated by the small arrow-heads, the conductor will tend to move from the left to the right in the direction in which the two large arrows are pointing. If the direction of the lines of force only is changed, the conductor will tend to move in the opposite direction, i. e., from the right to the left; or, if the direction of the current in the conductor only is reversed, the conductor will tend to move also from right to left across the field. But, should both the direction of the lines of force and the direction of the current in the

conductor be changed, the conductor would still tend to move from left to right.

2239. There is a convenient thumb-and-finger rule for remembering the direction of motion imparted to a conductor conveying an electric current when placed in a magnetic field; it is similar to the rule for generated currents, Art. **2221**, with the exception that the *left hand* is used instead of the *right*.

Rule.—Place thumb, forefinger and middle finger of the left hand each at right angles to the other two; if the forefinger points in the direction of the lines of force, and the middle finger points in the direction towards which the current flows, then the thumb will point in the direction of movement imparted to the conductor.

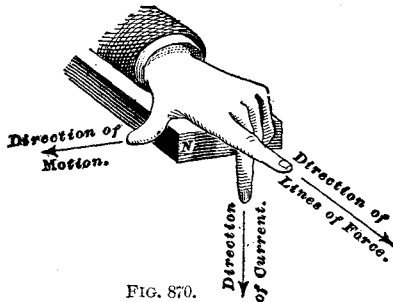


FIG. 870.

For example, in Fig. 870, if a vertical conductor in which a current is flowing downwards is placed in front of the north pole *N* of a magnet, it will tend to move in the direction as indicated by the thumb.

2240. Comparing the rule in Art. **2221** with that given above, it will be seen that the two appear to oppose each other; or, in other words, the current which flows in the former case, according to the latter rule, tends to oppose the motion of the conductor and move it in the opposite direction. This is exactly what takes place. When a conductor is moved across lines of force, an electromotive force is generated which tends to send a current in a definite direction; if the circuit is open and no current flows, it requires no force to move the conductor across the field; but if the circuit is closed and a current flows through the conductor, then the action of the lines of force on the current opposes the original motion and tends to stop or retard the conductor. The opposing force is proportional to the strength

of current flowing in the conductor; that is, if a current of 10 amperes acts with a certain force, a current of 20 amperes will act with twice that force, and so forth. Hence, the stronger the current in the conductor, the greater will be the force necessary to keep the conductor moving in the original direction. The above explanation will be made clearer by the graphical illustration in Fig. 871. The diagram represents a cross-sectional view of a magnetic field, the direction of the lines of force being downwards, piercing the paper. If the conductor $c\ c'$ be moved across the field by some exterior motive power in the direction indicated by the arrows a, a , a current will flow through the circuit in the direction indicated

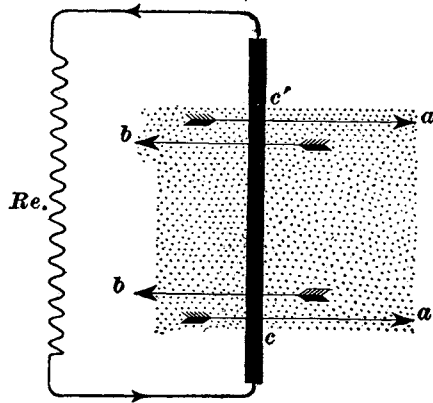


FIG. 871.

by the small arrow-heads, according to the rule given in Art. 2221. The length of the arrows a, a may also serve to represent the magnitude of the force that moves the conductor. As the current flows through the conductor, the lines of force immediately react upon it, producing a *counter* force which tends to stop the conductor and move it in the direction indicated by the arrows b, b . The counter force would never actually move the wire in the direction of the arrows b, b , but it exerts a dragging effect upon the conductor, which would reduce its speed and almost stop its motion, if the exterior motive force were not increased. So long as the conductor is moved, the applied motive force is always larger than the counter force, as graphically represented by the relative length of the arrows.

2241. The above principle explains the action of converting the mechanical energy into electrical energy in the

dynamo. For example, suppose that an armature is rotated at a constant speed in a magnetic field by some exterior motive force, as, for instance, by a belt from an engine. If the armature is properly wound and connected to a commutator, an electromotive force is generated in the outside conductors on the core, causing a difference of potential between the brushes. If the brushes are not connected to an external circuit and no current is flowing through the armature, it requires no energy to rotate the armature, excepting a small amount to overcome the friction of the shaft in the bearings and the loss in the armature iron by eddy currents. By connecting the brushes to an external circuit, however, and allowing a current to flow through the armature, the conditions are altered. The lines of force react upon the current in the conductors, tending to rotate the core in an opposite direction and to retard its motion; the stronger the current, the greater the retarding effect. Hence, in order to keep the speed constant and to generate a constant E. M. F., more energy must be supplied to the pulley from the engine. This retarding effect of the current is known as the **counter torque** of a dynamo. The word torque, which will appear later in connection with the action of motors, means simply *turning* force.

It can be mathematically proven that the mechanical energy delivered to the armature from any exterior source is exactly equal to the electrical energy obtained from the armature, plus the energy lost in mechanical friction, eddy currents in the iron, and other small losses, which will be described subsequently.

2242. Besides producing a counter torque in the armature, the current tends to distort or crowd the lines of force from their original position in the magnetic field. This effect is termed **armature reaction**, and will be understood by investigating the magnetic effects of the current in the armature when the armature is removed from between the poles of the field magnets. In the diagram, Fig. 872, the current is flowing through the armature coil in the

same direction as represented in Fig. 866. The current, circulating around the armature coil in two directions, acts as a magnetizing force upon the core and produces two electro-magnets. According to the rule for magnetic polarity, the two magnets thus formed oppose each other at the two neutral spaces of the armature; that is, their like poles N, N' and S, S' tend to act in opposite directions at the neutral spaces.

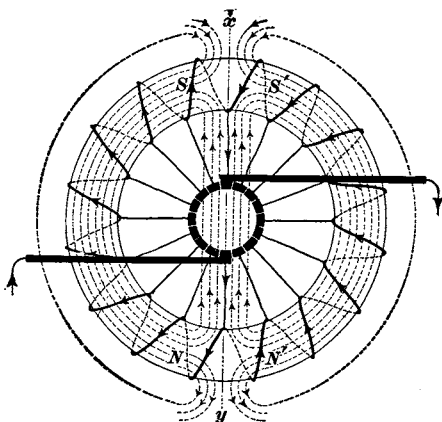


FIG. 872.

As previously explained, lines of force can never intersect each other, and will always produce consequent poles when acting in opposite directions at one place. Therefore, in this case, two consequent poles are formed in the core, one at each neutral space, as shown in the diagram. The polarity of the consequent poles, of course, depends upon the direction in which the coil is wound upon the core and the direction in which the current is generated. The same action occurs when the armature is rotated between the poles of a magnet and a current flows through the coil, although the conditions are somewhat altered. The lines of force from the magnet tend to pass through the core nearly at right angles to those produced by the current. The lines can never intersect, however, and they crowd and distort one another in order to coincide in direction. The lines that pass out from the north pole of the magnet tend to enter the core at the south consequent pole and to pass out from the core at the north consequent pole. At the same time, the south consequent pole is shifted towards the north pole of the magnet, and the north consequent pole towards the south pole of the magnet. The diagram in Fig. 873 represents the manner in which the magnetic field is distorted by the

reaction of the armature current. In the case where the armature was removed from the magnetic field, the consequent poles coincided with the neutral space; but when the armature is replaced, as in the diagram, the consequent poles are shifted backwards against the direction of rotation, and the neutral spaces are moved forwards in the opposite direction, as indicated by the imaginary diameter xy . As the positions of the neutral points on the commutator depend upon the positions of the neutral spaces on the core, they are

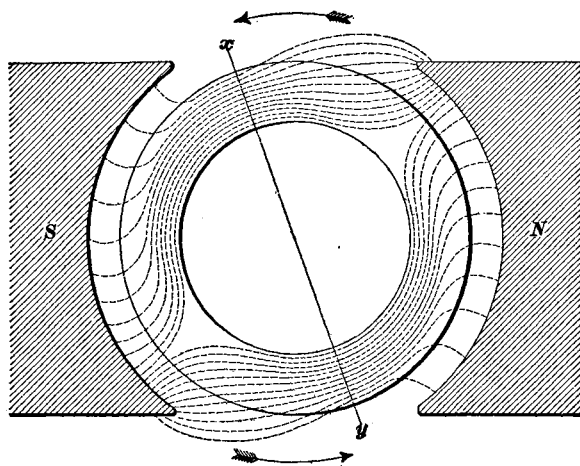


FIG. 873.

also shifted forwards in the direction of rotation when the current flows through the armature; hence, the brushes must be moved forwards in order to obtain the full E. M. F. generated in the coil. The stronger the current, the farther forwards the brushes should be shifted.

2243. From the fact that in all dynamos of this character the relation of the lines of force, direction of rotation, and direction of current are constant, *the neutral spaces are always shifted forwards in the direction of rotation when the current becomes stronger, no matter how the coil is wound upon the armature, or in which direction the lines of force pass through the core.*

These armature reactions are not confined entirely to the

ring core, but are produced with the same effects in a drum-core armature, such as represented in Fig. 868. If the direction of the current is traced by the arrow-heads upon the conductors, it will be seen that the current is flowing upwards along the face of the core in front of the north pole, as represented by the open circles, Fig. 874, and downwards in front of the south pole, as represented by the solid circles. The

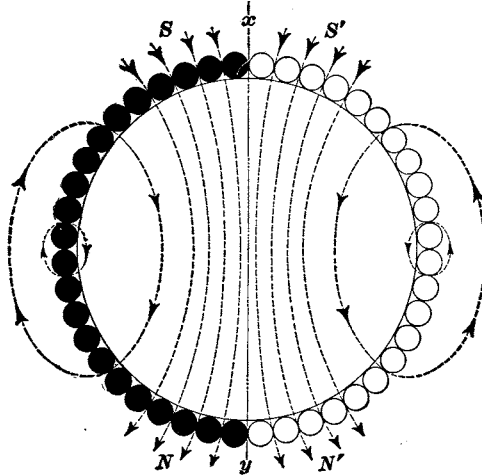


FIG. 874.

lines of force surrounding each conductor in which the current is flowing coincide with those around the adjacent conductors, forming a large number of long lines which pass through the core and produce consequent poles at the neutral spaces, as shown in Fig. 874. The direction of lines of force around the conductors in which the current is flowing downwards corresponds with the movements of the hands of a watch; while the direction of the lines around the other conductors is opposite. The lines from all conductors, however, coincide in direction in passing through the center of the core. When the armature is rotated between the poles of a magnet, the field is distorted, and the neutral spaces shifted forwards in a manner similar to that described for the ring core.

2244. Armature reactions not only distort the magnetic field, but also have a tendency to reduce the total

number of lines of force from the magnet, and thereby diminish the E. M. F. generated in the armature. This effect, however, can be almost entirely eliminated by increasing the strength of the field, or, in other words, by increasing the number of lines of force passing through the core. This fact leads to the consideration of *field magnets*.

FIELD MAGNETS.

2245. In Art. **2237** it was stated that the magnetic field in all dynamos is produced from either a permanent magnet or an electro-magnet. A dynamo of the first class is called a **magneto-machine**. Such machines are necessarily small on account of the difficulty of making large permanent magnets; in fact, the field in most magneto-machines is produced by several permanent magnets placed side by side. The magnets are usually of the **U-shaped**

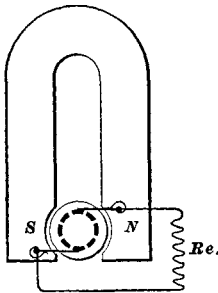


FIG. 875.

pattern, of hard steel, with a recess bored out between the ends of the poles to admit the armature, as shown in the diagram, Fig. 875.

As the majority of magneto-machines are made for testing and signaling purposes where alternating currents can be used to advantage, the armature is wound with one large coil of wire, and the two ends of the coil are connected to two separate collector rings, as shown in Fig. 876. The alternating current is obtained from two

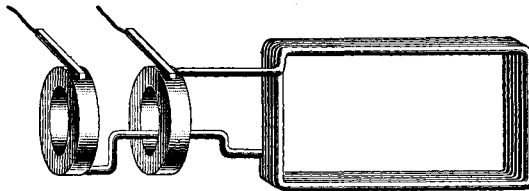


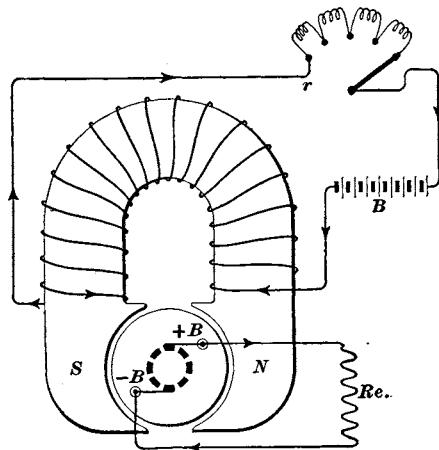
FIG. 876.

brushes, one rubbing against each collector ring. The brushes can bear upon the collector ring at any position

relative to the coil and the field magnets, since all parts of one collector ring are at the same potential in any one instant. By comparing this coil with that in Fig. 851, it will be seen that the current obtained from the two brushes flows in two directions during every revolution.

2246. In nearly all dynamos furnishing current for lamps, power, and other commercial purposes, the magnetic field is produced by an electro-magnet. This class of dynamos is divided into various types, depending upon the manner in which the current is obtained to excite the field magnets.

2247. The first class of machines to be considered is termed a **separately excited** dynamo, from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery, or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 877. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery B . The exciting current flows from the battery around the cores of the field magnet in such a direction as to produce a closed magnetic circuit through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo when the armature is rotated at a uniform speed remains constant so long as the external circuit is open;



but when the external circuit is closed, the difference of potential gradually diminishes as the strength of current increases, owing to the internal resistance of the armature conductors and the reactions of the armature current on the field.

2248. The **magnetizing force** is that which produces the lines of force in the magnet. Its strength is proportional to the strength of current flowing, and to the number of coils or complete turns around which the current circulates. The total number of turns, multiplied by the strength of the current in amperes, will give the magnetizing force in **ampere-turns**. It has been proven that 10 amperes circulating around 20 turns exert precisely the same magnetizing force as 1 ampere circulating around 200 turns, or as 200 amperes circulating around 1 turn. In each of these cases, the magnetizing force is 200 *ampere-turns*. But the number of lines of force produced in an electro-magnet is not directly proportional to the magnetizing force in *ampere-turns*. The strength of the magnet in lines of force depends upon the permeability of the magnetic substances used in the core. The permeability varies greatly in different magnetic substances, depending both upon the physical condition and the chemical composition of the substance. In general, *wrought iron*, *soft sheet iron*, and *steel* have greater permeability than cast iron, and, whenever available, should be used in field magnets in preference. The permeability, however, of all magnetic substances changes with every stage of magnetization. In all kinds of magnetic substances, the permeability decreases when the magnetism is increased beyond a certain limit. This tendency of the substance to become less permeable is called **magnetic saturation**; that is, the substance becomes *saturated* with lines of force and can not hold any more. A limit is never reached where actual saturation takes place, but there is a limit beyond which it becomes impracticable to magnetize the substance. The practical saturation in wrought iron, soft sheet iron, and cast steel is when there

are between 120,000 and 130,000 lines of force per sq. in. of sectional area of the iron, measured on a plane at right angles to the lines of force in the magnet. In gray cast iron, the practical saturation limit is from 60,000 to 70,000 lines of force per sq. in. Hence, when these limits are exceeded, it requires an enormous increase in the *ampere-turns* to produce a slight change in the number of lines of force in the magnet. In general, however, the field magnets of dynamos are designed with the density of the lines of force below the saturation limits, and it is safe to assume that any change in the strength of the current circulating around the magnetizing coils produces a corresponding change in the number of lines of force passing through the magnetic circuit. Consequently, if the strength of the current in the field coils of a *separately excited* dynamo is increased as the current in the armature becomes stronger, the E. M. F. obtained from the brushes will remain practically constant. This is usually accomplished by inserting an adjustable resistance box, or field rheostat r , in series with the battery and field coils, and decreasing the resistance as the difference of potential between the brushes tends to drop.

2249. The second class of machines with an electro-magnet is termed a **self-exciting shunt dynamo**, or simply a **shunt dynamo**, from the fact that the exciting current for the field magnet is furnished by the dynamo itself, the field coils being connected in *shunt* with the external circuit from the brushes. In Fig. 878, one terminal of the magnetizing coil is connected to the positive brush and the other to a binding post on the field rheostat r ; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum E. M. F. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential

between the field terminals. In well-designed dynamos the resistance of the shunt coil is large enough to allow not

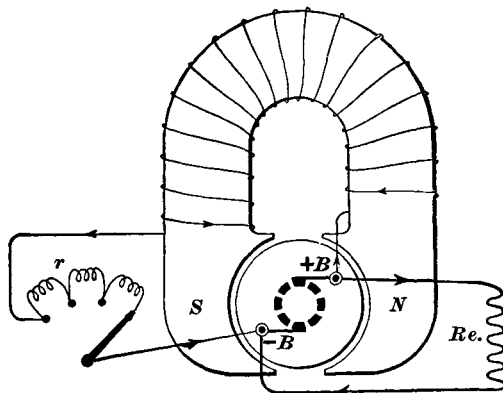


FIG. 878.

more than about 5% of the total current of the dynamo to pass through the field coils; for, according to Ohm's law, the strength of current in amperes circulating around the field coils is equal to the difference of potential in volts between the brushes, divided by the resistance in ohms in the field coil, neglecting the resistance of the rheostat. For example, suppose that the difference of potential between the brushes of a shunt dynamo is 500 volts when a current of 10 amperes is flowing from the armature. If 5% of this current is required to excite the field magnets, the strength of current circulating around the field coils is $10 \times .05 = .5$ ampere; and if E_e is the E. M. F. at the brushes, C_s is the current in the shunt field, and R_s is the resistance of the shunt field; then, according to Ohm's law, $R_s = \frac{E_e}{C_s} = \frac{500}{.5} = 1,000$ ohms.

2250. When a shunt dynamo is rotated at a constant speed, an appreciable length of time elapses before the armature generates a maximum E. M. F. after the field circuit is closed, and, in some cases, a self-exciting dynamo will generate no E. M. F. until after it has been once separately excited. The starting of a dynamo to generate an E. M. F. is termed **picking-up**, or **building-up**. If the field current

of a dynamo is open so that no current flows through the magnetizing coil, the armature would generate no E. M. F. when rotated, providing the field magnets were not permanent magnets; consequently, when the field circuit is closed on a shunt dynamo, no current will flow through the magnetizing coils, because there is no difference of potential between their terminals. But nearly all magnetic substances become permanent magnets in a slight degree after once being magnetized.

This permanent magnetism is called **residual magnetism**, since it *resides* in the metal after the magnetizing force has been removed. In general, soft iron and annealed steel retain only a small amount of magnetism, and, in some cases, the residual magnetism is imperceptible. Chilled iron and hardened steel retain residual magnetism in large quantities. Artificial or permanent magnets are made by placing a piece of hardened steel in a dense magnetic field or in contact with another magnet. Lodestone is the result of a natural residual magnetism. Iron and its alloys will also become slightly magnetized in the process of refining and working.

From these facts it will be seen that the cases where field magnets do not exhibit some residual magnetism are exceedingly rare. The armature conductors when cutting the lines of force of the residual magnetism generate a small E. M. F., and this E. M. F., in turn, causes a feeble current to circulate around the magnetizing coils when the field circuit is closed. The residual magnetism is, therefore, reenforced by the magnetizing effect of the current, which is followed by an increase in the E. M. F. generated, and that, in turn, by a stronger current in the field. These actions and reactions continue until a limit is reached where the fields become saturated with magnetism and the number of lines do not increase at such a rapid rate; finally, both the E. M. F. and the current in the field become constant.

2251. The difference of potential between the brushes of shunt dynamos gradually decreases as the current from

the armature becomes stronger, on account of the internal resistance of the armature conductors, and the reactions of the current on the field. The effect is even more marked than in separately excited dynamos, because a decrease in the difference of potential between the brushes causes a corresponding decrease on the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the E. M. F., a field rheostat r of comparatively high resistance is connected in the field circuit, and so adjusted that when no current is flowing in the external circuit only enough current flows through the field to produce the normal difference of potential between the brushes; this normal difference of potential between the brushes is kept constant, as the load increases, by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

NOTE.—The word *load* as used above is a common expression for *current* in dynamos generating a constant potential, and the student should become familiar with its use.

2252. The third class of machines whose field magnets are excited by an electric current are termed **self-exciting**

series dynamos, or simply **series dynamos**.

The magnetizing coils of a series dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a *series* dynamo are shown in Fig. 879; the current

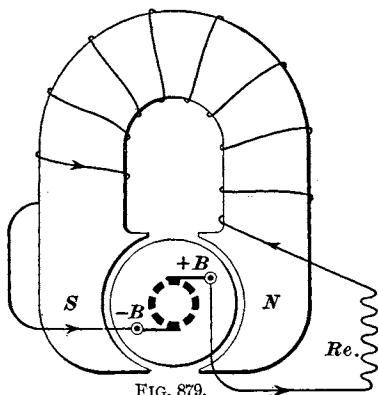


FIG. 879.

starts from the positive brush $+B$, circulates around the external circuit Re , from thence through the magnetizing coils, back to the negative brush $-B$. The action of a series dynamo differs widely from that of a shunt dynamo.

In the first place, no E. M. F. is generated in the armature unless the external circuit is closed and a current flows from the brushes; that is, neglecting the small E. M. F. generated by the residual magnetism. In the second place, the difference of potential between the brushes depends upon the strength of current flowing from the armature. The E. M. F., however, is not directly proportional to the strength of the current unless the internal resistance and reactions of the armature are negligible. Compared with the coils on a shunt dynamo, the magnetizing coils of a series dynamo are made of a few turns of a large conductor. This is necessary, because the coils, usually, are required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are used to secure the proper magnetizing, since that is proportional to the *ampere-turns*.

2253. The E. M. F. of a series dynamo may be regulated in three different ways, viz.: (1) By controlling the strength of current in the external circuit as previously described; (2) by *short-circuiting*, or *cutting out*, part of the magnetizing coils, and (3) by *shunting* part of the current around the magnetizing coils.

The second of the above methods of regulating the E. M. F. will be understood from the diagram in Fig. 880. SF represents the magnetizing coils. A is a contact arm which travels in either direction along the line xy , one end making contact with the ends a, b, c, d , etc., of the series field, and the other being always connected to the external circuit Re . As the arm is moved towards x , the turns between it and k are cut out of circuit; that is, the current from the armature circulates around

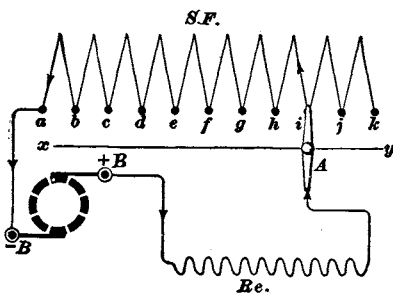


FIG. 880.

only those coils between the arm and a ; if the strength of the current remains constant, the magnetizing force is thereby reduced. On the contrary, when the arm is moved towards y , additional turns are connected in circuit and the magnetizing force is increased.

2254. The third method of regulating the E. M. F. of a series dynamo changes the strength of the magnetizing current instead of varying the number of turns in the coil

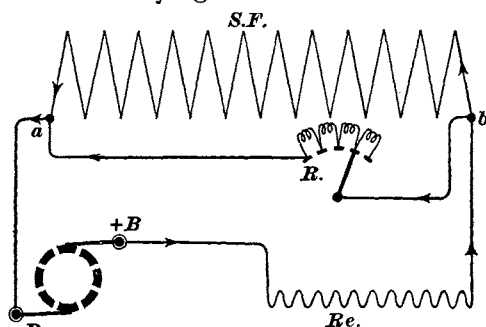


FIG. 881.

This effect is accomplished by connecting a resistance R , Fig. 881, in parallel or shunt with the series field coils $S F$, the current dividing between the two circuits inversely proportional to their separate resistances. Consequently, to increase the magnetizing force on the field magnets, the resistance R of the shunt circuit is increased, and *vice versa*. The total current from the armature is made to pass through the magnetizing coils by opening the shunt circuit entirely.

2255. In the dynamo previously described, the regulation of the E. M. F. is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement is sometimes imparted by a magnet controlled by the current from the armature, but more often the E. M. F. is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils. Such machines are termed **compound**, or **shunt-and-series**, dynamos. In Fig. 882, the shunt coils consist of a large number of turns of fine insulated wire wound upon the core

of the magnet. The series coils, consisting of a few turns of large insulated wire, are wound over the shunt coils. The main part of the current from the armature flows from the positive brush $+B$ through the external circuit Re , thence through the series coils to the negative brush $-B$. The two terminals of the shunt coils are connected to the two brushes $+B$ and $-B$, respectively. But the series and shunt coils are so wound that the currents in both circulate around the core of the magnet in the same direction when connected, as shown in the diagram. The ac-

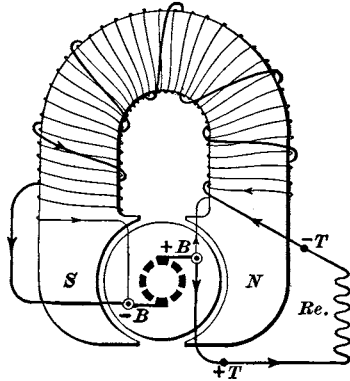
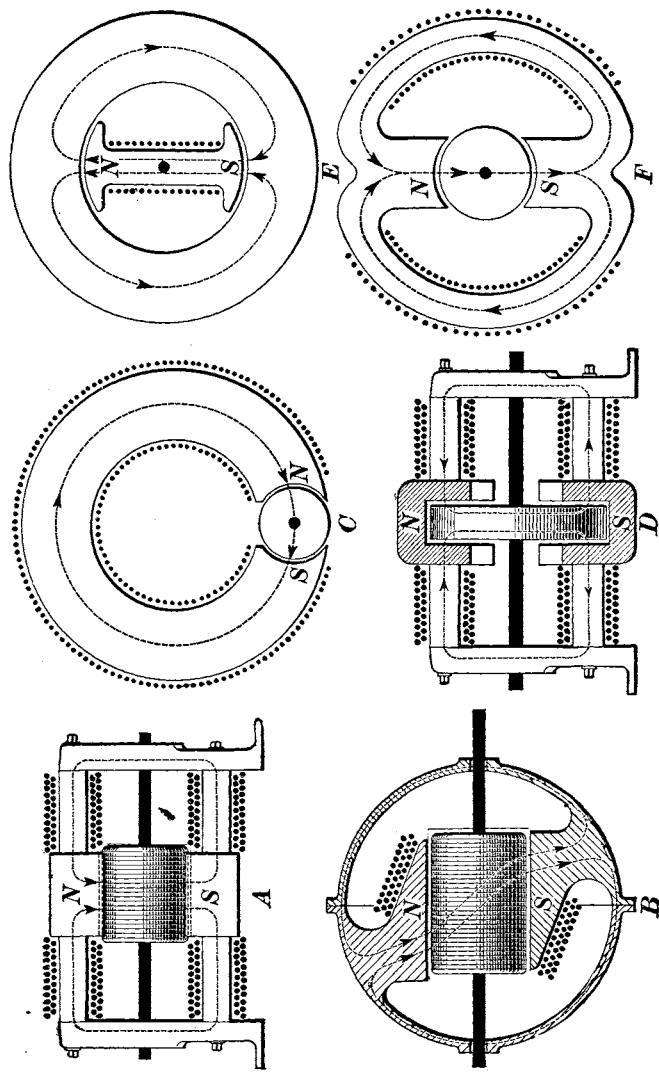


FIG. 882.

tion of both currents, therefore, is to produce the same polarity in the magnet, the shunt current being reenforced by the series current. When the dynamo is not loaded, that is, when no current is flowing in the external circuit and the armature is rotated at normal speed, the normal E. M. F. is generated in the armature due to the magnetic field produced by the shunt coils alone. Upon closing the external circuit, however, the difference of potential between the brushes *tends* to decrease, and would continue to decrease, as previously described in a simple shunt machine, if the series coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for all changes of load in the external circuit. This method of regulating the E. M. F. of a dynamo is called **compounding**. The **terminals** of a dynamo are the binding posts to which the external circuit is connected; in a series, or compound, dynamo one terminal is attached to the outside end of the series coils,

as $-T$ in Fig. 882, and the other terminal is connected directly to the brush, as represented by $+T$ in the figure.



It is desirable in a great many cases to **over-compound** a dynamo, or, in other words, to wind a sufficient number of

turns on the series coils so as to increase the difference of potential between the terminals of a dynamo above normal when the load increases. The expression **per cent. over-**

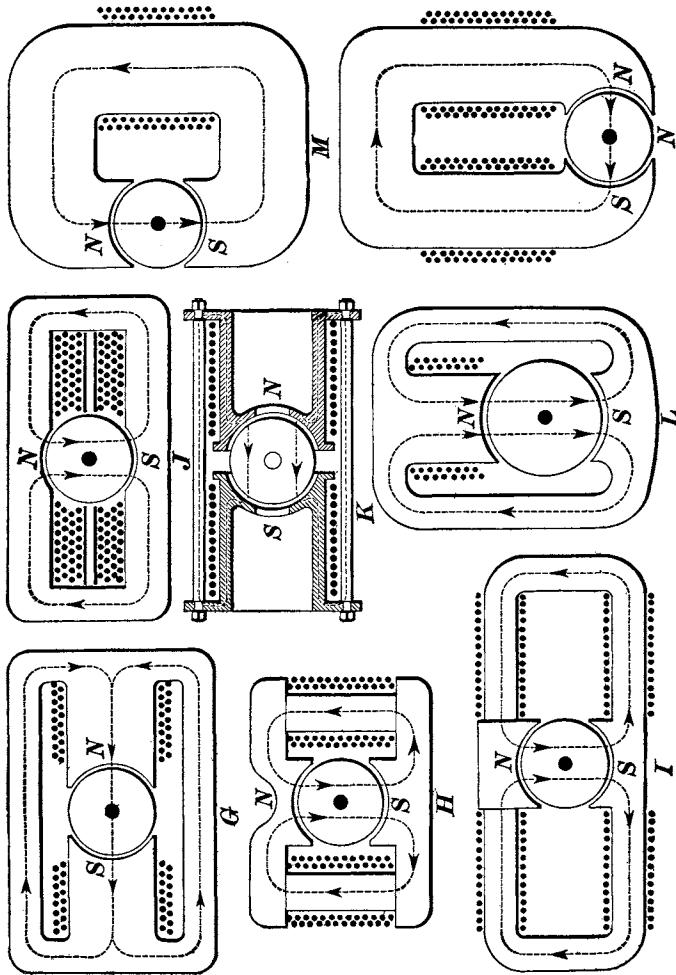


FIG. 883.

compound means that the difference of potential between the terminals increases a given per cent. of the normal when the load is at a maximum. For example, supposing

the normal voltage of a dynamo is 500 volts, and it is 10% over-compound at full load; the difference of potential between the terminals of the machine at full load is, therefore, $500 + (500 \times .10) = 550$ volts.

In some cases it is an advantage to connect the shunt field outside the series coils; that is, in Fig. 882, to connect the negative end of the shunt coil to the negative terminal — *T*, instead of being connected to the negative brush — *B*. This connection is seldom used in practice.

TYPES OF BIPOLAR FIELD MAGNETS.

2256. The various types of field magnets for dynamos in which the armature revolves between only one pair of poles are shown in Fig. 883. It is customary to speak of such machines as **bipolar dynamos**, from the fact that only one pair of poles is presented to the armature. The broken lines and arrow-heads in each of the foregoing cuts represent the paths of the lines of force which must pass lengthwise through the coils from the north pole to the south pole. The black dots indicate a cross-section through the wires which form the coils. In all cases where a single coil is used, or where if two coils are used both are wound in the *same* direction, the poles are called **salient poles**, and the lines of force pass from the north pole, through the armature, to the south pole. See *B, C, E, G, J, K, L, M,* and *N*. When two coils are used which are wound in *opposite* directions, the poles are called **consequent poles**. Thus, *A*, Fig. 883, has consequent poles, the coils being wound in opposite directions. This was necessary, since, if the coils had been wound in the same direction, the north pole of one coil would have been opposite the south pole of the other coil, and the lines of force would have passed from one pole to the other and circulated around the magnets without passing through the armature. By winding in opposite directions, like poles face each other, and the lines of force are *deflected through the armature*. See *A, D, F, H,* and *I*.

TYPES OF DYNAMOS.

2257. Dynamos are divided into three general types, depending on the character of their currents. These three types are:

1. **Constant-potential dynamos**, in which the E. M. F. remains constant and the strength of current (continuous) changes with the load or external resistance.

2. **Constant-current dynamos**, in which the strength of current (continuous or pulsating) remains constant and the E. M. F. changes with the load.

3. **Alternating-current dynamos**, the current from which alternates or reverses direction with great rapidity. In ordinary alternating-current dynamos the reversals average about 16,000 per minute.

NOTE.—A dynamo which generates current for power purposes has been conventionally termed a *generator*, to distinguish it from a machine for lighting.

CONSTANT-POTENTIAL DYNAMOS AND GENERATORS.

2258. The foregoing articles have demonstrated the principle and regulation of constant-potential dynamos, but only one form has been considered, namely, a dynamo in which a ring or drum armature is rotated between only one pair of poles from a U-shaped magnet. Theoretically, however, constant-potential dynamos can be built with one armature revolving between any number of pairs of poles, although in practice eight pairs of poles are seldom exceeded. Machines having more than one pair are called **multipolar dynamos**.

In multipolar dynamos, the pole pieces and field cores are fastened into one magnetic yoke, more or less circular in shape, as shown in Fig. 884, which represents the magnetic circuits of a four-pole dynamo. A magnetizing coil is wound upon each field core, and the four coils are connected in series in such a manner that when a current circulates around the coil, it produces first a north pole and then a south pole. The lines of force from each field core divide into two magnetic

circuits in the yoke and armature, as represented in the dia-

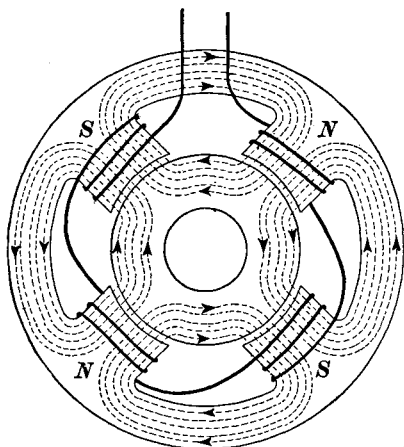


FIG. 884.

gram. Their density is practically uniform, however, where they pass from the north pole into the armature core, or from the armature core into the south pole. In nearly all multipolar dynamos this same principle of polarity is applied, that is, every *other* pole is of like polarity, and lines of force from each core divide into two mag-

2259. The process of generating an E. M. F. is similar to that in bipolar machines, but there are some points which

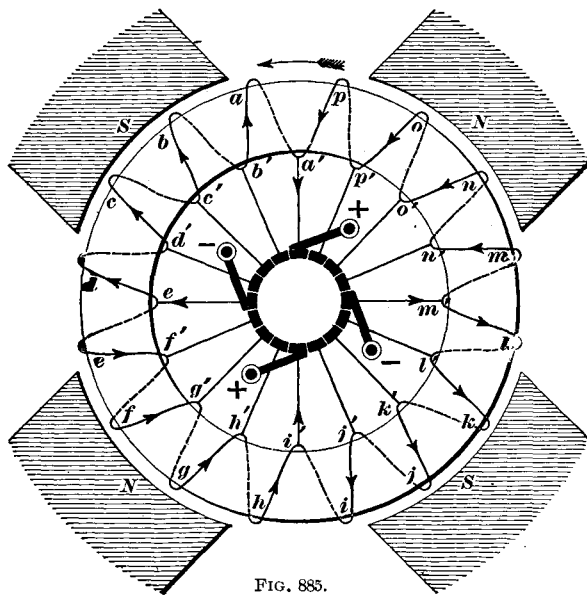


FIG. 885.

should be understood. Consider first the case of a ring core

with a closed coil winding as shown in the diagram, Fig. 885. If the armature is rotated in the direction of the large arrow, the E. M. F. generated in the conductors in front of the south poles will tend to act downwards along the face of the pole; while that generated in front of the north pole will tend to act upwards. By tracing out, by aid of the small arrow-heads on the conductors, the direction in which the E. M. F. acts, it will be seen that there are four points where the E. M. F. acts in opposite directions. The action of the electromotive forces is to meet at a' and i' and to divide at e' and m' . The segments connected to a' and i' have the same potential and form two *positive* neutral points of the commutator; the segments connected to e' and m' have the same potential and form two neutral points of the commutator. Hence, four brushes are necessary—two positive and two negative. The current is obtained from the armature, by connecting the two positive brushes in parallel to one terminal of the external circuit, and the two negative brushes to the other terminal, as shown in Fig. 886. The currents from the positive brushes unite to form the current in the external circuit and divide again between the negative brushes. The current in the armature is divided into four circuits in parallel instead of two, as in bipolar dynamos, and the maximum E. M. F. that is obtainable from the brushes is equal to that generated by the active conductors in one of the circuits only. For example, the difference of

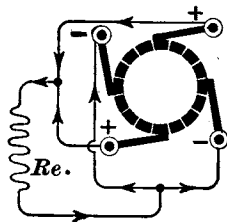


FIG. 886.

potential between the positive and negative brushes in Fig. 885, when no current is flowing, is equal to the E. M. F. generated in one-quarter of the outside wires on the core; or, in other words, the total E. M. F. of the armature is proportional to the number of outside wires connected in series.

The current in a ring armature wound and connected in this manner, if placed in a field magnet of six poles, would divide into six circuits in parallel; if the armature is placed in a field magnet of eight poles, the current would divide

into eight circuits in parallel, and so on. An armature winding of this character is called a **parallel** or **multiple**

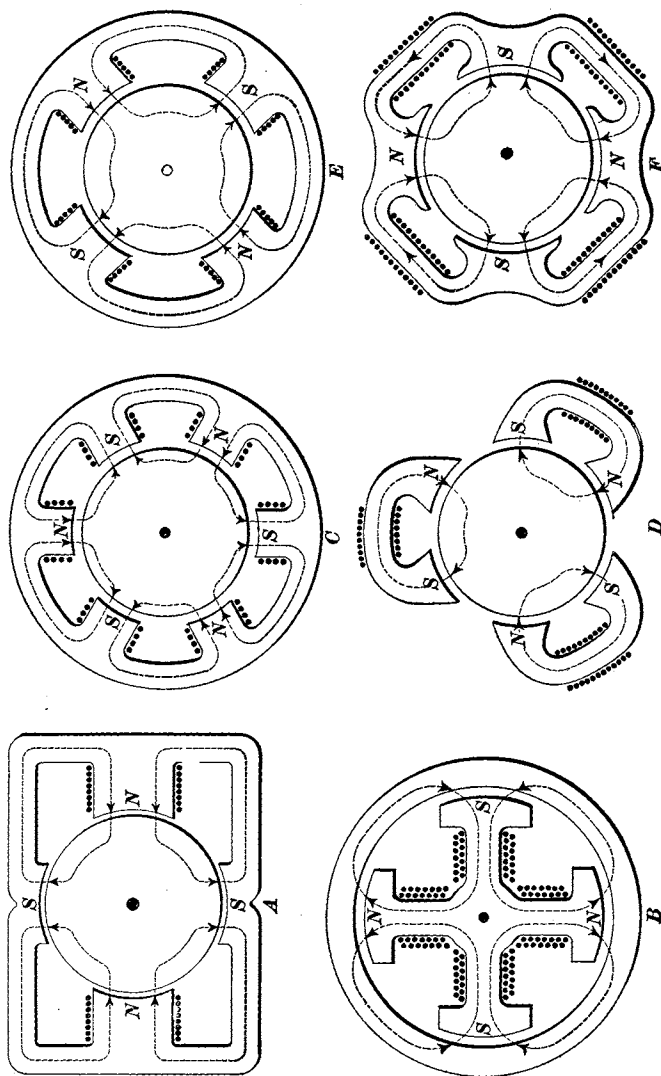


FIG. 887.

winding, since the current divides into as many circuits in parallel as there are poles in the field magnet.

2260. It is possible, however, to connect and group the conductors in an armature for a multipolar dynamo so that the current divides into two circuits only, making the number of active conductors in series equal to one-half the total number of outside wires on the core. This armature winding is termed a *series* winding, since one-half of the total outside wires is the largest possible number that can be connected in series and produce a continuous current.

There are many different methods of connecting and winding armatures for generating a continuous current, the method used depending upon the character of the current and E. M. F. desired. Drum windings as well as ring windings are connected in a variety of ways for multipolar and bipolar dynamos, but the principle of commutation and generation of E. M. F. does not differ from that previously described; the E. M. F. is always proportional to the number of outside or active wires connected in series.

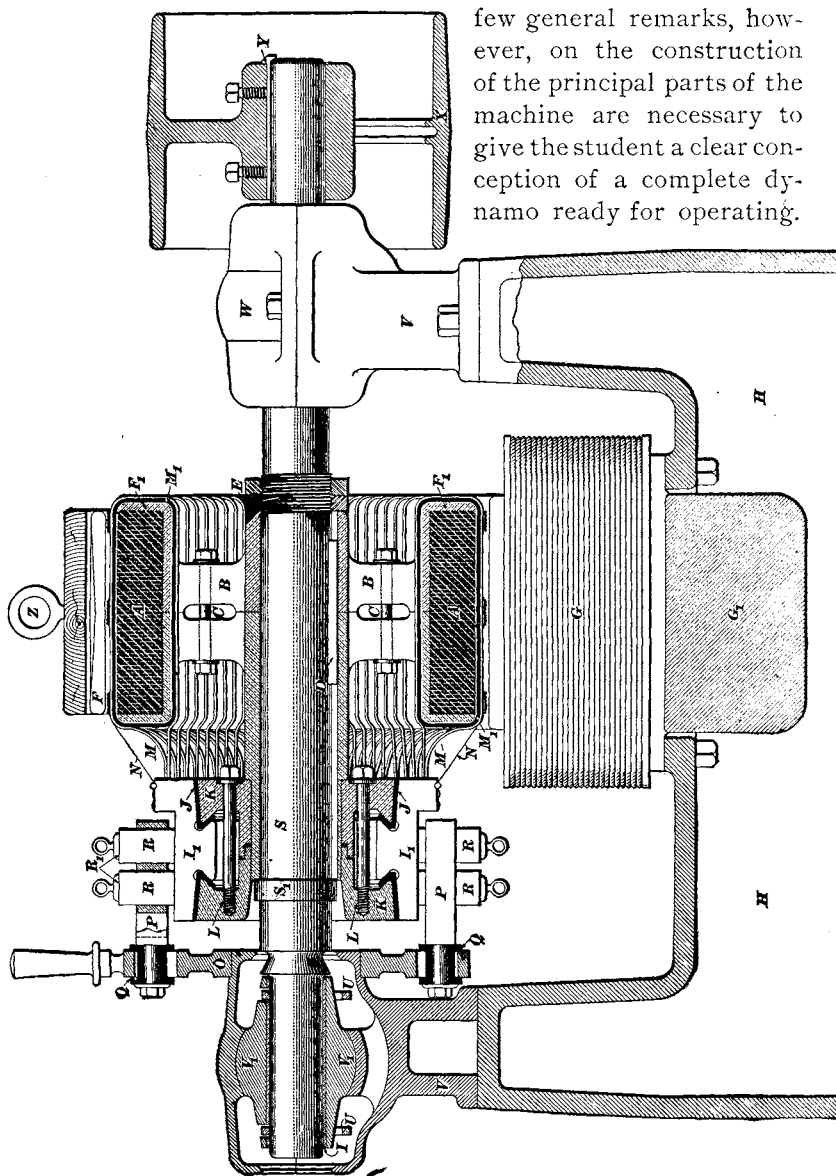
2261. The regulation of multipolar dynamos for constant potential is accomplished by the changing of the strength of the magnetizing force as in the bipolar machines. In a compound dynamo, the series coils are wound on each field core and all connected together in parallel or series, as is most expedient.

2262. Types of Multipolar Field Magnets.—The various types of multipolar field magnets are shown in Fig. 887. Consequent and salient poles are used as in bipolar field magnets, but the type generally employed has salient poles alone, as in *C* and *E*. *A* embodies both consequent and salient poles. In *B* the field magnet is surrounded by the armature and is known as an *internal-pole* dynamo. The field of this dynamo revolves and the armature is kept stationary. The armature in all cases is that part of a dynamo in which the current is generated. Each type of field magnet in the above figure has its own special advantages, but all represent good design.

2263. Mechanical Construction.—Heretofore, only the principles of a dynamo have been considered; its mechani-

cal construction in detail depends upon the requirements of the machine, and upon the originality and taste of the designer. A

few general remarks, however, on the construction of the principal parts of the machine are necessary to give the student a clear conception of a complete dynamo ready for operating.



The mechanical construction of a typical bipolar dynamo is shown in Fig. 888, which is a vertical section taken along the center of the armature shaft. The parts of the machine shown in the figure are lettered, and the names of the parts corresponding to the letters are as follows:

- A* = Armature core, which may be either punchings from sheet iron or built up of fine annealed iron wire.
- B* = Armature spider for connecting core to shaft.
- C* = Armature spider bolts.
- D* = Armature key for fastening spider to shaft.
- E* = Armature locknut.
- F* = Pole piece.
- G*₁ = Magnetic yoke.
- G* = Magnetizing or field coil.
- H* = Frame.
- I*₁ = Commutator bars or segments.
- J* = Commutator insulation.
- K* = Commutator shell or body and rings for holding commutator segments in place.
- L* = Bolt for clamping commutator frame.
- M* = Armature leads, connecting armature winding to commutator.
- N* = Armature dressing or covering.
- O* = Rocker arm or brush-holder yoke.
- P* = Brush holder.
- Q* = Insulating bushings.
- R* = Carbon brushes.
- R*₁ = Carbon brush hammers.
- S* = Shaft.
- I* = Bearing or brass.
- U* = Oil rings.
- V* = Standard.
- W* = Cap for standard.
- X* = Pulley.
- Y* = Key for pulley.
- Z* = Eye bolt.

}	Complete outfit called pillow block.
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2264. Frame.—The frame is made up of two castings; the upper forms the magnetic yoke *G*₁ and pole pieces *F*, and

is bolted to the lower one H , which forms the base and is extended on either side to support the standards V, V . The pole pieces are bored out to admit the armature core when wound; the standards are bolted to the base casting, and are so adjusted as to allow the armature core to revolve centrally between the pole pieces. The magnetizing or field coils G , only one of which is shown in this cut, are wound on separate bobbins or spools, and one is slipped over each pole piece.

2265. Armature.—As generally used, the word **armature** includes the wound core and commutator mounted on the shaft ready for operating. In Fig. 888, the armature spider B is made in two halves; each half is provided with flanges F_1 at the ends to hold the disks or sheets of iron A in place. The disks are punched in circular rings from thin sheet iron, annealed, and a large number are slipped over each half of the spider, which is then bolted together by long spider bolts C as shown. The spider usually has three or four arms joining the flanges to the hub, the armature conductors on the inside of the ring, in case of ring winding, being wound between the arms. The hub of the spider is bored out to slip over a portion of the shaft S ; it rests against a turned shoulder S_1 , and is held in this position by the armature nut E . The spider and core are made to revolve with the shaft by the aid of a key or feather D , fitted into the spider hub and into the shaft. The core and spider are insulated by mica, cloth, paper, etc., M_1 , and the armature conductors are wound on them in the manner previously described, with armature leads properly connected to the winding at suitable places. After the core has been wound and the leads connected to the commutator, the winding is sometimes covered or dressed with cloth of suitable texture to prevent flying particles and dust injuring or short-circuiting the coils. The armature leads should be made of a flexible conductor or cable, insulated from one another with cotton or rubber tape; an electrical contact of two leads will short-circuit and burn out the intervening coil. It is sometimes the practice to use the armature conductors themselves

for leads by looping the conductor and connecting the end of the loop to the commutator. This is bad practice, however, and, except for small dynamos, ought not to be followed. A large solid copper wire is liable to become crystallized by the repeated vibration of the machine, and will eventually give way.

2266. Commutator.—Every maker of dynamos has a special design of commutator, but all embody the same general construction. Fig. 889 shows two enlarged views of

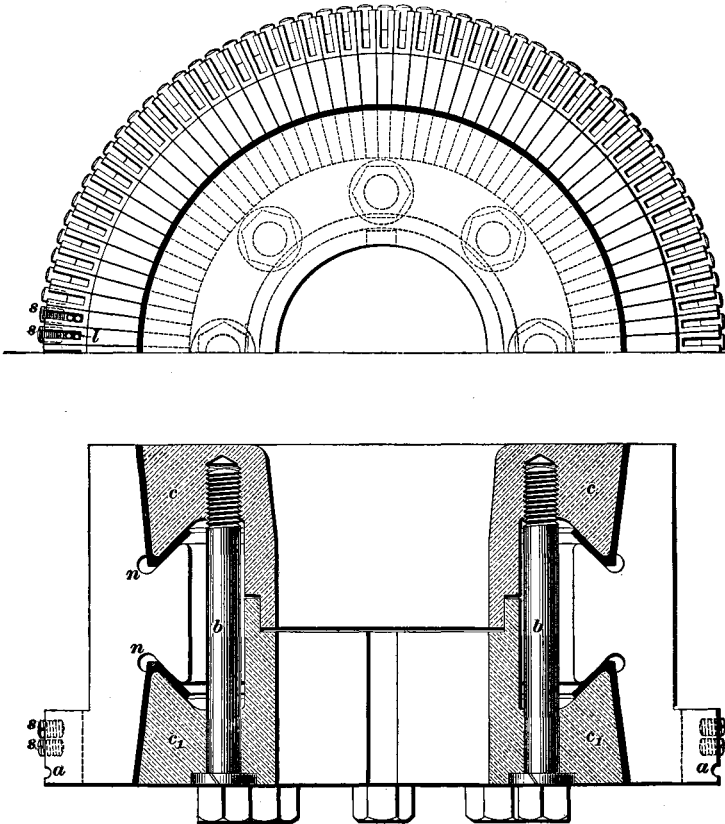


FIG. 889.

a commutator such as is shown in place in Fig. 888. It will be noticed that the segments are broader on the outside

of the commutator than near the center, thus providing for an equal thickness of insulation between all parts of adjacent bars. A portion a of each segment projects above the general level of the commutator surface, and is provided with a slot into which the armature leads are securely fastened by screws s, s , as shown at I . Sometimes the leads are soldered to the segments. The method of clamping and securely holding the segments is shown in the lower view. The commutator shell, it will be seen, consists of two rings c, c and c_1, c_1 clamped together by bolts b, b . The notches n in the segments fit over corresponding projections on the rings, and as the bolts are tightened the segments are drawn firmly against the insulation which separates them. The commutator shell is usually made of brass, sometimes of cast iron. This shell is, of course, thoroughly insulated from the commutator segments. A key is fitted into the commutator shell and shaft to cause the commutator to turn with the shaft. The armature leads from the winding are soldered or screwed to ears or clips extending from each commutator bar, as shown by the cross-sectional view.

2267. Brushes and Brush Holders.—In the cut of the machine, Fig. 888, the brushes shown are made of carbon and rub against the segments of the commutator radially, the pressure being regulated by a spring which is attached to a hammer pressing on top of the carbons. The carbons slide in slots in the brush holders, fitting snugly, with but little play or lost motion sideways. Both brush holders are provided with studs which pass through holes in the rocker arm, each stud being insulated from the arm by insulating bushings, as shown in the cross-sectional view. The rocker arm is fitted over the journal-box, and can be rocked or rotated to change the position of the brushes on the commutator as the position of the neutral points changes when the load is varied. This action is usually accomplished by a handle attached to the rocker arm; and a thumb or set screw is provided to hold the rocker arm in position when properly adjusted. The current is taken from the brushes

by a cable or flexible conductor connected to the brush holder, generally by the use of a small cable clip surrounding the stud. On a large class of dynamos it is customary to use copper brushes; that is, brushes made either of copper leaves, strips, wires, or gauze. Such brushes are built in a great variety of ways, and on constant potential machines are generally used where the E. M. F. does not exceed 125 volts.

2268. Journals or Bearings.—The armatures of most dynamos are generally driven at a high speed compared with the average rotating machinery, and, hence, it is important that the journals or bearings should be of the best design possible. In the dynamo shown in Fig. 888, the bearings are called **self-aligning** boxes; that is, the linings are allowed to find their own alignment with the shaft. This is accomplished by turning a spherical surface V_1 around the center of the lining, and turning the cap and standard to match as shown in the cross-sectional view. The linings I in such a bearing are usually made of some composition metal, as bronze or gun-metal, for small machines; on larger machines the linings are made of cast iron covered on the inside with babbitt metal.

The best practice in lubricating high-speed journals in dynamos is to make the bearings *self-oiling* or *self-lubricating*; that is, to design the bearings with a reservoir of oil below the journal, using some device to carry the oil from the reservoirs to the top of the journal, from whence it flows around the journals and drops back into the reservoirs again. This method produces a constant circulation of oil around the journals and allows the oil to be used over and over again.

A good method of automatically oiling or lubricating bearings on journals is shown in the cross-sectional view in Fig. 888. Two slots are cut across the top of each lining, permitting two circular *oil rings* U to rest upon the journals of the shaft; the diameters of the rings are made large in comparison with the diameter of the shaft, and their lower

parts dip into the reservoirs of oil. When the shaft is rotated, the friction between it and the inside of the oil rings causes the latter to revolve, thus carrying the oil which adheres to the bottom part of the rings to the top of the journal, where it finds its way between the linings and the shaft.

In general, any freely lubricated journals can be used in dynamos or generators.

2269. Driving Mechanism.—The armatures of nearly all dynamos are driven in one of the following ways: 1. By using a flat belt passing over a pulley on the armature shaft. 2. By using several ropes, side by side, running in a grooved pulley. 3. By connecting the armature directly to the crank-shaft or shaft of the driving machine, which, in most cases, consists of a steam engine, steam turbine, or water-wheel. In any of the above methods the driving mechanism should be amply capable of transmitting the total output of the dynamo with a suitable factor of safety.

2270. A perspective view of the bipolar dynamo just described is shown in Fig. 890. In the cut the machine is

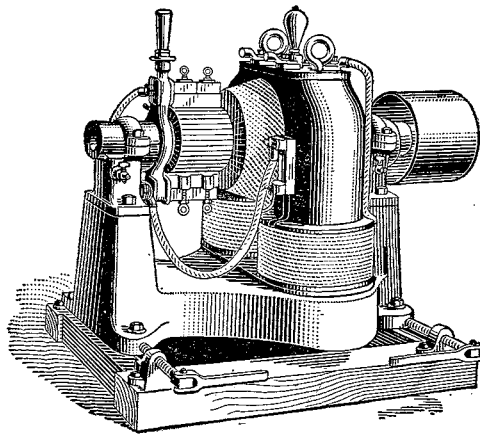


FIG. 890.

represented as ready for operating, and is mounted upon sliding rails which are attached to the wooden *bed-plate*.

Two adjusting screws, one on each side of the machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals the current passes through the series winding on the field or magnetizing coils, and thence to a small connection board on the top of the

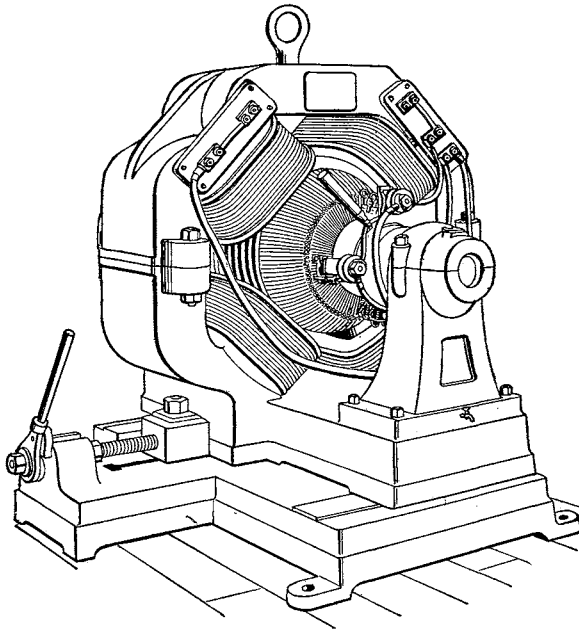


FIG. 891.

pole pieces. An incandescent lamp is connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal E. M. F. A lamp used for this purpose is usually called a **pilot lamp**.

2271. A multipolar dynamo for developing a constant potential and ready for operating is shown in Fig. 891. In this machine the frame is made of two main castings; one consisting of the upper magnetic yoke and two pole pieces,

and the other consisting of the lower magnetic yoke and two pole pieces, from which project two extensions for supporting the pillow-blocks. The dynamo slides upon a cast-iron bed-plate, and adjustment is made by a screw, as in the case of the bipolar dynamo.

The two dynamos previously described are illustrations taken from actual practice, and embody some special features which are not found in other machines of the same character; they were selected, however, on account of their simplicity, to convey to the student a general idea of how electrical principles are combined with mechanical construction.

EFFICIENCY OF CONSTANT-POTENTIAL DYNAMOS.

2272. As previously stated, a dynamo is a machine for converting or transforming mechanical into electrical energy. In any transformation of energy, the total amount of energy is constant; when energy which is manifested in one form disappears, the same quantity will always appear again in another form or in several other different forms. This action is exactly that which takes place in a dynamo. A certain amount of mechanical energy is delivered to the armature shaft of the dynamo by a belt or some other transmitting device; a large portion of the energy is converted into electrical energy in the armature conductors, and is transmitted to the external circuit, while the rest of the energy, usually the smaller portion, is converted directly or indirectly into heat energy in the different parts of the dynamo itself. The amount of energy delivered to the armature shaft is always equal to the energy appearing in the external circuit from the brushes, plus the energy converted into heat in the dynamo itself.

In a dynamo the mechanical energy delivered to the armature shaft is usually called the **input**; the electrical energy appearing in the external circuit from the brushes is called the **output**, and the energy converted into heat directly or indirectly in the dynamo itself is termed **energy**

losses, or simply **losses**. This last term is not a strictly true one; for the energy converted into heat in the dynamo is lost only in relation to its utility—it can not be utilized to an advantage, and if too intense endangers the life of the machine.

From what has been stated, it will be seen that the *input* to a dynamo is always equal to the *output* at the brushes, plus the *losses* in the machine itself; or, in other words, the losses in the dynamo are equal to the difference between the *input* and the *output*. It is assumed in the above statement that the *input*, *output*, and *losses* are reduced to the same units. For example, suppose that 20 horsepower is delivered to the armature shaft of a dynamo where the *output* from the brushes to the external circuit is 13,428 watts. Reducing the 20 horsepower to watts gives $20 \times 746 = 14,920$ watts; hence, the losses in the dynamo are equal to the difference between the input of 14,920 watts and the output of 13,428 watts, or $14,920 - 13,428 = 1,492$ watts.

2273. It is more convenient, however, to express the relation of the *input*, *output*, and *losses* of a dynamo in percentage; that is, the output as well as the losses may be expressed as a certain per cent. of the input. The relation of the input to the output of a dynamo, expressed in percentage, is termed the **efficiency** of the machine.

Let I = the input of a dynamo;

O = the output;

E = the per cent. efficiency.

Then, the per cent. efficiency of a dynamo may be found by the formula,

$$E = \frac{100 \times O}{I}. \quad (330.)$$

That is, to find the per cent. efficiency of a dynamo, divide the output in watts by the input in watts and multiply by 100.

For instance, in the above example, the efficiency, by formula **330**,

$$E = \frac{100 \times 13,428}{14,920} = 90 \text{ per cent.}$$

2274. The relation of the input to the heat losses in a dynamo, expressed in percentage, is termed the **per cent. loss**.

Let L = per cent. loss.

Then, the per cent. loss in a dynamo may be found by the following formula:

$$L = \frac{100 (I - O)}{I}. \quad (331.)$$

That is, *to find the total per cent. loss in a dynamo, divide the difference between the input and the output in watts by the input in watts and multiply by 100.*

EXAMPLE.—(a) What is the per cent. efficiency of a dynamo if 10 horsepower is delivered to the armature shaft and the output from the brushes is equivalent to 6,341 watts? (b) What is the total per cent. loss in the dynamo when running under these conditions?

SOLUTION.—Reducing the input of 10 H. P. gives $10 \times 746 = 7,460$ watts input. (a) By formula **330**, the efficiency,

$$E = \frac{100 \times 6,341}{7,460} = 85 \text{ per cent. Ans.}$$

(b) By formula **331**, the total loss,

$$L = \frac{100(7,460 - 6,341)}{7,460} = 15 \text{ per cent. Ans.}$$

The efficiency of a dynamo depends upon its character, construction, condition when tested, its capacity (or output), losses, and various other conditions; in fact, two dynamos of the same construction and capacity seldom show exactly the same efficiencies. The following list, however, will give the student a general idea of the approximate per cent. efficiencies which should be obtained from constant-potential machines of different capacities, or outputs, under ordinary conditions to be met with in practice:

From 750 to 1,500 watts output inclusive, about 75% efficiency.

From 3,000 to 5,000 watts output inclusive, about 80% efficiency.

From 7,500 to 10,000 watts output inclusive, about 85% efficiency.

From 15,000 to 100,000 watts output inclusive, about 90% efficiency.

From 150,000 watts output and upwards, from 91 to 93% efficiency.

The method of actually testing a dynamo to find its efficiency and losses is beyond the scope of this paper; the above, however, will serve as a guide to the student when computing the necessary power required to drive dynamos of different capacities or outputs.

2275. When the output of a dynamo and its corresponding efficiency are given, the input necessary may be found by the following formula:

$$I = \frac{100 \times O}{E}. \quad (332.)$$

That is, *the input necessary to drive a dynamo, when its output and efficiency at that output are given, is obtained by dividing the output by the per cent. efficiency and multiplying the quotient by 100.*

EXAMPLE.—The efficiency of a constant potential dynamo is found to be 85% when giving an output of 6,341 watts; find the input in horsepower necessary to drive its armature shaft under these conditions.

SOLUTION.—By formula **332**, the input necessary $I = \frac{100 \times 6,341}{85} = 7,460$ watts. The equivalent of 7,460 watts in horsepower is $\frac{7,460}{746} = 10$ horsepower, which is the power required to drive the armature shaft of the dynamo under the stated conditions. Ans.

2276. When the input of a dynamo and its corresponding efficiency are given, the output may be found by the following formula:

$$O = \frac{IE}{100}. \quad (333.)$$

That is, *the output of a dynamo, of which the input and the efficiency at that input are given, is obtained by multiplying the input by the per cent. efficiency and dividing by 100.*

EXAMPLE.—An input of 35 horsepower is delivered to the shaft of a dynamo; if its efficiency at that input is 89.5%, find its output in watts.

SOLUTION.—The equivalent of 35 horsepower is $35 \times 746 = 26,110$ watts. By formula **333**, the output of the dynamo under these conditions, $O = \frac{26,110 \times 89.5}{100} = 23,368.45$ watts. Ans.

2277. The total loss of power in a dynamo can be separated into smaller losses, depending upon the manner in which the loss is produced and the part of the dynamo in which it occurs. In ordinary cases, all the losses will come under one of the following heads:

1. Mechanical friction loss.
2. Core loss.
3. Field loss.
4. Armature loss.

Friction Losses.—The larger part of the loss due to mechanical friction takes place between the bearings and journals. The brushes rubbing on the commutator produce some friction and consequent loss, but the amount is small, and in most cases need not be considered. The per cent. of power lost in mechanical friction necessarily depends upon the construction and condition of the bearings and journals, upon the size of the machine, and to some extent on the method of driving the armature shaft. Under ordinary conditions, the loss in mechanical friction should not exceed 5% of the input of dynamos from 1,500 up to about 10,000 watts output, and 3% of the input of dynamos from 15,000 to 100,000 watts output. For example, suppose that a dynamo has an efficiency of 88% at its rated output of 22,000 watts, and a test shows that 2.5% of the input is lost in mechanical friction. The total loss in the machine is $100 - 88 = 12\%$, of which 2.5% is lost in friction; the remaining 9.5% loss is due to other causes. The total input to the machine, from formula **332**, is $\frac{22,000}{88} \times 100 = 25,000$ watts; hence, the power lost in friction is $\frac{25,000 \times 2.5}{100} = 625$ watts.

2278. Core Losses.—The *core loss* is the energy converted into heat in the iron disks of the armature core when they are rotated in the magnetic field. A small portion of this loss is due to eddy currents generated in the revolving core disks as explained in Art. **2229**; the larger portion of the loss is due to a *magnetic friction* which occurs whenever the direction of the lines of force is rapidly changed in a magnetic substance. When the magnetism of an electro-magnet is rapidly reversed—that is, when the direction of the lines of force is suddenly changed several times in rapid succession by reversing the direction of the magnetizing current—the iron or steel in the core becomes heated, which necessitates a certain amount of energy being expended. This effect is due to a kind of internal *magnetic friction* by reason of which the rapid changes of magnetism cause the iron to grow hot. This effect is called **hysteresis**.

The energy expended by hysteresis is furnished by the force which causes the change in the magnetism, and, in the case of an electro-magnet where the magnetism is reversed by the magnetizing current being reversed, the energy is supplied by the magnetizing current.

The same effect is produced when the iron of the armature core is rapidly rotated in the constant magnetic field of the dynamo; this case differs from the electro-magnet only in the fact that the magnetic lines of force remain at rest and the iron core is made to rotate. Since the core is rotated from the armature shaft, the energy lost in hysteresis is furnished by the force which drives the shaft.

The loss of energy due to hysteresis depends (1) upon the hardness and quality of the magnetic substance in which the magnetic change takes place; (2) upon the amount of metal in which the reversal takes place; (3) upon the number of complete reversals of magnetism per second, and (4) upon the maximum density of the lines of force in the metal. Building the core of iron disks does not affect the hysteretic loss; it only reduces the eddy currents. Hysteretic loss is greatly reduced by using soft annealed iron which exhibits only slight traces of residual magnetism;

for, where the residual magnetism is large, the loss due to hysteresis is large in proportion. The hysteretic loss increases in a certain ratio with the magnetic density and the number of reversals per second; hence, these quantities are kept within reasonable limits. In well-designed dynamos, the magnetic density in the armature rarely exceeds 85,000 lines of force per sq. in.; and the maximum number of complete reversals of magnetism in the armature core is about 133 per second. In bipolar dynamos the number of complete reversals of magnetism in the armature is equal to the number of revolutions per second at which the armature shaft is driven; in multipolar machines the number of reversals is equal to the number of revolutions of the armature shaft, multiplied by the number of *pairs of poles*. For example, if the armature of a four-pole dynamo is driven at 600 revolutions per minute, or 10 revolutions per second, the number of complete reversals of magnetism in the armature core is $10 \times 2 = 20$ per second.

In a well-designed dynamo, the core loss, including eddy currents and hysteresis, should not exceed 2% of its input when delivering its rated output from the brushes.

2279. Field Losses.—In self-exciting dynamos, a portion of the electrical energy generated in the armature is required to excite the field magnets. This energy is considered as one of the losses of the dynamo, since it does not appear in the external circuit and it is entirely dissipated in the form of heat.

In a series-connected dynamo, where the total current from the armature passes through the magnetizing coils, the power in watts is equal to the square of the current, multiplied by the resistance of the series turns, as already demonstrated in formula **325**. If, then, C is the total current from the armature; r is the total resistance of the series coils, and W is the watts lost in the series coils, then, $W = C^2 r$. For example, suppose that a series dynamo generates 200 volts between its terminals when a current of 100 amperes is flowing from its brushes through its series coils and

through the external circuit. The total output of the dynamo is, then, $100 \times 200 = 20,000$ watts. If the total resistance of the series coils is .1 ohm, then the number of watts (W) required to excite the field magnets $= C^2 r = 100^2 \times .1 = 100 \times 100 \times .1 = 1,000$ watts.

2280. In a shunt dynamo which generates a nearly constant potential for limited strengths of current in the armature, the field coils, as stated in Art. **2249**, usually consist of a large number of turns of fine wire, offering a high resistance compared with the field coils of a series dynamo. The inside and outside ends of the shunt field coils are connected to the positive and negative brushes, respectively, of the dynamo in parallel with the external circuit, thereby allowing the full potential of the dynamo to act against the resistance of the coils. Then, from Ohm's law, the current in the shunt coil is equal to the electromotive force of the brushes, divided by the resistance of the coils. Let E_e represent the difference of potential between the brushes of the dynamo when running at normal speed and fully excited; let r_s represent the resistance of the shunt coils, and C_s represent the current in the shunt coils. Then, from Ohm's law, the current in the shunt coils is

given by the formula, $C_s = \frac{E_e}{r_s}$. For example, suppose that

a shunt dynamo, when running at a constant speed, generates a constant difference of potential of 110 volts, and the resistance of the magnetizing coils from the positive connection to the negative connection is 55 ohms; or $E_e = 110$ volts and $r_s = 55$ ohms. Then, the current in the shunt coils would be given by substituting these values in the above formula, or $C_s = \frac{E_e}{r_s} = \frac{110}{55} = 2$ amperes.

This gives the strength of current in the shunt coils, but does not indicate the amount of power required to constantly excite the field magnets. By formula **324**, the power in watts, $W = C E$; that is, it is equal to the current in amperes flowing through the shunt coils, multiplied by the

difference of potential in volts between the terminals of the shunt coils. We have found in this case that the current $C = 2$ amperes and the E. M. F. $E = 110$ volts; then, $W = 2 \times 110 = 220$ watts, which represents the power required to excite the field magnets.

Since the power in watts can be expressed in terms of resistance and electromotive force, or resistance and strength of current, the number of watts dissipated in the shunt coil is also given by either formula **325** or **326**.

All other conditions being similar, the same number of watts will be dissipated in a shunt field coil as in a series coil, provided an equal amount of magnetizing force is produced in the two cases.

2281. In a compound-wound dynamo, the field loss consists of two losses; one in the series coil and the other in the shunt coil. The loss in the series coil depends upon the strength of current flowing from the dynamo, as in the case of a simple-series dynamo; while the loss in the shunt coil is constant, irrespective of the load on the machine; provided, of course, the dynamo generates a constant electromotive force for all loads. This can readily be understood from the following example: A dynamo is compounded to generate 220 volts between its terminals for all loads up to its rated capacity; that is, when the current from the armature becomes stronger and the difference of potential between the terminals tends to fall, the current in passing through the series coil strengthens the field magnets sufficiently to keep a difference of exactly 220 volts between the terminals of the dynamo. Assume the resistance of the shunt coil to be 275 ohms, and that of the series coil to be .055 ohm. At a rated output of 4,400 watts, the current flowing through the series coil and into the external circuit is $\frac{4,400}{220} = 20$ amperes (assuming the connections are made for a *short shunt*). At all loads, the current in the shunt coil is $C_s = \frac{E_e}{r_s} = \frac{220}{275} = .8$ ampere; and the loss of power in the shunt coil is $W_s =$

$E_s \times C_s = 220 \times .8 = 176$ watts; even when the external circuit is open the loss in the shunt coil remains constant, or 176 watts in this particular case. The loss in the series coil, however, varies directly with the square of the current passing through it. In this example, the loss in the series coil is $W = C^2 \times r = 20^2 \times .055 = 22$ watts; at half load, or 10 amperes, the loss is $W = 10^2 \times .055 = 5.5$ watts, etc.; at no load there is no current in the series coil, and, consequently, no loss. The total field loss in a compound dynamo is the sum of the losses in the series and shunt coils. For instance, in this example, the total field loss at full load is 198 watts; at half load, 181.5 watts, and at no load, 176 watts.

2282. The amount of power lost or dissipated in the field coils of a dynamo depends (1) upon the capacity of the dynamo; (2) upon its design, and (3) upon the amount of copper used in the coils. In the last condition it is obvious that in order to produce a certain number of *ampere-turns*, the current in amperes required could be made exceedingly small by using a large number of turns of copper wire, thereby reducing the electrical loss. A limit is reached, however, where it is not economical from a commercial standpoint to increase the amount of copper in order to save in electrical loss.

The per cent. loss in the field coils of dynamos varies from about 10% of the input to dynamos having an output of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having an output of 100,000 watts and upwards. For example, suppose that the input to a dynamo from an engine was 100 horsepower and the loss in the field coils was 2.5%. Under these conditions, how many watts are lost or dissipated in the field coils? Changing the input from horsepower to watts gives $100 \times 746 = 74,600$ watts, since one horsepower is equivalent to 746 watts. Hence, the number of watts lost in the field coils is $74,600 \times .025 = 1,865$ watts.

2283. Armature Losses.—The principal armature loss is that produced by the current in flowing against the

internal resistance of the armature; that is, the resistance of the armature *conductors*. The *core losses* previously described could also be classed as part of the armature losses; but it is usual to consider them apart. The armature loss proper is usually termed the *copper* or *wire loss*, since it is due to the resistance of the armature conductors, which are composed of copper wire or bars. The internal resistance of an armature is an exceedingly variable quantity, depending upon the form, construction, size, number of conductors, size of conductors, etc. In constant-potential dynamos, generally speaking, the internal resistance of the armature must necessarily be comparatively small, since it determines the maximum strength of current that can be obtained from the dynamo, as will be seen subsequently.

The armature loss depends upon the amount of internal resistance and upon the strength of current flowing through the armature conductors. In a given armature the internal resistance remains constant at equal temperatures, while the strength of current varies with the load upon the dynamo at that particular moment; in other words, this loss only occurs when there is a current flowing through the armature—the stronger the current, the greater is the loss, and *vice versa*. As previously shown (formula **325**), in all cases where an electric current flows against the resistance of a conductor, the loss of power in watts is equal to the resistance of the conductor in ohms, multiplied by the square of the current in amperes; hence, in an armature the number of watts lost in the armature conductors is equal to the square of the current in amperes flowing through the armature, multiplied by the internal resistance in ohms of the armature from the positive to the negative brush. If C represents the total current in amperes flowing through the armature and r_i the internal resistance in ohms from the positive to the negative brush, then $W_i = C^2 r_i$, where W_i is the number of watts lost in the armature conductors. From this fact, this armature loss is also designated as the $C^2 r$ loss. For example, suppose that the internal resistance of

an armature from brush to brush is .125 ohm, and a total current of 40 amperes is flowing through the armature. Determine the number of watts lost in the armature. Using formula **325**, let $C = 40$ amperes, and $r_i = .125$ ohm; then, $W_i = C^2 r_i = 40^2 \times .125 = 200$ watts.

The per cent. loss in armatures of constant-potential dynamos varies from about 12% of the input to dynamos having a rated capacity of about 1,000 watts to as low as 1.5% to 2% of the input of dynamos having a rated capacity of about 100,000 watts and upwards. For example, suppose that a dynamo was working under a load which required 50 horsepower to run it, and, at this rating, the armature loss alone amounted to 3% of the input; determine the number of watts dissipated or lost in the armature conductors. Changing the input from horsepower to watts gives $50 \times 746 = 37,300$ watts, since 746 watts are equal to one horsepower. The armature $C^2 r$ loss is, therefore, 3% of the input, or $37,300 \times .03 = 1,119$ watts.

2284. Other Losses.—Aside from the four principal losses mentioned, other small losses occur in some machines when the armature is revolving. If large conductors are used in the winding of the armatures, a difference of potential is sometimes generated between the edges of the conductor in such a manner as to give rise to small eddy or local currents in the conductors themselves, and which do not appear in the external circuit and are useless. In some cases these local currents dissipate considerable energy and heat the armature badly when the machine is not loaded; but in a well-designed dynamo they are too small to be considered.

In an armature in which the conductors are wound in slots cut in the core disks, the teeth between the slots have a tendency to disturb the position of the lines of force where they enter and leave the polar faces. This movement causes local or eddy currents to be generated in the pole pieces, thereby dissipating a certain amount of energy. These eddy currents in the pole pieces are sometimes termed

Foucault currents, in memory of the man who first recognized their existence. But, as in the previous case, a well-designed dynamo will show but few traces of Foucault currents. Other local currents may occur in various parts of some dynamos on account of bad design, but it is only necessary here to treat specifically upon such losses as are common to all dynamos and impossible to eliminate.

2285. From the four previous articles, the following summary will be a help to establish the rules of efficiency and losses:

Input = the power driving the dynamo, which is derived from some outside agency.

Output = input minus the total losses.

Total losses = the sum of the friction, core, field, armature, and other losses.

Per cent. efficiency = $\frac{\text{input minus total losses}}{\text{input}} \times 100$
 or $\frac{\text{output}}{\text{input}} \times 100$.

Per cent. loss in friction = $\frac{\text{friction losses}}{\text{input}} \times 100$.

Per cent. loss in core = $\frac{\text{core losses}}{\text{input}} \times 100$.

Per cent. loss in field = $\frac{\text{field losses}}{\text{input}} \times 100$.

Per cent. loss in armature = $\frac{\text{armature losses}}{\text{input}} \times 100$.

THE OUTPUT OF CONSTANT-POTENTIAL DYNAMOS:

2286. If a dynamo is so constructed as to give a constant potential at any load, it is evident that the current flowing is inversely proportional to the resistance of the external circuit; that is, if the external resistance is reduced, the amount of current will be correspondingly increased. There is a limit, however, to the amount of current that any given

machine can give, depending on one (or both) of two factors; namely, the **heating** and the **sparking**.

The heat that is being continually generated in the armature and field coils of a dynamo when working under load, due both to the $C^2 r$ loss and the *core loss*, is given off from the surface of the armature and of the whole machine to the surrounding air. This giving off of heat can only occur when the dynamo is hotter than the air, for if two bodies are equally hot, one cannot give any heat to the other. Conversely, the greater the difference in temperature between two bodies, such as a dynamo armature and the surrounding air, the more heat will be given from the hot body to the cool.

2287. When a dynamo is first started, it is at about the same temperature as the air, so that when the losses in the armature begin to generate heat, this heat cannot pass off to the air, but instead it raises the temperature of the armature, until it is enough hotter than the surrounding air to cause all the heat which is being generated to be given off.

If the amount of heat generated is practically constant, as will be the case if the load remains constant, the temperature of the armature will also remain constant, because the heat is given off as fast as generated; and if the load is increased so as to increase the amount of heat generated, the temperature will again rise until the armature is enough hotter than the air to give off all of this increased amount of heat.

It is evident, then, that when other conditions remain the same, the greater the load on a dynamo armature, that is, the more current it gives, the hotter it will get.

Now, at a certain temperature, the materials used in insulating the conductors of the armature, such as cotton, silk, shellac, paper, etc., will become *carbonized*, that is, charred, or otherwise rendered useless as insulating material. For a short time these materials will withstand a temperature considerably above the boilingpoint of water (212° F.), but it has been found that if they are *continually* subjected to a

temperature greater than about 180° F., they will gradually become carbonized; hence, as armatures are expected to last for several years, they should never be subjected to a continual temperature greater than about 170° F. Consequently, the amount of current which will cause a dynamo armature to heat to about 170° F. is the limiting amount which that armature can *safely* give.

2288. As an armature must be a certain number of degrees hotter than the air in order to give off the heat generated, it is evident that if the air itself were originally of a high temperature, the armature would actually have a higher *temperature* when giving off a certain amount of heat than if the air were cooler; that is, for a certain amount of heat generated, the temperature of the armature will rise to a certain number of degrees *above the temperature of the air*. The average temperature of the air in places where dynamos are installed is often as high as 90° F., so the allowable rise in temperature of the armature above that of the air is about $170 - 90 = 80^{\circ}$ F., and dynamos are usually rated according to this rise in temperature.

As *still* air is a very poor conductor of heat, most of the heat given off to it is carried away by motion of the air; this motion is partly due to the air-currents set up by the rise of the heated air and the flowing in of the cooler air to take its place, but mainly to the air-currents set up by the motion of the armature itself. This latter effect is usually greater in ring than drum armatures, due to the more open construction of the former and to the *fan* action of the spider arms.

The heat generated in the field coils is disposed of in the same way as is that of the armature; that is, it is given off to the surrounding air. The rise in temperature of the field coils is subject to the same limitations as is the rise of the armature; i. e., it is usually limited to about 80° F. above the temperature of the air.

2289. By the *sparking* of a dynamo is meant the sparks which appear at the brushes, due to the *reversal of the*

current in the armature coils. If the commutator is out of true, or has one segment higher or lower than the others, or from other similar causes, there will be flashes or sparks at the brushes; but these are merely *mechanical* faults which can be easily remedied, and this is not what is meant by *spark-ing*. Referring to Fig. 866, it will be seen that in the armature coil $a' p p'$, when in the position shown, the general direction of the current is from right to left; but as soon as it moves into the position occupied by coil $b' a a'$, the general direction of the current is from left to right. Between these two positions the direction of the current must have been reversed, and this occurs during the time that the brush $+B$ is resting on *both* the commutator segments which are connected to this coil ($a' p p'$).

Now, it has been shown (Art. **2218**) that if the amount of current in a coil is suddenly increased or decreased, the *self-induction* of the coil tends to set up an E. M. F. in the coil which *opposes* the change in the strength of the current. Hence, when the current is reversed in the armature coil as it passes from one side of the brush to the other, the self-induction of the coil tends to prevent this reversal, so that when one of the commutator bars to which the coil is connected passes out from under the brush, the current flowing from the side of the armature into which the coil is entering (the left side in Fig. 866) in trying to pass through this coil is opposed by the E. M. F. of self-induction of the coil. Instead of passing through the coil, then, the current jumps from the commutator bar through the air to the end of the brush, making a spark. The same action takes place at each point of commutation.

In order to prevent this sparking, which burns the commutator bars and the brushes, the brushes are shifted forwards ahead of the actual neutral point, until at the same instant that the current in a coil is reversed the coil is moving in the edge of the magnetic field that spreads out from the pole pieces, which generates in the coil an E. M. F. that is *opposite in direction to the E. M. F. of self-induction*. The consequence of this is that the E. M. F. of self-induction

is diminished, which decreases the sparking. If the brushes are shifted to just the right position, the E. M. F. generated in the coil by the magnetic field will just equal the E. M. F. of self-induction, and there will be no opposition to the reversal of the current; hence, no sparking. This is seldom actually done, as the E. M. F. of self-induction changes with every change in the strength of the current; but the effect of a certain amount of shifting of the brushes will usually so nearly counterbalance the E. M. F. of self-induction that the sparking will be slight at different loads.

2290. It has been shown (Art. **2242**) that the current in the armature winding reacts upon the magnetic field, forcing the actual neutral point ahead (in the direction of rotation). Now, if the brushes are moved ahead of this neutral point to avoid sparking, the effect is to move the consequent poles (due to the current circulating in the armature winding) also ahead, which shifts the neutral point still farther ahead, which requires a further slight shifting of the brushes. As long as the field due to the magnetizing coils is much stronger than the reactive effect of the armature, this action is slight, so that only a slight shifting of the brushes is necessary for practically sparkless operation. As the current in the armature increases, its reactive effect grows stronger, and a movement of the brushes is followed by a considerable movement of the neutral plane. Indeed, if the current in the armature is strong enough, the brushes may be shifted more than half-way around the commutator without coming to the sparkless position. There is, therefore, a limit to the amount of current which can be taken from an armature, aside from its heating limit, which is reached when the amount of shifting of the brushes necessary for sparkless running becomes excessive.

This amount of shifting is generally confined to the space between the tips of the pole pieces; that is, the brushes may be shifted until the coil short-circuited by a brush is at or just under the tip of a pole piece.

In dynamos of good design the heating limit and sparking limit are reached with about the same current; that is, a current which will raise the temperature of the armature above that of the air by the amount decided upon as a limit will also necessitate the brushes being shifted to the maximum allowable extent.

2291. It is evident that while a brush is resting on two commutator bars at the same time, the coil connected between these two bars is *short-circuited*, the current from the two sides of the armature passing into the brush, one-half through each of the two commutator bars, without passing through the short-circuited coil. The resistance which the current meets in passing from the bars into the brush is evidently the *contact resistance* of the surfaces which are in contact. When the brush rests equally on both commutator bars, the contact resistance opposed to each half of the current is the same; but as one of the bars moves out from under the brush, and the other moves further under it, the contact resistance is altered, and there is more opposition to the passage of one-half the current into the brush than there is to the other. Now, with *metallic* brushes, which have a very low contact resistance if properly made, this difference is not enough to give any appreciable opposition to the current until the commutator bar is actually leaving the brush; hence, the current is *suddenly* forced to pass through the coil which has just been short-circuited. With *carbon* brushes the contact resistance is much greater than with metallic brushes; when the two bars are equally under the brush, this contact resistance is opposed equally to the current from each half of the armature, but as the one commutator bar begins to move from this position, the resistance opposing the current which is passing from that bar into the brush is great enough to force a part of the current around through the short-circuited coil and into the brush through the *other* commutator bar, in spite of the E. M. F. of self-induction of the coil.

From this it follows that with metallic brushes much more

care must be taken to place the short-circuited coil in a field which will generate an E. M. F. equal to the E. M. F. of self-induction, since the absence of sparking depends mainly on this point, than with carbon brushes, since with these the absence of sparking depends both on generating an E. M. F. in the coil and on the contact resistance of the brush. Consequently, carbon brushes require less shifting for variations in load than do metallic brushes, and are generally used on machines where the variations in load are so frequent and extensive that a great deal of time would be spent in shifting the brushes, if this had to be done for every change in the load.

2292. If the brushes are shifted so far forwards that the E. M. F. generated in the short-circuited coil is *greater* than the E. M. F. of self-induction, not only will the latter be neutralized, but a current will be sent around the coil through the commutator bars and the brush which short-circuits the coil. If this current is greater than the current which one-half the armature is supplying to the external circuit, it is evident that when the short-circuited coil moves over and becomes a part of that half of the armature, its current will be *reduced*; this reduction is opposed by the self-induction of the coil, as before, and sparking results. Since the circuit of the short-circuited coil is partly through the brush and its contact with the commutator bars, it is evident that with metallic brushes of low resistance the liability of the current in this coil becoming excessive is greater than with carbon brushes of (comparatively) high resistance. For this reason, again, carbon brushes will spark less than metallic brushes under the same conditions.

The cause and remedy for flashing and sparking at the brushes, due to mechanical imperfections or accident, will be taken up later.

DYNAMOS AND MOTORS.

(CONTINUED.)

CONSTANT-CURRENT DYNAMOS.

2293. If an ordinary series-wound dynamo is connected to an external circuit whose resistance is variable, both the current and the E. M. F. will vary. For example, if the external resistance is increased, the current will be diminished; as the machine is series wound this weakens the field, which lowers the E. M. F., and still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

In order to obtain a constant current in a circuit of variable resistance, it is necessary then to vary the E. M. F. of the machine as the resistance changes, and in the same proportion. There are many different devices for accomplishing this, as will be described.

In general, the field magnets of constant-current dynamos may be bipolar or multipolar, with salient or consequent poles, according to the ideas of the designer. They are usually series wound. The armature windings, however, may be divided into two classes, **closed coil** and **open coil**.

CLOSED-COIL ARMATURES.

2294. These have already been described in connection with constant-potential dynamos. Ring armatures are generally used in constant-current dynamos, on account of their good ventilation (see Art. **2288**), and from the ease with which any damaged coil may be repaired, since a coil can be replaced without disturbing others, which is not the case in the usual form of drum windings where the coils overlap.

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C. Vol. III.—25.

2295. The methods used to regulate the E. M. F. of closed-coil armatures are as follows: (1) Varying the speed, (2) varying the strength of the field, and (3) shifting the brushes.

The first method is seldom used, though in special cases it is very convenient. The principle of this method is, that with a simple series-wound dynamo, if the external resistance is increased, decreasing the current and E. M. F.'s (Art. **2293**), the speed may be increased until the E. M. F. rises to a point where it will force the normal current through the external circuit; if this adjustment of the speed is made as rapidly as the external resistance changes, the current will be maintained at a constant value.

2296. The second method has been described in Arts. **2253** and **2254** in connection with series-wound dynamos. It is evident that this same principle may be applied to constant-current machines, so as to properly vary the E. M. F. The range of this method of regulation is quite limited, because the strength of the field can not be economically forced beyond the point where the iron begins to be saturated (Art. **2248**), and if it is much reduced, the armature reaction (which is constant, since the current is constant) will cause the neutral point to considerably alter its position.

2297. The third method is almost universally used in this type of machines. It has been pointed out (Art. **2232**) that the greatest difference of potential in a (bipolar) closed-coil armature exists between the two opposite coils which are in the neutral spaces; so, to get this maximum difference of potential between the brushes, they are placed on the opposite commutator segments which are connected to these two coils. Now, if the brushes are shifted from this position, although the E. M. F. generated in the armature is not altered, the *difference of potential between the brushes is reduced*; for, although the circuit through the armature winding is still divided into two parts connected in parallel between the brushes, the separate E. M. F.'s of all the coils

in each of the two parts are not all in the same direction. This may be more plainly seen by examining Fig. 866.

2298. If there were no armature reaction, shifting the brushes to a point half way around the commutator from the neutral space would reduce the difference of potential between them to zero, and in positions between these two the difference of potential would be proportional to the amount of shift. Since the coils short-circuited by the brushes would be moving in strong magnetic fields, there would also be violent sparking. (See Art. **2292**.)

There is, however, a very considerable armature reaction in dynamos of this type, which is so proportioned with respect to the strength of the field that it has two effects. One is to shift the neutral point so that the difference of potential between the brushes is not quite proportional to the amount of shift; but this is of little importance compared to the second effect, which is that the tendency of the current in the armature winding to form consequent poles at the points where the current enters or leaves the winding through the leads to the commutator (Fig. 872) actually *forces the lines of force of the field away from the armature at these points*, leaving only a weak field to influence the short-circuited coil. By proper proportioning of the armature winding, this results in little or no sparking at the brushes, especially as the amount of current in a constant-current machine seldom exceeds 10 amperes, which allows of the use of such a narrow brush that the time during which a coil is short-circuited is so short that the current in the coil does not have time to become large enough to cause serious sparking.

The brushes may be shifted by hand to get the desired regulation, but as this would require constant attention, it is usual to shift the brushes automatically, by devices on or near the dynamos. These devices are usually controlled about as follows: Electro-magnets are connected in the main circuit, and are so adjusted that when any change in the external resistance causes the current to increase or decrease from normal, the corresponding movement of the

magnet keeper mechanically connects the rocker-arm of the dynamo to some sort of driving mechanism, so that the brushes are properly shifted. When they reach such a point that the current is again at its normal value, the electromagnet (usually called the *controlling magnet*) disconnects the rocker-arm from the driving mechanism, and the motion of the brushes ceases until some change in the external circuit calls for a new adjustment.

The mechanical parts of the various brush-shifting devices are quite different in the different makes of constant-current machines. In the following description of the principal features of some of the best known types of closed-coil, constant-current machines, the types of regulating devices used will be taken up more in detail.

PRINCIPAL CLOSED-COIL CONSTANT-CURRENT DYNAMOS.

2299. Wood Dynamos.—These machines have bipolar, consequent pole, series-wound field magnets of the type illustrated at *A*, Fig. 883, and ring-wound armatures of quite large diameter.

The regulator on all except the largest size of this dynamo is such as is shown in Fig. 892 (*a*) and (*b*). To reduce the sparking to a minimum, it has been found desirable to use two positive brushes *a*, *a*₁ located a little distance apart on the commutator, and two negative brushes *b*, *b*₁ located opposite the positive brushes. The brushes are mounted on opposite ends of the rocker-arms *r* and *r*₁, so that simply shifting these two effects the shifting of the four brushes. The angle between the rocker arms *r* and *r*₁ of each pair of brushes is variable, preserving a distance between the bearing ends of the brushes equal to about 3 commutator segments at light loads (low E. M. F.), and about double this at heavy loads (high E. M. F.). This variation in distance is accomplished by shifting the *back* brushes *a*₁ and *b*₁ of each pair a little faster than the front brushes *a* and *b* are shifted, so that the back brush gradually overtakes the front

one, lessening the distance between them, in shifting from the heavy-load to the light-load position.

The electro-magnet e is connected in series with the armature, field, and external circuit, and furnishes the power for regulating the current. The cores c, c of this electro-magnet are free to move into or out of the coils, the attraction of the magnet being balanced by a tension spring provided with an adjustment at d . The lever arm m is raised by the electro-magnet when the current increases, and is lowered when the current weakens. A small gear g on the end of the shaft continuously drives two friction rollers f_1, f_2 in opposite directions by means of the gears g_1, g_2 . The movement of the lever arm m presses the friction wheel f by means of the intermediate links n, o against one or other of the friction rollers, thereby turning the friction wheel in a forward or backward direction. This motion is then communicated by means of gearing to the rocker-arms, producing the relative movement already referred to. The two positive and the two negative brushes are connected by short, flexible cables, so that the intervening coils on the armature are short-circuited, and as the distance between the brushes increases, a further number of coils will be short-circuited; as these coils lie, however, in the neutral space, the effect of cutting them out is to neutralize their demagnetizing action, thereby increasing the E. M. F. of the dynamo. In order to facilitate adjustment, the brushes are set to a certain length, the amount of their projection from the holders being determined by means of a gauge. The regulator is fastened to one of the yokes y of the field. In the larger sizes, friction clutches are driven by a light belt from a small pulley on the end of the armature shaft, but otherwise operate in the same manner as that described.

2300. Standard Dynamos.—These machines have bipolar, consequent-pole, series-wound field magnets of the type illustrated at H , Fig. 883. The armature is of the ring type, and differs from that of the Wood machine only in the details of its construction. A single pair of brushes

is used, which is shifted to vary the E. M. F., and to keep the current constant by a mechanism situated on the base of the machine, which is driven by a light belt from a small pulley fastened to the end of the armature shaft.

In these machines the field-magnets themselves act as a controlling magnet, a short bar of soft iron pivoted in the center being placed between the tips of the pole pieces on one side to act as a keeper. The tendency of this keeper is to move around until it is in a straight line between the two pole tips, but it is held at an angle to this position by the pull of a spring. Attached to this keeper is a lever which is also attached to two *pawls*, or pointed strips of iron, hinged at one end and pointing in opposite directions. These two pawls are kept at a certain distance apart, but the attachment to the keeper is so arranged that when the keeper moves away from its normal position against the pull of its spring, the pawls move so that the points of both are lowered, and when the spring pulls the keeper away from its normal position, the points of both the pawls are raised.

These pawls are given a continuous back-and-forth movement by an eccentric driven by the belt from the pulley on the armature shaft, and between them there is a flat bar, notched or toothed on the edges, which is attached to the rocker-arm of the machine.

The method of regulation is then as follows: If the resistance of the external circuit decreases, the corresponding increase in the current strengthens the field-magnets, which causes the keeper to move away from its normal position against the pull of the spring. This lowers both the pawls, and the top pawl which points *towards* the commutator catches in the teeth on the top edge of the flat bar which is attached to the rocker-arm, and as the pawl moves back and forth the rod is pushed ahead (towards the commutator), thus shifting the brushes away from the neutral point. When the reduction in the difference of potential is sufficient to reduce the current to its normal value, the keeper returns to its normal position, lifting both pawls so that neither catches on the teeth of the flat bar, which therefore becomes

stationary. If the current is reduced below its normal value by an increase in the external resistance, the keeper is pulled away from its normal position by the spring, the pawls are lifted still farther until the lower pawl catches on the teeth on the under side of the flat bar. As this pawl points away from the commutator, its motion causes it to push the rod in the same direction, rocking the brushes *towards* the neutral point, and increasing the difference of potential between them until the current is again at its normal strength.

2301. Western Electric Dynamos.—In the smaller sizes these machines have bipolar, consequent-pole, series-wound field magnets of the type illustrated at *I*, Fig. 883, with drum-wound armatures; in the larger sizes the field magnets are multipolar, with salient poles, and ring-wound armatures are used.

The machines are regulated to give a constant current by shifting the brushes, as in those previously described; the mechanism for shifting the brushes is driven by a belt from the end of the armature shaft, and controlled by a separate controlling magnet, as in the Wood dynamo. The controlling magnet throws into or out of gear, or reverses, a friction-clutch arrangement, which shifts the brushes forwards or backwards, as the load is increased or diminished.

2302. Excelsior Dynamos.—These machines have bipolar, salient-pole, series-wound field magnets, and use ring armatures. The type of field-magnet used is similar to what the type illustrated at *D*, Fig. 883, would become if the field cores, yoke, and spools on one side of the magnet were removed, leaving the pole pieces covering three faces of the armature. An iron arm projects from each pole piece, forming the pole pieces for a small armature which is operated as a motor to shift the brushes of the machine. This small armature is geared to the rocker-arm, and the controlling magnet is so arranged that if the current in the machine rises above the normal, a portion of the current is shunted through the armature of this small motor, which causes it to turn in such a direction that the brushes are

moved away from the neutral point, thus reducing the current.

At the same time the motion of the rocker-arm operates a switch which cuts out some of the turns of the magnetizing coils, which lowers the E. M. F. of the armature. It will be seen that this method of regulating the difference of potential between the brushes is a combination of the methods described in Arts. **2296** and **2297**.

If the current is decreased below the normal strength, the controlling magnet reverses the current in the armature of the small motor, so that it runs in the opposite direction and shifts the brushes towards the neutral point, at the same time cutting *in* some of the turns of the magnetizing coils, all of which brings the current back to its normal strength.

2303. Ball Dynamos.—These machines are of a very peculiar construction. The magnetic circuit is represented in Fig. 893, from which it will be seen that two armatures are employed, each with an independent commutator. The field magnet is arranged with only one pole piece for each armature, as represented; but as the lines of force must complete their circuit, they form irregular poles on the opposite side of the armature, the paths of the lines of force being represented by the dotted lines in the cut. The armatures are ring wound, and may each be used separately or connected in series.

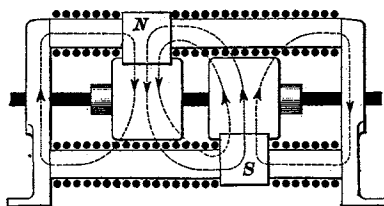


FIG. 893.

In the larger machines of this type the regulation is obtained by automatically shifting the brushes; the field magnets of the machine itself acting as the controlling magnet, and also furnishing the necessary power. A circular opening is made in the magnetic yoke (on each end of the machine) of such size that the area of the magnetic circuit at that point is much reduced, which causes a leakage of the

lines of force across the opening. Two iron segments are supported on a non-magnetic hub in this opening; now, if these iron pieces were free to move they would take up such a position in the opening as to make up as much as possible for the reduction in the area of the magnetic circuit, and allow the lines of force to pass directly through them. They are free to rotate about the hub to which they are attached, which revolves on ball bearings, but are prevented from taking up their natural position by a counterweight, which deflects them more or less, according to the strength of the field of the machine.

The brush-holder studs are connected directly to this movable part of the magnetic yoke, so that when the strength of the field increases, due to an increase in the current above the normal strength, this movable part is pulled around against the opposition of its counterweight until the brushes are shifted to the point where the current again becomes of normal strength.

OPEN-COIL ARMATURES.

2304. Open-coil windings consist of a comparatively small number of coils, which are connected directly to the external circuit (through the commutator) when in the position where the E. M. F. generated in them is a maximum. (See Art. **2233.**)

As the coils move away from this position, they are connected in parallel with other coils, and are finally, when near the position where their E. M. F. is zero, disconnected entirely from the external circuit. These various connections are made by the brushes and the commutator, by means which will be explained in speaking of the principal makes of machines of this type. The changes in the connections of the coils, and the small number of coils used, make the difference of potential between the brushes fluctuate, so that the current in the external circuit is *pulsating* in character; in speaking of it as a *constant* current, it is meant that the *average* current strength is constant.

PRINCIPAL OPEN-COIL CONSTANT-CURRENT DYNAMOS.

2305. Brush Dynamos.—These machines use a disk-shaped ring-wound armature with projections on both sides of the ring, between which the coils are wound.

The magnetic circuit has four poles, but is really a consequent-pole, bipolar field magnet, as will be seen from Fig. 894, which represents the field magnets as seen from the top. This type of field magnet is what that shown at *D*, Fig. 883, would become if that part of each pole piece which covers the cylindrical face of the ring were removed.

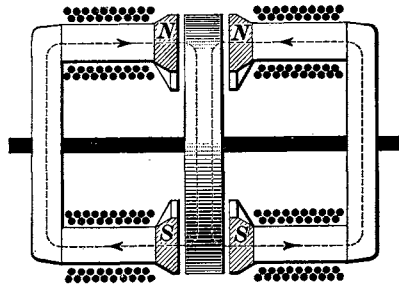


FIG. 894.

The armature winding of these machines consists really of a number of windings, each with a separate commutator. Each winding consists of four coils, arranged in two sets of two coils each. The two coils of each set are placed on opposite sides of the armature core, so that one coil is always in the same position relative to one pole piece that the other coil is to the other pole piece; this being the case, the E. M. F.'s generated in the coils are equal at all parts of their revolution, and they are permanently connected in series, so that they really act as one coil. The other set of coils belonging to the winding is placed on the core in the same manner, but at right angles to the first set, so that when the coils of one set are under the center of the pole pieces, that is, are in their most active position, the coils of the other set are in the neutral spaces, that is, in their least active position.

2306. It will be seen that this arrangement of the two sets of coils corresponds to the arrangement of the two loops of wire described in Art. 2228, and illustrated in Fig. 857; the ends of each of the two sets of coils are connected to two

opposite segments of a commutator just as there described, except that, instead of each segment being a little less than $\frac{1}{4}$ of the circumference, so that the brushes leave one pair of segments at the same time that they begin to bear on the other pair, in the Brush commutator each segment covers a little more than $\frac{1}{4}$ the circumference, the segments of one pair being placed alongside the segments of the other pair to allow for this extra length.

This is represented in Fig. 895, a and a' being the two segments connected to one set of coils, and b and b' being the two that are connected to the other set. It will be seen from this figure that each of the brushes (1 and 2) rests on one of the two opposite segments b and b' ; but as the commutator revolves, each brush rests on one segment of *each* pair, a' and b' , and a and b , where they overlap. Consequently, the coils connected to each pair of segments are connected in parallel with each other

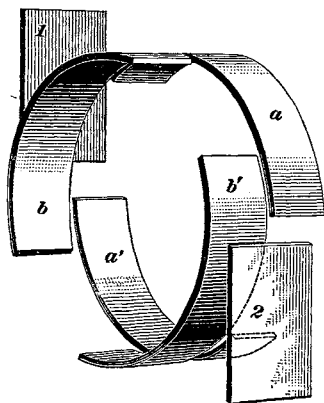


FIG. 895.

during a part of each half revolution.

If this form of commutator with overlapping segments be applied to Fig. 857, it will be seen that at the moment when the two loops of wire are thrown in parallel by each brush resting on two segments, the E. M. F. in the two loops is not the same; that of the loop which had just before alone been connected to the brushes being higher than that of the other. A little later, at the moment when one of the loops is disconnected from the circuit by each brush passing from two segments to a single segment, the coil which is disconnected has a less E. M. F. than the other.

If the loops had little self-induction this would result in the greater E. M. F. of the one loop sending a current around through the other loop against the E. M. F. generated in it, which current would not appear in the external

circuit, and would, therefore, represent so much wasted energy.

This *local current* would evidently be greatest when the difference between the E. M. F.'s of the two coils is greatest, that is, at the moment when the two loops are connected in parallel, and at the moment one of the loops is disconnected from the brushes.

Then, when the one loop is disconnected from the other, this local current would be suddenly broken, which would result in sparking.

In the Brush machines the self-induction of the coils is considerable, so that when two sets of coils are connected in parallel the self-induction of the coil having the lower E. M. F. prevents this sudden rush of local current, and takes up its share of the output of the machine gradually.

At the same time, the parallel connection of the sets of coils is not broken until the E. M. F. of the set which is disconnected is enough lower than that of the other set so that it is furnishing practically none of the current output; hence, there is little sparking when it is disconnected.

2307. As stated, the Brush armature winding is made up of two or more separate windings, the action of each of which is as has been described.

Fig. 896 represents a Brush armature with two separate windings. In this figure the pole pieces are represented by the heavy dotted lines as they face the sides of the armature, as shown in Fig. 894. The segments of the two separate commutators are, for convenience, represented as concentric, with the brushes resting on their edges; whereas, actually, they lie side by side, forming two separate commutators of the same diameter, each having four segments, and the brushes rest on their circumference.

One winding consists of two pairs of coils $A A'$ and $B B'$, located at right angles to each other, the coils of each pair being connected in series, as represented.

This winding is connected to its commutator, coil A to segment a , coil A' to segment a' , coil B to segment b , and

coil B' to segment b' , as represented. Brushes 1 and 2 rest on this commutator, making contact on the line of maximum action of the coils $x y$. It will be seen that this line is not from center to center of the pole pieces, but is moved ahead (in the direction of rotation, as indicated by the arrows) from this position by the armature reaction.

The second winding consists of two pairs of coils $C C'$ and $D D'$, located at right angles to each other and half way between the coils of the first winding. These coils are connected in series and to the segments of the second commutator, coil C to segment c , coil C' to segment c' , coil D to

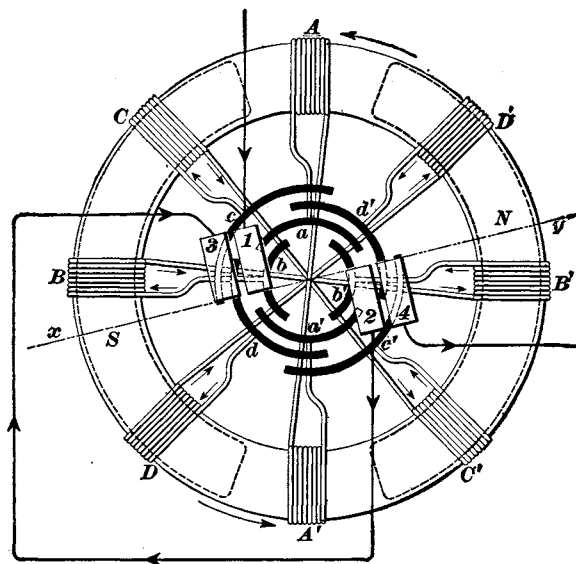


FIG. 896.

segment d , and coil D' to segment d' , as represented. Brushes 3 and 4 rest upon the segments of this commutator on the same line of maximum action of the coils.

Taking each winding separately, it will be seen that its two sets of coils pass through the following combinations: One set of coils only connected to the brushes; then the two sets, connected in parallel, both connected to the brushes; then one set only; then both sets in parallel, and so on.

The maximum E. M. F. occurs when the single set of coils is connected, and is directly in the line of maximum action; the minimum occurs $\frac{1}{2}$ of a revolution ahead of this point, when both sets of coils are in parallel, and are equally distant from the line of maximum action. (See Fig. 858, and compare the accompanying text with the above.)

This being the case, it is evident that as the coils of one winding are half way between the coils of the other, *the maximum E. M. F. of one winding occurs at the same instant as does the minimum E. M. F. of the other.* On account of this, when the two windings are connected in series, the fluctuations of the current are much reduced.

This connection of the two windings is obtained by connecting the positive brush (2, Fig. 896) of one winding with the negative (3, Fig. 896) of the other, the external circuit being connected between the two remaining brushes (1 and 4, Fig. 896).

In the large sizes of these machines three and even four separate windings are used, each with its commutator, and all connected in series. In the larger multipolar machines each winding consists of two sets of coils, each set containing four coils, one for each pole piece. The action is precisely the same as in the bipolar machine.

2308. The regulation of the Brush machines is nearly automatic; that is, a machine will give *nearly* a constant current without any regulation whatever. This is due to the fact that the armature reaction increases so much with any increase in the current that the line of maximum action is shifted farther ahead, which changes the relations of the various coils at the time when they are connected with, or disconnected from, each other or the external circuit.

This regulation is, however, not close enough for commercial working, so in addition a resistance is placed in shunt to the magnetizing coils, which is varied by a controlling magnet in the main circuit, thus making the regulation very exact. (See Art. **2254**, and Fig. 881.)

This resistance consists of a series of blocks of carbon—a material which has the property of lessening its resistance if subjected to pressure. In this case the pressure is obtained by the pull of the controlling magnet on its keeper, which forms the end of a lever that presses upon the carbon blocks. If the current in the external circuit increases, due to a lessening of the external resistance, the controlling magnet pulls on its keeper with greater force, thus increasing the pressure on the carbons, decreasing their resistance, and weakening the strength of the field magnets, which reduces the E. M. F. of the armature coils until the current is again at its normal strength.

The shifting of the point of maximum action, due to the weakening of the field at light loads, causes a certain amount of sparking, which is remedied by slightly shifting the brushes. In the multipolar machines this shifting is performed automatically by mechanism driven by a belt from a small pulley on the end of the armature shaft, and controlled by the controlling magnet, as in the closed-coil dynamos described.

2309. Westinghouse Dynamos.—These machines, which are comparatively new, use a multipolar field magnet with six salient poles, of the type illustrated at *C*, Fig. 887. The armature coils are wound around eight projecting teeth on the armature core, there being, therefore, eight armature coils. With eight coils and six poles it is evident that only two coils can be directly under any two pole pieces at the same instant. This armature winding, as in the Brush machine, is divided into two separate windings, each consisting of two pairs of opposite coils, and each connected to a separate commutator. The combination of connections of the various sets of coils is similar to that of the Brush machine; that is, the set of coils in the position of least action is disconnected entirely from the circuit, those near the position of maximum action are connected in parallel, and in series (by external connection of the brushes) with that set which is actually in the position of maximum action.

In this machine a coil is in the position of least action when the projection on which it is wound is directly under a pole piece; for when in this position all the lines of force from the pole piece pass directly through the center of the coil, which, therefore, cuts none of the lines of force. As soon as the coil moves from this position one side begins to cut the lines of force of the pole piece it is moving away from; as it moves still farther, the *other* side of the coil begins to cut the lines of force of the pole piece *towards* which it is moving, so that when half way between the two, both sides of the coil are cutting lines of force equally and at the maximum rate, and this is, therefore, the position of *maximum* action.

2310. A diagram showing the connections of the armature winding to the commutator of the Westinghouse machine is given in Fig. 897. As in Fig. 896, the two commutators are represented as concentric, though they are actually side by side on the shaft, and, as in the Brush machine, are situated on the end of the shaft outside one of the bearings, the leads to the commutator being brought out through a hole in the shaft, instead of being connected directly as represented in the diagram.

The two pairs of coils A and A' and B and B' make up one winding, and are connected to one commutator, as represented. The two opposite coils A and A' and B and B' are connected in series, by connections across the back of the armature core (not shown in the diagram).

The other winding is made up of the two pairs of coils C and C' and D and D' , the coils of each pair being connected in series, as before.

It will be seen that each commutator is made up of twelve segments separated by a considerable width of insulating material (indicated by the solid black parts). These twelve segments are connected together by cross-connecting wires in three sets (one for each pair of poles) of four segments each (one for each coil of the windings).

Instead of the segments overlapping as they do in the

Brush machine, each brush is divided into two parts, which rest on the commutator at a distance apart equal to the length of one segment, as represented at $1, 1'$ or $2, 2'$.

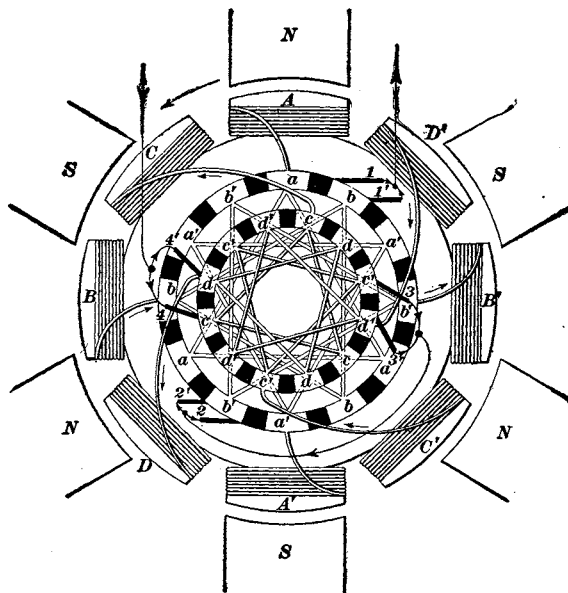


FIG. 897.

Applying the statement made in Art. **2309** to Fig. 897, it will be seen that coils A and A' are in the position of least action, and are disconnected from the external circuit. The other set of coils of this winding, B and B' , is, however, in the position of maximum action, and is connected to the circuit through brushes 1 and $1'$ and 2 and $2'$, which rest on segments b and b' , respectively. Of the second winding, each set of coils C and C' and D and D' is equally distant from the position of maximum action, and these two sets are, therefore, connected in parallel with each other through brushes 4 and $4'$ which rest on segments c and d , and brushes 3 and $3'$ which rest on segments c' and d' , and are connected in series with the set of coils B and B' by the external connection between the two sets of brushes 2 and $2'$ and 3 and $3'$.

To follow out the changes in the connections of the coils,

consider that the armature is moving in the direction indicated by the arrows.

As coils B and B' move away from their position of maximum action, brushes $1'$ and $2'$ are disconnected from segments b and b' , and, as the armature moves, finally come into contact with segments a and a' , thus throwing the two sets of coils A and A' and B and B' in parallel. At the same time, brushes 4 and 3 being disconnected by the insulating segment from segments c and c' , coils D and D' only of the second winding are connected to the circuit through brush $4'$, and in series with the coils of the other winding (now connected in parallel) through brush $3'$ and its connection with brushes 2 and $2'$, coils C and C' being entirely disconnected.

It will be seen that these successive combinations of coils are precisely the same as take place in the Brush machine, except that each combination takes place six times in each revolution instead of twice, which is due to the multipolar field. The regulation of this machine is entirely automatic. The field magnets are separately excited, the current being furnished by a separate constant-potential dynamo, which gives a constant magnetizing force; but the strength and distribution of the resulting field are dependent on the armature reaction, which is so proportioned that any excess of current over the normal so reduces and distorts the field that the E. M. F. generated in a winding during the time that it is connected to the brushes is reduced until the current is again at its normal strength.

2311. Thomson-Houston Dynamos.—These machines have bipolar, series-wound, salient-pole field magnets, of the type illustrated at K , Fig. 883. The completed armature is very nearly spherical in shape, and the pole pieces are bored out accordingly, so that they almost entirely enclose the armature.

In the older machines the armature is drum wound, although the core is a ring, but in the newer machines a ring winding is used; in either case three separate coils, or sets

of coils, make up the winding. One end of each of these coils (or sets of coils) is connected to a commutator segment, all the other ends being joined together.

The commutator has three segments, each covering nearly $\frac{1}{3}$ of the circumference, the balance being made up by the air spaces which separate the segments.

Two positive and two negative brushes are used, those of each pair resting on the commutator at two points at a distance apart equal to one-half a commutator segment, that is, nearly $\frac{1}{3}$ the circumference, when the machine is giving its greatest E. M. F.

2312. A diagram of the connections, etc., of the drum-wound armature is shown in Fig. 898. $A A'$, $B B'$, and $C C'$ are the three coils, wound on the core $\frac{1}{3}$ of the circumference

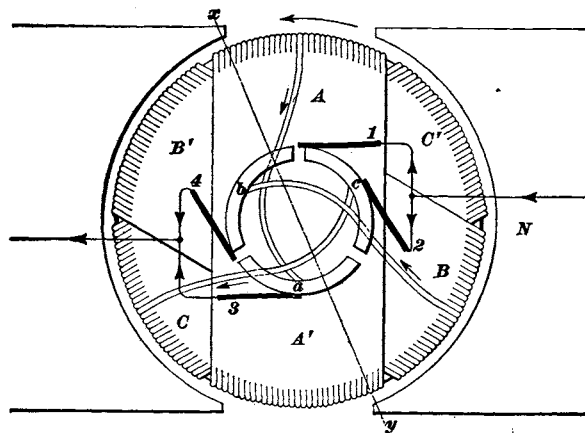


FIG. 898.

apart. One end of each of the coils is joined to a metal ring (not represented in the cut) on the back of the armature, which forms a common connection for the three. The other ends are joined to the commutator segments, that of $A A'$ to segment a , that of $B B'$ to segment b , and that of $C C'$ to segment c , as represented: 1 and 2 are the negative, and 3 and 4 the positive, brushes. Brushes 2 and 4 are usually called the *primary* brushes, and 1 and 3 the *secondary* brushes, to distinguish them.

From the diagram (Fig. 898) it will be seen that coil $A A'$, though half way between the pole pieces, is partly active, since the neutral line is shifted forwards by armature reaction, as indicated by the line xy . This coil, $A A'$, is connected in parallel with coil $B B'$ by the two positive brushes, and the two are in series with coil $C C'$. If the armature be considered as moving in the direction indicated by the arrow, it will be seen that as coil $A A'$ gets to the position of least action it is disconnected from the circuit by segment a passing out from under brush 3, leaving coil $B B'$ and coil $C C'$ in series. However, as the distance between brush 3 and brush 2 is only slightly greater than the span of one segment, coil $A A'$ is almost immediately connected in parallel with coil $C C'$, as segment a passes under brush 2, making the following combination: Coil $B B'$ in series with coils $A A'$ and $C C'$ in parallel.

As the rotation of the armature continues, coil $C C'$ is disconnected from the negative brush 1, and connected to the positive brush 4, being thus thrown in parallel with coil $B B'$, the two being then in series with coil $A A'$.

Completing the half revolution, coil $B B'$ is disconnected from the positive brush 3, and is joined in parallel with coil $A A'$ by the two negative brushes 1 and 2, leaving coil $C C'$ connected to the positive brushes.

Further rotation of the armature repeats this series of connections; that is, during every half-revolution, one of the coils ($A A'$ in the preceding paragraphs) is first in parallel with the coil *behind* it, then momentarily disconnected from the circuit, then connected in parallel with the coil *ahead* of it, then connected in series with the other two, which are then in parallel.

From the diagram (Fig. 898) it will be seen that when a coil is disconnected from one set of brushes it is very nearly in the position of least action, and the coil with which it was just before connected in parallel has the higher E. M. F. of the two. As explained in Art. **2306**, the self-induction of the coil prevents the higher E. M. F. of the other sending a current through it in opposition to its own E. M. F.

at the time when they are connected in parallel; in fact, when the coil is disconnected from its mate it is still supplying some of the current, so that there is a spark at the brushes.

2313. The regulation of this machine is effected by varying the distance between the two brushes of each set, the primary brush being moved back, and the secondary ahead. This movement of the brushes decreases the distance between the primary brush of one set and the secondary of the other; now, as when in the position shown in the cut (Fig. 898), this distance is only slightly greater than the span of one commutator segment, it is evident that lessening this distance will allow of one segment being under *both* one of the positive and one of the negative brushes during a part of a revolution, which *short-circuits* the armature, reducing the difference of potential between the brushes (momentarily) to zero.

As the field magnets are in series with the armature, their great self-induction prevents the strength of the current from falling to zero, its fluctuations being comparatively small. At the same time the self-induction of the armature coils prevents any excessive flow of current from one to the other through this short-circuit; for, there being two places where the short-circuit occurs, i. e., between brushes 1 and 4 and 2 and 3, and there being three commutator segments, it is evident that six short-circuits occur during every revolution, and if the armature is revolving at 850 revolutions per minute, there are $6 \times 850 = 5,100$ short-circuits every minute, so that each lasts only an extremely short time.

As the distance between the brushes of a set is increased, each short-circuit is kept up for a slightly longer time; it will be seen that this momentary reduction of the difference of potential between the brushes to zero reduces its effect in sending a current through the circuit, although its maximum value is not much reduced, so that by shifting the brushes at the proper time the current in the external circuit can be kept at a constant strength in spite of variations in the external resistance.

This shifting of the brushes is done automatically by the following apparatus: The primary and secondary brushes are mounted on separate rocker-arms, which are connected together by a system of levers, so that when the primary brushes are shifted back, the secondary are moved ahead. The amount of movement of the secondary brushes is very little, being for the purpose of following the line of maximum action, which moves ahead slightly at light loads (low E. M. F.). A large magnet, attached to the frame of the machine, has attached to its keeper a lever which is connected to the rocker-arm that carries the primary brushes, so that when the keeper of the magnet is pulled up, the primary brushes are shifted back and the secondary ahead, thus reducing the effective difference of potential between the brushes as explained. The current for operating this regulating magnet is supplied by the main current, but it is not continually in circuit, being cut in or out, as occasion requires, by a controlling magnet, which is placed on the wall of the room at some convenient place.

2314. Fig. 899 is a diagram of the connections used in this apparatus. R represents the regulating magnet, and K its keeper, which is connected to the rocker-arms by a lever (not shown) as described. C, C represent the coils of the controlling magnet, which are stationary, and D, D represent the cores of this magnet, which are movable. Their weight is partly counterbalanced by the spring s , the tension of which is adjusted by means of the nuts at N . Attached to these cores is a contact point, which touches a stationary contact piece at B . The connections being as represented, $+$ being the positive terminal of the dynamo, it is evident that when the two contact points at B are touching, the regulating magnet R is short-circuited, the current flowing from $+$ to p^2 , thence to P^2 , thence through the contact points at B to P , thence through coils C, C to P^1 , and out to the line. Now, if this current exceeds a certain strength, the pull of the coils C, C on the cores D, D becomes sufficient to raise them, breaking the contact at B .

This forces the current around from P^2 through the regulating magnet R to P , thence to P^1 where it passes out to the line as before; the regulating magnet then attracts and pulls up its keeper K , which in moving shifts the brushes and reduces the current as described.

When the current is reduced to its normal value the cores of the controlling magnet descend, contact is made at B ,

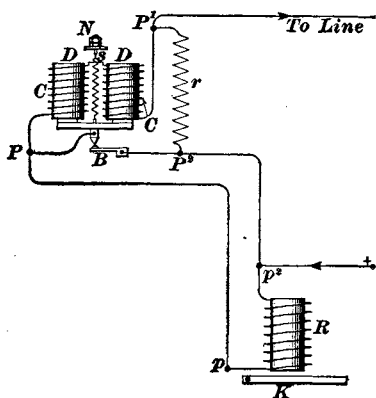


FIG. 899.

which short-circuits the regulating magnet, and allows its keeper to drop; this shifts the brushes again so as to increase the current. This action is kept up, so that the cores of the controlling magnet and the brushes of the machine are continually in slight motion. In order to prevent the self-induction of the regulat-

ing magnet causing a serious spark at B when the contact is broken, a shunt of high resistance is permanently connected around the break at B , as represented at r . This self-induction is produced in the regulating magnet R whenever the circuit is opened at B , for this suddenly diverts the main current through the regulating magnet, whose momentary self-induction opposes the current, forcing it along by way of P^2 , P^1 , and the resistance r to the line. If the resistance were not there the current would cross the air gap at B , making a destructive spark.

The space between the ends of the commutator segments being small, some device is necessary to prevent the spark which occurs when a segment passes from under one of the secondary brushes from continuing to pass from segment to segment, for that would permanently short-circuit the machine. This device consists of a small rotary blower, which is situated between the commutator and the bearing.

This blower is so arranged as to deliver a puff of air right at the end of the secondary brushes, at the moment that the spark occurs, so that it is immediately broken and does no damage.

The adjustment of the commutator, brushes, air blast, etc., of this machine requires considerable attention, in order that the machine should run well. The manufacturers supply printed matter with each machine, giving full particulars of these operations, hence they need not be taken up here.

THE OUTPUT OF CONSTANT-CURRENT DYNAMOS.

2315. From the nature of the output, the heat losses in constant-current dynamos are practically constant at all loads. In some of the open-coil machines, the local currents which circulate in the coils may be of greater strength than the current in the external circuit, at light loads, so that the heating of the armature may be even greater at light loads than at full load. It is evident, however, that the heating is not the factor which limits the load, nor is the sparking, since the machine must be so designed that the sparking is the same at all loads. The factor of the load which varies is the E. M. F., so that when this has reached its highest value, any further increase in the external resistance can only reduce the current, since the E. M. F. can not increase further. The maximum E. M. F. which the machine can give is then the limit of its output.

Constant-current machines may be rated according to their output, expressed in kilowatts (1 kilowatt being one thousand watts), as are constant potential machines; but as they are almost invariably used for operating *arc lamps*, they are usually rated according to the maximum number of lamps for which they can supply current. The strength of the current most used is from 9.5 to 10 amperes, 9.6 being the standard adopted by many manufacturers. With this current each arc lamp requires from 45 to 50 volts; all lamps being connected in series, this makes the maximum E. M. F. of, for

example, an 80-light dynamo $80 \times 50 = 4,000$ volts. Machines are built of 150 lights capacity, but the sizes most generally used have a capacity of from 50 to 80 lights.

Almost all of the regulating devices used are practically independent of the speed, so that they will maintain the current constant when the speed varies somewhat, if the variations are not too sudden. Any reduction in the speed, however, reduces the maximum E. M. F. which can be obtained, which reduces the output, and, conversely, an increase in the speed will increase the possible output.

ALTERNATING-CURRENT DYNAMOS.

DEFINITIONS.

2316. The definition of an alternating current is given in Art. **2226**. In speaking of alternating currents, each reversal of the current, that is, each increase of the current from zero to its maximum, and the decrease to zero again, is called an **alternation**. In the case of a simple loop of wire rotating in a magnetic field, the current in the loop goes through one *alternation* in each half revolution; in a complete revolution it passes through two alternations—one in one direction and one in the contrary.

If the rotation is continued this process is repeated for every revolution, so that an alternating current is made up of a number of repetitions of a pair of opposite alternations. This pair of alternations is called a **cycle**. The number of cycles which occurs in a given time (usually one second) is called the **frequency**, so that if the simple loop referred to above is rotated at the rate of 60 revolutions per second, the frequency of the alternating current generated would be said to be 60, that is 60 cycles per second.

In treating of alternating currents, the graphical method of representing the value of the E. M. F., or current, explained in Arts. **2225** and **2226** is much used. It is only necessary to represent one cycle, since under similar conditions they are all alike, and for convenience, the length of one cycle is

taken to represent 360° , whatever may be the length of time required to complete it. Different parts of the curve may then be said to be so many degrees apart; for example, if the base line AE in Fig. 852 is taken as 360° , each division will then represent 30° , since there are twelve divisions, and any two succeeding zero points, as A and C , or C and E , will be 180° apart, or a zero point and a maximum point, as A and B , are 90° apart.

Further, any point on the curve may be said to be so many degrees ahead or behind some other point. For example, in this same figure, point C is 180° *behind* point A , because point C represents a later period of time than does point A , and is 180° *ahead* of point E , because it represents an earlier period of time.

ALTERNATORS.

2317. The current in the separate conductors of a direct-current armature is naturally alternating; for when the conductors pass over from one pole piece to another, the direction of the current in them is reversed. It is often necessary to use alternating currents in the external circuit, and when this is the case there is substituted for the commutator which is used for the purpose of changing the alternating current of the armature conductors to a direct current for the external circuit, a pair of collector rings, which make continuous contact between the ends of the armature winding and the brushes connected to the external circuit. (See Fig. 876.)

The principle of the winding of alternating-current dynamos (commonly called **alternators**) is the same as that of direct-current machines, and either a ring or a drum winding may be used; but in order to get the best results, it is necessary to use a different method of connecting and locating the coils of the winding.

If a single coil of wire is wound on a ring core, and the core is rotated in a magnetic field, it is evident that if the coil occupies a space on the core greater than the width of the neutral space (see Art. **2234**), there will be two points in each revolution where a part of the coil is under *each* pole

piece, as represented in Fig. 900. Under these circumstances the E. M. F. generated in that part of the coil under

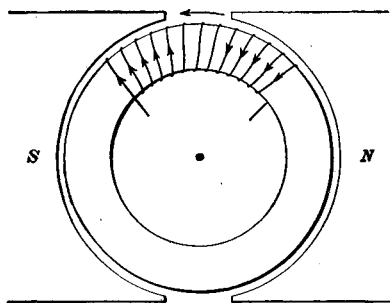


FIG. 900.

one pole piece is opposite in direction to that generated in the part under the other pole, as represented by the arrow-heads, so that they neutralize, or partly neutralize, each other, until the coil has moved entirely out from under one pole piece.

In order to prevent this opposition of the E. M. F.'s generated, it is necessary to make the coil no wider than the neutral space. Now, if the pole pieces cover a large part of the surface of the armature, as is the case in the direct-current machines described, the coil must be very narrow, so that only a small part of the surface of the core is utilized. To remedy this, the pole pieces of alternators are made narrow, usually so that the width of the neutral spaces is equal to the width of the fields. A coil may then be wound on the core equal in width to the width of the neutral space (or of the field, since these are equal), and there will be no opposition of the E. M. F.'s when the armature is rotated.

As the armature is rotated the coil enters and leaves the field gradually; that is, first one conductor moves into the field and becomes active; then, the next; then, the next, and so on until the entire coil is in the field, when it moves out in the same manner. On this account, although the field is practically of uniform strength, the *total* E. M. F. of the coil rises gradually from zero, when it is wholly in a neutral space, to a maximum when it is wholly in one field, then falls gradually to zero again when in the other neutral space. Thus the graphical representation of the values of the E. M. F. of such a coil at any instant would correspond with those given for the single loop in Art. 2225.

2318. If only a single coil is wound on the core, and its width is confined to that of the neutral space, only a small part of the surface of the core will be covered; but it is evident that another coil of equal width may also be wound on the core directly opposite to the first.

This second coil will then enter or leave one field at the same time that the first is entering or leaving the other field, and with the same velocity, so that if the number of turns in the two coils is the same they will have equal E. M. F.'s generated in them at any instant.

This being the case the two coils can be connected in series, so that their E. M. F.'s will add together. Fig. 901 represents a ring-wound armature rotating in a bipolar field, with two opposite coils, each equal in width to the width of the neutral space, which is equal in width to the field. These two coils are connected in series, and to the two rings of a collector (shown for convenience as being concentric) on which bear two brushes B and B_1 , between which an external circuit may be connected.

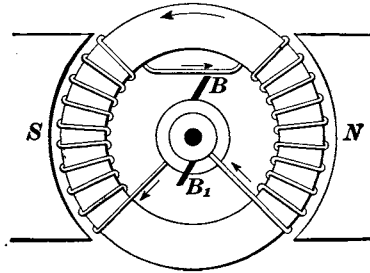


FIG. 901.

In this case, as in the simple loop, the E. M. F. (and the resulting current) passes through one complete cycle during each revolution, so that the frequency is equal to the number of revolutions per second. The frequency of the alternating currents used for lighting is usually 125, although, recently, lower frequencies, down to about 60, have been adopted. It is evident that it would be very difficult to run an armature in a bipolar field at a number of revolutions per second equal to even the lower of the above frequencies, and for this reason it has been necessary to use multipolar fields for alternators.

With a multipolar field the widths of the neutral spaces and of the fields are about equal in the best machines, and a number of coils, each equal in width to the width of a neutral

space, is wound on the core, the number of coils being made equal to the number of poles, and arranged, as in the bipolar machine described, so that each coil is in the same part of a field or neutral space at the same instant.

It is evident that the E. M. F. of each coil passes through one complete cycle during the time that it is passing under two successive poles. This being the case the frequency is then equal to the revolutions per second multiplied by the number of *pairs* of poles.

For example, in a ten-pole machine running at 1,500 revolutions per minute, the frequency is $\frac{1,500}{60} \times \frac{10}{2} = 125$.

2319. For these multipolar machines, ring windings are seldom used in this country. Instead, a form of drum winding is used, the coils of which are wound in the form of a flat rectangle with rounded ends, and are placed flat on the surface of the armature core. Fig. 902 is a diagram of the

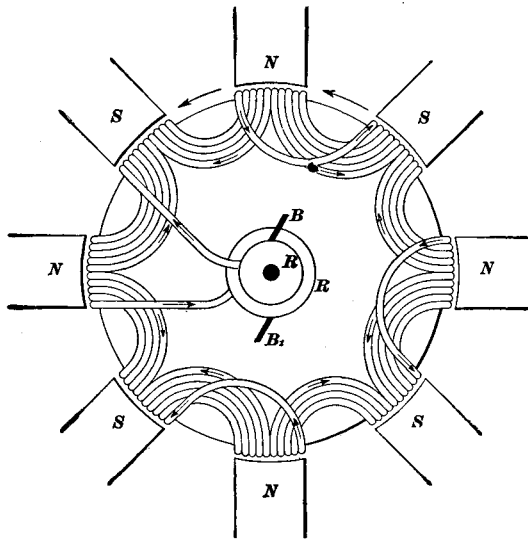


FIG. 902.

winding of such a machine, an 8-pole field and an armature with 8 coils connected in series, being represented. It will be seen from this diagram that each coil covers enough of

the armature surface to have one half under each of two poles at the same time. The width of each of these halves is equal to $\frac{1}{2}$ the width of the field (or of the neutral space), which makes the width of the *whole* coil equal to the width of the neutral space, as in the ring winding. It is necessary, however, that the space between the two halves of any one coil be also made equal to the width of the field, as represented in the diagram, for if this were not the case a part of each of the two halves would be in the same field at the same time, which would cause the E. M. F.'s generated to oppose each other.

A ring core is used with this form of winding, since the armatures are usually of quite large diameter, and there is no need of a solid core. The winding is a drum winding, however, and not a ring.

In some of the more modern alternators the armature coils are wound around projecting teeth on the armature core, similar to the Westinghouse constant-current dynamo (Fig. 897). This is still a drum winding, however.

2320. Alternators are usually constructed to give a constant potential, and are generally compound-wound for this purpose; but, instead of a shunt winding, separate excitation is almost invariably used, a small constant-potential direct-current dynamo furnishing the necessary current. This small dynamo is sometimes coupled directly to the end of the shaft of the alternator, but more usually belted to a pulley on that shaft.

The series coils of the field magnets are excited by the main current of the alternator, just as in direct-current machines. As the alternating current could not be used directly for this purpose, a commutator is used, which changes the alternating current into a direct but pulsating current, in which form it is used to excite the series coils.

This commutator has as many segments as there are poles, but alternate segments are connected together, making practically a two-part commutator.

Two brushes rest upon this commutator at opposite points,

and are so adjusted that they rest on two adjacent segments only at the moment that the E. M. F. of the armature winding is zero, so that the alternating current is changed to a pulsating current, just as described in Art. 2227.

2321. If the series coils alone were connected between these brushes, their self-induction would oppose both the rise and fall of the current, and would, therefore, cause sparking at the commutator; hence, a resistance coil, so wound as to have very little self-induction, is connected in parallel with the series coil, which so acts as to steady the current through the series coils and prevent the sparking at the commutator.

This circuit through the series coils being in series with the armature winding, it forms a loop in that winding, and may be connected in at any convenient place; a point in the

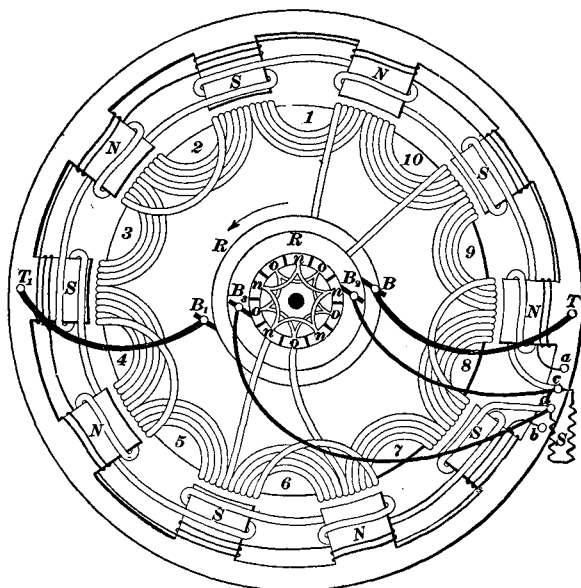


FIG. 903.

winding about half way between the ends which are connected to the collector rings is usually taken.

This is represented in Fig. 903, which is a diagram

representing a 10-pole alternator, with a drum-wound armature of 10 coils, all connected in series. The beginning of coil 1, and that of coil 10, are both connected to one of the collector rings R, R , on which bear the brushes B and B_1 , which are connected to the line terminals T and T_1 , as represented. Coil 5 is not connected directly to coil 6, but its end is carried to one of the sections n, n, n, n, n of the commutator, these sections being all connected together as represented.

The end of coil 6 is connected to one of the rest of the sections o, o, o, o, o of the commutator, these being also all connected together.

At opposite points on this commutator rest two brushes B_2 and B_3 , which are connected to the terminals c, d of the series winding on the fields. To these terminals the resistance S is also connected, it being in parallel with the series coils.

The permanent excitation of the machine is supplied by a separate direct-current dynamo, as stated, which is connected to the terminals a, b .

In the position shown, the armature coils are most active, and the brushes B_2 and B_3 rest upon the middle of the commutator segments. At this instant the path of the current flowing is as follows: Entering at terminal T it passes through brush B to the inner collector ring, then through coils 10, 9, 8, 7, and 6 of the armature winding, then to one of the commutator segments marked o , and through brush B_3 to terminal d of the series field coils. Here it divides between these series coils and the resistance S , and reunites at terminal c , from whence it passes through brush B_2 to one of the commutator segments marked n , then through coils 5, 4, 3, 2, and 1 of the winding to the outer collector ring, then through brush B_1 to terminal T_1 , and out through the external circuit.

As the armature revolves, bringing the coils into the neutral spaces, its current falls to zero; at this point the brushes B_2 and B_3 pass from segments n and o to segments o and n , respectively, so that when the coils enter the fields again, and the current flows in the opposite direction

through them, the direction of the current through the series winding is not reversed, but remains in the same direction as before.

It will be seen that the difference of potential between brushes B_2 and B_3 is only that due to the drop in the series coils and the resistance, which are in parallel. The difference of potential, therefore, between either of these brushes and one of the main brushes is practically the same, being equal to $\frac{1}{2}$ the total E. M. F. generated in the coils.

The above arrangement is that generally used in this country, although the type of the field magnets and the details of construction vary considerably in the different machines.

MULTIPHASE ALTERNATORS.

2322. The **phase** of an alternating current refers to the period of time at which it is at some particular point of its cycle; this term is generally used in comparing two or more different alternating currents. For example, if two alternating currents of the same frequency arrive at similar points in their cycles, the maximum or the zero points, for instance, at the same instant, the two currents are said to be *in phase*; while if one current does not arrive at its maximum value at the same instant that the other does, the two currents are said to *differ in phase*.

The amount of this difference can be expressed in degrees, just as is the difference between any two points in the cycle of a single alternating current. (See Art. **2316**.) Thus, if of two alternating currents one reaches its maximum value at the same instant that the other is zero, they differ in phase by $\frac{1}{4}$ cycle, or 90° , and every point in the cycle of one current is 90° ahead of (or behind) the similar point in the cycle of the other current.

2323. The alternators which we have been considering have a single winding, and furnish only one current; for this reason, when it is desired to make a distinction, these machines are called **single-phase** alternators, and their current a single-phase current. The word *monophase* is also

used to express the same meaning. For certain applications, alternators are provided with several windings, so arranged as to each give an alternating current differing in phase from the others. Such a machine is called in general a **multiphase** alternator. Those in general use have either two or three separate windings, and are called **two-phase** or **three-phase** alternators, as the case may be.

In the two-phase machines, the difference in phase is 90° , and each armature winding is usually provided with a pair of collector rings, making four rings, although three may be used if desired, one for each of the windings, and the third common to both.

When this arrangement is used only three wires are necessary to convey the two currents to the point where they are used. Of these three, the wire connected to the third, or common collector ring, carries at any instant an amount of current equal to the *sum* of the currents in the other two wires at that instant.

2324. The graphical representation of these two currents shows that their sum at any instant is never as much

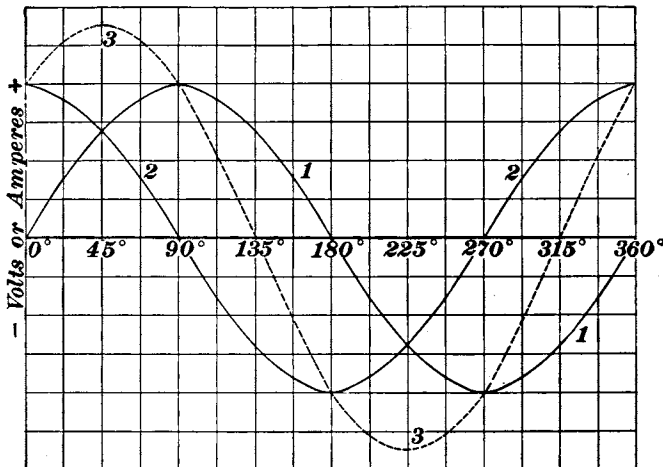


FIG. 904.

as twice the maximum of one of the currents; this is represented in Fig. 904.

In this diagram, 1 and 2 are the curves of the two currents, their difference in phase being 90° . It will be readily seen that there are parts of the cycle when the two currents are equal in value, but in opposite direction, as at 135° and 315° , and their sum at these points is then zero. At points 90° from these, the currents are again equal, but in the same direction, so that their sum is a maximum. Between these points their sum varies, its value at any instant being indicated by the dotted curve 3, 3. It will be seen that the maximum point of this curve is about 1.4 times the maximum of either of the others, and occurs 45° ahead of the maximum of the one, and 45° behind the maximum of the other; consequently, the sum of the two curves which differ 90° in phase is a similar curve which differs in phase 45° from each of the others.

2325. In the three-phase machines, three windings are used, giving three separate currents differing 120° in phase; these are graphically represented in Fig. 905. It will be seen from this diagram that at any instant *the amount of*

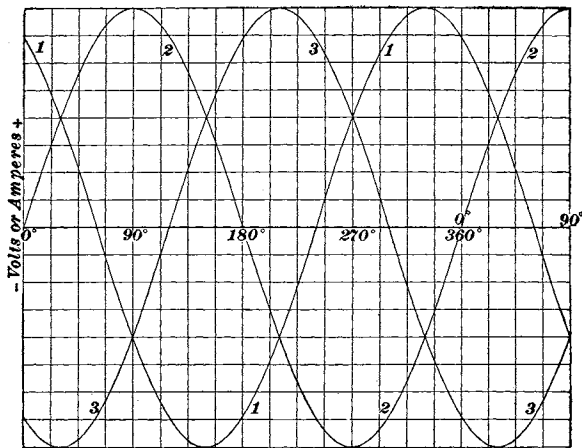


FIG. 905.

current flowing in one direction is equal to the amount flowing in the opposite direction. For example, at the moment when the current represented by curve 2 is at its maximum, as at

90° , the other two currents are in the opposite direction, and are each equal to half their maximum value; their sum is then equal and opposite to the other current. At 180° , when curve 2 is at zero, the other two curves indicate that the currents are equal in value, and opposite in direction. At any other part of the cycle the above statement still holds true, as will be seen by measuring off with a pair of dividers the vertical distances of the three curves above or below the base line at any point, and comparing the sum of the distances found below the line with that of those found above it.

This property of the three-phase current has a very important result, namely, that only three wires are required for the three separate currents, since at any instant some one of the wires can act as a return conductor for the current in the other two. This also allows the use of but three collector rings on the armature windings, one winding being connected either between each two rings, or between one of the rings and a common junction. The former is represented in the diagram, Fig. 906, the latter in the diagram, Fig. 907. In each, R , R_1 , and R_2 are the three collector rings, on which bear the brushes B , B_1 , and B_2 , and

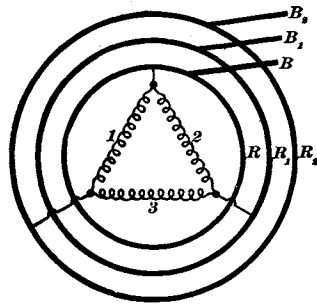


FIG. 906.

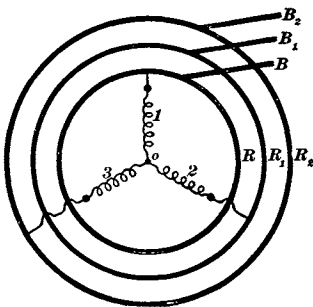


FIG. 907.

to which are connected the three armature windings 1, 2, and 3. In Fig. 906, winding 1 is connected between rings R and R_2 , winding 2 between rings R and R_1 , and winding 3 between rings R_1 and R_2 ; while in Fig. 907, windings 1, 2, and 3 are respectively connected between rings R , R_1 , and R_2 , and a common junction o .

It should be understood that the above representations

(Figs. 906 and 907) are merely *diagrammatic*; the separate windings are actually wound on the core in the same manner as illustrated in Fig. 902; the space between the two parts of each coil of each winding being made great enough to admit the coils of the other two windings, so that the surface of the core is entirely covered.

It will be seen that the method of connecting the windings shown in Fig. 907 is the same as is used in the Thomson-Houston constant-current open-coil dynamo (see Art. **2312**), collector rings being here substituted for the commutator segments of that machine

PROPERTIES OF THE ALTERNATING CURRENT.

2326. It has been pointed out (Art. **2283**) that the heat generated in a conductor by a current, that is, the loss, is equal to $C^2 R$. As the strength of the current changes at every instant in an alternating-current circuit, it is evident that the heat generated also varies in the same manner; the temperature of the conductor does not correspondingly fluctuate, because the variations in the current are too rapid at the frequencies commonly used, but instead rises to some value where it remains steady. Now, if a certain direct current will cause the temperature of a conductor to rise to a certain point, it is evident that an alternating current may be sent through this same conductor, which, under the same conditions, will cause its temperature to rise to the same point, in which case the *effective* strength of the alternating current will be the same as the strength of the direct current.

In order that the alternating current may fulfil these conditions, the *mean* of the *square* of all its different values during a complete cycle must be equal to the square of the direct current with which it is compared; then, the *square root* of this *mean square* will be its *effective strength*, which may be expressed in amperes.

As in a circuit which does not have any self-induction, the

current is directly proportional to the E. M. F., it is further evident that the *effective* E. M. F. of an alternating current is also equal to the square root of the mean square of the various values of the E. M. F. which occur throughout the cycle.

When the form of the curve is about that shown in Figs. 904 and 905, as is usually the case, the effective current is equal to (very nearly) .7 of its maximum value, as is also the E. M. F. In speaking of an alternating current of so many amperes or volts, the *effective* current strength or voltage (.7 of the maximum) is meant, unless otherwise stated.

2327. When the external circuit of an alternator is completed, the self-induction of that circuit prevents the current from being proportional to the E. M. F. of the alternator; that is, when the E. M. F. is rising towards its maximum, the tendency of the current to increase is opposed by the self-induction of the circuit, and when the E. M. F. begins to decrease towards zero, the self-induction tends to keep up the current. In other words, the current *lags behind* the E. M. F.

If the circuit has little self-induction, this lag will be very slight; but if the self-induction is considerable, the lag is also considerable, and its effect must be considered.

If the current lags behind the E. M. F., the one is not proportional to the other; that is, C does not equal $\frac{E}{R}$, if E represents the applied E. M. F. This is due to the E. M. F. of self-induction, which opposes any change in the current due to a change in the applied E. M. F.; so that the *actual* E. M. F. which is sending the current through the circuit is equal to the *difference between the applied E. M. F.* (that of the alternator) and the *counter E. M. F.* (that due to self-induction). Using the value of this difference for E , $C = \frac{E}{R}$ with alternating currents just as with direct.

2328. To find the applied E. M. F. necessary to send a given (alternating) current through a circuit having a

certain resistance and a certain self-induction, it is necessary to find the E. M. F. due to the self-induction at various instants during each cycle; the *actual* E. M. F. being directly proportional to the current, the difference between it and the counter E. M. F. (of self-induction) at any instant is the applied E. M. F. required. It is to be observed that if at any instant the signs of the two values are opposite, i. e., if one is + and the other —, the actual difference between them is the *sum* of their numerical values.

The E. M. F. of self-induction is, of course, proportional to the rate at which the lines of force generated cut the conductors of the circuit, that is, the *rate at which the number of lines of force generated changes*. This is in turn proportional to the *rate at which the strength of the current changes*, which is greatest when the actual value of the current is zero (for then it is changing from a certain strength in *one* direction to the same strength in the *opposite*), and is least (zero) when the strength of the current is at its maximum, for then the current is not changing at all.

2329. If the instantaneous values of the current and the resulting E. M. F. of self-induction are graphically

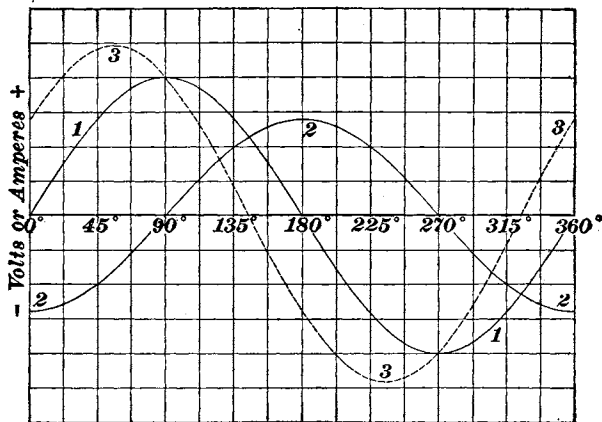


FIG. 908.

represented, the latter will be found to be a curve similar in shape to the current curve, and of the same frequency:

but as its maximum value occurs at the instant the current curve is zero, the *difference in phase* (see Art. **2322**) between the two curves is 90° .

This is represented in Fig. 908, curve 1 being the current curve, and curve 2 the curve of the E. M. F. of self-induction.

As the *actual* E. M. F. which is forcing the current through the circuit is of necessity proportional to that current, it is evident that by properly choosing the scale to which it is drawn the current curve (curve 1, Fig. 908), may also represent the curve of this *actual* E. M. F.

Considering this to be the case in Fig. 908, the *applied* E. M. F. curve may be constructed by taking the difference between the number of vertical divisions between curves 1 and 2 and the base line at various instants (or the *sum*, if one is + and the other -), and taking the result as the distance between the base line and the applied E. M. F. curve at those instants; in other words, applying the principle given in Art. **2328**.

This applied E. M. F. curve, so constructed, is represented by curve 3, Fig. 908.

It will be seen that in this curve for a part of the time the E. M. F. of self-induction acts in the *same* direction as the applied E. M. F., while at other times it acts in the opposite direction. The effect of this is, as stated in Art. **2327**, that the current curve lags behind the E. M. F. curve, and the greater the self-induction the greater the lag.

The effect of this lag is to *increase the apparent resistance of the circuit*; for, as shown by Fig. 908, it takes a greater applied E. M. F. to force the current through the circuit than is represented by the drop (CR) due to that current; consequently, the energy expended in the circuit is *not* equal to the product of the E. M. F. and the current.

On this account ordinary measurements of resistance, watts, etc., can not be relied upon if made with alternating currents, unless instruments especially designed for the purpose are used.

TRANSFORMERS.

2330. The principal value of alternating currents is due to the fact that they can be *transformed*; that is, a current of 10 amperes at a pressure of 1,000 volts may be transformed to any higher or lower pressure, with a correspondingly less or greater current, and this transformed current will represent nearly as much energy as the original current. On this account the energy necessary to operate, say a number of incandescent lamps, may be sent out from the dynamo at a high pressure and small current strength, so that only a small wire is needed to transmit the energy, effecting thereby a large saving in copper expense; then, at the point where the lamps are to be used, the current may be transformed from the high pressure used on the line, which would be dangerous to use inside a house, to a current of any convenient low pressure, which may then be used for operating the lamps.

This transformation is effected by setting up a mutual induction between a coil of wire connected to the source of the alternating current (the alternator), which coil is called the **primary**, and a second coil, called the **secondary**, which is connected to the circuit in which it is desired to utilize the electrical energy. (See also Art. **2219**.)

These two coils are wound upon a closed magnetic circuit of *laminated* iron, such as is used in armature cores. The lamination is intended to serve the same purpose here, namely, to prevent the generation of eddy currents which would otherwise be set up in the core, owing to the continual change of direction of the lines of force in the iron. This arrangement of primary and secondary coils, wound upon a magnetic circuit, is called a **transformer**.

2331. The primary coil of a transformer has a great deal of self-induction, since a small current through it will cause a large number of lines of force to pass through the closed magnetic circuit, which cut the turns of the primary coil at a certain rate. Now, these lines also pass through the secondary coil, and cut its turns at the same rate, so that

if the number of turns in both primary and secondary is the same, the same E. M. F. will be set up in each; while if the number of turns differs, the E. M. F. set up in each will be in the *same ratio as the number of turns*. Thus, if the number of turns in the primary is 1,000 and in the secondary 100, the E. M. F. in secondary will be $\frac{1000}{10000} = \frac{1}{10}$ of that in the primary.

On account of its great self-induction, a high E. M. F. is required to send even a small current through the primary coil; in other words, the E. M. F. of self-induction is very nearly equal to the applied E. M. F., so that, generally speaking, the ratio between the applied E. M. F. of the primary and that generated in the secondary, is the same as the ratio of the number of turns.

When the secondary circuit is closed a current begins to flow in it. The effect of this current is to tend to send lines of force around the magnetic circuit of the transformer in the *opposite* direction to those which are due to the current in the primary coil; that is, to oppose the change in the lines of force which is producing the change in the current by changing the E. M. F.

This reduces the E. M. F. of self-induction of the primary coil, which results in an increase in the primary current, which restores the number of lines of force to its original value. The result of these various reactions is that the E. M. F. generated in the secondary coil is (practically) constant, whatever the current in the secondary, within reasonable limits.

The current in the primary circuit is thus directly proportional to the current in the secondary *plus* a certain constant amount, which is necessary to send the lines of force through the magnetic circuit and to make up for the hysteresis and eddy-current losses in the iron due to the rapid reversals of the magnetism.

A transformer is similar in action to a dynamo and a motor connected together, and is subject to the same losses, except friction, which does not appear since the material parts of the apparatus are stationary. The C^2r loss of both

primary and secondary, and the hysteresis and eddy-current loss in the magnetic circuit, are present, and may be calculated in a similar way as for a dynamo.

2332. Fig. 909 represents one form of transformer, without the outside case. C is the *core*, or magnetic circuit.

The primary coil is divided into two parts P and P_1 ,

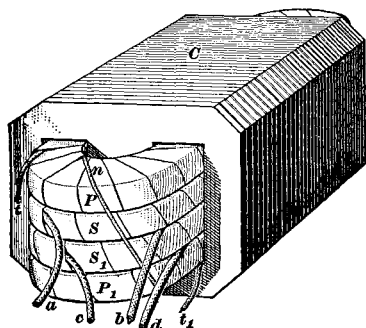


FIG. 909.

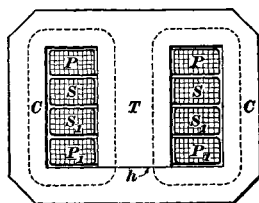


FIG. 910.

which are located on each side of the secondary coils S and S_1 . The two parts of the primary coils are connected in series by the connection shown at n ; t and t_1 are the primary terminals. The ends a and b of coil S , and c and d of coil S_1 , are brought out separately, in order that the two coils may be connected either in series or in parallel, as may be desired.

Fig. 910 represents a cross-section of this transformer, showing the method of construction. Here C represents one of the punchings of which the core is built up. In making the punching it is cut across at h , leaving the tongue T which is located between the coils P , P_1 , S , S_1 , and P_1 , P_1 . These coils are wound separately, and when completed are placed together, and the punchings of the core slipped over them; the tongue T being bent out to one side until the punching is in place, when it is bent back again. The path of the lines of force through the magnetic circuit is indicated by the dotted lines. In some forms of transformers the central piece T is made entirely separate; a number of these pieces is assembled together and placed within the coils, the part C being slipped over. The

magnetic circuit is then broken in two places, while in the case shown it is broken only at one place, *h*.

2333. For ordinary work transformers are wound for a primary E. M. F. of 1,000 or 2,000 (effective) volts, each secondary coil being wound to give about 50 volts. These may then be connected in parallel or in series, giving 50 or 100 volts as the secondary E. M. F. The efficiency of a 100-light transformer is about 96% at full load; in larger sizes the efficiency is higher, and in smaller sizes it is lower, as in dynamos.

ELECTRIC MOTORS.

PRINCIPLES.

2334. The principle upon which all electric motors operate is that given in Art. **2238**, that is, *that a conductor carrying a current will tend to move if placed in a magnetic field*. A motor then consists chiefly of a magnetic field, and a conductor, or series of conductors, arranged to move in this field; that is, the requirements for a motor are the same as for a dynamo, and, as in a dynamo, the conductors are arranged around the surface of a drum, or ring core, which rotates between the poles of an electro-magnet.

2335. Motors may be divided into the same general classes as dynamos, according to the character of the current they require, as follows:

Constant-potential motors, which are supplied with a continuous current at a constant potential.

Constant-current motors, which are supplied with a continuous current of a constant strength.

Alternating-current motors, which are supplied with an alternating current.

CONSTANT-POTENTIAL MOTORS.

2336. If the fields of a constant-potential dynamo are excited, and a current is supplied to the armature from some source, as represented at *D* in Fig. 911, so that the current enters at the brush $\div B$ and, passing through the winding in

the opposition to motion, so that it causes the armature to revolve, the motion of the conductors through the field generates in them an E. M. F. which is *opposed to the E. M. F. that is sending the current through the armature*, as will be seen by applying the thumb-and-finger rule given in Art. **2221** to Fig. 911.

This opposing E. M. F., or **counter E. M. F.** as it is called, then diminishes the effect of the applied E. M. F., so that the current is reduced, reducing the torque. Should the torque still be greater than the opposition to motion, the speed of the armature will continue to increase, increasing the counter E. M. F., and thereby further reducing the current and the corresponding torque, *until the torque just balances the opposition to the motion*, when the speed will remain constant.

2338. At all times the drop of potential through the armature is equal to the *difference between the counter and the applied E. M. F.'s*, and as the product of this drop and the current represents energy wasted, it is desirable to make it as low as possible. In good motors of about 10 horsepower output, the drop in the armature is seldom more than about 5% of the applied E. M. F., and is less in larger machines.

This being the case it is evident that if the armature is at rest, so that it has no counter E. M. F., and is connected directly to the mains, a very large current will flow through it, which would be liable to damage the armature. On this account an external resistance, called a **starting resistance**, is connected in series with the armature when it is to be started. This resistance is made great enough to prevent more than about the normal current from flowing through the armature when it is at rest; as the armature speeds up and develops some counter E. M. F., this resistance is gradually cut out, until the armature is connected directly to the mains, and is running at its normal speed.

The energy represented by the product of the drop in the armature and the current is wasted; that represented by the product of the current and the rest of the

E. M. F., that is, the counter E. M. F., is the energy required to keep the armature in motion. This energy is expended in overcoming the friction and core losses in the motor, which are of the same nature and effect as the similar dynamo losses, and also in overcoming the resistance to motion of the external apparatus driven by the motor.

Aside from the comparatively small amount of current required to furnish the torque necessary for overcoming the losses in the motor itself, which is practically constant, the amount of current taken from the mains is directly proportional to and varies automatically with the amount of the external load; for, if this external load is increased, the current which has been flowing in the armature can not furnish sufficient torque for this increased load, so that the machine slows down. This decreases the counter E. M. F., which immediately allows more current to flow through the armature, increasing the torque to the proper amount. If the external load is decreased, the current flowing furnishes an excess of torque, which causes the speed to increase, increasing the counter E. M. F., and decreasing the current until it again furnishes only the required amount of torque.

Since the counter E. M. F. is very nearly equal to the applied, it is only necessary for it to vary a small amount to vary the current within wide limits. For example, if the resistance of a certain armature is 1 ohm, and it is supplied with current at a constant potential of 250 volts, then, when a current of 10 amperes is flowing through it, the drop is $10 \times 1 = 10$ volts, and the counter E. M. F. is $250 - 10 = 240$ volts. Now, if the current is reduced to 1 ampere, the drop is $1 \times 1 = 1$ volt, and the counter E. M. F. is $250 - 1 = 249$ volts; that is, the counter E. M. F. only varies $\frac{9}{240}$, or 3.75%, while the current varies $\frac{9}{10}$, or 90%.

2339. The field magnets of constant-potential motors may be either shunt-wound or series-wound.

If shunt-wound, and supplied from a constant-potential

circuit, the magnetizing force of the field coils is constant, giving a practically constant field. This being the case the counter E. M. F. is directly proportional to the speed, so that variations of the load make only slight variation in the speed. A shunt-wound motor is then (practically) a *constant-speed* motor.

With series-wound motors the strength of the field varies with the current; if the load on such a motor is reduced the excess of torque makes the armature speed up, but as the resulting decrease of the current decreases the field strength, the armature must speed up to a much greater extent, in order to increase the counter E. M. F. to the right degree, than would be necessary if the field were constant. If the load is increased the increase in the current so increases the field strength that the speed must decrease considerably, in order to decrease the counter E. M. F. by the right amount. The speed of a series-wound motor, then, varies largely with variations in the load.

An advantage of the series motor is that if a torque greater than the normal is required, it can be obtained with less current than with a shunt motor, since the increased current increases the field strength, and the torque is proportional to both these factors (Art. 2336).

2340. It would not be practicable to make the field strength of a shunt motor as great as is possible to get with a series motor, since it would require a very large magnetizing force (Art. 2248), and with the shunt winding, this extra magnetizing force would have to be expended all the time, whether the strong field was required or not, which would be very wasteful; in the series motor, however, this extra magnetizing force is only expended while it is needed.

A disadvantage of the series winding is that if all the load is taken off, the current required to drive the motor is very small, making a weak field, which requires such a high speed to generate the proper counter E. M. F. that the armature is liable to be damaged. In other words, the motor will *race*, or *run away*, if the load is all removed. This can not occur

with the shunt motor as long as the field circuit remains unbroken.

On account of the above features, shunt motors are used to drive machinery that requires a nearly constant speed with varying loads, or which would be damaged if the speed should become excessive, such as ordinary machinery in shops and factories, pumps, etc. Series motors are used on street cars, to operate hoists, etc., where, on account of the gearing used, the load can not be entirely thrown off, and the torque required at starting and getting quickly up to speed is much greater than the normal amount.

REGULATION.

2341. The *torque* of a motor is a matter of current only; that is, for a given current, the torque will be the same whatever may be the speed, under otherwise the same conditions. The *speed* at which the armature runs is a matter of E. M. F. only; that is, with a given current the speed will be proportional to the applied E. M. F., or, more strictly, the counter E. M. F., other conditions remaining the same.

It has been shown that the torque will automatically regulate itself for changes in the load. The speed, however, may be varied by varying the applied E. M. F. or the strength of the field. A change in speed may or may not result in a change in the torque required, depending on the character of the work done by the motor.

The simplest way to vary the applied E. M. F. is to insert a resistance, in series with the armature, similar to the starting resistance. By varying this resistance the applied E. M. F. at the terminals of the motor is also varied, although the E. M. F. of the mains remains constant. It is evident that the energy represented by the drop through the resistance is converted into heat, and is thereby wasted; therefore, for great variations in speed this method is not economical, though often very convenient.

The applied E. M. F. may also be varied by varying the

E. M. F. of the generator supplying the current, but this can only be done where a single generator is supplying a single motor or several motors, whose speed must all be varied at the same time; so that this method is only used in special cases.

If the strength of the field is changed the speed necessary to give a certain counter E. M. F. will also be changed, which gives a convenient method of varying the speed. If the strength of the field is lessened the speed will increase, and if the field is strengthened the speed will decrease. With shunt motors the field may be weakened by inserting a suitable resistance in the field circuit, as in shunt dynamos; with series motors the same result may be obtained by cutting out some of the turns of the field coils or by placing a suitable resistance in parallel with the field coils, as in series dynamos.

This method of regulation is also of limited range, since it is not economical to maintain the strength of the field much above or below a certain density. The resistance method described above being rather more simple, it is generally used. For special cases, such as street railroad work, various special combinations of the above methods of regulation are used, which need not be described here.

CONNECTIONS.

2342. Fig. 912 shows the manner in which a shunt motor is connected to the terminals $+$ and $-$ of the circuit. It will be seen that the current through the shunt field does not pass through the resistance R which is connected in the armature circuit. This is necessary, since to keep the field strength constant the full difference of potential must be maintained between the terminals of the field coil, which would not be the case if the rheostat were included in the field circuit, for then the difference of potential would be only that existing between the brushes $+B$ and $-B$. As on starting the motor this difference of potential is small, only a small current would flow through the field coils, which

would generate such a weak field that an excessive current would be required to furnish the necessary torque for starting the motor.

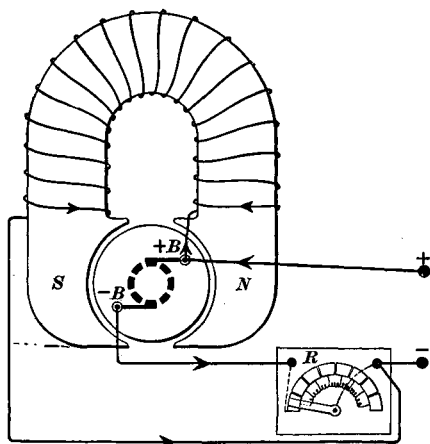


FIG. 912.

When connected as shown, however, the field is brought up to its full strength before any current passes through the armature, so this difficulty does not arise.

2343. Since in a series motor the same current flows through both armature and field coils, the starting resistance may be placed in any part of the circuit. The diagram in Fig. 913 illustrates one method of connecting a series motor to the line terminals + and -; here the starting or regulating resistance R is placed between the - line terminal and the brush - B of the motor.

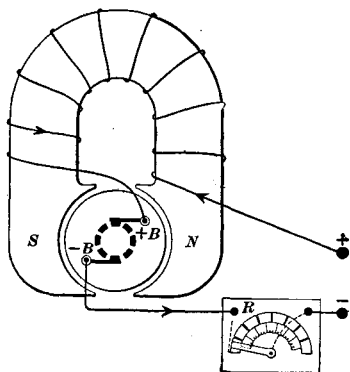


FIG. 913.

To reverse the direction of rotation of a motor it is necessary to reverse *either* the direction of the field or the direction of the current through the armature. (See Art. **2239**.) It is usual to reverse the direction of the current in the armature, a switch being used to make the necessary changes in the connections.

Fig. 914 shows the connections of one form of reversing switch. Two metal bars B and B_1 are pivoted at the points T and T_1 ; one is extended and supplied with a handle H ,

and the two bars are joined together by a link L of some insulating material, such as fiber. Three contact pieces a , b , and c are arranged on the base of the switch so that the free ends of the bars B and B_1 may rest either on a and b , as shown by the full lines, or on b and c , as shown by the dotted lines. The line is connected to the terminals T and T_1 , and the motor armature between a and b , or *vice versa*, a and c being connected together.

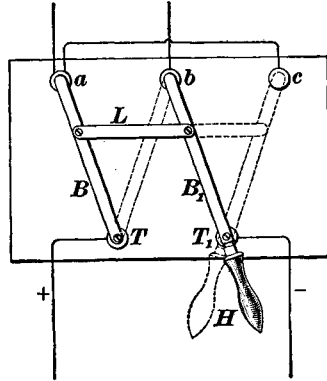


FIG. 914.

When the switch is in the position shown by the full lines, T is connected to a by the bar B , and T_1 to b by the bar B_1 . If the switch is thrown by means of the handle H into the position indicated by the dotted lines, T is connected to b by the bar B , and T_1 to a by the bar B_1 and the connection between c and a . The direction of the current through the motor armature, or whatever circuit is connected between a and b , is thus reversed.

In order to reverse only the current in the armature, the reversing switch must be placed in the armature circuit only. Fig. 915 represents the connection for a reversing-shunt motor (a) and a reversing-series motor (b); $+$ and $-$ are the

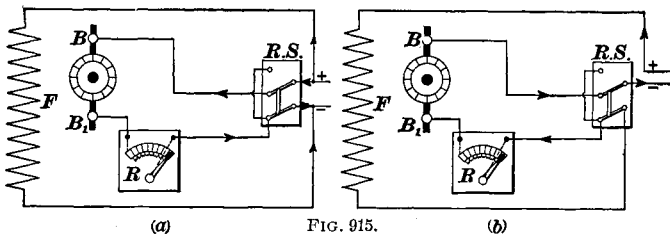


FIG. 915.

line terminals; R , the starting resistance; B and B_1 , the brushes of the motor, and F , the field coil of the motor. Some manufacturers combine the starting resistance and reversing switch in one piece of apparatus.

2344. In connecting up motors some form of main switch is used to entirely disconnect the motor from the line when it is not in use.

To prevent an excessive current from flowing through the motor circuit from any cause, short strips of an easily melted metal, known as **fuses**, mounted on suitable terminals, known as **fuse boxes**, are placed in the circuit. These fuses are made of such a sectional area that a current greater than the normal heats them to such an extent that they melt, thereby breaking the circuit and preventing damage to the motor from an excessive current. The length of fuse should be proportioned to the voltage of the circuit, a high voltage requiring longer fuses than a low voltage, in order to prevent an arc being maintained across the terminals when the fuse melts.

If desired, measuring instruments (ammeter and voltmeter) may be connected in the motor circuit, so that the condition of the load on the motor may be observed while it is in operation. All these appliances, regulating resistance, reversing switch, fuses, instruments, etc., are placed *inside* the main switch; that is, the current must pass through the main switch before coming to any of these appliances, so that opening the main switch entirely disconnects them from the circuit, when they may be handled without fear of shocks.

2345. To illustrate the manner in which these various apparatuses are connected, the following example in connecting the series-wound motor is given:

EXAMPLE IN CONNECTING.—Draw a diagram showing the connections of a series-wound motor with reversing switch, regulating resistance, ammeter, fuse boxes, main double-pole switch, and voltmeter, indicating the potential of the line inside the main switch.

Fig. 916 shows the connections that should be made. The terminals of the circuit supplying the current are connected to the upper contacts of the main switch M. S., and the terminals of the motor circuit are connected to the lower contacts. A fuse box F. B. is placed in each side of the

motor circuit, just inside the main switch. The voltmeter V. M. is connected to each side of the circuit just above the

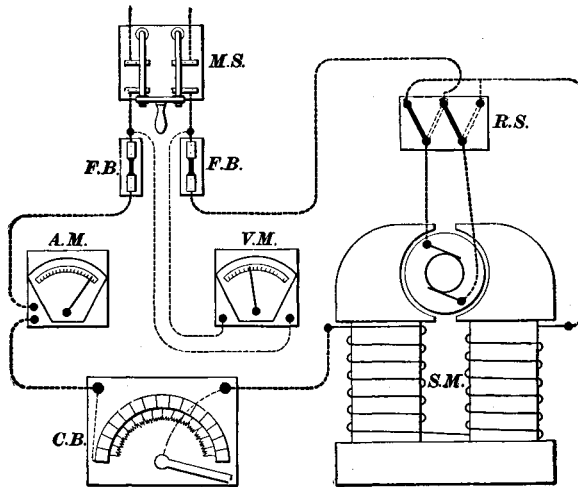


FIG. 916.

fuses, so if a fuse is blown, the voltmeter will still indicate the difference of potential between the mains if the circuit is "alive."

The armature terminals of the motor S. M. are connected to one side of the reversing switch R. S., the other terminals being connected to the fuse boxes; one directly, the other through the field coils of the motor, starting and regulating resistance C. B. and ammeter A. M.

OUTPUT.

2346. The *torque* of a motor corresponds to a certain number of *pounds pull* exerted at the circumference of the pulley, or at the pitch circle of the gear, or, in general, at some radial distance from the center of the shaft. As stated, this torque is the same for a given current whatever the speed. But for each revolution of the motor, the point at which the pull (torque) is exerted moves through a certain distance, equal to $3.1416 \times$ the diameter of the circle, or to $2 \times 3.1416 \times$ the *radius* of the circle, at the circumference

of which the torque is considered to act. Each revolution of the motor, then, when a certain torque is exerted, corresponds to a certain number of *foot-pounds of work done*.

This number of foot-pounds will be the same for a given torque whatever the radius of the circle through which its point of application moves, for, if a radius be taken that is twice as long as another, the distance moved through will be twice as great, but the pull in pounds will be only half as much, so that their product remains the same. For the sake of uniformity a standard radius of one foot is used, and the torque is expressed in *pounds at one foot radius*. (See, also, Art. **2336**.)

It will be noticed that the words *moment* and *torque* have nearly the same meaning. If the distance from the center to the line of action of the force whose moment it is desired to express was always measured in feet, then the words moment and torque would have the same meaning.

The foot-pounds of work done in each revolution, and the number of revolutions per minute being known, the foot-pounds of work done per minute, and from that the horsepower, may be found by the following formula:

If T represents the torque in pounds at one foot radius, and S the number of revolutions per minute, then the horsepower

$$\text{H. P.} = \frac{2 \times 3.1416 TS}{33,000} = .0001904 TS. \quad (334.)$$

That is, *to obtain the horsepower of a motor, multiply 3.1416 by 2, this product by the torque expressed in pounds at one foot radius, and this product by the number of revolutions per minute; divide this product by 33,000.* An alternative method is to use the constant .0001904, and multiply this by the product of the torque and speed expressed as above.

If the H. P. and the torque are known, the number of revolutions per minute may be found from a modification of the above formula:

$$S = \frac{33,000 \text{ H. P.}}{2 \times 3.1416 T} = \frac{\text{H. P.}}{.0001904 T}. \quad (335.)$$

Or, if the H. P. and the number of revolutions per minute are known, the torque may be found from the formula

$$T = \frac{33,000 \text{ H. P.}}{2 \times 3.1416 S} = \frac{\text{H. P.}}{.0001904 S} \quad (336.)$$

2347. Fig. 917 illustrates a method of measuring the torque of a motor by means of a **Prony brake**.

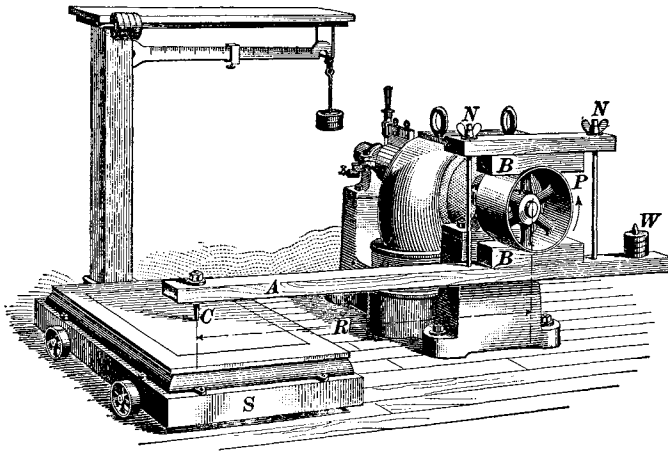


FIG. 917.

This brake consists of two blocks of wood *B*, *B*, made to fit the surface of the pulley *P*. These two blocks bear upon the pulley on opposite sides, as represented, and their pressure on the pulley is regulated by means of the thumb nuts *N*, *N* on the bolts which hold the two parts of the brake together.

The lower of the two blocks of wood is extended in both directions, forming on the one side an arm *A* which presses on the platform of a set of scales *S*, and on the other a place where weights *W* may be placed to balance the weight of the arm *A*. A spike, or lag bolt, *C* should be driven through the end of the arm *A* to better locate the point where it presses on the scale platform.

If the pulley *P* is revolved in the direction indicated by the arrow, the friction of the brake will cause it to tend to rotate with the pulley, which will cause the spike in the end

of the arm A to press down on the scale platform, and the amount of this pressure may be weighed by the scale beam. The *product* of the number of pounds pressure, and the *horizontal* distance R between the point C and the center of the pulley in feet, will give the torque in *foot-pounds*. Then, if the number of revolutions per minute of the motor is counted, the horsepower absorbed by the friction of the brake, that is, the output of the motor, may be calculated by formula **334**. If at the same time the amperes input and the voltage at the motor terminals are measured, their product will be the watts input, and by reducing the output and the input to the same units, the efficiency may be calculated by dividing the output by the input. (See formula **330**.)

2348. The following example shows the application of the above rules and method of testing motors:

EXAMPLE.—A given shunt-wound motor is designed for an output of 10 H. P., and to be run on a constant-potential circuit of 230 volts.

When driving a certain piece of machinery it requires an input (to both field and armature) of 35 amperes at 230 volts. It is desired to find the actual horsepower required to drive this machinery. The motor is disconnected from its load and a Prony brake rigged up as shown in Fig. 917. The thumb nuts are screwed up until an ammeter in the motor circuit indicates that 35 amperes are flowing through the motor circuit, and the voltage at the terminals is found to be 230 volts. Under these conditions the pressure on the scale platform is found to be 24 pounds, and the speed of the motor 800 revolutions per minute. The horizontal distance between the center of the shaft and the point where the brake arm rests on the scales is 30 inches. What is the output of the motor at this load in horsepower, and what is its efficiency?

SOLUTION.—The distance R (Fig. 917) being 30 in., or $2\frac{1}{2}$ ft., and the pressure on the scales being 24 lb., the torque of the motor is $24 \times 2\frac{1}{2} = 60$ foot-pounds. Substituting this value for T , and 800 for S , in formula **334**, gives H. P. = $\frac{2 \times 3.1416 \times 60 \times 800}{33,000} = \frac{301,593.6}{33,000}$.

NOTE.—As the instruments used are liable to slight errors, four figures (other than the zeros) left in the calculations will be near enough; if the last figure dropped is equal to 5 or more, the last figure *kept* should be increased one.

Then, $\frac{301,600}{33,000} = 9.1393$, or 9.139 H. P. is the output of the motor.

The input is $35 \times 230 = 8,050$ watts.

Reducing 9.139 H. P. to watts gives

$$9.139 \times 746 = 6,817.694, \text{ or } 6,818 \text{ watts.}$$

Then, by formula **330**, the efficiency $E = \frac{6,818 \times 100}{8,050} = 84.7$ per cent.

2349. The loss represented by the difference between the input and the output is made up of exactly the same elements as the total loss in dynamos; that is, mechanical friction, core loss, field loss, and armature loss. As in dynamos, the armature loss and field loss may be calculated from the resistance of the armature and field coils, remembering that in a shunt motor the *armature* current is *less* than the *total* current, since the field circuit is in parallel with the armature. The core loss and friction taken together evidently equal the difference between the total loss and the sum of the armature and field losses; they can not be separated without making special tests.

In a shunt motor the field loss, core loss, and friction are all practically constant at all loads, since the speed is nearly constant. This being the case the *watts required to run the motor without any external load whatever* is a measure of these losses plus a certain small amount of armature $C^2 r$, which may be calculated, though it is usually small enough to be neglected without much error. This being the case, the output which a motor will give at any given input will be very closely equal to that input less the watts required to run the motor free, and also less the armature $C^2 r$ loss at the given input; from this, the efficiency may also be calculated. To determine the efficiency of the motor at any load within its rated capacity, then, it is only necessary to carefully measure its input at no load (running *light* or *free*), and to make the above calculation. This, however, will give no idea of its performance as to heating and sparking, under the calculated load, so that the Prony-brake test is more satisfactory.

For example, a certain shunt-wound motor requires a current of 1.2 amperes at 500 volts when running *free*, i. e., without external load. Its armature resistance is 2.4 ohms,

and its field resistance is 834 ohms. Its field current is then $\frac{500}{834} = .5995$ ampere, or say .6 ampere. Its armature current is then $1.2 - .6 = .6$ ampere, and its armature loss only $.6 \times .6 \times 2.4 = .864$ watt, which may be neglected.

The input amounts to $1.2 \times 500 = 600$ watts, of which the field loss is $.6 \times 500 = 300$ watts.

If the efficiency when taking 10 amperes at 500 volts is wanted, it may be found from the above figures, as follows: Total input, $10 \times 500 = 5,000$ watts. Field loss, and core loss, and friction combined, amount to 600 watts, as found above. The armature loss amounts to $9.4 \times 9.4 \times 2.4 = 212.064$, or say 212 watts. The total loss is then $600 + 212 = 812$ watts, so that the output is $5,000 - 812 = 4,188$ watts, and by formula **330** the efficiency $E = \frac{4,188}{5,000} = .837$, or 83.7%.

In a similar manner the efficiency at any other input, or the input required for any given output, may be found.

The input, consequently the output, of constant-potential motors is limited by the same factors that limit the output of dynamos, namely, heating and sparking.

In motors, as the direction of the current, for the same direction of the lines of force of the field and of rotation, is *opposite* to that in a dynamo, the armature reaction shifts the neutral space in the opposite direction, that is, *backwards*, *against* the direction of rotation. (Compare Fig. 911 with Fig. 866. See also Art. **2242**.) Consequently the brushes of a motor must be shifted *backwards* as the load increases.

THE CONSTRUCTION OF CONSTANT-POTENTIAL MOTORS.

2350. It should be clear that any direct-current constant-potential machine can be used either as a motor or a dynamo. If supplied with current, it turns and furnishes mechanical power; if supplied with mechanical power, it turns and furnishes an E. M. F. which can be used to supply a current. Consequently, the statements already made

concerning the construction of dynamos apply equally well to the construction of motors, and the same varying types of field magnets, bipolar and multipolar, are used with either drum-wound or ring-wound armatures. (See Figs. 883 and 887.)

For certain special applications of motors, such as for street cars, locomotives, and the like, certain features must be introduced in the design to meet the peculiar conditions under which the motor is to operate; these features need not be discussed here.

EXAMPLES FOR PRACTICE.

1. A certain shunt-wound motor gives an output of 28 H. P., and requires an input of 96.6 amperes at 240 volts. Its armature resistance is .096 ohm and its field resistance 150 ohms. Find the per cent. of the above input lost in the core and in friction combined. Ans. 4.51%.

2. What is the counter E. M. F. generated in the above motor, when running under the conditions given? Ans. 230.88 volts.

3. A series-wound motor has an armature resistance of .5 ohm and a field resistance of .35 ohm. When tested with a Prony brake it gave a torque of 62 foot-pounds when running at a speed of 950 revolutions per minute, and took 44 amperes at 240 volts. Find (a) the efficiency of the motor, (b) the armature loss in per cent. of the input, (c) the field loss in per cent. of the input, and (d) the core loss and friction combined in per cent. of the input.

Ans. (a) 79.22%; (b) 9.167%; (c) 6.42%; (d) 5.153%.

4. After the test made in Art. 2348 is completed, the tension on the brake thumb nuts is slackened until the motor takes 24 amperes, the E. M. F. remaining at 230 volts. The pressure on the scale platform is found to be 15.66 lb. The armature resistance is then measured and found to be .4 ohm, and the field resistance 230 ohms.

Using only four figures in any of the calculations, etc., calculate (a) the speed (assuming it to be proportional to the counter E. M. F., and taking it to the nearest whole revolution only); (b) the horsepower output; (c) the input in watts; (d) the efficiency; (e) the per cent. of the input lost in the fields; (f) the per cent. of the input lost in the armature, and (g) the per cent. of the input lost in the core and in friction combined.

Ans. { (a) 816 R. P. M.
(b) 6.083 H. P.
(c) 5,520 watts.
(d) 82.156%.
(e) 4.167%.
(f) 3.833%.
(g) 9.844%.

CONSTANT-CURRENT MOTORS.

2351. If a series motor be supplied with a constant current the resulting torque will also be constant. This being the case, if this torque is in excess of that required to overcome the opposition to the motion of the armature, the speed of the motor will increase indefinitely; that is, the motor will run away, until the armature bursts from centrifugal force. The increase in the counter E. M. F. of the machine merely increases the applied E. M. F. in the same proportion, this being automatically regulated by the dynamo.

Motors intended for constant-current circuits must then be provided with some sort of regulator for varying the torque according to the load.

The usual method of regulation is to attach to the motor shaft a device like a centrifugal governor. If the speed of the motor exceeds a certain limit, by reason of the load being thrown off, the weights of the governor move outwards, and this motion is made to decrease the torque of the motor, either by cutting out some of the turns of the field coils or by shifting the brushes around the commutator. The first method reduces the torque by weakening the field; the second causes the torque of a part of the armature winding to oppose that of the rest, so that the resulting torque is diminished.

Constant-current motors are made only in the smaller sizes, and are little used, being generally less satisfactory in their operation than constant-potential machines; they need no further description here.

SINGLE-PHASE ALTERNATING-CURRENT MOTORS.

2352. If an alternating-current generator has its fields excited from some source of direct currents, and a simple single-phase, alternating current is supplied to the armature, the rapid reversal of the current will produce a torque that as rapidly reverses its direction; consequently,

the armature will remain at rest, since the tendency to turn in any one direction is reversed before the armature has time to start.

If, however, the armature is rotated from some external source until its own E. M. F. is not only of the *same frequency*, but *in phase* with the E. M. F. of the source of the alternating current, and is then connected to the alternating-current circuit, the torque will be continuous in one direction, and the armature will continue to rotate, because each time the current reverses its direction in the armature conductors they will have moved into a field of the *opposite* polarity, so that the *reversed* current will give a torque in the *same* direction.

It is necessary that the two E. M. F.'s (that of the circuit and that of the motor armature, i. e., the *counter* E. M. F.) should be in phase, for if that is not the case the maximum E. M. F. of the circuit will occur at the instant that there is little or no counter E. M. F. to oppose it, so that an excessive current will flow through the armature, which will not produce a corresponding torque, since the reaction of this excessive current will very much weaken the magnetic field of the machine.

In order that the frequency of the counter E. M. F. should be the same as that of the applied E. M. F., it is evident that the motor must be driven at such a speed that the product of the number of revolutions per second and the number of *pairs* of poles of its field magnets shall equal the frequency desired. (See Art. **2318**.)

2353. When the counter E. M. F. of the motor is exactly in phase with the applied E. M. F., it is evident that a coil of the motor armature must be in exactly the same position relative to the fields through which it is moving as a coil of the generator is to its fields. On this account these motors are called **synchronous** motors, synchronous meaning "occurring at the same time."

If these two E. M. F.'s are made exactly equal, then no current can flow through the motor ~~armature~~ when they

are connected together, but just as soon as the motor armature *slips back* a sufficient fraction of a revolution for its coils to be in a certain position (relative to the fields) *an instant later* than the generator coils, then a current can flow through the motor armature and exert a torque to drive it.

If this torque is sufficient to drive the armature it does not slip back further; if not sufficient it slips back a little more until the increased current does furnish torque enough. If the load changes the armature slips back a little or moves ahead a little, according to whether the load increases or decreases.

The total amount of this slip of the armature at the maximum load does not exceed about a quarter of the width of a pole piece, or in a ten-pole machine, about $\frac{1}{80}$ revolution, so that the *revolutions per minute* do not change with changes in the load, if the frequency is kept constant. If the load increases beyond the capacity of the machine, so that more than this amount of slip takes place, the excessive current which flows distorts and weakens the field to such an extent that little or no torque is exerted, and the armature stops.

The action of a synchronous motor may be likened to a pulley (the generator) driving another (the motor) by means

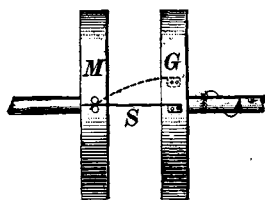


FIG. 918.

of a spring, as represented in Fig. 918, where *G* represents the driving pulley, *M* the driven, and *S* is the spring fixed firmly to the driving pulley and playing between two pins on the driven pulley. If there is no load on the driven pulley the spring will be nearly straight, as represented by the full lines; but if a load is thrown on the driven pulley, the additional torque required will bend the spring, as represented by the dotted lines, so that the driven pulley *slips back* a little, with reference to the driving pulley, although the number of revolutions per minute of each remains the same.

If the torque becomes excessive so that the spring is bent beyond its elastic limit, it breaks, and the driven pulley stops.

When supplied from a circuit of a constant frequency,

there is then only one speed at which the motor can run, and there is no method of regulating the speed, except by varying the frequency of the applied E. M. F., which is not practicable. If the field is weakened, more current is required to give the same torque, but the speed remains the same; if the applied E. M. F. is decreased (without changing the frequency) the armature must *slip back* a little more to allow the same current to pass through the armature, but the speed remains the same.

In addition the single-phase synchronous motor is not self-starting; that is, it must be brought up to its normal speed by applying some external power before it can be connected to its circuit, which is a great disadvantage. Where this can be readily done, however, the single-phase synchronous motor is very useful, since by transforming the current to one of high E. M. F., it may be transmitted a long distance over small wires with little loss, making it possible to locate the motor a long distance from the generator.

MULTIPHASE MOTORS.

2354. Fig. 919 represents a section of the armature of a two-phase alternator; coils A and A' belong to one winding, and coils C and C' to the other. These coils are wound around teeth projecting from the armature core 1, 2, 3, 4, 5. (See Art. **2319**.) Each coil embraces two teeth, and is wound in the *opposite direction* to its mate, with which it is connected in series. (Compare this winding with that shown in Fig. 902.) One end of one of the windings (which are supposed to be continued all around the armature) is connected to the inner, and the other end to the middle one of the three collector rings, while the ends of the other winding are connected to the middle and outer rings, as represented in the cut. (See, also, Art. **2323**.)

Suppose that the current from a two-phase alternator is sent through this armature winding by means of the brushes B_1 , B , B_2 . The maximum current in each winding will not then occur at the same instant, as is represented by the curves in Fig. 904 (Art. **2324**). Applying these curves

to Fig. 919, and supposing that curve 1 represents the current in coils A and A' , then the current in these coils at

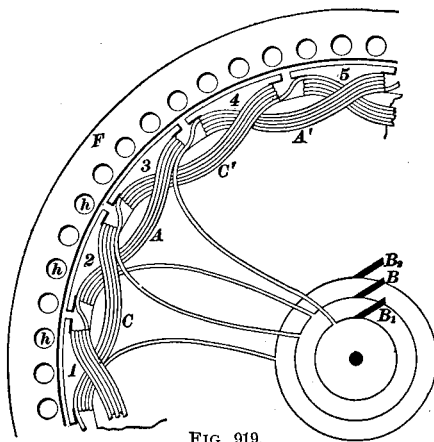


FIG. 919.

the instant represented by 0° (Fig. 904) will be zero, and the current in coils C and C' will be a maximum in the positive direction. Suppose that the current enters at brush B when positive in direction, then it will circulate around coils C so as to make the teeth 1 and 2 together become a *north* pole; coil C' being wound in the opposite direction, teeth 3 and 4 become a *south* pole.

At the instant represented by the 45° division (Fig. 904) the current in coils C and C' has been reduced, and the current in coils A and A' increased, they being equal and in the same direction. The current in coils C and C' still tends to make teeth 1 and 2 a north pole, and teeth 3 and 4 a south pole, but the current in coils A and A' now tends to make teeth 2 and 3 a south pole, and teeth 4 and 5 a north pole. The result of these two actions is that tooth 1 remains a north, and tooth 3 a south pole, the intermediate teeth becoming neutral. The rest of the two windings around the armature make this action uniform all around; i. e., every alternate tooth is neutral, and of the rest every other one is north, and *vice versa*.

At the instant represented by the 90° division (Fig. 904) the current in coils C and C' is zero, and that in A and A' is maximum, still in the positive direction. Consequently, teeth 2 and 3 now form a south pole, and teeth 4 and 5 a north pole. That is, *during 90° of a cycle, the poles of the magnetic field due to the current in the armature winding shift around the armature a distance equal to one-half the*

width of a coil. During a complete cycle, then, these poles would shift around the armature a distance equal to *twice* the width of coil, as will be seen by following out the polarity of the armature coils during a complete cycle.

2355. The effect, then, of sending a two-phase current through the winding of a stationary two-phase armature is to cause a multipolar magnetic field to revolve around the armature, at a speed depending upon the frequency of the current supplied, and upon the number of coils in the windings. Now, if the armature is surrounded by a series of conductors, wound through holes *h, h*, etc., in an independent external frame *F*, and separate from its own winding, these conductors will be cut by the lines of force of the revolving field, and an E. M. F. will be set up in them; and if their circuit is completed, a current will flow through them.

This current will react on the moving field, the tendency of this reaction being *to cause the magnetic field to become stationary with respect to the external conductors*. That is, if the armature is held stationary, and the external conductors are free to move, they will revolve in the *same* direction that the field moves; while if the external conductors are fixed, and the armature is free to move, the armature will rotate in the *opposite* direction to that in which the field moves.

2356. This series of external conductors, which should be called the *armature*, has no connection whatever with the external circuit, that being connected only to the winding which produces the rotary magnetic field, which winding should be called the *field winding*. Consequently, if the armature (previously called external conductors) is stationary, the current must be led to the revolving field winding (previously called armature) by means of collector rings; while if the field winding is stationary, and the armature revolves, no collecting devices are required. Both the above plans are used in practice.

It will be seen that when the machine is at rest, and the current is turned on, the rate at which the lines of force cut

the armature conductors is a maximum; but as the resulting current causes the armature conductors to move relative to the moving field, the rate of cutting becomes less and less, until finally the velocity of the armature conductors is nearly that of the field, if the armature be the moving part, or, if the field winding is the moving part, it revolves at such a speed that the magnetic field it produces is nearly stationary with respect to the armature conductors.

It is evident then that the maximum current in the armature winding occurs at the time of starting, but this does not necessarily give a maximum torque, because if the resistance of the armature winding is too low, the enormous current which will flow so distorts the revolving field as to very much weaken it, so that only a slight torque results. The resistance of this winding must be so adjusted that the current at the start will be enough to furnish a sufficient torque to start the machine, even if it is fully loaded, without much distortion of the revolving field. Under these circumstances this form of motor is then *self-starting*.

As the armature (or the field winding) speeds up, the E. M. F. generated in the armature winding is reduced, reducing the current, and, consequently, the torque; as in the constant-potential motor, this action will continue until the torque just balances the opposition to motion when the speed will become constant, the armature rotating at a *slightly lower* speed than does the revolving field. The difference between the two speeds is called the *slip* of the motor, and it is evident that the *amount of the E. M. F. generated in the armature winding, consequently the current, consequently the torque, depend upon the amount of the slip.*

2357. From the above it also follows that to get good speed regulation, that is, to get little variation in speed with extreme variations in the load, the armature resistance should be low, so that a small amount of slip will cause a considerable current to flow in the armature winding, in which case the considerable changes in the *slip* necessary to change the amount of current flowing in the armature to

correspond with the load may be brought about with only slight changes in the actual *speed*.

But this requirement is contrary to that given in Art. **2356**, so in commercial machines, either some of the starting torque is sacrificed to getting good speed regulation, or *vice versa*, or else the armature winding is so arranged that a resistance may be put in series with it at starting, which gives a powerful starting torque, and which is cut out as the motor gets up to speed.

If the armature winding is stationary this extra resistance may be located at any convenient point, and cut in or out by suitable switches. If the armature winding revolves, the external resistance may be mounted in the interior of the armature, it being cut in or out by a switching device either operated by a centrifugal governor or by hand. Or, the resistance may be outside the machine, connected to the armature winding through brushes and collector rings, and cut out or adjusted by suitable switches.

This type of motor is called the **rotary-field** type, and may be designed for either two-phase or three-phase alternating currents. The action in either case is similar, the three-phase field winding being furnished with three separate sets of windings instead of two.

The usual construction of rotary-field motors is to wind the field winding around teeth or in slots on the *inner* face of a stationary laminated iron ring. The armature winding usually consists of a series of copper bars or rods laid in slots in the periphery of a circular laminated core, which turns within the ring on which the field winding is placed. The ends of these bars are connected to each other, directly on one end of the core and through the starting resistance, which is cut out by a switch, on the other.

In case the armature is stationary and the field winding revolves, the position of the two windings is reversed.

Both parts of the magnetic circuit are laminated, for the magnetic field through the part on which the field winding is placed moves at a rate depending on the frequency, while that through the part on which the armature winding is

placed moves at a rate depending on the amount of the slip, so that if either part were solid, eddy currents would be set up in it by the motion of the field.

2358. As stated above, the speed at which the magnetic field rotates in a rotary-field motor depends upon the frequency. If the field winding of the motor is wound so as to have, for example, 4 pairs of poles, and the frequency used is 60, the speed of the field will be $\frac{60}{4} = 15$ revolutions per second, or $15 \times 60 = 900$ revolutions per minute. The speed of the armature itself (or the field winding, if that is the moving part) will then equal the speed of the rotary field less the slip. If the slip is 3% at full load—a very usual figure—the speed of the motor above considered will be $900 - (900 \times .03) = 873$ revolutions per minute. At no load the speed would be very nearly 900, as then the slip would be very slight.

The frequency generally used for multiphase motors seldom exceeds 75, 60 being a very usual figure. This is much lower than the frequency usually used for lighting (125), but is much better adapted to motor work.

Multiphase generators are sometimes used directly as motors, being then similar in action to the single-phase synchronous motors (Art. **2353**). While starting, the multiphase current in the armature winding causes it to act as the field winding of the rotary-field motor which, by the reaction of the rotary field upon the pole pieces of the regular field magnets of the machine, causes it to have a certain amount of starting torque, and although this starting torque is not as great as the maximum required when running, it is sufficient to start the machine if the load is disconnected.

When the machine gets up to its full speed as a rotary-field motor, the field magnets are excited in the regular way, when the machine acts as a synchronous motor, just as with the single-phase current, and will continue to run in that manner. Generally, however, when multiphase currents are available, rotary-field motors are used.

OUTPUT.

2359. The output of an alternating-current motor, in fact, of *any* motor, steam, hydraulic, or electric, may be measured by the method given in Art. **2346**. As stated in Art. **2329**, the ordinary methods of measuring the input to the machine can not be relied upon with alternating currents, so that special methods are required. The efficiency of good alternating-current apparatus is, however, equal to that of similar direct-current machines, and the losses are distributed in about the same proportion.

As no sparking occurs in alternating-current machinery, it obviously does not affect the output. Armature reaction, however, does affect it, as has been pointed out in the case of synchronous motors (Art. **2352**). With rotary-field motors, if the load on the machine becomes so great as to require an excessive torque, the increased current in the armature will, at a certain point, so weaken the field that it can furnish no increased torque, in which case the machine will stop.

The effect of the heat generated by the current in alternating machines is the same as in direct-current machines, so that the same limitations exist; that is, they should not heat to more than 80° F. above the temperature of the surrounding air.

**THE INSTALLATION AND CARE OF
DYNAMO-ELECTRIC MACHINERY.**

INSTALLING.

2360. Dynamo-electric machinery should always be located in a dry place, where the air is cool (see Art. **2288**), and where it will not be exposed to dust, especially metallic or mineral dust. Moisture will soon injure the insulation, and dust will, if metallic, often cause damage by settling in the winding or in the bearings.

For dynamos or motors up to about 30 H. P. capacity, a good, substantial floor affords a sufficient foundation.

Machines of larger size should be provided with brick or stone foundations, of a size and weight depending on the size of the machine. For machines of 100 H. P. or greater capacity, the foundations should not be less than five feet deep.

The machines should be supported on a wooden sub-base, resting on the foundation or floor, which should be about 8 inches high. This sub-base serves to insulate the frame of the machine from the ground, so the bolts which hold it down to the foundation should be so located as not to touch the bolts which hold the base of the motor down on the sub-base. The sub-base should not be painted, but should be oiled or filled, to prevent it from absorbing moisture.

If the machine is driven by a belt, and the belt passes a part of the frame before reaching the pulley, the static electricity generated in the belt will sometimes pass into the frame of the machine, when it is liable to injure the insulation by *jumping through* it to the winding. A path for this static electricity to escape to the ground may be made by charring with a red-hot iron a fine line on the wooden sub-base, extending from one of the bolts which holds the sub-base to the foundation to one of the bolts fastening the dynamo base to the sub-base. A heavy pencil line drawn with a soft pencil will answer the same purpose. This will not materially affect the insulation of the machine from the ground, but will afford a path for the static electricity to escape.

It is a good plan to place a tin drip pan about 1 inch deep between the base of the machine and the sub-base, large enough to catch whatever oil may drip from the bearings, thereby preventing it from soaking into the floor.

2361. The foundation should be located with respect to the driving pulley, or shaft, so that the length of the belt used should not be too small nor too great. Fifteen to twenty feet between centers is about right, unless the driving pulley is more than about six times the diameter of the driven, in which case longer belts should be used, so as

to get sufficient arc of contact on the driven pulley to drive it without making the belt too tight.

Belted machines of the smaller sizes (less than 150 H. P. capacity) are usually provided with a *sliding bed-plate* with guides or rails on which the machine slides, it being moved backwards or forwards by screws operated by levers or hand wheels. (See Figs. 890 and 891.) The machine is not then bolted directly to the sub-base, but may be fastened down on the bed-plate which is bolted to the sub-base.

If a new belt is to be used, its length should be calculated for that position of the pulleys when they are *nearest together*. Then, as the belt stretches with use and becomes slack, the machine may be slid along the guides and the proper tension of the belt maintained.

The width of belt necessary to transmit the power to or from the machine may be calculated by the rules given in previous articles. It will usually be found that the pulley furnished with the machine is about 1" wider than the belt required. For machines of between 10 and 50 H. P. capacity, the belting used should be that known as *light double* or *dynamo* belting, which should be of about $\frac{3}{4}$ the width of a single belt to transmit the same power. Dynamo and motor belts should have cemented or riveted joints, to ensure smooth running. The size of the pulley on the engine or shaft to which the machine (dynamo or motor) is belted may be calculated from the size of the pulley and its number of revolutions, using the formula $N = \frac{dn}{D}$. To the calculated size of the driver should be added 2%, to allow for the slip of the belt. *The size of the pulley on the machine should not be altered*, except by the advice of the makers.

2362. In the following articles upon the setting up and the testing of machines, only direct-current constant-potential dynamos will be considered. Other classes of machines will be taken up later. On setting up a new machine the foundation and sub-base should first be prepared, then the bed-plate set in position on the sub-base, but not fastened.

The machine should then be *very carefully* unpacked, and set in position on the sliding base. Small machines, up to 10 or 15 H. P. capacity, are usually packed in a box, with the armature and field coils in position, and connections made, so it is only necessary to take them out of the box and set them upon the bed-plate.

Machines from 15 to about 50 H. P. capacity usually have the armature removed and packed separately, the field coils being left on the frame, which is boxed. Still larger machines usually have the armature, field coils, connection boards, rocker-arm, etc., removed and packed separately, and the frame skidded.

When this is done the bearings, joints in the magnetic circuit, and similar bright surfaces are slushed with grease, or painted with thick white-lead paint; this should be cleaned off, using benzine or kerosene oil for the grease, and turpentine for the paint. Joints in the magnetic circuit should be wiped off with a cloth, not with waste, for the latter will catch on the tiny points on the surface of the iron, and will prevent the two surfaces from coming tightly together.

Most machines of the larger sizes are now made multipolar, and the top part of the magnetic circuit may be removed, down to the center line of the shaft, to allow of removing and replacing the armature. Others have the magnetic circuit solid, but the standards are made removable, so that the armature may be slipped out endways. If there is little head room, it is desirable that the machines have both the upper part of the magnetic circuit and the standards removable, so that the armature needs to be lifted only two or three inches, instead of more than half its diameter, as would be the case with standards cast solid with the base.

2363. After cleaning up the bearings and joints, the lower half of the machine should be set up in position on the bed-plate, and the field coils and the pole pieces (if removable) placed in position, care being taken to get the field coils on in the right *order* and *position*, so that they will connect together properly.

If the bearings are *self-oiling*, the cavity in the standard which contains the oil should be examined to see if all the sand from the mold in which it was cast has been removed. If this has not been done it should be blown out with a hand bellows, or, better, with a jet of live steam from the boilers, if that is obtainable. The caps for the standards should be examined and cleaned in the same manner. The bearings should then be wiped out, cloth being preferable to waste for this purpose also.

After this has been done the armature should be looked over to see if the winding and commutator are uninjured, and all dirt or sawdust should be brushed or blown out of the spaces between the coils, etc.; it should then be placed in position in the bearings.

2364. As it is very important not to bump the armature against the projecting corners of the machine in putting it in place, it should not be lifted in by "main strength," if so heavy that two men can not handle it readily, but a crane or other hoisting mechanism should be used.

To lift the armature, a rope sling should be used, which should be looped around the ends of the armature shaft, never around the commutator. To this sling the hook of the tackle, or chain block, may be fastened, and to prevent the sling from bearing against and possibly injuring the armature winding, or the commutator, a piece of board, notched at the ends, should be placed between the two parts of the sling.

This is represented in Fig. 920, *B* being the notched piece of board and *S* the sling. The sling should be crossed in the hook, as represented, for otherwise it is very liable to slip and drop the armature.

A single chain block, or tackle, is not desirable to use in handling a heavy armature, as, either in raising or lowering, the armature must be swung out to one side, which is very inconvenient, and the armature is liable to swing around unexpectedly and damage itself by bumping against the frame. If an overhead traveler is not at hand to attach

the tackle to, two tackles should be used, one hung directly over the center of the machine, and the other directly over

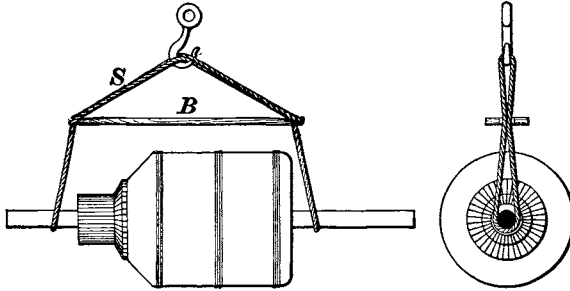


FIG. 920.

the nearest point on the floor to which the armature can be brought.

The armature may then be lifted by this latter tackle until high enough to clear the frame of the machine, when the other tackle may be hooked on, and by slacking off on the one and hauling in on the other, the armature may be lowered directly into place. In this way two men can easily handle a heavy armature.

The top part of the magnetic circuit, or other heavy parts of the machine, may be put in place in the same manner.

If the armature winding is on the surface of the core, it should not be rested directly on the floor, but on a pad of waste or rags, or the end of the shaft should be supported on a couple of wooden horses. If the armature is of the "ironclad" type, in which the winding is embedded in slots cut in the periphery of the core, this precaution is not necessary. In either case the armature should always be *lifted* by means of the shaft.

After placing the top part of the magnetic circuit with its pole pieces and field cores in position and setting up of the bolts or screws which hold it in place, the bearings should be filled with oil, and the armature turned over a few times by hand to make sure that it does not touch the pole pieces at any point, and that the shaft runs easily and true; if it binds at any particular point of a revolution the shaft may have been sprung in transit, and it should not be run in that

condition. The armature shaft should have an end play of from $\frac{1}{4}$ to $\frac{1}{2}$ an inch, except in those machines in which the pole pieces face the end surface of the armature, like the Brush constant-current machine. This end play allows of a slight end motion of the armature as it runs, which makes the wear on the commutator and bearings more uniform, and prevents the shaft from sticking by any slight endwise expansion it may undergo.

TESTING, AND LOCATING AND REMEDYING FAULTS.

2365. If everything appears to be all right, the pulley should then be put on and the machine carefully lined up with the shaft and pulley to which it is to be belted, and the bed-plate fastened permanently to the sub-base. Then the belt should be put on and the machine run without load, and with no field excitation, for two or three hours, if possible, to make sure that the bearings and oiling arrangements are in working order.

If the bearings begin to heat badly, the oil in the bearings should be examined to see if it is gritty, and if so, it should be drawn off and fresh oil substituted. *Only the best grades of light mineral oil should be used*; any cheaper oil costs more in the end. If the bearings still heat, they should be taken out and examined for rough spots, and, if necessary, scraped.

If taken in time, the corresponding roughness of the journal may be removed in the following manner: Take a piece of crocus cloth of a width equal to the length of the journal, wet it with oil, and wrap it around the journal; then take a turn around the journal with a piece of cloth tape or strip of cloth, take one end of the strip in each hand, and by alternately pulling on each end rotate the piece of crocus cloth around the journal, which will effectually polish it and remove all slightly rough spots. If the shaft has been bruised or dented the high spots should be carefully brought down with a fine file before polishing with the crocus cloth.

If self-oiling bearings are used they should be examined to see if the rings turn freely; if they show a tendency to hug the sides of the slots in the bearings, and turn very slowly, or not at all, they should be bent a trifle so that all parts of the ring do not lie in the same plane, so that as they turn they will run from side to side of the slots in the bearings. This may usually be done with a pair of heavy pliers or a small wrench, without removing the bearings from the machine. It should be carefully done, and the "wind" of the ring made uniform, so that it will not catch in the slots at any point.

If a new belt is used, and it has been made of the proper length, it will usually be tight enough to cause the bearings to get hot, at first, but in half an hour or so, it will stretch sufficiently to relieve the pressure, and the bearings should cool off. Large belts that are made endless by the manufacturers are usually stretched by them, in which case they should be put on without quite as much tension as an unstretched belt. (See Art. **2361**.)

2366. If the machine runs all right it should then be prepared for a run under load. Before stopping the machine the commutator should be examined for high or low bars or rough spots, by touching it lightly with the finger nail or the end of a lead pencil all along its length, as it turns, which will show if the above defects exist. Rough spots can be removed with sandpaper (*never* emery paper or cloth) folded around a bit of board and pressed evenly on the commutator as it turns. High or low bars, or "flats," can only be removed by turning the commutator down to a uniform diameter, using for this purpose a sharp **V**-pointed tool, a fine feed and a high speed, finishing with fine (0 or 00) sandpaper or a smooth file.

After the commutator has been turned up it should be carefully gone over to see that the tool has not left chips that have become embedded in the insulation between the bars. If any such exist they should be carefully picked out, and all copper dust wiped or blown off the commutator and armature.

The yoke and brush holders should then be placed in position, and the brushes, if not of the radial type, carefully adjusted so that they bear on the commutator the proper distance apart. This may be done by counting the commutator segments, and dividing their number by the number of poles, the result being the number of segments which should lie between the tips of successive sets of brushes. Some multipolar machines use only two sets of brushes, but the fraction of the circumference of the commutator that separates the two is indicated by the rocker-arm.

It is often convenient to make marks by means of a prick punch on the end of the commutator shell, which will indicate the segments on which the various sets of brushes would rest when the proper distance apart. These reference marks will serve to re-locate the brushes at any time.

The brushes should bear evenly on the commutator throughout their whole end surface. Metallic brushes are usually flexible enough to take care of this point, but carbon brushes should be fitted to the commutator surface. This may readily be done by putting them in position in the brush holders, and dragging a sheet of medium fine sandpaper back and forth between the brushes and the commutator, keeping the paper side of the sandpaper down on the commutator; this will grind the ends of the brushes down to the same curve as that of the commutator.

The tension used on the brushes should be uniform—light with metallic and heavier with carbon brushes.

Machines which are shipped with the connections broken are usually accompanied with a diagram showing the proper method of connecting them up; if this is not the case some one perfectly familiar with the apparatus should make the connections. In any case the connections should be carefully looked over to see if they are all right, and all screws, binding posts, and other connections fastened firmly.

2367. The machine should then be run up to its proper speed, the brushes placed in the approximate neutral position, the shunt-field circuit closed, and the resistance

gradually cut out. If everything is all right the machine will build up to its proper voltage (see Art. **2250**); but if this does not occur, the trouble may be looked for as follows: Attach a voltmeter to the brushes, with the field circuit *open*; the voltmeter should show a slight deflection, due to the E. M. F. generated by the residual magnetism. Then, close the field circuit, and if the voltmeter needle goes back towards zero, it shows that the *current sent around the field coils by the E. M. F. due to the residual magnetism tends to magnetize the fields in the opposite direction*, so that the few lines of force of the residual magnetism are opposed and destroyed, and the machine can not build up.

If this seems to be the case rock the brushes ahead or back until any one set occupies the position formerly occupied by its neighbor. Then, close the field circuit again, and if this is the only trouble, the machine will build up. If it does, and this position of the brushes is inconvenient for any reason, they may be put back in their former position and the connections of the shunt fields reversed.

If the machine still does not build up, it may be due to the absence of any residual magnetism, in which case the current from a few cells of battery, or another dynamo, sent through the coils will establish a sufficient amount to enable the machine to build up. The presence (or absence) of residual magnetism may be shown by a voltmeter, as described above.

If this is not the trouble, the field circuit may be broken somewhere. Examination of the connections between the various coils will show if they are defective or loose; quite frequently the wire in the leads from the spools becomes broken at the point where they leave the spool, while the insulation remains intact, so that the break does not show. This may be readily detected by "wiggling" the leads.

If the break is inside the winding of one of the coils, it can only be detected by testing out each coil separately to see if its circuit is complete. This may be done with a Wheatstone bridge (Art. **2184**) or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit, and the other to the other side, so that a voltmeter connected between these terminals would show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool, and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

2368. This method of testing is represented by the diagram, Fig. 921; 1, 2, 3, and 4 represent the field coils of a 4-pole dynamo, there being a break in coil 2 at *B*.

The terminals *a* and *e* of the field winding are connected to the + and - terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil 1 are both connected to the + side of the circuit, and as there is no current flowing through the field

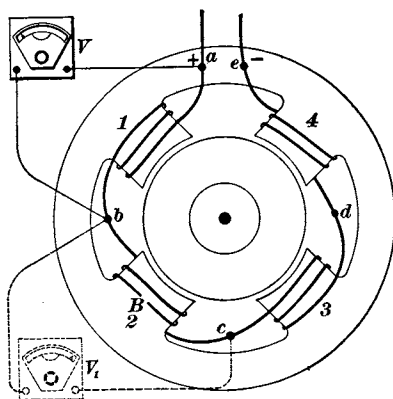


FIG. 921.

circuit, there is no difference of potential between *a* and *b*, therefore, a voltmeter connected to *a* and *b*, as at *V*, will show no deflection; but terminal *c* of coil 2 is connected to the - side of circuit, so a voltmeter connected to *b* and *c*, as at *V*₁, will show a deflection, and, in fact, will indicate the difference of potential between *a* and *e*.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a* for instance, and the other on *b*, it will not affect the circuit any; but if touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current would flow.

2369. If the machine builds up to about half its normal voltage or less, and refuses to come up higher when all the external resistance is cut out of the field circuit, the trouble may be due to too low speed, which may be easily tested by counting the number of revolutions made by the machine. If this is not the fault the brushes should be rocked back and forth, and if the voltage increases with a motion of the brushes in either direction, this motion should be continued until the voltage will not increase further, in which case the brushes are probably in the proper neutral plane.

If the voltage is still considerably too low, it is probable that one of the field coils is wrongly connected, so that the fields are not all of the proper polarity. This can be tested with a small compass, and if one field is found to be of the wrong polarity, the connection of its coil should be reversed, in which case the machine will probably build up properly, unless there is some serious defect in its construction.

When the machine has built up to its proper voltage, and the brushes have been adjusted to the non-sparking position, the armature should be examined for *short-circuits*. These occur when the ends of one of the coils form accidental contact with each other, or when two neighboring wires touch each other; the effect in either case is to form a closed circuit of one or more active conductors, which circuit, being of low resistance, has an excessive current generated in it, causing it to heat badly, and finally destroying its insulation.

This fault may be detected by holding a nail, screw-driver, or other small piece of iron over the surface of the armature between the poles. The fluctuations in the current flowing in the short-circuited coil, as it passes from one pole to another, sets up corresponding fluctuations in the stray field between the pole pieces, so that the piece of iron held in this stray field will be vibrated quite strongly. Care should be taken not to allow the bit of iron to be pulled into the armature by the attraction, as that would probably destroy the winding.

2370. Armatures in which the winding is embedded in slots cut in the periphery of the core will sometimes cause a piece of iron held between the poles to vibrate, especially if the slots are comparatively few in number; but this action can be readily distinguished from that due to a short-circuited coil, as the vibrations due to the teeth on the armature occur several times in a revolution, while those due to the short-circuited coil occur only once in a revolution. The difference in the rate of the vibration may be easily distinguished.

If a short-circuited coil appears to exist, the machine should be run for some time (with no external load), perhaps ten minutes, and then shut down. By feeling of all the armature coils in succession on the back end of the armature, the defective coil may be readily picked out by its being much hotter than the others. It should then be marked in some way and the armature taken out and the coil re-wound, or the short-circuit otherwise removed.

2371. If the armature shows no short-circuit, it should be run under load for some time before being put regularly in commission. It is usually not desirable to connect it for this test to the circuit which it is to supply with current, since the load can not be readily controlled. It is better to provide an artificial load for the machine which may be readily controlled, so that any desired load may be obtained.

With small machines of the proper voltage, this artificial load may be made by using a **lamp bank**; that is, a num-

ber of incandescent lamps arranged so that few or many may be connected in circuit by manipulating the necessary switches.

With larger machines, especially of the higher voltages (230 or 500 volts), this method is not so convenient as a **water rheostat**, which consists of a wooden tank filled with salted water, in which are hung two iron (or other metal) plates, that are attached to the terminals of the dynamo. The circuit is thus completed through the water between the plates, and, by varying the distance between the plates, the resistance of the external circuit can be adjusted between wide limits.

An old oil barrel makes a good tank if the dynamo to be tested has an output of not more than about 15 kilowatts. If a greater amount of energy must be disposed of, the surface and the amount of the water must be greater than a barrel will afford, and a tank should be made for the purpose, especially if several machines are to be tested. Fig. 922 illustrates a form of water rheostat, in which *T* is

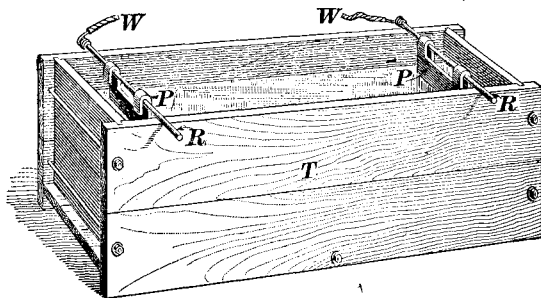


FIG. 922.

the wooden tank, which should be about 7 feet long and about $2\frac{1}{2}$ feet square, inside measurements, made of $1\frac{1}{2}$ in. or 2-in. pine plank, with tongued and grooved joints which should be leaded to make them tight, the whole being held together by cross bolts, as represented in the cut.

Two iron rods *R*, *R* are placed across the top of the tank, and to them the terminals of the dynamo circuit are attached, as represented at *W*, *W*. From these rods two iron plates *P*, *P* are hung, which should have about $3\frac{1}{2}$ or 4 square

feet of surface (on one side) below the water level. These plates may be made of a couple of pieces of old boiler plate or heavy ($\frac{1}{4}$ inch or thicker) sheet iron, cut with two projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods R, R . Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins.

When ready for use the tank should be filled with water, and from 5 to 20 lb. of rock salt or washing soda added to reduce the resistance to the required figure, as water alone would give altogether too high a resistance. The resistance should be made such that when the two plates are at opposite ends of the tank about $\frac{1}{10}$ the normal current of the generator will flow when the circuit is closed. An ammeter should be connected in circuit with the rheostat, of a capacity sufficient to measure the full-load current of the machine.

When all preparations are completed, connections firmly made, and the plates at opposite ends of the tank, the external circuit should be closed, and the plates moved closer together until the current is about $\frac{1}{4}$ the full-load current of the machine. The machine should then be examined for further faults, which will generally be indicated by sparking at the brushes.

2372. If the brushes spark badly they should be shifted backwards and forwards a little, and the position of least sparking found. If they are too far back the spark will occur at the forward tips of the brushes, and will generally, especially with copper brushes, be short, bluish in color, and confined to one or two points along the row of brushes in each set. If too far forwards, the spark will appear to come from *under* the brush, will generally be more yellowish in color, and will occur all along the rows of brushes.

Even when in the best position, the sparking will not entirely disappear, for by looking carefully under the brushes a tiny twinkling spark will be seen, which, however, does no damage.

If there is an intermittent sharp flash at the brushes, occurring at each brush once in a revolution, it is probably due to an *open circuit* in the armature winding, which usually occurs in the leads from the armature coils to the commutator segments. The break may be located by running the armature and allowing it to flash for half a minute or so, when it will be found that one, perhaps two, commutator bars are noticeably burned, the burn extending from the *forward* edge of the bar (in the direction of rotation) back half its width or more. The armature head should then be removed and the lead from the winding to the burned bar examined.

If the lead is only disconnected from the bar by having become unsoldered or by the wire slipping out from under the screw which holds it, the fault may be quickly repaired. If it is necessary to re-solder the connection, care should be taken that particles of the solder do not fall on the back of the commutator in such a way as to connect two bars or two leads together, or to connect a commutator bar with the shell. *Acid or "soldering salts" should not be used* in soldering these connections, since the acid will corrode the joint, and finally cause a break; the surfaces should be scraped bright and resin used as a flux.

If the break is such that it cannot readily be repaired, and there is not time to put in a new connecting wire, the machine may be temporarily used by connecting the burned bar with either of the adjacent bars by a drop of solder, or by hammering lightly on the *end* of the bars until the space between the two is bridged over by the soft metal. *This should never be done* if possible to repair the broken connection, but will sometimes be necessary in case of an emergency. When the break is repaired, which should be as soon as possible, the connection between the bars must be removed.

When the break is in the connection between the winding and the commutator bars, the continuity of the winding is not usually disturbed, since the leads to the commutator do not usually form a part of the winding. In case the break

is in the coil itself, the expedient described above can not be used without affecting the capacity of the machine, and the break must be located and repaired, which will usually require the rewinding of the broken coil.

A high bar or a "flat," and sometimes a *badly* short-circuited coil, will cause a flashing similar to that due to an open circuit, but these should have been looked for and remedied before, as described in Arts. **2366** and **2369**. If none of the above troubles develop, the load on the machine should be gradually increased by moving the plates of the water rheostat closer together, until the current is as great as the rated capacity of the machine will allow.

2373. If the dynamo is compound-wound, the voltmeter should be watched as the load is increased, to see if the compounding is of the correct amount. If the voltage falls off rapidly as the load is increased, the series coils are probably connected wrongly, and their connection should be reversed, when the voltage should remain constant, or slightly increase, as the load increases, without changing the resistance in the shunt-field circuit.

The brushes should be carefully shifted as the load increases, if necessary to prevent sparking, and the position of the brushes at the different loads noted. If the machine is to be used under a suddenly variable load, the shifting of the brushes should be slight, and, in fact, there should be a position of the brushes where the sparking will be nothing at medium loads, and not serious at either full load or no load, and they should be kept in this position at all times.

2374. In multipolar machines with as many brushes as there are poles, the sparking between one pair of brushes may become violent as the load increases, while the others run quietly. This may be due to a wrong adjustment of the brushes, which may be readily detected and remedied, but if this is not the trouble, the series coil (in compound-wound machines) of that pole piece between the two sets of brushes may be short-circuited or wrongly connected. This may be detected by trying the strength of that pole piece relative

to one of the others, by noting the pull required to detach a screwdriver or other bit of iron from similar points on the two pole pieces. If the series coil is defective there will be a noticeable difference in the pull of the two pole pieces, that on which the defective coil is wound being much weaker than the other.

If the series coil is connected wrongly the error can be readily rectified, and a further test will show if this is the fault. If the coil has some of its turns short-circuited, it is difficult to locate the fault except by unwinding and rewinding the coil, which should only be done by representatives of the company furnishing the machine, or by their direction.

If one of the shunt coils is affected in the same way, that is, wrongly connected or partially short-circuited, the trouble will manifest itself before the load is put on. (See Art. **2369**.) If one of the coils is partially or wholly short-circuited, the field current will be greater than the normal, which will cause the *good* coils to heat excessively, while the defective coil remains cool.

While running under full load the bearings and belt should be watched; if the bearings have a tendency to heat excessively, the belt should be slacked off, if possible. If the belt squeaks loudly in passing over the pulley it is too slack, and if it can not be tightened without causing the bearings to heat excessively, a wider belt should be substituted, unless the heating is due to dirty oil or rough spots in the bearings. These last causes will usually show up in the first part of the run, however, when the machine is not loaded.

2375. After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter, such as a Weston, as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter to the frame of the machine, as represented in Fig. 923, where T and T_1 are the

terminals of the dynamo, and V and V_1 two positions of the voltmeter, connected as described above.

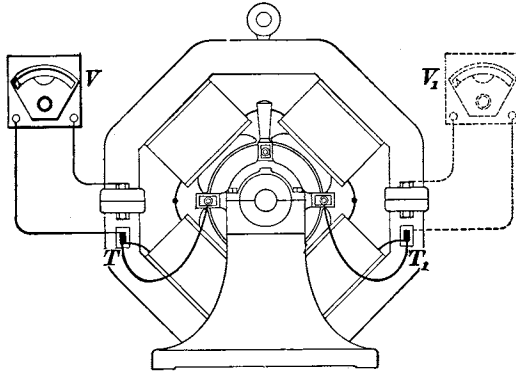


FIG. 923.

If, in either position, the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the terminal T_2 , and *vice versa*. If the needle shows a deflection in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If, in either case, the deflection does not amount to more than about $\frac{1}{20}$ the total E. M. F. of the machine, the ground is not serious, but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed.

2376. To locate the ground, if thought to be in the field coils, each should be disconnected from its neighbor (with the machine shut down, of course) and “tested out,” by connecting one terminal of another dynamo (or of a “live” circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the end of the shaft or a bolt head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 924.

Here C and C_1 represent the terminals of a “live” circuit, which should have a difference of potential between them

about equal to the E. M. F. of the machine when it is in operation, but also not greater than the capacity of the voltmeter will allow of measuring.

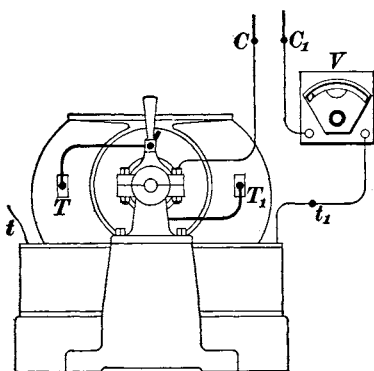


FIG. 924.

T and T_1 represent the terminals of the dynamo, as before, and t and t_1 , the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal C of the circuit is connected to the frame of the machine; the other terminal C_1 of the circuit is connected through the voltmeter V to the terminal t_1 of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit $C C_1$, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal t_1 may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown up by a considerable deflection of the voltmeter needle.

2377. If the machine tests out clear of grounds, it should be shut down after the proper length of time, and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted thermometers should be used, by placing the bulb on the various parts (armature, field coils, etc.) and covering with a wad of waste or rags. They should be looked at from time to time, until it is seen that the mercury no longer rises, when the point to which it has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit. (See Art. **2288**.)

When the dynamo has been found or made to be in good condition, it may be connected to the circuit which it is to supply and put in commission. The oil used in the bearings during the preliminary runs should be drawn off and a fresh lot substituted. All connection to the dynamo and to the switchboard terminals should be made firm and tight; surfaces in contact should be made bright and clean before fastening together.

DIRECT-CURRENT MOTORS.

2378. In setting up direct-current motors the same remarks apply that have been made concerning the location and assembling of dynamos. After having set up the motor and made the necessary connections to the circuit which is to supply it with power, it should be tested and run without its load to develop any faults which may exist.

After making sure that the connections are such that when the main switch is closed, or the arm of the starting box turned on to the first contact, the field circuit is closed *separately* and *before* the armature circuit (if it is a shunt motor), the current should be turned on to the field circuit, and the pole pieces tested for magnetism with a bit of iron (a screwdriver or a nail). If they are not magnetized, and the circuit to which they are connected is *surely* "alive" (which may be tested with a voltmeter, lamps, or, if the E. M. F. of the circuit is not more than 125 volts, by lightly touching the terminals of the circuit with the thumb and finger of one hand), the field circuit is probably open, and the break should be located by the methods described in Arts.

2367 and 2368. It is sometimes the case that in the style of starting box in which the movement of the contact arm first closes the field circuit and then the armature circuit, that a particle of dirt will prevent the field-circuit contact from being made.

If the fields show that they are magnetized then polarity should be tested with a compass, and if any one is wrong, its field coil should be reversed. When the fields are found to be of the proper polarity (with respect to each other) the

armature circuit should be completed through the resistance or starting box, with the belt or other connection to the load removed, if possible.

If the motor refuses to start when the current is turned on, it should at once be examined to see if this is due to the shaft sticking in the bearings, or to some similar cause which binds the armature fast. If this is not the case, and the armature turns freely by hand, the armature circuit may be open in the armature, in the connections or in the starting box. If the current is actually passing through the armature, which can be shown by lifting the brushes on one side, a slight spark showing the presence of the current, the brushes may be in the wrong position. They should be shifted backwards or forwards, when the motor will start if this is the trouble. If the fields are not magnetized the motor will not start, except with an excessive current; this point, however, should have been previously looked into.

If the motor starts off all right, the armature should then be examined for short-circuits, open circuits, defective commutator, etc., in the same manner as has been described for dynamos, and these faults, if they exist, remedied. When this has been done, the load should be put on the machine, and its performance carefully watched for an hour or so, to see that no defects develop themselves.

If the installation is large enough to warrant it, the temperature should be taken at the end of the run, providing the conditions are such that the motor has been subjected to as much load during the run as it is liable to get. If this is not the case it is often desirable to make a test of its efficiency and behavior (as to sparking, etc.) under full load, using for the load a Prony brake, as described in Art. 2347.

CARE OF DIRECT-CURRENT MACHINERY.

2379. The most essential feature in caring for dynamo machinery is **cleanliness**. The machine should be kept thoroughly cleaned, and oil should never be allowed to accumulate on either the armature or the field windings, as it will gradually affect the insulation.

Whenever the commutator is polished off with sandpaper, the fine copper dust should be wiped or blown off from the machine, especially from any part of the winding.

The commutator should *not* be kept bright; it is in its best condition when covered with a brownish glaze. This condition can be arrived at by carefully turning up the commutator, adjusting the brushes until there is little or no sparking, and then wiping the commutator off at frequent intervals with a cloth just moistened with oil or vaseline. Waste should not be used for wiping off the commutator, as its threads are liable to become caught in the brushes. A soft pine stick makes a very good burnisher for a commutator.

A convenient tool for wiping off the commutator may be made from a strip of heavy canvas, three or four inches wide and, perhaps, 18 inches long. Spread a thin layer of vaseline over one side of the cloth, roll it up like a jelly cake, and fasten the end by sewing, or wrapping the roll with string. The end of this roll applied to the commutator will wipe it off and grease it to just about the right extent, and as the end becomes frayed or dirty it can be trimmed off.

Too much oil or grease will cause the brushes to flash, long yellow sparks being thrown out from under the brush; at each point where a spark appears a black ring will form around the commutator, which should be wiped off.

2380. Carbon brushes should not be used on machines of over 10 or 15 H. P. capacity if of low voltage, i. e., 125 volts or less, as their high resistance will cause heating, owing to the large currents required. In any case they should be carefully fitted to the commutator, and examined from time to time to see that the bearing surface (of the brush on the commutator) is as great as the size of the brush will permit. When taken out after running for some time the end of the brush should look smooth and glossy; if rather rough, grayish in color, and gritty to the touch, the carbon is "hard," and should be discarded.

It often improves a carbon brush to soak it in oil or

vaseline, over night. If vaseline, which is better than oil, is used, it should be kept warm enough to be liquid by setting it on top of the boiler or a steam pipe.

Metallic brushes are made of strips of copper, bundles of copper wires, or, more frequently, copper gauze folded into shape and stitched. Those made of strips or wires are very liable to have the edges or ends of the laminæ fused together by sparking, forming hard points that cut the commutator. Whenever this occurs they should be taken out and the ends trimmed off. To get them to the proper bevel, so that they will rest evenly on the commutator at the proper angle, it is customary to use a "filing jig," which consists of a block of steel with a hole through it the size of the brush, and with one end beveled off to the proper angle and hardened. The brush is placed in the jig with the end projecting a little from the beveled face, and clamped in position by a thumb-screw. The end of the brush may then be filed or ground down flush with the face of the jig, thus giving it the correct bevel.

Metallic brushes should not be allowed to become filled with oil or dirt; if they get in this condition they may be readily cleaned with benzine or kerosene. If a commutator becomes very dirty it may be cleaned in the same way, when the machine is not running.

This is preferable to sandpapering so long as the commutator is smooth and round; sandpapering should only be resorted to when the commutator is rough, and not even then if there is a high bar or "flat," for in that case the only remedy is turning down the commutator. (See Art. **2366.**)

2381. If short-circuits or open circuits develop in the armature winding after the machine is in operation, they may be detected and remedied in the manner described in Arts. **2369, 2372**, and the following:

In dynamos a break in the (shunt) field circuit will simply cause the dynamo to cease generating, and the break may be found as previously described. In shunt motors,

however, a break in the field circuit will cause an excessive current to flow through the armature, and if the motor is not loaded it will speed up excessively.

If the motor circuit is properly protected by fuses (Art. **2344**) this excessive current will probably do no further damage than to blow the fuses. If not so protected the armature will be overheated and the insulation damaged or destroyed. The break in the field circuit may be found as previously described. (Art. **2367**.)

The overheating of the insulation of an armature or field coil may be readily detected by the smell.

If the coil is new and is not much overheated, the smell will be that of hot shellac; but if old, or if the coil is much overheated so as to char the insulation, the smell is very peculiar, and once experienced, will not be forgotten. It is something like the smell of a strong solution of soot in rain-water. It is usually present to some extent in machines which have been running a long time, especially if their normal working temperature is high. Whenever this peculiar smell becomes apparent the electrical machinery should *at once* be examined for some overheated part, which may be a field coil, the armature winding as a whole, or a short-circuited coil in the armature.

When the insulation of any part of a dynamo or motor has become badly charred, the part is said to be *burned out*; a burn-out requires that the part affected be replaced. A short-circuited armature coil will usually burn out in a very short time if not attended to (see Art. **2370**); with short-circuited field coils it is the *good* coil that burns out (see Art. **2374**), so that in case a burn-out of one of the field coils occurs before the trouble is located, the other coils should be examined for the cause of the trouble.

REPAIRS.

2382. In case of accident to parts of the machinery it is sometimes very convenient to make repairs on the spot, saving the time lost in sending the injured apparatus to the makers.

Shunt-field coils, especially of the smaller sizes, may be readily rewound in a lathe. In rewinding such a coil the damaged wire and insulating material should be carefully removed, noticing while so doing just how they are disposed in the coil, the thickness and character of the insulating material at different points, especially on the heads and barrel of the spool, and the manner in which the leads or terminals of the coil are attached to the winding, and brought out.

The size of the wire and character of its insulation (i. e., whether single or double-covered with cotton or silk) should also be carefully noted.

When rewinding the coil all of these features of the old coil should be duplicated. The number of turns of wire in the new coil should be as nearly as possible the same as in the old; this may be arrived at nearly enough by weighing the old coil before stripping off the winding, and bringing the new coil up to the same weight.

If necessary to make a joint in the wire, the ends of the wires should be rubbed bright with fine sandpaper twisted firmly together and soldered with a hot iron, using *only* resin as a flux. Only solder enough should be left on the joint to make the connection between the wires solid. The joint should then be covered with extra insulation, such as silk, cotton, or adhesive tape. All projecting ends of wire or drops of solder must be removed from the joint, or they will pierce the insulation and make contact with neighboring wires.

2383. Armature coils require more care and experience in rewinding, so that their repair should not be attempted except in the case of the very simple forms of ring armatures, when a coil may be removed and replaced without disturbing in the least the other coils or connections.

If it is decided to rewind a damaged coil the binding wires should first be removed, by filing them through at some point where the winding will not be injured. The number, size, and material of the wires in each band, and

the character and thickness of the insulation used between the bands and the winding, should be carefully noted.

The damaged coil should then be carefully disconnected from the others and removed, noting the exact number and arrangement of the turns in the coil, the thickness, character, and location of whatever insulation is used, and the method of bringing out the leads of the coil and connecting them to the commutator or the rest of the winding. The length of the piece of wire removed should be measured, and a new piece, a little longer than the old, cut for the new coil, of the same size wire and the same kind of insulation.

The new piece of wire should be carefully wound in place of the old coil, duplicating it in every feature, taking great pains not to kink the wire or bruise its insulation in the operation. It may be necessary for an inexperienced hand to make two or three trials before the coil is successfully rewound.

When complete the binding wires should be replaced, and the coil tested for grounds by the method illustrated in Art. **2376**, before connecting it to the commutator. If free from grounds it should be connected up, the heads on the armature replaced, and the armature put in its frame and tested for short-circuits.

In replacing binding wires they should be subjected to a considerable tension, so that when they expand as the armature heats up they will not become loose. They should be soldered together quickly with a very hot iron, using again only resin as a flux.

2384. Many makers balance their armatures by means of small masses of solder secured to the binding wires. If these binding wires are replaced the armature must be rebalanced in order that it may run without excessive vibration.

For this purpose two iron or steel ways should be provided from $\frac{1}{8}$ to $\frac{3}{8}$ in. wide on the upper edge and 12 to 18 in. long, depending upon the weight and size of the armature to be balanced. These ways should be true and straight,

set up level, and at such a distance apart that the journals of the armature shaft will rest upon them.

To balance the armature it should be placed upon the ways, when it will turn over until the heavy side is beneath. A small weight (a piece of solder, for instance) should then be temporarily fixed to the upper part of the armature, which should then be just started in motion by the hand. It will then settle in some new position, when another weight should be temporarily placed on the armature, or a little of the other weight removed, according to the judgment of the workman. This operation should be continued until the armature shows no decided tendency to remain in any one position, when the weights may be permanently fastened in place.

The method of repairing broken leads, connections, and the like may be readily seen from the nature of the fault. In any kind of a repair the object in view should be to replace the defective part so that it will be exactly as it was before being damaged.

CONSTANT-CURRENT DYNAMOS.

2385. All of the preceding remarks concerning constant-potential dynamos (except those concerning shunt-field coils) apply equally well to constant-current dynamos of the closed-coil armature type, and they should be installed and cared for in the same manner, and are subject to the same faults and injuries. In addition, whatever controlling apparatus is used should be kept in good working order, and well oiled, especially when first started. The moving parts should not be allowed to get gummed up with oil and dust, and should move freely without sticking.

Machines of the open-coil type, of which there are but few makes, usually require special precautions in setting the brushes, adjusting the controlling apparatus, etc., and their manufacturers supply pamphlets in which these, and directions for otherwise adjusting and operating the machines, are clearly set forth.

Open-coil machines, when running normally, always show

a bluish spark from $\frac{1}{4}$ to $\frac{1}{2}$ in. long, but the commutators are so designed that this spark does no harm, and, in fact, is an indication that the machine is running properly; any fault in the machine is usually indicated by some change in the character of the spark.

ALTERNATORS.

2386. Alternators require no special directions for setting up, other than those given for constant-potential machines. The way in which the exciter (see Art. **2320**) is to be set up will be evident from the construction of the machine.

Alternators should be given a trial run, without load, to make sure that the bearings are in good condition, and to locate short-circuits and open circuits in the windings. Short-circuits manifest themselves just as they do in direct-current machinery, and may be similarly located (Art. **2369**). If the armature is open circuited it will simply refuse to show any E. M. F. Some alternators have the armature divided into two parallel circuits, and an open circuit in one of these will not affect the E. M. F. at no load. When the load is put on, however, the open circuit will be indicated by excessive heating of the armature, excessive drop in the voltage, and generally by a fluctuation in the stray field similar to that produced by a short-circuit.

An open circuit in the field winding may be easily detected, since the machines are separately excited. The exciter being a constant-potential direct-current machine, its faults or troubles may be detected as already described.

In setting the brushes those on the collector rings require no particular adjustment, except to see that they bear evenly and firmly on the surface of the rings.

The brushes on the commutator should be set opposite one another, and at such a point that the insulation between two segments is under a brush at the moment that the armature coils are in the position of least action (see Art. **2320**). It should be remembered that in the *drum-wound*

alternators, or those in which the coils are wound around teeth, the position of least action occurs when the coil or tooth is wholly under *one* pole piece. (See, also, Arts. **2309** and **2321**.) When running under load these brushes may need a slight adjustment forwards or back, as indicated by the sparking.

The operation of multiphase machines does not differ from that of ordinary alternators, except that they are not usually compound-wound, so that there is generally no commutator to require attention. On account of the simplicity of the winding and connections, alternators are, as a rule, less subject to electrical troubles than are direct-current machines; but as the voltage used is usually high, any accident which does occur is generally quite disastrous. For the same reason, cleanliness is a most important feature in the care of alternating-current machinery, and oil from the bearings must be rigidly excluded from the armature and field windings.

ALTERNATING-CURRENT MOTORS.

2387. Synchronous motors are used only in the larger sizes, whose installation and preliminary operation are in the hands of experienced men who thoroughly understand the special features of starting and operating this class of machinery, and who make sure that these features are understood by the persons who are to have the machinery in charge. The rotary-field motors, however, are being installed in all sizes and places; but they require no special directions for operation, being usually even simpler than a direct-current motor.

The device for cutting out the starting resistance (see Art. **2357**) should work freely and make good and firm contact. If at any time the motor should become overloaded and stop, the current should be at once cut off, and the machine turned over by hand with the load removed as far as possible, to see if the overload was due to excessive friction of the bearings; if this is the case the trouble may be remedied as already described.

If found to be in the machinery the motor is driving, a part of the load should be removed and the machine started again.

If the current is left on the machine after it has stopped from overload, the field coils will become overheated and will eventually burn out.

ELECTRICAL MACHINERY IN GENERAL.

2388. As before remarked, cleanliness is the essential feature in operating electrical machinery successfully, and care in this respect will usually prevent the development of serious trouble. Most of these troubles manifest themselves by excessive heating of one or more parts of the machine; so, if at any time more than the normal amount of heating is noticed in any part of the machine, it should be at once examined, as already described, to discover the source and nature of the fault.

Noise is usually another indication that all is not working well, and all rattling, pounding, or squeaking should be investigated and the fault corrected, if possible. Carbon brushes which bear radially upon the commutator are the source of much noise, but with a glazed smooth commutator and well-fitting brushes this need not occur. A newly-turned commutator will cause the brushes to "sing," as it is never exactly true, owing to the "jumping" of the tool in passing from segment to segment in turning it down.

To prevent unpleasant and even dangerous shocks, all electrical apparatus in operation should be handled with *one hand* only; that is, only one part of the machine should be touched at a time, and then only when the surrounding floor and the shoes of the operator are dry, or a dry piece of board is used to stand upon.

The shock of any circuit of less than 500 volts E. M. F. is not dangerous of itself to a person in good health, but may often cause one to lose his balance and fall upon or into moving machinery, and cause serious injury. The voltage of most alternators and the larger constant-current machines is high enough to give a fatal shock in most instances. If

necessary to expose one's self to the liability of receiving such a shock, a pair of rubber gloves worn on the hands will afford protection; but even then care should be exercised in handling the wires or in touching "live" parts of the circuit.

NOTE.—In case a person has been exposed to a shock so violent as to cause insensibility, he should be treated as if drowned; that is, his breathing should be kept up artificially, by alternately pulling and releasing the tongue, and raising and depressing the arms, with slow, rhythmical motions, until a physician can take charge of the case.

All permanent connections around a machine should be kept firmly fastened, as a loose connection will frequently be the cause of much more serious trouble. Whenever convenient these connections should be soldered, and large wires and cables should be provided with brass or other metal tips or terminals, with which the necessary connection may be made.

It is not possible to lay down a set of rules by which all the troubles with dynamo-electric machinery that may occur may be located and obviated, but from those given, and from a knowledge of the principles under which these machines operate, most of the difficulties ordinarily met with may be overcome if *good judgment* and *common sense* are also used.

SWITCHBOARDS.

2389. The switchboard is a necessary part of every plant. Its object is to group together at some one convenient and accessible point the necessary apparatus for controlling the dynamos and distributing the current to the various circuits, and the safety devices for properly protecting the lines and machinery. The number and kind of these appliances depend upon the character and size of the plant.

There are four general types of switchboards in use, as follows:

1. Switchboards for arc-lighting circuits using constant currents.
2. Switchboards for incandescent-lighting circuits using direct currents at a constant potential.

3. Switchboards for incandescent-lighting circuits using alternating currents at a constant potential.

4. Switchboards for electric railroads using (ordinarily) direct currents at a constant potential.

Switchboards of all kinds are frequently made of wood, but this is not desirable on account of the danger from fire. The least dangerous type of wood switchboard is the skeleton type, which is merely an open framework of hard wood beams, or joists, with its members so spaced as to properly support the instruments on the board. When properly built this form of board is safer than any other wooden board, and in many places is the only type of wooden board allowed by the fire underwriters.

Switchboards of slate, marble, or soapstone are coming into more extensive use on account of their safety and appearance. These are made up in panels, or slabs, of convenient size, and from $\frac{3}{4}$ " to 2" thick, according to circumstances. Being in themselves insulating material, the switches, etc., are usually mounted directly on the face of the board.

When all the wiring and connections are upon the face of the board, it may be mounted directly on the wall of the room; but if the wiring is all on the back of the board, as is the general custom, it should be placed at least two feet from any wall, so as to give a space for examining and making alterations in the wiring. A clear space of at least two feet should also be left between the bottom of the board and the floor.

SWITCHBOARDS FOR ARC-LIGHTING CIRCUITS.

2390. This type of board is one of the simplest. Arc-lighting plants usually consist of several dynamos, of which any one must be capable of being switched into any one of several circuits. This may be accomplished in a variety of ways, but there are two in general use.

In the first method the terminals of the various dynamos are led to a row of contacts on the bottom of the board. The terminals of the various circuits are led to a similar row

(or rows) higher upon the board, and connection between the various members of the two rows is made with flexible insulated cables, provided with tips which are so arranged that the connection may be readily made.

To facilitate changing over from one circuit to another, the contacts are usually made double, so that two cables may be connected to the same point if desired. The form of the contact varies with the different manufacturers, but is usually of the plug type; that is, the tip on the cable is in the form of a cylindrical brass plug, provided with a wooden or rubber handle, and the contact on the board is a short brass tube into which the plug fits. This tube is generally split to ensure firm contact, and often a spring latch is added to hold the plug in place when inserted.

Fig. 925 represents one form of this sort of board arranged for two dynamos and four circuits. Each terminal is double,

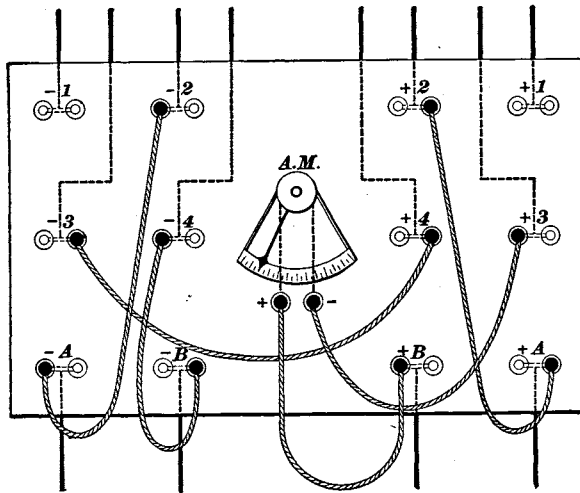


FIG. 925.

and those for the dynamos are arranged in the lower row, and marked $+A$, $-A$, $+B$, and $-B$, each dynamo being distinguished by its letter (A or B). The terminals of the four circuits are arranged in two rows at the top of the board, and are marked $+1$, -1 , $+2$, -2 , $+3$, -3 , $+4$, and -4 ,

each circuit being distinguished by its number (1, 2, 3, or 4). The ammeter *A. M.* is mounted in the center of the board, and provided with terminals (marked + and -) to enable it to be connected into any circuit, to determine if the current of that circuit is of normal strength. In this figure the circuits are connected up as follows: Circuit 1 is "dead"; circuit 2 is on dynamo *A*, and circuits 3 and 4 are in series with each other, and are on dynamo *B*. The ammeter is also in this circuit.

2391. The necessity for the two contacts at each terminal is obvious when it is considered that the external circuit of a constant-current dynamo should never be opened while the machine is running, because that would be equivalent to increasing the resistance of the external circuit, which would cause the E. M. F. to rise so suddenly as to endanger the insulation, besides making a long and vicious arc at the switchboard. It is often necessary to cut in or out circuits, machines, or the ammeter without stopping the plant, and, as stated above, without opening the circuit; with the two contacts at each terminal, and by the use of a sufficient number of connecting cables, these various changes in the connections may be easily made.

For example, suppose it is desired to connect the ammeter (in the above figure) into No. 2 circuit. To disconnect it from circuits 3 and 4, a cable is plugged in between the vacant contact at + *B* and that at + 3; this short-circuits the ammeter, which may then be disconnected from terminals + *B* and + 3, and connected to terminals + *A* and + 2. Then, on removing the cable directly connecting + *A* and + 2, the ammeter is in No. 2 circuit.

Again, suppose it is desired to connect No. 1 circuit in series with No. 2, without shutting down either the dynamo or No. 2 circuit. The first step would be to connect terminal + 1 with terminal + 2, then terminal + *A* with terminal + 1. These two make the same connection as the cable directly connecting terminal + *A* and terminal + 2, and this latter may be removed without affecting the circuits any.

Terminals -1 and $+2$ are now connected together, and the connection between terminals $+1$ and $+2$ removed, throwing the two circuits (Nos. 1 and 2) in series.

An examination of the board and a little practice in "plugging in" circuits when the dynamos are not running, will soon enable the operator to make any desired combination at will.

2392. In the second method the cables hanging across the front of the board are done away with, connection being made by means of plugs. This is accomplished by means of two groups of contacts, arranged in two parallel planes a little distance apart. The contacts in one group are divided into pairs of horizontal rows, each pair being connected to the terminals of one of the dynamos; the contacts of the other group are divided into pairs of vertical rows, each pair being connected to one of the circuits. The contacts are directly opposite each other, and the connection between any dynamo contact and any circuit contact is made by a long brass plug which is pushed through the outside contact to the inside.

Fig. 926 is a diagram showing the connections of this form of board arranged for four dynamos and four circuits. The contacts in the front board are connected to the dynamo terminals, and those on the back board to the circuit terminals, as described above. It will be seen that owing to the way the connections are arranged, any dynamo may be connected to any circuit by simply pushing a plug (P , P , etc.) through the contacts connected to the dynamo that correspond in position to those of the circuit it is desired to connect.

The back or *circuit* board is provided with an extra row of contacts at the bottom, by which circuits may be connected in series, using for the purpose cables with suitable terminals similar to those used for connections in the first form of board described. One of these cables (called a *jumper*) is shown in the figure at J . In the diagram, circuit No. 4 is represented as being connected to dynamo B , and

circuits Nos. 2 and 3 are in series and connected to dynamo *A*. Circuit No. 1 is "dead."

The method of connecting from one circuit to another,

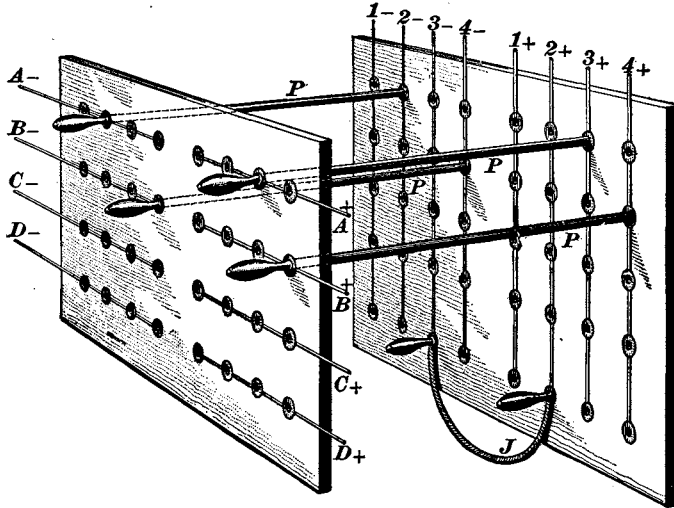


FIG. 926.

etc., will be evident from an inspection of the diagram (Fig. 926).

2393. As constant-current dynamos are self-regulating, there is no liability of an excessive current flowing through any circuit, so that there is no need of safety devices to prevent the damage which such excessive current might do. The considerable length of overhead wire which is used for arc-light circuits is exposed to the high potentials of lightning discharges, which are liable to puncture the insulation of the dynamo windings in the effort to get to the ground. To prevent this from occurring, apparatus called **lightning arresters** are used.

The simplest form of lightning arrester consists of a spark gap, or narrow space between the edges of two notched carbon or metal plates, one of which is connected to the line, the other to the ground. When the line becomes charged with atmospheric electricity (lightning) which is of the

nature of static electricity, and therefore of very high potential, it is discharged by the lightning jumping across this narrow gap and passing into the earth. With this form of arrester, however, the dynamo current can follow the arc of the lightning discharge, and if the line happens to be grounded elsewhere, the current will flow through the circuit thus formed, which now presents a comparatively low resistance, and the arc will burn and destroy the arrester.

To prevent this many forms of lightning arresters have been constructed, in which the two plates between which the arc may form are suddenly moved apart whenever such an event takes place, thus rupturing the arc. Most of these are quite complicated, and are seldom sure to act; the *Thomson* arrester, however, performs the same office without moving parts, by taking advantage of the mutual reaction between a current and a magnetic field.

This arrester is illustrated in Fig. 927. The spark gap across which the lightning charge jumps exists between the

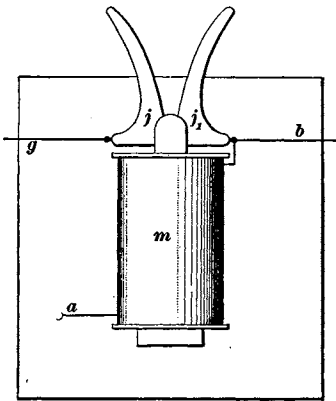


FIG. 927.

two curved jaws j and j_1 , jaw j being connected to the ground at g , and jaw j_1 being connected to the line at b . The gap between these jaws is not uniform in width; the lightning discharge jumps across at the point where the jaws are nearest, and this point is situated between the poles of an electro-magnet m , which is in series with the main or dynamo circuit, which is connected at a . Any current

which passes across the gap between the jaws j and j_1 is, therefore, in the field of this magnet, whose polarity is so chosen that the reaction of the current on the field repels the current out towards the tips of the jaws, thus making its path so long that it cannot follow it, and the arc is, therefore, "blown out," or ruptured.

2394. The windings of the electro-magnet serve another very important purpose. Without them the lightning charge would have no particular preference for the spark gap of the arrester over the gap (insulation) between the winding and the frame of the dynamo, but as these magnets have considerable self-induction, the sudden rush of the lightning charge is prevented from passing through the magnet coils, and is, therefore, forced to pass across the spark gap in the arrester.

All good lightning arresters should have a **choking coil**, as a coil is called which is inserted in a circuit merely for the effect of its self-induction or the obstruction it offers to rapidly changing currents. It should be remembered that the best arresters are useless unless their connection with the ground is carefully and thoroughly made, and unless they are carefully installed.

The usual location for lightning arresters is at the point where the circuits enter the station, one arrester being placed in each side of each circuit. A common ground connection will do for the entire bank of connectors, if the number does not exceed ten. This ground connection should be of two or three strands of No. 6 or No. 8 (B. and S. gauge) wire, run with as few bends and turns as possible to a thorough ground connection, which should be either a large plate of copper buried in an excavation which has been carried down to *moist* earth, and surrounded with coke or charcoal, or a piece of 1" or 1½" iron pipe at least ten feet long, driven its full length into the ground, and provided with a brass plug in the top, to which the ground wire is attached. A supplementary connection may be made with a system of water piping, if desired.

2395. In using arc (constant-current) switchboards, it should be remembered that it is dangerous to break the circuit of a dynamo, while it is safe to short-circuit one. Breaking the circuit is liable, from the sudden rise in the potential, to puncture the insulation where it is weakest, on the line or in the machine, causing a ground. (See Art. **2391.**)

Lines should be tested daily, when not in operation, for open circuits and grounds. A rough way of making such a test is by means of a magneto (Art. 2245) which will show the presence of either an open circuit or a ground, but will not locate them from the station. Some manufacturers of arc-lighting apparatus furnish with their switchboards appliances for locating the position of a ground with considerable precision, which greatly facilitates its removal.

SWITCHBOARDS FOR DIRECT-CURRENT INCANDESCENT-LIGHTING CIRCUITS.

2396. Incandescent lamps are usually operated in parallel, at a constant potential. When direct currents are used the potential on a single circuit is seldom greater than 125 volts, and as each 16 candle-power lamp takes nearly .5 ampere at this voltage, the volume of current is considerable if a large number of lamps is operated. Consequently, the fittings, switches and appliances on an incandescent-circuit switchboard are of more massive construction than those for arc-light circuits.

Direct current for incandescent lighting is distributed according to one of two general systems—the **two-wire** and the **three-wire systems**.

In the two-wire system all the lamps are connected in

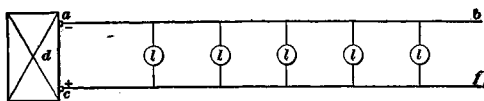


FIG. 928.

parallel on a single circuit, or set of circuits, there being but two wires to each circuit, the wire which carries the current to the lamps being considered positive, and marked + in Fig. 928, and the wire carrying the current from the lamps back to the dynamo, which is called the negative, and is indicated by the sign -. The two-wire system is represented in Fig. 928, where *d* represents the dynamo which supplies the current to the lamps *l*, *l*, *l*, etc., by means of the two mains *a b* and *c f*. It will be seen that in this system each lamp or other device using the current is independent of the

others, and may be turned off or on without affecting them. The current may be supplied from one dynamo or from several connected in parallel.

In the three-wire system, illustrated in Fig. 929, two dynamos d and d_1 are necessary.

These are connected in series as represented, and a main $a b$ led out from the $-$ terminal of one machine, and another $c f$ from the $+$ terminal of the other machine. A third main $e h$ is led out from the junction of the two machines, and it is between this main, called the *neutral* main,

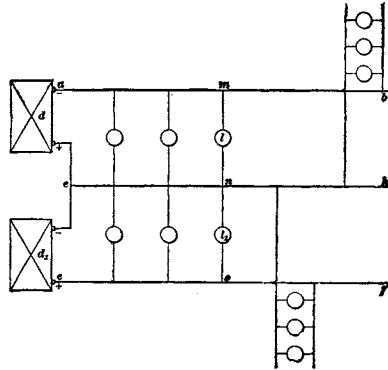


FIG. 929.

either of the other two that the lamps or groups of lamps are connected in parallel as shown.

If the number of lamps connected between the neutral wire and either the $+$ or the $-$ main is the same, no current will flow from the dynamo through the neutral wire, since the current which flows through the lamps on one side is just that necessary for the lamps on the other, and it will flow through them; but if a few more lamps are connected in on one side than on the other, then the *excess* of current required for the greater number of lamps over that required for the lesser will flow through the neutral wire.

If the lamps are so grouped that there will always be about the same number burning on each side of the neutral wire, only a small current will flow through it, and it may, therefore, be of much smaller wire than the $+$ and $-$ mains, although it is usually made the same size. The three-wire system requires at least two dynamos, although any number of pairs of machines may be used.

The exact arrangement of switchboards for incandescent-lighting circuits varies with the skill or judgment of the designer, and the requirements of each case.

In general, however, the same apparatus is used in all boards, with about the same general arrangement, and a description of these general features will answer for almost all switchboards for either the two or three-wire method of distribution.

2397. Regulating Devices.—These consist chiefly of rheostats, or resistance boxes, one being included in the shunt-field circuit of each dynamo. The construction varies largely, the most usual, perhaps, being a box containing coils of German silver or tinned iron wire, which are connected at various points to contact segments, over which a traveling contact arm moves and cuts in or out the resistance as desired. (See Art. **2182**.) This arm may be operated by a knob or hand-wheel, suitably connected to the contact arm.

The rheostat is usually located on the lower part of the switchboard, so that the operating handle is about $3\frac{1}{2}$ ft. from the floor. It may be mounted wholly on the front of the board, but, unless of extremely neat and compact appearance, it is usually better to mount it on the back of the board, the hand-wheel projecting through the board so it may be operated from the front. In some cases the contact segments and contact arm are mounted directly on the front of the board, connection to the resistance coils being made from the back.

It is usual to provide the resistance box with an "open circuit" point, so that after the contact arm has been so moved that all the resistance is in circuit, further movement breaks the circuit, thus shutting down the dynamo.

2398. Switches.—Switches for incandescent work are usually of the *jack-knife* type, illustrated in Fig. 930. In this form of switch the circuit is made or broken by means of a copper contact blade *k*, which fits between the flexible copper tongues of two contacts, as *c* and *d* or *a* and *b*. These are shown in perspective at *r*. Each contact blade is fitted to a lever *l*, *l*₁, pivoted at one end at *p*, *p*₁, and provided at the other with a handle *h* by which it may be operated.

These switches are provided with one, two, or three blades and sets of contacts, each insulated from the others, and are

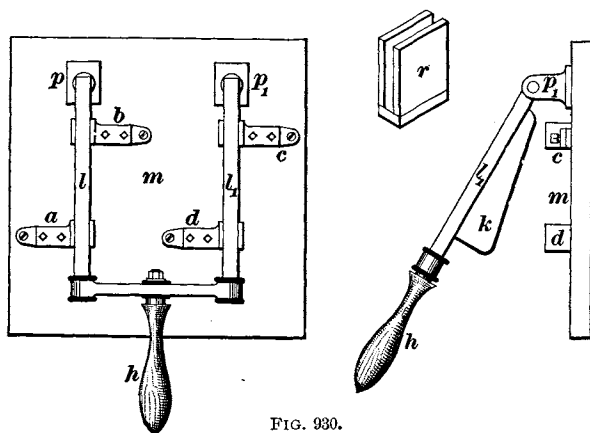


FIG. 930.

accordingly called single, double, or triple pole. These names are usually abbreviated to S. P., D. P., and T. P. Sometimes the levers are provided with two contact blades, one on each side, and a second set of contact points is placed on the other side of the pivot, so that by throwing the switch completely over, that is, moving the handle through 180° , the contact points of this second set are connected together. Such a switch is called a double-throw switch; the switch illustrated in Fig. 930 is a double-pole, single-throw switch.

The contact points are provided with terminals of varying forms, to which the ends of the wires are connected. For use on wooden switchboards, and for separate use, jack-knife switches are provided with a slate or marble base (*m*, Fig. 930), on which all the parts are mounted. On slate or marble switchboards the various parts of the switch are mounted directly on the face of the board, connection with the contact pieces being usually made from the back of the board, so that no wires show in front. These switches should always be mounted on the board with the handle up, so that when opened they will have no tendency to close by their own weight.

2399. Bus-Bars.—When several dynamos are to be run in parallel to supply a common set of circuits, it is customary to run a set of heavy wires or bars across the board, to which the dynamo terminals and the circuits may be attached at convenient points. These are called **bus-bars**. For three-wire systems three bus-bars are necessary, and where two or more *compound-wound* dynamos are run in parallel, for a two-wire system, three bus-bars are also used, two being for the + and — terminals, the third being for the *equalizing connection*, the office of which will be explained later.

Bus-bars are usually made of bare copper rods to facilitate making connection at any desired point, and are mounted either on the front or on the back of the board. When on the front they are polished and add much to the appearance of the board. They are usually supported two or three inches from the face of the board by brass castings, whether on the front or back, and are made of large cross-section, so that the difference of potential between them is practically uniform at all points, even when large currents are flowing through them.

2400. Instruments.—It is very desirable to know the output of each dynamo; consequently, an ammeter should be connected in circuit with each machine. The best forms of switchboard ammeters do not require that the whole current should enter the instrument, but instead only a small part, so that the ammeter may be located at any convenient point on the board, and the current carried to it by means of small wires. This is accomplished by making the ammeter of such resistance that when connected in parallel with a short length of the main conductor, or a specially prepared low resistance inserted in the main circuit, enough current will flow through the instrument to cause it to indicate, on a properly divided scale, the amount of the current flowing in the circuit to which it is connected. This often saves a great deal of wiring on a switchboard.

In incandescent-lighting plants it is very necessary that

the voltage of the circuits be maintained as nearly constant as possible, as variations of more than about 2% from the normal will affect either the life of the lamps or the quality of the light. For this reason a reliable and sensitive voltmeter should be used to indicate the voltage of the various circuits. More than one instrument for the various circuits and dynamos is not necessary, for by the use of a small plug switchboard, which need be only a few inches square, or by the use of a specially devised switch, known as a **volt-meter switch**, a single instrument may be connected at pleasure with the terminals of any dynamo or any circuit, or may be used to indicate the presence of a ground in the dynamos or circuits in the manner described in Art. **2375**.

Switchboard instruments are, as a rule, made with large open scales, so that they may be read at a distance. Voltmeters are often provided with a pointer, which may be moved by hand to the point where it is desired to keep the voltage constant; then, when the voltage is at the proper point, the voltmeter needle coincides in position with this pointer, which may be seen at a greater distance than the scale can be read.

Incandescent lamps are often so arranged on the switchboard as to illuminate the scales of the instruments; if this is the case the lamps should be shaded to prevent the light from shining in any other direction than directly on the face of the instrument, as otherwise they are practically useless.

2401. Safety Devices.—To prevent the possible damage to dynamos and circuits, due to an excessive flow of current from any cause, fuses (see Art. **2344**) are placed in each lighting circuit, also in each dynamo circuit. Those for the lighting circuits are usually placed at the top of the board, and form convenient points to which to attach the circuits. The dynamo fuses are sometimes placed at the bottom of the board, but more often on the connection board of the dynamo. The fuses should be of sufficient size to carry all the current that the various parts of the circuit in which they are connected will safely transmit.

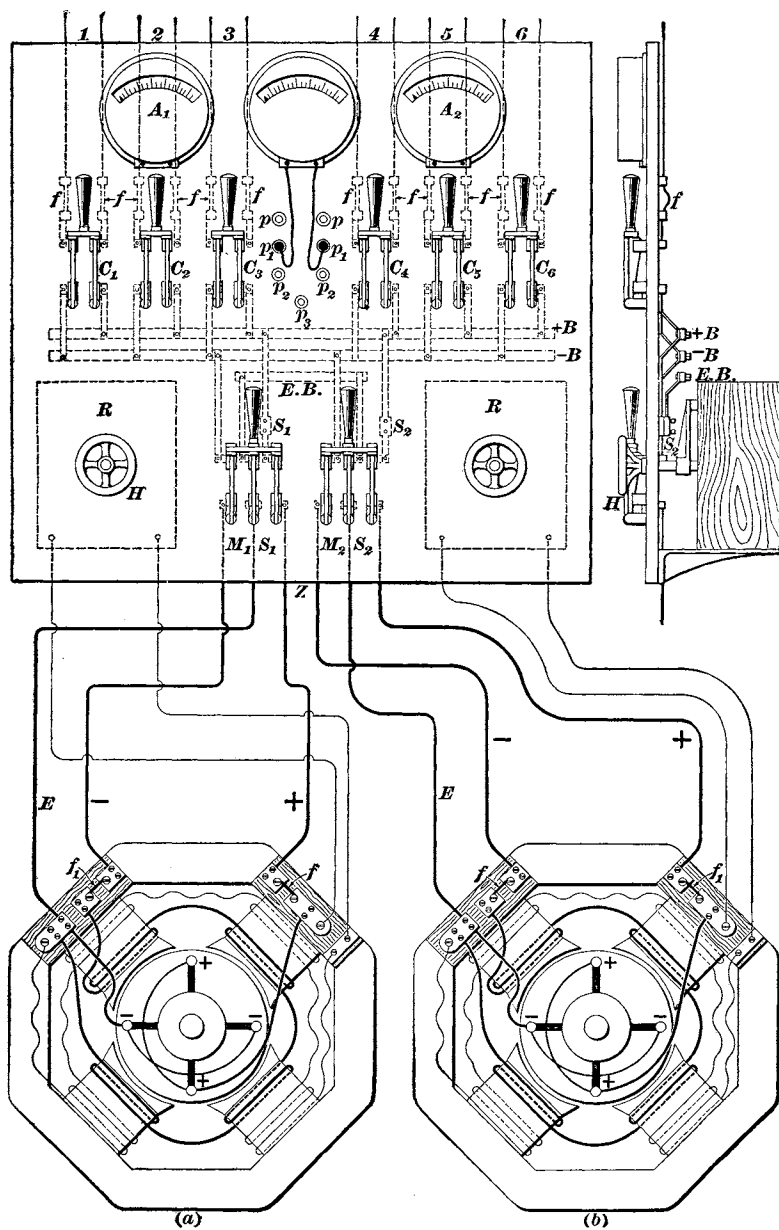


FIG. 931.

The larger sizes of fuses are usually made in the form of strips, of rectangular section, mounted on copper terminals of suitable shape and size to clamp under the binding screws of the fuse block.

The fuse blocks should be located on the back of the board, if possible, for if on the front the board will be disfigured when the fuses "blow" unless they are completely enclosed.

Lightning arresters similar to those described in connection with switchboards for arc-lighting circuits are also used for incandescent circuits, provided any part of the circuit runs out of doors for any distance. They are not usually installed on the switchboard itself, but at the point where the circuits leave the building.

2402. Equalizing Connection.—When two compound-wound machines are connected in parallel by simply connecting the $+$ terminals together, and also the $-$ terminals, each machine will furnish an equal share of the total current at all loads, providing their E. M. F.'s and their internal resistances are always exactly equal. This is seldom the case, however, especially as no two compound-wound machines are overcompounded exactly alike. To enable them to be run in parallel satisfactorily, some device similar to the equalizing connection must be used. This is the simplest of the several methods, and the one most generally used, so the others need not be described.

Fig. 931 shows a switchboard embracing the features previously described, and showing the equalizing connection for running the two compound-wound dynamos in parallel. In this cut two 4-pole compound-wound dynamos (a) and (b) are represented. From the terminal boards of each machine three heavy leads E , $-$, and $+$ are carried to the triple-pole single-throw switches $M_1 S_1$ and $M_2 S_2$. The $+$ lead is connected to the right-hand blade of the switch, the $-$ lead to the left-hand blade, and lead E to the central blade.

It will be seen that lead E is connected to the *armature* terminal on the side that the series coil is connected.

Now, suppose that both machines are running, and that both switches $M_1 S_1$ and $M_2 S_2$ are closed. This connects the positive or $+$ lead of each machine to the bus-bar $+B$, the negative or $-$ lead of each machine to the bus-bar $-B$, and the E lead to the equalizing bus-bar EB . By tracing out these circuits it will be seen that the current from the $-$ bus-bar has two paths open for it to reach the armature brush of either machine, one of which is through the $-$ lead and the series coils of that machine, and the other is through the series coils of the *other* machine and the two E leads.

If both machines are furnishing the same amount of current, there will be no current through the equalizing connection; consequently, the current from each machine will flow through its own series coils alone. If, however, through some change in the load, or from some other cause, the E. M. F. of one machine falls below that of the other, so that it (momentarily) furnishes less current, the drop through its series coils will be less than the drop through the series coils of the other machine, so that some of the current furnished by the other machine will flow through the equalizing connection and through the series coils of the first machine, thus bringing up the E. M. F. of this machine to its proper value, and causing it to furnish its share of the current. When the machines are first connected in parallel their E. M. F.'s are adjusted by the field resistances until the load is equally distributed between them. When this has been done, the equalizing connection will take care of variations in the load.

2403. Referring again to Fig. 931, R, R are the resistance boxes which are included in the field circuits of the two machines, the connections being as indicated. These resistance boxes are mounted on the back of the board, as indicated in the side view to the right, and the contact arm of each resistance box which cuts in or out the resistance is operated by a shaft passing through the board and turned by a hand wheel H .

The bus-bars are located on the back of the board, as indicated, and from them connection is also made on the back

of the board to the lower terminals of the six double-pole, single-throw, circuit switches, C_1 , C_2 , C_3 , C_4 , C_5 , and C_6 . Just above and connected to the upper terminals of these switches are a series of terminals for attaching the fuses f , f , f , etc., one of which is located in each side of the circuits 1, 2, 3, 4, 5, and 6. The main fuses f_1 , f_1 , etc., are located on the dynamo terminal boards.

Above the row of circuit switches are located the instruments, two ammeters A_1 and A_2 , and a voltmeter V . The small leads from the ammeters (not indicated in the cut) are carried down the back of the board and connected to shunts S_1 and S_2 , located in the connection between the + terminals of the switches $M_1 S_1$ and $M_2 S_2$ and the + bus-bar. The ammeters are connected in the + lead of the circuit, because all of the current from one machine does not always pass through the - lead, on account of the equalizing connection. (See Art. 2402.) It will be seen that this method of connecting up the ammeters results in a great saving of connecting wire over the method which requires that the leads to the ammeter shall be of a size sufficient to carry the total current to be measured.

The voltmeter is provided with a pair of leads terminating in plugs, so that it may be connected to any of the plug contacts p , p , p_1 , p_1 , p_2 , p_2 , or p_3 , as desired. These contacts are respectively connected by leads (not shown) on the back of the board, as follows: p p to the lower (outside) terminals of switch $M_1 S_1$, so that when the voltmeter is connected to these terminals it measures the E. M. F. of machine No. 1, whether it is connected to the bus-bar or not; p_1 p_1 to the similar contacts of switch $M_2 S_2$; p_2 p_2 to the bus-bars + B and - B , and p_3 to the ground for the purpose of testing the insulation of the circuits or of the machines.

If desired, lamps may be mounted on the board to illuminate the instruments, and in this case it would be well to supply two for each instrument, and connect one to each of the circuits *outside* the fuses, so that if any fuse should blow, the lamp connected to that circuit would indicate the fact by going out.

2404. The above cut and description show the general arrangement of switchboards for incandescent lighting with constant-potential dynamos. The exact arrangement for any particular case, of course, depends upon the circumstances of that case, and the taste and judgment of the designer of the board, the principal object being to get, first, an economical and convenient arrangement of the necessary apparatus, and second, a neat and symmetrical appearance. In large plants, employing a number of machines, it is more usual to use shunt-wound dynamos, the potential of which is kept constant by means of resistance boxes in the field circuits operated by an attendant who has no other duty.

In isolated plants, such as those in theaters, office buildings, and the like, it is often desirable to run the plant on the two-wire system, but also desirable to have it arranged so that in case of accident to the plant the lighting service can be continued from the mains of some central station, which are quite generally operated on the three-wire system.

To accomplish this three bus-bars are used on the board, and each circuit has three wires, all lights being connected between one or the other of the outer wires and the center one, which is made twice the size of the others. When run as a two-wire system a large single-pole, single-throw switch connects the two outside bus-bars together as one, thus making the two outside wires of each circuit operate as one wire split into two parallel branches.

When it is desired to connect to the three-wire system, this single-pole switch is opened, and the three bus-bars connected to the mains of the three-wire system in the regular way. This is known as the **flexible two-wire system**, and is very useful.

SWITCHBOARDS FOR ALTERNATING-CURRENT CIRCUITS.

2405. Alternating currents are used largely for incandescent lighting in places where the lights are scattered over a considerable area. The current is generated and distributed at a high pressure (usually about 1,000 volts) to

transformers (see Art. **2330**) located at various points near where the lights are to be used.

This distribution being at a constant potential, the switch-board used is not much different in its essential features from that just described for direct currents. The exciter for each dynamo must be provided with switches and a field resistance box on the board; an ammeter is also usually provided, to measure the field current of the alternator. For each alternator there are, therefore, two resistance boxes (one in the exciter field circuit and one in the alternator field circuit) and two ammeters. When several circuits are operated, each circuit is usually provided with a switch, so that in such cases the alternating-current board has somewhat more apparatus than the corresponding direct-current board.

Alternators may be run in parallel, but first must be brought into synchronism (see Art. **2353**). This involves a considerable amount of extra apparatus on the switchboard, and is liable to result in damage to the machinery if not properly done. For these reasons, alternators are seldom run in parallel in this country, except in the large stations. If two or more machines are used, it is customary to divide the circuits into a suitable number of groups, and run each group from one machine; provision is usually made, however, for throwing any group of circuits from one machine to another, generally by the use of double-throw switches.

On account of the above circumstances, the bus-bars used do not serve quite the same purpose in the alternating-current switchboard that they do in the direct-current, as they act only as connectors for the terminals of all the circuits comprising one group, there being, therefore, a pair of bus-bars for each group of circuits.

Instead of measuring directly the E. M. F. of the alternator, it is customary to use, in connection with the voltmeter, a small transformer, which has the same ratio of transformation as those used in the circuits. The secondary of this transformer is connected to the voltmeter, which, therefore, indicates the E. M. F. of the secondary circuits of the lighting system, 50 or 100 volts, or whatever it may be.

The alternating current at the potentials used on the primary circuits will give a dangerous, probably fatal, shock; the switchboard should, therefore, be carefully arranged so as to reduce the liability of accidental contact with any part of the primary circuit to a minimum. The high potential also increases the possibility of destructive arcs at the switch points and between the fuse terminals, when a loaded circuit is broken, so that the length of such breaks should be made great, to prevent as far as possible the occurrence of such arcs.

SWITCHBOARDS FOR ELECTRIC RAILROADS.

2406. Electric railroad systems, like incandescent lighting systems, are operated with constant-potential circuits, usually of about 500 volts potential.

The general features of their switchboards are then similar to those for the lighting systems, some of the details, however, being necessarily somewhat different.

Compound-wound dynamos are generally used, being usually overcompounded from 8 to 12% or more. These are run in parallel, being connected through triple-pole main switches to three bus-bars, as in the lighting switchboard illustrated in Fig. 931.

The current is conveyed to the cars by means of an overhead line supplied by a number of feeders which go out from the station and connect with it at various points, the circuit being completed through the tracks and the ground. The feeders correspond to the various circuits in the lighting system, but are usually connected directly to the proper bus-bar, no switch or fuse being used. The part of the circuit connecting the station with the track or ground circuit is similarly connected to the other bus-bar, an ammeter being usually placed in this circuit to indicate the total output of all the dynamos.

In the circuit of each dynamo, between the main switch and one bus-bar, is connected the ammeter which measures the output of that dynamo, and also a **circuit-breaker**, which is an electromagnetic device for opening the circuit

when the current exceeds a certain limit. This device takes the place of the fuses in the lighting system, and is used because it is much more rapid and certain in its action than a fuse. In case of a bad short-circuit which causes an extremely heavy current to flow, the electromagnetic circuit-breaker operates almost instantaneously, while a fuse requires a certain length of time to heat up to the melting point, which may be long enough to allow some damage being done to the dynamos or engine by the overload.

The electric railroad being much more subject to short-circuits and excessive currents than a lighting system, the use of fuses would require the expenditure of a great deal of time in replacing blown fuses, which is saved by the use of the circuit-breaker, since that requires only the movement of its handle to again make the circuit.

Lightning arresters are provided in railroad as in other electric circuits, and are usually similar in character to those described. One arrester is connected in each feeder circuit, and, as in the arc-lighting system, they are all connected to a common ground connection. In addition to this ground connection, the common connections of all the arresters may be connected to the track or ground bus-bar, but this latter connection should never be used as the only connection to the ground.

2407. It will be seen from these remarks that, in general, the object of a switchboard is to enable each dynamo and each circuit to be treated as separate units; and, further, to admit of connecting up these various units in any combination that the business of the station may demand, with ease and rapidity, and without danger to the machines, circuits, or operator. To accomplish this requires different apparatus and connections for different circumstances, and no general rule can be given for the arrangement of switchboards for even a particular system; but from the statements made, the manner in which the arrangement and apparatus of any particular switchboard serves its purpose should be readily understood after examining it and tracing out the connections.

A SERIES
OF
QUESTIONS AND EXAMPLES
RELATING TO THE SUBJECTS
TREATED OF IN VOL. III.

It will be noticed that, although the various questions are numbered in sequence from **959** to **1273**, inclusive, these questions are divided into six different sections, corresponding to the six sections of the preceding pages of this volume. Under the heading of each section is given, in parenthesis, the numbers of those articles which should be carefully studied before attempting to answer any question or to solve any example occurring in the section.

MACHINE DESIGN.

(ARTS. 1901-2003.)

(959) What procedure is adopted in estimating the cost of making a machine?

(960) What is a shrink rule, and why is it used?

(961) (a) What are chilled castings? (b) What is the chief difficulty encountered in using cast iron?

(962) (a) Name the different kinds of screw threads. (b) Describe the United States standard (U. S. S.) thread.

(963) Calculate the diameter at the bottom of the thread for the following U. S. S. screws: $\frac{1}{2}$ ", $\frac{7}{8}$ ", $1\frac{1}{4}$ ", and 2 " diameter.

(964) (a) Calculate the number of threads per inch for the following U. S. S. screws: $\frac{1}{4}$ ", $\frac{5}{8}$ ", 1 ", and $1\frac{1}{2}$ " diameter. (b) What is the pitch in each case?

(965) (a) What is the object of using multiple-threaded screws? (b) If a triple-threaded screw has a pitch of $\frac{1}{2}$ ", what is the divided pitch?

(966) Why are triangular threads more suitable for fastenings than square threads?

(967) Calculate the nominal diameter of a wrought-iron bolt subjected to a varying tensile stress of 11,800 lb.

SUGGESTION.—See Table 28, for proper factor of safety.

Ans. $1\frac{1}{2}$ ".

(968) Calculate the diameter of the bolt in the last example by taking the value of S_t as 6,000 lb., as recommended in Art. **1935**. Can you suggest any reason why the diameter here obtained should be used instead of that obtained in example 967?

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(969) Find (*a*) the outside diameter; (*b*) the diameter at the root, and (*c*) the number of threads in the nut for a single square-threaded screw to transmit motion to a load of 12,000 lb.

$$\text{Ans. } \left\{ \begin{array}{l} (a) \ 2\frac{1}{2}'' \\ (b) \ 2'' \\ (c) \ 10 \text{ threads.} \end{array} \right.$$

(970) Calculate the various dimensions of a finished bolt and hexagonal nut, with washer, the bolt being $\frac{1}{2}$ " in diameter and 4" long under the head. Make a full-sized drawing showing nut on bolt and the bolt threaded for $1\frac{3}{4}$ " of its length. Show a hexagonal bolt head.

(971) Make a drawing of a wrench similar to that shown at *A*, Fig. 606, which will fit the nut in example 970. Take length of wrench as 16". Draw to a half size scale.

(972) A wrought-iron eye bolt, similar to that shown in Fig. 612, is subjected to a varying tensile stress of 2,500 lb. Calculate the values of *a*, *b*, *d*, and *d*₁. (See Table 28, for factor of safety.)

(973) (*a*) What is the object of using a jam-nut? (*b*) For what reason should the smaller nut be placed at the bottom?

(974) Make a drawing of the locking device shown in Fig. 623 to a full size scale, taking the diameter of the bolt as 1".

(975) What keeps the nut from turning in the devices shown in Figs. 628 and 629? Is not the principle the same in both? If so, why?

(976) Make a drawing of the knuckle joint shown in Fig. 642. Take *d* equal to $1\frac{1}{4}$ ", and make drawing half size.

(977) Calculate the dimensions of an ordinary sunk key for a shaft 4" in diameter.

$$\text{Ans. } 1'' \times \frac{11}{16}''.$$

(978) Calculate the dimensions of a key for a 12" shaft by formula **233**.

$$\text{Ans. } 3'' \times 2''.$$

(979) Calculate the dimensions of a key for a driving pulley on a $2\frac{1}{16}$ " shaft.

$$\text{Ans. } \frac{11}{16}'' \times \frac{7}{16}''.$$

(980) Calculate the dimensions of a feather key for a shaft $1\frac{1}{2}$ " in diameter. Ans. $\frac{1}{4}$ " $\times$ $\frac{3}{8}$ ".

(981) A pulley transmitting 1.85 H. P. is keyed to a $2\frac{7}{16}$ " shaft running at 110 revolutions per minute. Calculate the dimensions of a key for this pulley. Ans. $\frac{7}{16}$ " $\times$ $\frac{1}{4}$ ".

(982) Make a drawing of a rod, cotter, and socket (all of wrought iron) similar to that shown in Fig. 658, assuming that $S_t = 6,000$ lb. per sq. in., and the load or pull on the rod = 7,000 lb. Make drawing half size, and take taper of cotter as $\frac{1}{32}$.

(983) Find the diameter and length of a steel end journal supporting a load of 5 tons. Take S_f as 14,000 lb. per sq. in. and the pressure per square inch of projected area as 400 lb. Ans. 3" $\times$ $8\frac{3}{8}$ ".

(984) What should be the diameter and length of a neck journal for a steel shaft which is subjected to a total load of 15,000 lb.? Take p as 1,200 lb. per sq. in. of projected area and S_f as 14,000 lb. per sq. in. Ans. 2" $\times$ $6\frac{1}{4}$ ".

(985) The diameter and length of a certain journal were calculated to be $1\frac{1}{2}$ " and $2\frac{1}{8}$ ", respectively. For certain reasons it was desired to increase the length to $2\frac{1}{2}$ "; what should be the new diameter? Ans. $1\frac{11}{32}$ ".

(986) An 8" shaft is subjected to a thrust of 15,000 lb. Assuming 6 collars to be used, find the diameter and thickness of each. Ans. $10\frac{1}{8}$ " and $1\frac{3}{16}$ ".

(987) Find the diameter of a cast-iron pivot journal which supports a load of 1,200 lb., and turns at the rate of 90 R. P. M. Ans. $2\frac{7}{16}$ ".

(988) (a) Find the diameter to which a 10" solid steel shaft should be increased in order that it may have a hole through it and still be of the same strength, assuming the hole to be four-sevenths of the outside diameter. (b) What is the diameter of the hole? (c) What is the difference in weights per foot in length of the two shafts?

Ans. $\left\{ \begin{array}{l} (a) 10\frac{2}{3}" \text{, nearly.} \\ (b) 6" \text{, nearly.} \\ (c) 76 \text{ lb.} \end{array} \right.$

(989) (a) Determine the pitch of a screw with triangular threads and a diameter of $3\frac{1}{4}"$; (b) of a screw $7"$ in diameter, with square threads; (c) of a screw $12"$ in diameter, with trapezoidal threads.

$$\text{Ans. } \begin{cases} (a) .3". \\ (b) 1.4". \\ (c) 1.6". \end{cases}$$

(990) (a) In each of the cases of the last example, determine the number of threads per inch. (b) Calculate, also, the diameter of bolt at roots of thread.

$$\text{Ans. } (b) \begin{cases} (a) 2\frac{7}{8}. \\ (b) 5\frac{5}{8}". \\ (c) 9\frac{9}{16}". \end{cases}$$

(991) (a) Explain fully by diagram or otherwise the relation between the angle of the thread, the friction between thread and nut, and the force tending to burst the nut. (b) For what purposes are the triangular, the square, and the trapezoidal threads best adapted, and why?

(992) What should be the diameter of a wrought-iron bolt subjected to a load varying from zero to 15,600 lb.?

$$\text{Ans. } 2\frac{1}{4}".$$

(993) What steady load may be safely carried by two bolts, each $4"$ in diameter?

$$\text{Ans. } 80 \text{ tons.}$$

(994) (a) Calculate the outside diameter of the lead screw of a lathe which transmits motion against a pressure of 3,600 lb. (b) Calculate the necessary number of threads in the nut.

$$\text{Ans. } \begin{cases} (a) 1\frac{3}{8}". \\ (b) 10 \text{ threads.} \end{cases}$$

(995) Design and draw, full size, a finished bolt with square head and hexagonal nut, the bolt being $6"$ long and subjected to a varying load of 3,200 lb.

(996) Calculate the proportions of the locking arrangement shown in Fig. 625, assuming the diameter of the bolt to be $3\frac{1}{2}"$. Draw it half size.

(997) (a) Calculate the breadth and thickness of a sunk key for a shaft $3\frac{1}{2}"$ in diameter; (b) for a shaft $5"$ in diameter; (c) for a shaft $1\frac{1}{2}"$ in diameter.

$$\text{Ans. } \begin{cases} (a) \frac{7}{8}" \times \frac{9}{16}". \\ (b) 1\frac{1}{4}" \times \frac{13}{16}". \\ (c) \frac{3}{8}" \times \frac{1}{4}". \end{cases}$$

(998) A fly-wheel transmitting 1,000 H. P. at 50 R. P. M. is keyed to a shaft 10" in diameter by two steel keys, each 10" long. Calculate the size of the keys. Ans. $2'' \times 1\frac{3}{8}''$.

(999) A pulley keyed to a shaft $4\frac{1}{2}''$ in diameter drives another pulley keyed to a shaft $2\frac{3}{4}''$ in diameter. Calculate the widths and thicknesses of the two keys by formulas **234** and **235**.

Ans. $\left\{ \begin{array}{l} \text{Driving pulley, } 1\frac{1}{16}'' \times \frac{5}{8}'' \\ \text{Driven pulley, } \frac{5}{8}'' \times \frac{7}{16}'' \end{array} \right.$

(1000) Calculate the dimensions of a sliding feather key for a shaft $1\frac{3}{4}''$ in diameter. Ans. $\frac{5}{16}'' \times \frac{3}{8}''$.

(1001) A pulley transmitting 6 H. P. is keyed to a shaft $3\frac{3}{4}''$ in diameter, making 135 R. P. M. Find the breadth and thickness of the sunk key. Ans. $\frac{3}{8}'' \times \frac{5}{8}''$.

(1002) A wrought-iron rod is fastened by means of a gib and cotter into a wrought-iron socket in the same manner as shown in Fig. 656. The rod is to sustain a steady pull of 6,000 lb. Design and make a drawing. Assume a taper of $\frac{1}{32}$, and take S_t as 6,000 lb. per sq. in.

(1003) Two straps each $3\frac{1}{2}''$ wide and $\frac{3}{4}''$ thick are fastened to a rod 3" deep by a cotter and two gibs. Design the cotter and gibs and make a drawing of the arrangement. Taper to be $\frac{1}{32}$. See Fig. 661.

(1004) A wrought-iron rod is fastened by a steel cotter. The diameter of the rod is $2\frac{1}{2}''$. Calculate the dimensions of the cotter. Ans. $2\frac{1}{2}'' \times \frac{5}{8}''$.

(1005) A wrought-iron piston rod is $3\frac{1}{2}''$ in diameter where it passes through the piston. Which method will leave the rod the stronger to resist tensile stress, cutting a standard thread and using a nut, or using a cotter?

(1006) (a) Find the diameter and length of a cast-iron end journal subjected to a load of $2\frac{1}{2}$ tons, assuming the length to be $1\frac{1}{2}$ times the diameter, and the safe stress 4,250 lb. per sq. in. (b) What is the pressure per square inch of projected area?

Ans. $\left\{ \begin{array}{l} (a) 3'' \times 4\frac{1}{2}'' \\ (b) 370 \text{ lb.} \end{array} \right.$

(1007) Find the diameter and length of a wrought-iron end journal bearing a load of 5 tons, assuming the length

equal to the diameter, and a safe stress of 8,500 lb. per sq. in.

Ans. $2\frac{1}{2}'' \times 2\frac{1}{2}''$.

(1008) Calculate the dimensions of a steel end journal subjected to a load of 17,800 lb.; direction, variable. The bearing pressure is not to exceed 750 lb. per sq. in. of projected area.

Ans. $3\frac{5}{8}'' \times 6\frac{1}{2}''$

(1009) Calculate the dimensions of a wrought-iron end journal sustaining a load of 1,750 lb.; direction, constant. The pressure per square inch of projected area is not to exceed 275 lb.

Ans. $1\frac{5}{8}'' \times 4''$.

(1010) Calculate the dimensions of a wrought-iron end journal, assuming the length to be twice the diameter and the bearing pressure not to exceed 550 lb. per sq. in. The load on the journal is 3,750 lb.

Ans. $1\frac{1}{8}'' \times 3\frac{3}{4}''$.

(1011) Calculate the dimensions of the steel journal of a car axle bearing a load of 10,000 lb., which may be considered variable in direction on account of the spring of the car. Speed of car is 40 miles per hour; diameter of truck wheel, $2\frac{3}{4}$ ft., and the allowable bearing pressure is $p = \frac{220,000}{N}$, where N is the number of revolutions per minute. Design and draw the journal.

(1012) (a) Calculate the dimensions of a wrought-iron neck journal, assuming the length equal to $2\frac{1}{2}$ times the diameter. The load is 9,600 lb., variable in direction. (b) What is the pressure per square inch of projected area?

Ans. $\left\{ \begin{array}{l} (a) 2\frac{1}{8}'' \times 5\frac{5}{16}'', \text{ say } 5\frac{1}{4}'' \\ (b) 860 \text{ lb. per sq. in.} \end{array} \right.$

(1013) Find the diameter of a wrought-iron pivot running in gun-metal bearings, the load being 25 lb. and the number of revolutions 3,000 per minute.

Ans. $1\frac{1}{8}''$.

(1014) What should be the diameter of a steel pivot (on gun-metal bearings) carrying a load of $4\frac{1}{2}$ tons and making 65 R. P. M.?

Ans. $4\frac{3}{4}''$.

(1015) A shaft 6" in diameter receives an end thrust of 7,800 lb. on 4 collars. Find the diameter and thickness of collars. Draw the portion of the shaft with collars. Scale $3'' = 1'$.

(1016) Calculate the diameter of a steel engine shaft 8 ft. long carrying a fly-wheel weighing 10 tons; the center of the wheel is 3 ft. from the center of one of the bearings. The engine develops 300 H. P. at 60 R. P. M., has a stroke of 48", and a M. E. P. of 62 lb. per sq. in. Assume $S_s = 9,000$ lb. per sq. in. Ans. $8\frac{1}{4}"$.

(1017) A line-shaft is required to transmit 90 H. P. at 110 R. P. M. The average bending moment, due to weights of pulleys, belt pull, etc., is about $\frac{3}{4}$ of the twisting moment. Assuming a wrought-iron shaft and a safe stress of 7,000 lb. per sq. in., find the diameter of the shaft. Ans. $4\frac{1}{4}"$.

(1018) The inner diameter of a hollow shaft is 6", the outer diameter 13". Find the diameter of a solid shaft of the same material and having the same strength. Ans. $12\frac{1}{8}"$.

(1019) In designing a propeller shaft, it is found that the proper diameter of a solid steel shaft is $16\frac{3}{4}"$. It is desired, however, to make the shaft hollow. Assuming the diameter of the hole to be $\frac{1}{2}$ the diameter of the shaft, find the inside and outside diameters of the hollow shaft. Ans. $\begin{cases} d_1 = 17\frac{1}{8}" \\ d_2 = 8\frac{3}{8}" \end{cases}$.

(1020) Design and draw a universal joint for shafts $1\frac{1}{4}"$ in diameter. Draw full size.

(1021) Design and draw a flange coupling for a shaft $3\frac{1}{4}"$ in diameter. Draw half size.

(1022) Calculate the following for the solid flange coupling of a propeller shaft 11" in diameter: (a) Number of bolts; (b) diameter of bolts; (c) diameter of bolt circle; (d) diameter of flange; (e) thickness of flange. See Fig. 674.

$$\text{Ans. } \begin{cases} (a) \text{ 6 bolts.} \\ (b) \text{ } 2\frac{3}{8}" \\ (c) \text{ } 16\frac{1}{4}" \\ (d) \text{ } 22\frac{3}{16}" \\ (e) \text{ } 3\frac{1}{4}" \text{, nearly.} \end{cases}$$

(1023) A wrought-iron pivot runs at a speed of 600 R. P. M. in gun-metal bearings. The load being 100 lb., what should be the diameter? Ans. 1".

MACHINE DESIGN.

(ARTS. 2004-2074.)

(1024) For what purpose are bearings bushed?

(1025) For what reason are ball and socket bearings used?

(1026) A cast-iron gear makes 120 R. P. M. and transmits 20 H. P. If the pitch diameter is 30", what should be (a) the circular pitch, and (b) the number of teeth?

Ans. $\left\{ \begin{array}{l} (a) \ 1.2401". \\ (b) \ 76 \text{ teeth.} \end{array} \right.$

(1027) Compute the leading dimensions for a spur gear, working under the following conditions: Diameter of pitch circle = 4 ft. 8"; revolutions per minute = 60; horsepower transmitted = 300.

(1028) Suppose a friction wheel faced with wood to drive another 6 ft. in diameter, at 110 revolutions per minute, the force pressing the wheels together being 280 lb. Take f equal to $\frac{1}{3}$ and calculate the horsepower: Ans. 5.864 H. P.

(1029) What is meant by counterbalancing a pulley?

(1030) (a) What is the diameter of wires composing a 1" wire rope containing 42 wires? (b) What is the weight of this rope per foot of length?

(1031) What is the safe load for a crane chain, the links being forged from $1\frac{1}{4}"$ round iron? Ans. 10,312.5 lb.

(1032) When using divided bearings, how should the brasses be divided?

(1033) Design and draw a pedestal similar to the one described in Art. 2014, and shown in Fig. 692, taking d equal to 14", and using a scale of $3" = 1 \text{ ft.}$

(1034) Of what materials are gears usually made?

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(1035) How many arms should be given a gear having a diameter of 56" and a diametral pitch of $1\frac{1}{4}$ "? Ans. 6 arms.

(1036) For what purposes may friction gearing be used?

(1037) When transmitting power by means of a hemp rope, what should be the ratio between the diameter of the pulley and that of the rope?

(1038) What should be the least value for the ratio of the diameter of a wire rope pulley to that of the rope?

(1039) What are gaskets, and for what are they used?

(1040) What are the seats or steps of a bearing, and for what purpose are they used?

(1041) For what purpose are loose disks used in connection with pivot bearings?

(1042) Design a pedestal similar to the one described in Art. **2011**. Take d equal to $3\frac{1}{2}$ ", and use a scale of 6" = 1 ft.

(1043) (a) What is a hanger? (b) A wall bracket?

(1044) A cast gear 44" in diameter is to transmit 21 H. P. when making 50 R. P. M. What should be the least breadth of the teeth? Ans. $2\frac{1}{8}$ ".

(1045) The circular pitch of a 24" worm wheel is .5236"; if the worm has 4 threads, what is the efficiency? Take diameter of worm as $2\frac{1}{2}$ ". Ans. 62.62%.

(1046) (a) Of what materials are belts made? (b) For what situations are rubber belts preferred?

(1047) What should be the least thickness of the rim of a crowning belt pulley having a diameter of 52" and a breadth of 10"? Ans. $\frac{3}{8}$ ".

(1048) The distance between two wire rope pulleys is 420 ft. What will be the deflection of the rope midway between the pulleys, if the rope is $\frac{7}{8}$ " in diameter, is composed of 42 wires, and the tension due to its weight is 2,023 lb.? Ans. 12 ft.

(1049) What is considered to be the greatest safe rim speed of a cast-iron pulley?

(1050) What are the advantages claimed for rope belting ?

(1051) What horsepower may be transmitted by a rope wheel 18 ft. in diameter which is grooved for 24 turns of $1\frac{1}{4}$ " rope ? R. P. M. = 72. Ans. 484.32 H. P.

(1052) The deflection of a $1\frac{1}{4}$ " wire rope having 42 wires is 9 ft. 3"; the distance between the pulleys being 386 ft., what is the tension due to the weight of the rope ?
Ans. 4,511 lb.

(1053) Calculate the dimensions of the plate link gearing chain for a working load of 5,600 lb.

(1054) Design a wall bracket similar to the one described in Art. **2019**. Take d equal to $2\frac{1}{2}$ ", and use a scale of 6" = 1 ft.

NOTE.—Pay particular attention to the last sentence of Art. **2019**.

(1055) A gear-wheel 40" in diameter has 6 arms and a diametral pitch of $1\frac{1}{2}$. The breadth of the teeth being 6", find the dimensions of the arms. Consider the arms as being elliptical in cross-section.

(1056) Power is transmitted by a $\frac{3}{4}$ " iron rope having 42 wires. Find (a) the horsepower transmitted when the speed of the rope is 5,000 ft. per min., distance between pulleys is 425 ft., and the diameter of the pulleys is 13 ft. (b) Find the greatest deflection in the rope.

Ans. $\left\{ \begin{array}{l} (a) \text{ 189 H. P.} \\ (b) \text{ 14.7 ft.} \end{array} \right.$

(1057) How many arms should be given to a 21" gear-wheel having 84 teeth ?
Ans. 5 arms.

(1058) Calculate the size of the tapering arms of a 4-arm pulley, 22" in diameter, and with an 8" face; a double belt is to be used.

(1059) The hub of a split pulley is 7" long and $1\frac{3}{8}$ " thick. If the hub is held by 6 bolts, what should be the diameter of the bolts ?
Ans. $\frac{7}{8}$ ".

(1060) Design the following and draw on one plate :

1. A belt pulley similar to the one shown in Fig. 720. Take diameter equal to 48", face 12", and bore $2\frac{1}{2}$ ". Use a scale of 3" = 1 ft.
2. A foot-step bearing similar to that shown in Fig. 698. Take d equal to 3", and use a scale of 6" = 1 ft.
3. A crane hook similar to that shown in Fig. 735, except that the swivel end shown at A should be used instead of the eye. Take d equal to $2\frac{1}{4}$ ", and use a scale of 3" = 1 ft.
4. A pipe flange as shown in Fig. 736. Take a equal to 12", and use a scale of $1\frac{1}{2}$ " = 1 ft.

NOTE.—The dots in Table 52 indicate that the last dimension above them should be used.

(1061) What is the weight of 875 ft. of $1\frac{3}{4}$ " manila rope ?

Ans. 803.9 lb.

(1062) (a) Calculate the horsepower which can be transmitted by a $1\frac{3}{4}$ " cotton rope at a velocity of 3,800 ft. per minute. (b) What is the horsepower as estimated from the diagram, Fig. 723 ?

Ans. (a) 38.223 H. P.

(1063) (a) What should be the diameter of the wires composing an iron wire rope transmitting 125 H. P. at a velocity of 4,900 ft. per minute? (b) What should be the diameter of the pulley? (c) Of the rope? The rope is to contain 42 wires.

Ans. $\left\{ \begin{array}{l} (a) .0694". \\ (b) 9 \text{ ft. } 10". \\ (c) \frac{5}{8}". \end{array} \right.$

MACHINE DESIGN.

(ARTS. 2075-2131.)

(1064) (a) Why is the initial pressure less than the boiler pressure? (b) For ordinary cases, what per cent. of the boiler pressure may be assumed as the initial pressure?

(1065) Design a cross-head similar to that shown in Fig. 765, for an $8" \times 12"$ engine. Assume that a connecting-rod like that shown in Fig. 760 is to be used, and that its length is to be six times that of the crank. Take diameter of piston rod as $1\frac{3}{8}"$, the steam pressure as 100 lb. per sq. in., and the thickness of the guides as $1\frac{3}{8}"$. Scale full size.

(1066) State the boiler pressures commonly used in the different types of modern engines.

(1067) A plain slide valve is $9"$ long and $16"$ wide. What should be the diameter of a steel stem, if the pressure is 120 lb. per sq. in.?

Ans. $1\frac{1}{4}"$.

(1068) Design a piston similar to that shown in Fig. 751, Art. **2093**, for a cylinder $20"$ in diameter. Take d equal to $3"$, and use a scale of $6" = 1$ ft.

(1069) What is the maximum allowable velocity of steam through the ports?

(1070) A plain slide valve is $6" \times 8\frac{1}{4}"$ and is to be subjected to a steam pressure of 100 lb. per sq. in. What should be the diameter of a wrought-iron stem? Ans. $\frac{3}{4}"$.

(1071) How should the area of the exhaust port compare with that of the steam port?

(1072) The length of a steel piston rod is to be $32"$; size of cylinder, $12" \times 18"$; steam pressure, 100 lb. per sq. in.

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Calculate the diameter of rod to nearest $\frac{1}{16}$ " by (a) formula **300**; (b) by formula **301**; (c) by Art. **2103**. Account for the difference in results.

$$\text{Ans. } \left\{ \begin{array}{l} (a) \ 1\frac{7}{16}" \\ (b) \ 2\frac{3}{8}" \\ (c) \ 1\frac{1}{2}" \end{array} \right.$$

(1073) Determine the data for a simple high-speed automatic non-condensing engine which is to develop 200 horsepower at a piston speed of about 600 feet per minute. Boiler pressure is to be 100 pounds. Take clearance as 8 per cent.

(1074) What should be the diameter of crank-shaft for a $30" \times 60"$ Corliss engine? Ans. $12\frac{3}{4}"$.

(1075) The length of a wrought-iron piston rod for a $38" \times 60"$ engine is to be 79". If the steam pressure is to be 100 lb. per sq. in., what should be the diameter of the rod? Calculate to the nearest $\frac{1}{16}$ " (a) by formula **300**; (b) by formula **301**; (c) by Art. **2103**. Which dimension would you take, and why?

$$\text{Ans. } \left\{ \begin{array}{l} (a) \ 6\frac{3}{8}" \\ (b) \ 6\frac{1}{2}" \\ (c) \ 6\frac{5}{16}" \end{array} \right.$$

(1076) (a) Between what limits does the clearance vary?
(b) What is the piston clearance?

(1077) In well-designed engines, how much should the back pressure be?

(1078) Design a crank similar to that shown in Fig. 748, Art. **2090**, for a $24" \times 52"$ Corliss engine. Use a scale of $3" = 1 \text{ ft.}$

DYNAMOS AND MOTORS.

(ARTS. 2132-2213.)

(1079) Fig. 24 represents a helix of wire around which an electric current is supposed to be circulating in the direction indicated by the arrows. Which of the two ends, *a* or *b*, is the north pole of the solenoid? Why?

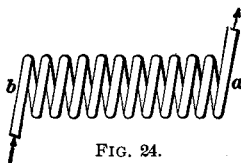


FIG. 24.

(1080) (*a*) What will be the sign of the static charge developed on a glass rod when rubbed with fur? (*b*) On a piece of hard rubber when rubbed with silk? (*c*) On a piece of flannel when it is rubbed against a piece of amber?

(1081) The electromotive force of a battery on open circuit is 20 volts, and its internal resistance is 30 ohms. What will be the strength of current flowing when its poles are connected to an external resistance of 80 ohms? Ans. .1818 ampere.

(1082) The separate resistance of two branches *A* and *B* of a derived, or shunt, circuit are 16.2 and 14.1 ohms, respectively. If the sum of the currents in the two branches is 6.37 amperes, what is the current in each branch?

Ans. $\begin{cases} 2.9643 \text{ amperes in branch } A. \\ 3.4057 \text{ amperes in branch } B. \end{cases}$

(1083) Express the equivalent of 2.33 horsepower in watts. Ans. 1,738.18 watts.

(1084) In a closed circuit, the resistance between two points is 2.3 ohms. (*a*) What current flowing between these points will cause a difference of potential of 58.4 volts?

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(b) What is the power in watts dissipated between these two points? (c) Give its equivalent in horsepower.

$$\text{Ans. } \begin{cases} (a) & 25.3913 \text{ amperes.} \\ (b) & 1482.8521 \text{ watts.} \\ (c) & 1.9877 \text{ horsepower.} \end{cases}$$

(1085) In a voltaic couple of zinc and platinum, which metal will be the negative element? Why?

(1086) The current in a horizontal conductor is flowing from the north towards the south. In what direction will the north pole of a compass needle point if the compass is placed under the conductor?

(1087) Fig. 25 represents a closed circuit consisting of a voltaic battery B and two conductors X and Y , connected in series. The internal resistance of the battery is 17.2

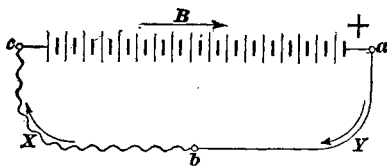


FIG. 25.

ohms, and the separate resistances of the conductors X and Y are, respectively, 8.2 and 11.3 ohms. What is the total E. M. F. in volts generated by the battery if a current of .75

ampere flows through the circuit? Find the difference of potential in volts between a and b , between b and c , and between c and a .

$$\text{Ans. } \begin{cases} \text{Total E. M. F. developed by battery} = 27.525 \text{ volts.} \\ \text{Difference of potential between } a \text{ and } b = 8.475 \text{ volts.} \\ \text{Difference of potential between } b \text{ and } c = 6.15 \text{ volts.} \\ \text{Difference of potential between } a \text{ and } c = 14.625 \text{ volts.} \end{cases}$$

(1088) If the specific resistance of silver is .5921 microhm per cubic inch, find the resistance in ohms of 1,000 feet of a round silver wire .2" in diameter. Ans. .2262 ohm.

(1089) A voltaic battery, whose internal resistance is 36.2 ohms, is connected to a copper wire having a resistance of 21.7 ohms. What is the total electromotive force in volts generated in the battery if a current of .127 ampere flows through the circuit? Ans. 7.3533 volts.

(1090) How many coulombs of electricity pass through a circuit in $2\frac{1}{4}$ hours when the strength of current is 8.32 amperes? Ans. 67,392 coulombs.

(1091) Given, electromotive force = 112.5 volts and strength of current = 12.2 amperes; find the power in watts. Ans. 1,372.5 watts.

(1092) The separate resistances of two branches A and B of a derived, or shunt, circuit are, respectively, 2.4 and 987.3 ohms. What is their joint resistance in parallel? Ans. 2.3941 ohms.

(1093) The resistance of a copper wire is 43.2 ohms at 60° F.; find its resistance at 85° F. Ans. 45.5274 ohms.

(1094) The separate resistances of three conductors A , B , and C are, respectively, 37, 45, and 72 ohms. What is their joint resistance when connected in parallel? Ans. 15.8383 ohms.

(1095) The total resistance of a closed circuit is 49.3 ohms. If the current flowing through the circuit is 2.73 amperes, what is the total E. M. F. in volts developed in the circuit? Ans. 134.589 volts.

(1096) The separate resistances of four conductors A , B , C , and D are, respectively, 3, 19, 72, and 111 ohms; find their joint resistance when connected in series. Ans. 205 ohms.

(1097) (a) What is the total resistance of a closed circuit in which a current of 5.2 amperes is flowing and the total E. M. F. developed is 28.2 volts? (b) If the external resistance is 7 times the internal, what are the separate resistances of each?

Ans. $\left\{ \begin{array}{l} (a) \text{ The total resistance of the circuit} = 5.423 \text{ ohms.} \\ (b) \text{ The internal resistance} = .677875 \text{ ohm, and the} \\ \quad \text{external resistance} = 4.745125 \text{ ohms.} \end{array} \right.$

(1098) How much energy in *joules* is expended in a closed circuit during $1\frac{1}{4}$ hours in which the current is maintained at 14.2 amperes, the resistance of the circuit being 8 ohms? Ans. 7,259,040 joules.

(1099) The resistance of a piece of silver wire is 214 ohms at 82° F.; find its resistance after its temperature has fallen to 50° F. Ans. 200.5608 ohms.

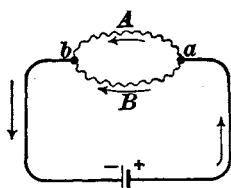


FIG. 26.

(1100) In Fig. 26, the difference of potential between a and b is 11.6 volts. If the strength of the current in branch A is 6.7 amperes, and the strength of the current in B is 4.9 amperes, what is the separate resistance of each branch?

Ans. $\left\{ \begin{array}{l} \text{The separate resistance of branch } A = 1.7313 \text{ ohms.} \\ \text{The separate resistance of branch } B = 2.3673 \text{ ohms.} \end{array} \right.$

(1101) The E. M. F. of a battery is 22.4 volts and its internal resistance is 13.4 ohms. What is the resistance of an external conductor connected to the battery when the current flowing in the circuit is .43 ampere?

Ans. 38.693 ohms.

(1102) What must have been the strength of current in amperes in a closed circuit through which 368,422 coulombs of electricity passed in $4\frac{1}{2}$ hours?

Ans. 22.7421 amperes.

(1103) Find the work done in foot-pounds when a current of 2.4 amperes flows against a resistance of 45 ohms for 50 minutes. Ans. 573,324.48 foot-pounds.

(1104) Given, the electromotive force = 525 volts and strength of current = 12.5 amperes, express the number of horsepower. Ans. 8.7969 horsepower.

(1105) (a) How many watts are dissipated by a current of 110 amperes flowing against a resistance of 4.2 ohms? (b) Give its equivalent in horsepower.

Ans. $\left\{ \begin{array}{l} (a) \text{ 50,820 watts.} \\ (b) \text{ 68.1233 horsepower.} \end{array} \right.$

(1106) The diagram in Fig. 27 represents a circular type of resistance box with coils arranged for a Wheatstone bridge;

X is an unknown resistance. Draw a diagram showing the proper connections of the battery and galvanometer circuits and designate the upper and lower balance arms and the adjustable arm.

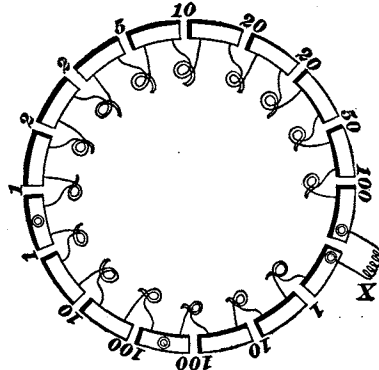


FIG. 27.

(1107) If the resistance of 1,000 feet of round copper wire .1 in. in diameter is 1 ohm, find the resistance of 2,000 feet of square copper wire .1 in. on a side.

Ans. 1.5708 ohms.

(1108) Find the equivalent of 54,200 watts in horsepower.

Ans. 72.6541 horsepower.

(1109) The specific resistance of mercury is 37.15 microhms per cubic inch; find the resistance in ohms of a round column of mercury 72.3" high and .04" in diameter at 32° F.

Ans. 2.1368 ohms.

(1110) The total E. M. F. developed within a battery is 45 volts and the internal resistance of the battery is 33 ohms; find the strength of current flowing when the battery is connected in circuit with a resistance of 30 ohms. Ans. .7143 ampere.

(1111) A voltmeter, $V.M.$, Fig. 28, is connected to the

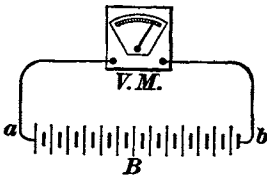


FIG. 28.

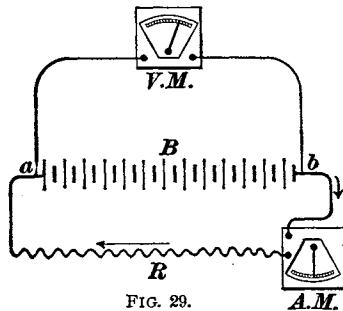


FIG. 29.

poles a and b of a battery B whose circuit is open and indicates an E. M. F. of 24.4 volts. The battery is then connected

in circuit with an ammeter $A. M.$, Fig. 29, and an unknown resistance R . After these last connections are made, the voltmeter indicates an E. M. F. of 18 volts and the ammeter indicates a current of .8 ampere; determine the internal and external resistance of the circuit.

Ans. $\begin{cases} \text{Internal resistance} = 8 \text{ ohms.} \\ \text{External resistance} = 22.5 \text{ ohms.} \end{cases}$

(1112) An E. M. F. of 510 volts is consumed in an electric receptive device and a current of 24.3 amperes is flowing in the circuit; calculate the power in watts supplied to the receptive device.

Ans. 12,393 watts.

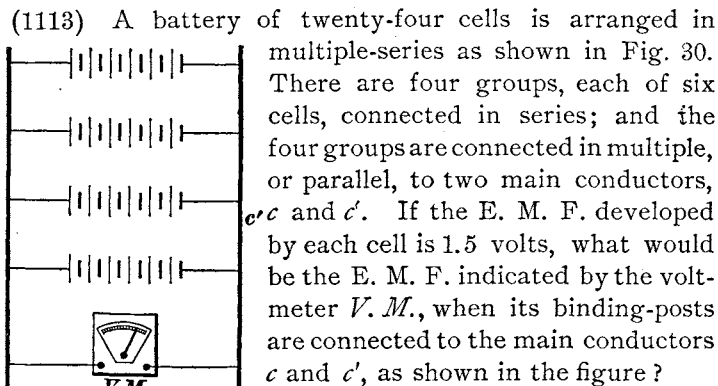


FIG. 30.

(1114) The available E. M. F. developed by an electric source is 250 volts and a current of 65.7 amperes is flowing from it; determine its output in horsepower.

Ans. 22.0174 horsepower.

(1115) A conductor conveying a current of electricity is placed in a horizontal plane pointing north and south. If the north pole of a compass needle tends to point towards the east when the compass is placed directly under the conductor, in what direction is the current flowing in the conductor?

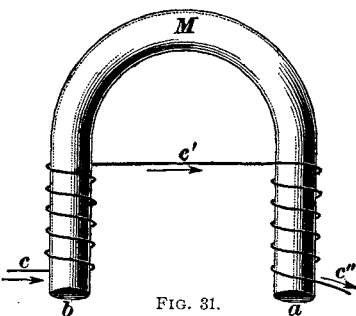


FIG. 31.

(1116) Fig. 31 represents a horseshoe electro-magnet M , around which is wound an insulated conductor $c\ c'\ c''$. If a current circulates through the conductor in the direction as indicated by the arrows, which of the two ends, a or b , is the south pole of the magnet?

(1117) A piece of ivory is rubbed with silk, and a stick of sealing-wax is rubbed with fur; would the ivory and sealing-wax tend to attract or repel one another when brought near together, and why?

(1118) The two voltaic elements in a cell are iron and graphite. Which of the exposed ends of the two elements forms the negative pole or electrode of the cell, and why?

(1119) Give the names of all the known magnetic substances.

(1120) A compass C is placed between the north and south poles of two magnets, as shown in Fig. 32. Towards which pole of the compass needle tend to point, and why?

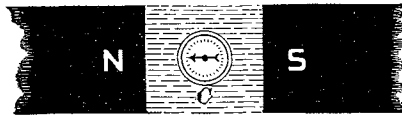


FIG. 32.

(1121) A compass C is placed alongside of a bar magnet opposite the neutral line, as shown in Fig. 33. Towards which pole of the magnet will the south pole of the compass needle tend to point, and why?



FIG. 33.

(1122) A conductor conveying an electric current is placed in a horizontal plane pointing north and south, and the south pole of a compass needle tends to point towards the east when the compass is placed directly over the conductor. In which direction is the current flowing in the conductor? Give reasons.

(1123) In an electro-magnet, Fig. 34, the coil of wire is wound around an iron core in a right-handed spiral. Through which end, a or b , of the wire must the current enter in order to produce the polarity as represented in the figure? Why?

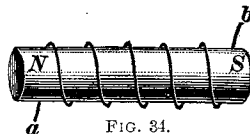


FIG. 34.

(1124) The resistance of a platinum wire 112 ft. 6 in. long is 100.8 ohms; calculate the resistance of 11.7 in. of the same wire, other conditions remaining unchanged.

Ans. .8736 ohm.

(1125) If the resistance of a round iron wire $0.1''$ in diameter is 86.5 ohms, calculate the resistance of a round iron wire $.02''$ in diameter, other conditions being equal in the two cases.

Ans. 2,162.5 ohms.

(1126) The resistance of a German-silver wire is 91.8 ohms at 45° F.; calculate its resistance when its temperature is 72° F., other conditions remaining unchanged.

Ans. 92.4048 ohms.

(1127) If the resistance of a copper wire is .144 ohm at 87° F., what is its resistance at 41° F., other conditions remaining unchanged?

Ans. .131 ohm.

(1128) If the specific resistance of platinum is 3.565 microhms per cubic inch, find the resistance in ohms of a round platinum wire 126 ft. long and $.1$ in. in diameter.

Ans. .6863 ohm.

(1129) The diagram, Fig. 35, represents a particular

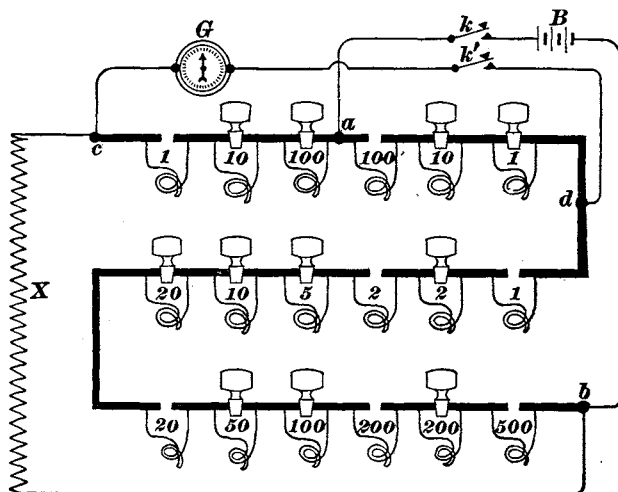


FIG. 35.

pattern of resistance box for Wheatstone bridge, with battery

and galvanometer circuits properly connected for taking resistance measurements. An unknown resistance X is connected to the terminals c and b . After adjusting the resistances of the same by withdrawing the plugs, as represented by the open spaces between the contacts, the galvanometer shows no deflection when the keys k and k' are pressed and the battery and galvanometer circuits are closed. Under these conditions, what ought to be the resistance of X ?

Ans. 7.23 ohms.

(1130) The total E. M. F. developed in a closed circuit is 36 volts; the internal resistance is 18 ohms and the external resistance is 24 ohms; determine the strength of current in amperes flowing in the circuit.

Ans. .8571 ampere.

(1131) A current of 2.7 amperes is flowing in a closed circuit. If the total E. M. F. developed in the circuit is 12.6 volts, what is the total resistance of the circuit?

Ans. 4.6667 ohms.

(1132) The external resistance of a closed circuit is 31.5 ohms and the internal is 11 ohms. If a current of .8 ampere is flowing through the circuit, what is the total E. M. F. in volts developed?

Ans. 34 volts.

(1133) A German-silver wire offers a resistance of 204 ohms. What would be the difference in potential in volts between its two extremities if a current of .12 ampere flowed through it?

Ans. 24.48 volts.

(1134) The total E. M. F. developed in an electric source is 250 volts. If 10% of this E. M. F. is required to transmit a current of 80 amperes to and from a receptive device situated 600 feet from the source, (a) what is the total resistance of the two conductors, and (b) what is their resistance per foot, considering each to be 600 feet long?

Ans. $\begin{cases} (a) & .3125 \text{ ohm.} \\ (b) & .00026 \text{ ohm per foot.} \end{cases}$

(1135) The internal resistance of a battery is 8.1 ohms and the total E. M. F. developed in it is 24 volts. What is the available or external E. M. F. of the battery when the

circuit is completed by an external conductor offering a resistance of 15.9 ohms? Ans. 15.9 volts.

(1136) The separate resistances of two branches A and B of a derived circuit are 1.2 and 2.2 ohms, respectively. If the sum of the currents in the two branches is 45 amperes, what is the current in each branch?

Ans. $\left\{ \begin{array}{l} \text{The current in branch } A \text{ is } 29.1176 \text{ amperes.} \\ \text{The current in branch } B \text{ is } 15.8824 \text{ amperes.} \end{array} \right.$

(1137) The separate resistances of two conductors are, respectively, 45 and 63 ohms; determine their joint resistance when connected in parallel, or multiple. Ans. 26.25 ohms.

(1138) The separate resistances of three conductors A , B , and C are 414, 810 and 1,206 ohms, respectively; determine their joint resistance when connected in parallel, or multiple.

Ans. 223.2534 ohms.

DYNAMOS AND MOTORS.

(ARTS. 2214-2292.)

(1139) Suppose that a ring-core armature of a bipolar dynamo is wound with 200 complete turns of wire which are properly connected to the segments of a commutator for generating a continuous current, and that there are 6,250,000 lines of force passing through the armature from the poles of the field magnets. If the strength of the field remains constant and the armature is rotated at a uniform speed of 1,200 revolutions per minute, what is the total electromotive force in volts generated in the armature? Ans. 250 volts.

(1140) If the resistance of the field coils in a shunt dynamo is 440 ohms, and the difference of potential between the brushes when the external circuit is open is 220 volts, what is the strength of current in the field coils?

Ans. .5 ampere.

(1141) What is the distinction between an alternating current and a continuous current?

(1142) Fig. 36 shows a cross-sectional view of a uniform magnetic field taken at right angles to the direction of the lines of force; that is, the dots represent the ends of the lines of force, their direction being downwards, piercing the paper. C represents a closed coil of some conducting material, such as copper, that is placed in the magnetic field with its plane at right angles to the direction of the lines of force. If the closed coil is suddenly moved from its

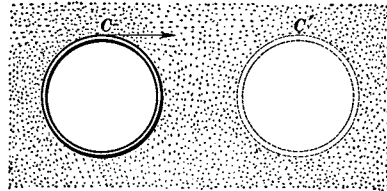


FIG. 36.

(1149) Fig. 37 shows the connections of a shunt dynamo and the direction in which the field coils are wound. If the current flows in the direction indicated by the small arrowheads, which of the two pole pieces, P or P' , is the north pole? Suppose that the winding of the right-hand coil were reversed, which pole piece would then be the north pole?

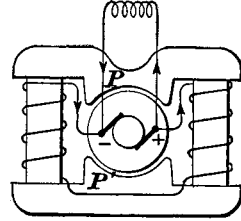


FIG. 37.

(1150) Define a ring winding and a drum winding, and point out the difference between the two.

(1151) The input to a dynamo is 10 horsepower and its output is 6,341 watts. What is its efficiency at this load?

Ans. 85%.

(1152) Fig. 38 represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole: c represents

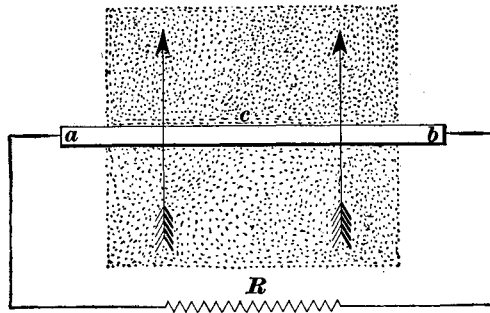


FIG. 38.

a moving conductor placed in the magnetic field with its length at right angles to the direction of the lines of force; its two ends are connected to an external circuit consisting of the resistance R . If the conductor is moving upwards across the magnetic field in the direction as shown by the large arrows, in which direction will the current tend to flow in the circuit?

(1153) A dynamo shows an efficiency of 85% when its output is 11,900 watts, and 1.8% of the input is lost in the core by eddy currents and hysteresis. What is the core loss in watts? Ans. 252 watts.

(1154) (a) What is meant by the *counter torque* of a dynamo? (b) What causes it?

(1155) A dynamo generates 125 volts at a normal load of 120 amperes output. If the resistance of the armature from brush to brush is .040 ohm, what is the armature loss in watts due to resistance? Ans. 576 watts.

(1156) In example 1155, if the efficiency of the dynamo at the normal output is 75%, what per cent. of the input is lost in the armature due to its resistance? Ans. 2.88%.

(1157) What is meant by the *sparking limit* of the load of a dynamo? What causes the sparking?

(1158) In a compound-wound dynamo, the resistance of the shunt-field coils is 550 ohms, and the resistance of the series-field coils through which all of the current to the external circuit flows is .04 ohm. The dynamo generates 550 volts between its brushes when the output is 40 amperes. Determine the total number of watts lost in the shunt and series field coils combined at this output. Ans. 614 watts.

(1159) Fig. 39 represents the field magnets of a bipolar dynamo with consequent poles. If the field magnets are separately excited by the battery *B*, which is connected to the four field coils, *a*, *b*, *c*, and *d*, and the coils are connected together in series as shown in the diagram, which of the two consequent poles, *P* or *P'*, will be the south pole of the field magnet?

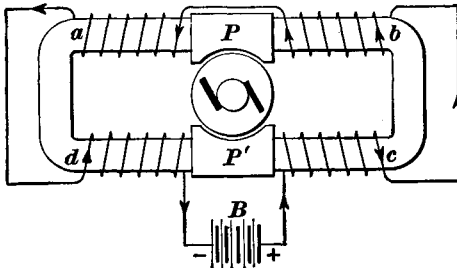


FIG. 39.

(1160) What causes the neutral points in a dynamo to shift when a current is flowing in armature conductors?

(1161) The separate losses at full load in a particular dynamo are as follows:

Loss in mechanical friction = 356 watts.

Loss in eddy currents and hysteresis = 178 watts.

Loss in field coils = 263 watts.

Loss in armature ($C^2 r$) = 423 watts.

All other losses = 50 watts.

If the output of the dynamo at full load is 15,000 watts, determine its per cent. efficiency. Ans. 92.1942%.

(1162) (a) In example 1161, what per cent. of the input is lost in mechanical friction? (b) In eddy currents and hysteresis? (c) In the field coils? (d) In the armature wires? (e) What is the total per cent. loss in the dynamo?

Ans. $\left\{ \begin{array}{l} (a) \text{ 2.1881\% loss.} \\ (b) \text{ 1.094\% loss.} \\ (c) \text{ 1.6165\% loss.} \\ (d) \text{ 2.5999\% loss.} \\ (e) \text{ 7.8058\% total loss.} \end{array} \right.$

(1163) If a certain dynamo generates 440 volts when driven at a speed of 1,200 revolutions per minute, what electromotive force will it generate when driven at 1,400 revolutions per minute; all other conditions in regard to strength of field, armature reactions, and number of armature conductors remain unchanged? Ans. 513 $\frac{1}{3}$ volts.

(1164) What limits the output of a constant-potential dynamo? Why?

(1165) In Fig. 40, C represents an iron magnet core around which the two coils P and S are wound. The coil P acts as a primary coil and is connected to the terminals m and n of a voltaic battery B . The coil S is, therefore, a secondary coil and its two ends are connected to the terminals x and y of an external resistance R .

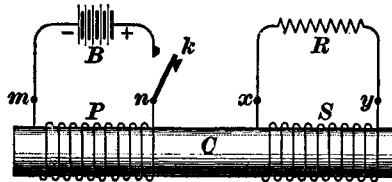


FIG. 40.

A key k is inserted into the primary circuit for opening and

closing the circuit at will. If the negative electrode of the battery is connected to the terminal m in the primary circuit and the circuit is suddenly closed at k , in what direction will the momentary current induced in the secondary coil S tend to flow?

(1166) In example 1165, suppose that the circuit of the primary coil P was closed until the current in the circuit had become perfectly steady and then suddenly opened at k . In what direction would the momentary current induced in the secondary coil S tend to flow?

(1167) Give two reasons why carbon brushes will spark less than copper brushes, under the same conditions.

(1168) Fig. 41 represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of

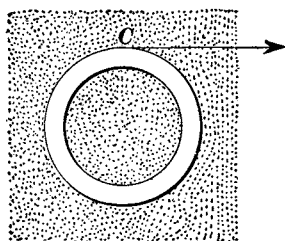


FIG. 41.

the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole.

The ring C is a closed coil of some conducting material, as copper, and is placed in the magnetic field with its plane at right angles to the direction of the lines of force. Imagine the coil to be suddenly jerked from its position to one outside the magnetic field, as, for instance, to C' , assuming, of course, that its plane is kept always at right angles to the direction of the lines of force. Will a momentary current be produced in the closed coil, and, if so, in which direction will it circulate around the ring?

(1169) What is a compound-wound dynamo, and why are dynamos compound-wound?

(1170) If a conductor cuts 8 million lines of force in one quarter of a second, what is the *rate of cutting* per second?

(1171) State why a solid piece of iron will not answer for a revolving armature core.

(1172) Suppose that a drum-core armature is wound with 150 complete turns of wire which are properly connected to the segments of a commutator for generating a continuous current, and the armature is placed in the field magnets of a bipolar dynamo. If there are 2,500,000 lines of force passing through the armature and the armature is rotated at a uniform speed of 1,020 revolutions per minute, what is the difference of potential in volts between the brushes in open circuit?
Ans. 127.5 volts.

(1173) In a particular dynamo, if an electromotive force of 200 volts is generated when there are 750,000 lines of force passing through the armature, what electromotive force would be generated if the strength of the field were increased so that 1,250,000 lines of force passed through the armature, assuming that all other conditions as to speed, number of conductors, armature reactions, etc., remain unchanged?
Ans. $333\frac{1}{3}$ volts.

(1174) To what are the following losses in a dynamo due:
(a) Core loss? (b) Armature loss? (c) Field loss?

(1175) In Fig. 42, the observer is looking at the face of a north magnetic pole N , and a straight conductor C is placed in a vertical position in front of the pole with its length at right angles to the direction of the lines of force as they pass out from the pole. If the two ends of the conductor are connected to the terminals of the battery B , and a current flows through the circuit thus formed in the direction indicated by the arrowheads, towards which side, a or b , of the pole face will the conductor tend to move?

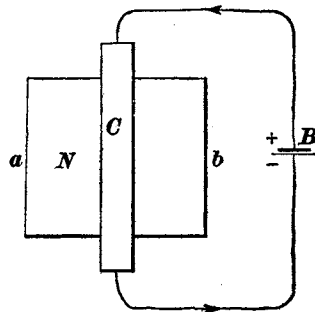


FIG. 42.

(1176) In a shunt dynamo, if the resistance of the field coil is 650 ohms and the difference of potential between the brushes remains constant at 525 volts when the armature is rotated at a constant speed, what is the strength of current in the field coil under these conditions?

Ans. .8076 ampere.

(1177) A compound dynamo generates 115 volts between its terminals when no current is flowing into the external circuit. At full load, however, the difference of potential between its terminals is 124.2 volts. What per cent. over-compounding do these figures represent?

Ans. 8%.

(1178) Define an open-coil winding and a closed-coil winding, and point out the difference between the two.

(1179) If it requires 44 horsepower to drive the armature of a dynamo when it is delivering 29,820 watts, what is the efficiency of the dynamo under these conditions?

Ans. 90.8481% efficiency.

(1180) Find the total per cent. of the input lost in a dynamo when it is delivering 17,500 watts, if it requires 20,000 watts to drive its armature shaft at this output.

Ans. 12.5% total loss.

(1181) The efficiency of a dynamo at its rated output of 12,500 watts is 92.5%. Determine the number of horsepower input necessary to give this output.

Ans. 18.1146 horsepower.

(1182) What becomes of the heat generated in a dynamo armature?

(1183) If 55 horsepower is the input to a dynamo and its efficiency at this input is 88.5%, find its output in watts under these conditions.

Ans. 36,311.55 watts.

(1184) The input to a generator is 45 horsepower, and 2% of this input is lost in exciting the field coils. State the field loss in watts.

Ans. 671.4 watts.

(1185) Point out the difference between separately excited, shunt, and series-wound dynamos.

(1186) The core losses in a particular generator amount to 800 watts and the input to the generator is 64 horsepower at full load. Determine the per cent. loss in the core at this input. Ans. 1.6756%.

(1187) Why must the brushes of the dynamo be shifted ahead of the neutral point when operating under load ?

(1188) What is the difference between a consequent pole and a salient pole ?

DYNAMOS AND MOTORS.

(ARTS. 2293-2407.)

(1189) (*a*) What is a transformer? (*b*) For what purpose is a transformer used?

(1190) What is the relation between the counter E. M. F., the applied E. M. F., and the drop or fall of potential, in a direct-current motor armature?

(1191) How can a short-circuited coil in an armature winding be detected?

(1192) (*a*) Which form (ring or drum) of armature core is most generally used for alternators? (*b*) Which form (ring or drum) of armature winding is most generally used for alternators?

(1193) Why will an ordinary series-wound dynamo, without regulating devices, not give a constant current through a circuit of varying resistance?

(1194) What causes the current in an alternating current circuit to lag behind the E. M. F.?

(1195) What is meant when two alternating currents are said to differ in phase?

(1196) Suppose that a direct-current motor when running shows a flash at each brush once in each revolution, and, on examination, it is found that one of the commutator segments is blackened and burned quite badly. What is the trouble?

(1197) (*a*) What causes an ordinary series-wound motor to race, or run away, when connected in a constant-current circuit? (*b*) When connected to a constant-potential circuit and all the load removed?

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C. Vol. III.—35.

(1198) (a) What is meant by a *cycle* in speaking of an alternating current? (b) What is meant by the *frequency* of an alternating current?

(1199) How is the Thomson-Houston constant-current dynamo regulated to give a constant current?

(1200) What is the *effective* strength of an alternating current?

(1201) A certain series-wound motor is tested with a Prony brake, the distance from the center of the shaft to the point where the arm of the brake rests on the scale platform being 36 inches. The brake is tightened until the pressure on the platform is 27 lb., when the following readings are taken: Current to motor, 25 amperes; volts at terminals, 480; speed, 900 R. P. M. (a) What is the output of the motor in H. P.? (b) What is its efficiency at this output?

Ans. $\left\{ \begin{array}{l} (a) \text{ 13.88 H. P.} \\ (b) \text{ 86.3\%} \end{array} \right.$

(1202) Why will an alternator armature not start to turn if supplied with an alternating current from some external source, the fields being excited?

(1203) In a bipolar shunt motor with two field coils, one of the field coils becomes short-circuited. (a) What is liable to happen to the other coil? (b) Why?

(1204) Draw a diagram showing the connections of a shunt-wound motor with main switch, reversing switch, starting resistance, and fuse boxes.

(1205) How may the speed of a direct-current motor be varied?

(1206) Why is the resistance of a circuit having self-induction apparently greater with alternating currents than with continuous?

(1207) When two coils or sets of coils in an open-coil constant-current armature are connected in parallel by the brushes, and the E. M. F. in one coil is less than that in the other, why does not a current flow from the coil having the higher E. M. F. around through the other?

(1208) What operations would be gone through with in cutting out circuit No. 4 and plugging in circuit No. 1 in series with No. 3 on dynamo *B*, using the switchboard represented in Fig. 925, Art. 2390, and starting with it in its present condition?

(1209) A four-pole shunt-wound motor is installed in a certain shop, but on trying to start it, it is found that no current will flow through the field coils, although the circuit to which they are connected is alive. (a) What is the trouble? (b) How may it be located?

(1210) (a) What three general methods of regulation are used with closed-coil constant-current dynamos? (b) Which of the three is most generally used?

(1211) In a certain three-phase alternator, at a certain instant, the current flowing out through one of the brushes is 10 amperes, and the current flowing in through another brush is 39 amperes. (a) What is the strength of the current flowing in or out through the third brush, and which way is it flowing? (b) What makes you think so?

(1212) How is it that the current taken by a synchronous single-phase motor can vary with the load, although the number of revolutions per minute does not vary?

(1213) A certain motor, being tested with a Prony brake, is found to have 85% efficiency when taking an input of 33 amperes at 230 volts. If the arm of the brake is 2 feet long, from center of shaft to point where it rests on the scale platform, and the pressure on the scale platform is 20 lb., at what speed (to the nearest whole revolution) is the motor running?

Ans. 1,136 rev. per minute.

(1214) What would be the frequency of the alternating current furnished by a 14-pole alternator running at 1,080 revolutions per minute?

Ans. 126.

(1215) (a) For what purpose is a lightning arrester used? (b) How does it work?

(1216) Why is the starting resistance of a shunt motor not included in the field circuit?

(1217) How is it that the magnetic field of a rotary-field motor rotates?

(1218) How may a grounded field coil in a shunt-wound generator be located, the current from another similar dynamo being available?

(1219) (a) What is a multiphase alternator? (b) How does the current it furnishes differ from that of a single-phase machine?

(1220) How is an alternator compounded?

(1221) How may a path be provided over which the static electricity which may accumulate in a dynamo frame escape?

(1222) In general, what is the object of a switchboard?

(1223) Why is it that there is no E. M. F. generated in the coil of a Westinghouse constant-current dynamo which is directly under a pole piece?

(1224) What is the general principle upon which all electric motors operate?

(1225) What are bus-bars, and for what are they used?

(1226) Why will an armature of too low resistance give little starting torque in a rotary-field motor?

(1227) What is the character of the current in the external circuit of open-coil constant-current dynamos?

(1228) For what purpose is the equalizing connection used in connecting compound-wound dynamos in parallel?

(1229) On starting up a dynamo, one of the bearings begins to heat badly, and on examination it is found that the shaft is dented in places, and has several rough spots. How may these defects be remedied?

(1230) Why is it that the speed of a shunt-wound motor varies very little from full load to no load, when supplied with a current at a constant potential?

(1231) What is meant by a burned-out armature coil?

(1232) How may an armature be balanced?

(1233) Why does the neutral line of a motor shift in the opposite direction to that of a dynamo?

(1234) Why should the ammeters on a switchboard for compound-wound dynamos to be run in parallel not be connected in the side of the circuit in which the series coils are connected?

(1235) What limits the output of constant-current dynamos?

(1236) What losses occur in a transformer?

(1237) What are some of the advantages of magnetic circuit-breakers as compared with fuses for use on switchboards?

(1238) What would be the successive combinations which any particular coil in the Thomson-Houston constant-current dynamo makes with the other coils during a half revolution, starting from a position where it is not active?

(1239) (*a*) How does armature reaction affect the output of synchronous alternating-current motors? (*b*) Of rotary-field motors?

(1240) A certain shunt-wound motor takes a current of 5 amperes at 125 volts when running free. Its armature resistance is .04 ohm, and its field resistance 62.5 ohms. (*a*) What would be its output in H. P. when taking a current of 77 amperes at 125 volts? (*b*) What would be its efficiency at this output?

NOTE.—As the method of finding the output and efficiency which should be used in solving the above problem is not strictly accurate, four figures are enough to retain in calculations or results.

Ans. $\left\{ \begin{array}{l} (a) \text{ 11.76 H. P.} \\ (b) \text{ 91.17\%} \end{array} \right.$

(1241) What is the effect of too much oil or grease on the commutator of a direct-current constant-potential machine?

(1242) (*a*) Why should the armature coils of an alternator be no wider than the neutral spaces? (*b*) Why should the neutral spaces in an alternator be made of the same width as the fields?

(1243) How is the E. M. F. of the Excelsior constant-current dynamo regulated to give a constant current?

(1244) What becomes of the energy in a direct-current motor armature represented by the product of the current flowing and the counter E. M. F.?

(1245) (a) By what two general systems is the current for incandescent lighting distributed? (b) Describe the essential features of each method.

(1246) What would be the speed at full load of a rotary-field motor, whose field winding has 10 poles, if supplied from a circuit whose frequency is 72, assuming 2.5% slip?

Ans. 842.4 rev. per minute.

(1247) Suppose that on starting a shunt-wound dynamo it should refuse to build up. What would probably be the trouble, and how would it be remedied?

(1248) (a) When a current is sent through a direct-current armature which is in an excited field, why does the armature tend to rotate? (b) Under what circumstances will it rotate? (c) Why does it not continue to speed up indefinitely when it has once started?

(1249) In what position with reference to the pole pieces are the armature coils of a drum-wound alternator when there is no E. M. F. generated in them?

(1250) Why should both parts of the magnetic circuit (field magnet and armature core) of a rotary-field motor be laminated?

(1251) Why is it necessary to use multipolar field magnets for alternators?

(1252) In what general respects do switchboards for incandescent lighting circuits using alternating currents differ from those using direct currents?

(1253) To reverse the direction of rotation of a motor, what changes in the connections are necessary?

(1254) Suppose that one of the field coils of a shunt-wound four-pole direct-current dynamo is wrongly connected. What effect would this probably have on the E. M. F.?

(1255) (a) To what classes of work are shunt-wound direct-current motors applicable? (b) Series-wound motors? (c) Why?

(1256) Describe the method of shifting the brushes used in the Thomson-Houston constant-current dynamos.

(1257) What is a water rheostat, and for what is it often used?

(1258) How is it that the armature winding of a rotary-field motor has no connection with the external circuit?

(1259) On what conditions does the torque of a direct-current motor depend?

(1260) Why does closing the secondary circuit of a transformer increase the current in the primary?

(1261) What is meant by the "slip" of a rotary-field motor?

(1262) Make a sketch showing your idea of the proper arrangement of the apparatus and the principal connections on a switchboard for a plant employing 3 compound-wound direct-current dynamos which are to be run in parallel and are to supply seven lighting circuits.

(1263) Describe the general features of the Prony brake.

(1264) Why is it desirable that the width of the open space between the two active parts of an armature coil of a drum-wound alternator should be not less than the width of the field?

(1265) A single-phase alternating-current synchronous motor, whose field has 22 poles, is supplied with an alternating current with a frequency of 132 cycles per second. At what speed will it run? Ans. 720 rev. per minute.

(1266) (a) Why is it desirable to use an external resistance in the armature circuits of a rotary-field motor? (b) Why is this resistance not left permanently in circuit?

(1267) How is it that the brushes of a constant-current dynamo with a closed-coil armature may be shifted to a considerable extent without causing excessive sparking?

(1268) How may the applied E. M. F. of a direct-current motor be varied ?

(1269) From the nature of the sparking, how can you tell whether the brushes of a direct-current constant-potential dynamo are too far forward or too far back ?

(1270) How are the devices for shifting the brushes of constant-current dynamos with closed-coil armatures usually thrown into or out of action ?

(1271) A dynamo having a 13" pulley is to be driven at a speed of 700 revolutions per minute from a countershaft running at 182 revolutions per minute. What should be the diameter of the pulley on the countershaft ? Ans. 51 inches.

(1272) An alternating current whose curve is of the form shown in Fig. 904 or 905, and whose maximum value is 12 amperes, is passed through a length of fine copper wire which it heats to a certain temperature. (a) What would be the number of amperes of a (steady) direct current that would heat the same wire to the same temperature, under similar conditions ? (b) Why ? Ans. (a) 8.4 amperes.

(1273) Why will the speed of a direct-current motor increase if the field is weakened ?

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