EDUCATIONAL COURSE

PAMPHLET EG-1
ELEMENTARY ELECTRICITY
THE DIRECT CURRENT GENERATOR
THEORY AND PRINCIPLE OF OPERATION

OFFICE OF
SUPERINTENDENT OF TELEGRAPH
PHILADELPHIA
PAMPHLET EG-1

ELEMENTARY ELECTRICITY

THE DIRECT CURRENT GENERATOR

THEORY AND PRINCIPLE OF OPERATION
COPYRIGHT, 1915,
BY
THE PENNSYLVANIA RAILROAD COMPANY.

Fig. 16 is from "Elementary Electricity and Magnetism" by Jackson.
Figs. 21, 22, 23, 24, and 25 are from cuts furnished by the Crocker-Wheeler Company.
Figs. 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, and 37 are from cuts furnished by the Westinghouse Electric and Manufacturing Company.
Table No. 1 is from "Practical Calculation of Dynamo-Electric Machines" by Wiener.
THE DIRECT CURRENT GENERATOR
THEORY AND PRINCIPLE OF OPERATION

1. A GENERATOR DEFINED.—In Pamphlet E-5 it was explained that an e.m.f. could be created in a wire by having it cut a magnetic field; and if a wire with such an e.m.f. in it were connected to a closed circuit, current would flow in that circuit. It is upon this principle that the construction of the electric generator is based. This machine may be defined as an apparatus in which a conductor or a system of conductors forming a part of an electric circuit is given continuous motion through a magnetic field or fields, and is thus caused to cut the lines of magnetic flux. An electromotive force is thereby induced in the conductors, with the result that when the external circuit is closed a current flows; and mechanical energy is converted into electrical energy. The essentials of a generator are then: first, a magnetic field; second, a conductor cutting the magnetic field; and third, a connection to an external circuit. The use of the words dynamo, generator, and motor may here be designated. A dynamo is an electric machine which transforms energy. Thus it may be either a generator—for a generator transforms mechanical energy into electrical energy—or it may be a motor—for a motor transforms electrical energy into mechanical energy. The word dynamo is often used to mean generator; but in reality, dynamo means either generator or motor.

2. A SIMPLE GENERATOR.—It was shown that the loop of Fig. 8, Pamphlet E-5, was in reality a type of generator. It is, however, evident that the motion there described, being simple rectilinear,—that is, motion in one and the same direction,—cannot be maintained practically for any length of time; for the obvious reason that the pole-pieces would have to be of great length in order to provide the indefinitely long magnetic field; and when the conductor reached the end of the pole, it would have to be brought back. Such a motion could be obtained by attaching the inductor directly to the piston of a steam engine, and the e.m.f. produced would be alternating in direction. However, such an arrangement is not convenient, since it is not easy to secure a speed sufficiently
high to give an appreciable voltage with any practical length of inductor and density of field. Hence a rotary motion is utilized, because high speeds are easily obtainable, air gaps can be made small, and flux density can be made high. Fig. 1 illustrates a simple rotary generator.

A stiff piece of wire, EF, is bent as shown, and fastened rigidly to rings—called collector rings—A and B. These rings are insulated from the shaft, GH. Of course, the shaft, GH, must be supported in bearings, but for simplicity these are not shown. As GH is rotated in the direction indicated by the curved arrow, an e.m.f. is induced in EF, which would cause current to flow away from the reader. If now an external circuit is connected to this wire, current will flow in that circuit. The external circuit is connected to EF by means of copper brushes, C and D, which rub continuously on the collector rings, A and B. The current thus flows from EF to collector ring, B; then to brush, D; through the external circuit and back to brush, C; then to collector ring, A; and back on EF. This current is an alternating current, because when the inductor is moved in front of the N pole, the e.m.f. will be induced in EF toward the reader. The e.m.f. induced in EF goes through a cycle exactly like the e.m.f. of inductor, AD, in Fig 9,
Pamphlet E-5. The whole loop of Fig. 9, Pamphlet E-5, could be used to deliver current to an external circuit. The collector rings, A and B, Fig. 2, and the wire are supported by a shaft (not shown) which is in turn supported in bearings. The brushes, C and D, are flat copper plates which rub on the metallic rings, A and B, as these rings revolve with the shaft and wire. By this arrangement any e.m.f. induced in the rotating coil is brought out to the brushes, C and D, and forces current through the external circuit. The e.m.f. of EF is in series with the e.m.f. of GH. The voltage impressed on the external circuit of Fig. 2 is therefore twice as great as the voltage obtained in Fig. 1, where only one inductor was used. The curve of e.m.f. induced in the coil of Fig. 2 in one cycle—that is, in one revolution—would be somewhat as shown in Fig. 3.
It is seen that the voltage, as the coil moves directly in front of the poles, is nearly constant, and suddenly drops to a low value after the poles are passed. This is strictly an alternating e.m.f. The following pages will explain: first, how an alternating e.m.f. may be rectified* and made a unidirectional e.m.f.—that is, the current of the external circuit is caused to flow always in the same direction; and second, how a steady and constant value of e.m.f. is obtained on the external circuit instead of a pulsating e.m.f. It might here be asked why it is necessary to rectify the alternating e.m.f. of the coils so as to obtain a direct e.m.f. on the circuit. In many cases, such as incandescent lighting, alternating current serves as well as direct current; but in many other cases it is essential to have direct current—especially for electromagnets, for charging batteries, for telephone lines, or for any circuit in which there are coils of wire and hence likelihood for large self-induction where self-induction is not desired. Direct-current motors are so easy to regulate and handle that direct current is largely used in electric railway work. It is very necessary, therefore, that means be employed whereby a unidirectional e.m.f. may be obtained from a generator.

The voltage in the circuit of Fig. 2 can be changed to a unidirectional voltage by the device shown in Fig. 4.

* Rectify in electricity means to change an alternating e.m.f. to a unidirectional e.m.f., or to change A. C. to D. C.
Instead of two solid collector rings, one split ring is used. EF connects rigidly to segment, \( S \) and GH to segment, \( N \). The segments are insulated from each other and from the shaft to which they are rigidly attached. The brushes, C and D, are stationary and bear on the segments at all times. A little thought will now reveal the fact that although the e.m.f. induced in the coil, FEGH, is alternating, the e.m.f. impressed on the external current circuit from the brushes, C and D, is always in the same direction. Consider first when EF is sweeping in front of the S pole in the rotary direction indicated. An e.m.f. will be induced into the page and current will flow, as indicated by the arrows in the external circuit. Second, when EF is sweeping past the N pole, the induced e.m.f. will be out of the page. When EF was passing the S pole, brush, C, was bearing on segment, B; when passing the N pole, brush, C, is bearing on segment, A. Therefore, due to the movement of the segments, the current in the external circuit will still flow as indicated by the arrows; although the direction of e.m.f. has changed in EF. The curve of e.m.f. impressed on the external circuit will now look like that shown in Fig. 5.
There will be two pulsations for every revolution, all the pulsations being in the same direction in the external circuit. It must be borne in mind that no matter how the e.m.f. appears in the external circuit, whether it be alternating, pulsating, or of a constant value, the induced e.m.f. is not altered, and continues to go through the cycles of e.m.f., as shown in Fig. 3. The e.m.f. in the coils of an ordinary direct-current machine is an alternating e.m.f., and often of high frequency.

In Fig. 4 it will be noticed there are but two segments, one connected to each end of the coil, FEGH. The e.m.f. impressed on the external circuit by such an arrangement is shown by Fig. 5. This e.m.f., while not alternating in direction—that is, it does not pass from positive to negative values—is nevertheless not strictly unidirectional, for it rises from zero to a maximum value and then goes back to zero, twice in each revolution. As this e.m.f. goes through the values shown, in regular intervals it produces a pulsating current. For the satisfactory operation of direct current machinery a continuous current of practically a constant e.m.f. is necessary. For this reason means must be employed to produce the same, and one of the first steps possible is to increase the number of coils on the armature and the number of segments on the commutator.
If, in Fig. 4, an additional coil be placed at right angles to the position of FEGH and the ends connected to additional segments formed by cutting segments, A and B, in half, an e.m.f. similar to that shown by the solid lines in Fig. 6 will be produced when the coils are rotated between the poles as previously mentioned. By adding additional coils and segments the e.m.f. may be made so nearly constant in value that the variations can only be detected by delicate measuring instruments.

The generator of Fig. 4 would not be of much value as a power producer for several reasons: its voltage is very low—not more than three volts; the air gap between the magnets is large—thus the flux to be cut is greatly reduced; the field at best is weak—because permanent magnets do not have very strong fields. Again, the e.m.f. produced in the external circuit is pulsating; that is, it goes through a cycle which starts from zero, reaches a maximum and returns to zero again twice in each revolution. Hence it does not produce steady value direct current.

3. DEVELOPMENT OF A PRACTICAL GENERATOR.—One of the first and simplest improvements which can be made is to replace the permanent magnets with strong electromagnets. Increasing the flux increases the voltage, and hence the power output. The air gap can also be greatly reduced. First, the pole faces, instead of being flat as in Fig. 4, can be curved as in Fig. 9, Pamphlet E-5. The conductors can be made to move very close to the pole faces by this arrangement.

![Diagram](http://PRR.Railfan.net - Collection of Rob Schoenberg - ©2020 - Commercial reproduction or distribution prohibited)

Characteristic lines of force showing crowding at pole tips, which increases the density of the magnetic flux per unit area.
The great drawback to the use of curved pole faces is that the flux in taking the path of least reluctance will hold to the iron, and crowd into the corners of the poles where it is least effective. This crowding effect is illustrated in Fig. 7.

It is seen that considerable flux would jump across from $b$ to $a$ and from $d$ to $c$ which would not lie in the path of a moving conductor. This flux is known as magnetic leakage. Even the flux which the conductor cuts does not move at right angles to the movement of the conductor, as it should to give the largest possible induced e.m.f. The most natural remedy which suggests itself is to support the coil of Fig. 4. The best support under the circumstances is a cylindrical, iron drum fastened rigidly to the shaft, on the surface of which drum, the inductor can be placed. This drum is often called the armature, or the armature core, because it acts just like the "keepers" or "armatures" of the magnets described in Pamphlet E-3. It greatly reduces the air gap and affords a good path for the flux; more flux is thus produced per ampere turn on the magnets—called field magnets. Two short air gaps are left instead of one of great length, and the flux density under the pole pieces will far exceed that of any lines between the pole tips which are not cut by the conductors. The resulting field is illustrated in Fig. 8.

![Fig. 8. Illustrating concentration of lines of force in iron armature core.](image)

This figure is another exemplification of the principle illustrated in Fig. 6, Pamphlet E-3. The drum thus serves three purposes: first, it reduces the number of necessary ampere turns to produce a strong field; second, it concentrates the lines of force where they can be cut by the moving conductors; and third, it serves as an excellent support for the conductors and necessary connections. Fig. 9 represents a one-coil generator with electromagnets and an iron drum, or armature core.
The electromagnet is one huge mass of iron, as shown. A strong flux, hence a strong field, is produced by the winding, \( F \), which is called the field winding. This winding consists of many turns of small insulated wire. The wire may be wrapped over all the iron or over any part of it, depending on how strong a field is desired. Frequently it is wound on the vertical parts. The ends of the winding in this case are connected to the terminals of a battery of primary cells. The path of the flux is indicated by dash lines through the drum. The only air gaps in the magnetic circuit occur between the curved pole pieces, \( N \) and \( S \), and
the iron drum. The connecting piece of iron, AB, is called the *yoke*. Instead of having the flux return to the N pole through air, which has high reluctance and which would seriously cut down the flux, this yoke is used for the return path of the flux. In many illustrations this yoke is not shown for the sake of simplicity; but in all practical machines the poles are bridged by just such an iron yoke. The e.m.f. produced in this machine is similar to, but much larger than, the e.m.f. produced in the machine of Fig. 4, for two reasons; the magnetic field is much stronger, and the speed at which the conductor can be moved is much greater because of a more substantial construction. However, the voltage obtained is still very small and means must be sought to increase this voltage.

Just as increasing the number of primary cells in series increases the voltage at the terminals of a battery, so increasing the number of inductors in series would increase the induced e.m.f. at the terminals of an armature winding. The simplest method of increasing the number of turns is to use an iron ring armature core instead of a solid iron drum. The magnetic field with such a core is shown in Fig. 10. N and S are the north and south poles, respectively, of an electromagnet; ab is an iron ring which may be rotated between the pole faces; and the lines of force are shown by the dotted lines and are in the direction indicated by the arrows. This form of core is called the *Gramme ring*, from its inventor.

![Diagram](image-url)
4. THE GRAMME ARMATURE.—In Fig. 11 is shown a Gramme ring which may be made up of a considerable number of thin sheets of iron or of coils of iron wire. Around the ring is wound uniformly a number of turns of insulated wire with the ends joined so as to form a continuous circuit. If the armature, $ab$, be rotated between the poles of an electromagnet and in the direction illustrated, a little study will show that an e.m.f. will be induced in the windings under the pole pieces, tending to send current from $a$ to $b$. If the field is uniform the current generated in the windings under the N pole piece will be equal and in the opposite direction to that generated in the windings under the S pole pieces; hence no current will flow in the circuit. If, however, the wires on the outside of the ring are arranged so that the insulation may be removed for a short distance, and brushes are placed at $a$ and $b$. 

Fig. 11.
Simple ring armature showing arrangement of conductors.

Fig. 12.
Ring armature showing arrangement for conducting current to external circuit.
so as to rub on the bare conductors, a fairly continuous current may be obtained from the winding and conducted through an external circuit. This arrangement would be somewhat as shown in Fig. 12, and if the conditions of magnetic field and direction of rotation be as indicated, the current will flow in the direction shown.

5. THE COMMUTATOR.—In actual practice the brushes are not made to rub directly on the bared insulated wire, but the turns on the ring are tapped at several points and connections made through short copper wires to a number of copper bars insulated from each other and fastened concentrically around the central shaft that also holds the ring, but also thoroughly insulated from this shaft. These bars are called the commutator segments, and the segments taken collectively are called the commutator. The arrangement of such a machine would be similar to that shown in Fig. 13. It will be noted in this figure that the brushes are in contact with commutator bars which are electrically connected to those turns of the winding which are cutting little or no flux; and hence have very little electromotive force generated in them. (See Fig. 10.) The brushes are usually constructed to cover one whole bar and a small portion at least of the two adjacent bars. With this arrange-
ment, it will be seen that at a certain period in the rotation of the commutator the brush bears considerably on at least two adjacent bars, and hence connects together through the brushes the ends of the coil which are electrically connected to these bars. This in effect short circuits the coil, and if any considerable amount of e.m.f. is being generated in it at the time, a large current will flow through it, which would result in the generation of a great amount of heat in the coil. This would reduce the efficiency of the machine and eventually destroy the insulation on the winding. Also the passage of large currents at considerable potential through the face of the brushes causes a great deal of sparking, which in turn results in the destruction of both the brushes and the commutator segments. For the reasons cited above, the brushes are always set at a point where the least sparking takes place. This position is called the neutral point, or neutral brush position.

6. ARMATURE REACTION.—On account of the iron in the armature core and the flow of current through the windings, a certain effect takes place which "bends" the lines of force in the direction of rotation; and for this reason the neutral point is never just exactly half way between the tips of the pole pieces. This effect is called armature reaction. On account of it the neutral point in a generator is slightly

![Lines of force in ring armature distorted due to armature reaction.](image)
advanced in the direction of rotation; and the brushes must be set accordingly. In Fig. 14 is shown the manner in which the magnetic field is distorted due to the flow or current through the coils wound on a ring armature. $cd$ would be the normal neutral axis with only the iron ring between the pole pieces, N and S, but when the ring is made to rotate, and current flows through the winding of the armature, the armature itself becomes an electromagnet producing lines of force within itself, some of which oppose the lines produced by the field magnets. It was previously studied that lines of force can not cross each other; hence at the point in the core where the lines of the two electromagnets oppose each other consequent poles are set up. These poles would normally be at a point midway between the pole pieces, or at $c$ and $d$. A little study will show that the lines of these consequent poles are nearly at right angles to the lines from N to S, and as the lines never intersect, the two sets crowd and distort each other so that they may coincide in direction. This results in the shifting of the neutral axis to the line $ab$. The position of this line will vary with the amount of current flowing through the armature coils, advancing in the direction of rotation as the current increases until it is sometimes under the tips of the pole pieces, as at $ef$, or even beyond the tips.

In the older types of machines this distortion, or armature reaction, was very serious, and the brushes had to be continually shifted with variations in the current output. In modern dynamo-electric machines the construction has been so improved that the armature reaction is neutralized, and little or no shifting of the brushes is necessary from no-load current to full-load current.

7. FAULTS OF RING ARMATURES.—Consider the ring in Fig. 14. It will be seen that the flux flows through the iron of the ring and does not go through the air in the central part of the ring. Hence the inside turns of a winding, similar to that shown in Fig. 11, would cut no flux and have no e.m.f.'s induced in them. For this reason these parts of the winding are of no value except to complete the circuit and thus carry the current generated in the outside windings from turn to turn. The conductors on the outside part of the ring may be called the active conductors, while those on the inside may be called the waste conductors. It will be seen that practically half the wire in an armature of this kind is waste and this constitutes a very serious fault with ring armatures.
Another objection is in the difficulty to manufacture. The wire passes from one end of the armature to the other on the outside and returns through the inside. This requires that the armature be wound by hand, which is rather a slow process in small machines and almost impracticable in quite large machines.

For the above reasons and others of lesser importance the ring armature is not in very general use at the present time in standard makes and sizes of dynamo-electric machinery.

8. DRUM ARMATURE.—The type of armature in which the winding passes on the outside from one end of the core to the other end, then across the end to the other side of the core, then back again to the first end, and across this end to where it started, is called a Siemens armature, or a drum armature, as shown in Fig. 16. The core may be of solid iron, but in practice it is usually made of thin disks of sheet iron, called laminations, laid compactly together, and may be either solid in form—as in the case of very small armatures (see Fig. 9)—or built up on what is known as a spider (Fig. 15) in armatures of the larger sizes.

![Fig. 15. Armature spider with laminations in place.](image)

The spider may be likened to the spokes of a wheel, and while the spokes might not be very thick, they might extend the whole length of the armature. The ends are usually shaped somewhat as shown at a and b, and the laminations are grooved out in a similar shape so as to make a close fit. The thin sheets are strung on the spider and pressed closely together until the desired length is obtained. A complete armature if very long may contain several hundred such sheets bolted together.

9. SMOOTH-CORE ARMATURE.—In the older type of drum armatures the coils were wound uniformly over the surface of the core (see Fig. 9), but on account of the pull on the conductors it was found very hard to keep the coils in place and they sometimes slipped out of position, causing damage to the windings. In order to avoid this trouble, small
pieces of insulating material were fastened at intervals in the edges of the core, and the windings laid between them. After all the conductors were on the core, a number of turns of bare, hard wire were placed at several points, and the whole winding bound firmly to the core. These wires, used to hold the conductors to the core, are called band wires.

Fig. 16.
Drum armature with smooth core, showing commutator of sixteen segments, and one coil in place on the core.

Armatures of the kind just described, where all the conductors are on the surface of the core, are called smooth-core armatures. Fig. 16 illustrates a solid, laminated, smooth-core armature with one coil of several turns of wire in position, and projections on the edges for holding the coils in place. This core is arranged for sixteen coils, but in many commercial sizes there may be as many as one hundred or more coils.

It will be noted that in the drum armature all the turns of the coils are active as they successively cut through the flux emanating from the pole faces. For this reason the number of conductors required on a drum armature to produce a given voltage is less than is required for a ring armature if all the other conditions are equal; viz., speed, length of active conductors, and field strength.

10. SLOTTED CORE.—In order to overcome the difficulty of keeping the coils in position on a smooth-core armature and also to reduce the air gap to a minimum, an armature was devised in which a number of slots were made in the outer surface of the core, and in these slots the coils were placed. Such an armature is called a slotted, or toothed-core, armature. In Fig. 17a is shown a side view of a laminated, slotted-core armature mounted on a shaft, with end plates riveted or bolted in place to hold the laminations tightly together. Fig. 17b is an end view with end plate removed showing the spider and slots, while Fig. 17c is an enlarged
part of a section showing eight turns of insulated wire in one of the slots. This view also shows the insulation to keep the coils from touching the punchings and also the insulation to keep the band wires from touching the coils.

![Diagram of an armature core with insulated wire, end plate, and slots.]

The foregoing discussion on armatures has been intended to bring out the fact that both the length and number of conductors may be considerably increased over what it would be possible to place in such a magnetic field as shown in Fig. 4, or what it would be possible to place on a simple core such as is illustrated in Fig. 9. It was stated in E-5 that by increasing the length and number of conductors in a given magnetic field the induced e.m.f. would be increased in direct proportion; hence the reason for placing a large number of fairly long conductors on any given armature core.

11. SPEED OF ARMATURE.—It has been stated that the e.m.f. generated is directly proportional to the rate of cutting flux by the conductors. If a pulley be placed on the end of the shaft of a complete armature, such as is shown in part in Fig. 17a, and the armature rotated in a strong magnetic field by being belted to a prime mover such as a
steam engine, turbine, or water-wheel, the conductors will cut the flux in
direct proportion to the speed of rotation. For low voltages or very
large armatures this speed may be as low as eighty revolutions per
minute, while for very high voltages or very small armatures the speed
may be as high as four thousand revolutions per minute. Any speed
within the limitations of the mechanical or electrical construction of
the machine is feasible. For many reasons the lower speed machines
are more desirable, although the higher speed machines are usually less
expensive on account of the smaller number of shorter conductors
required, and also on account of the smaller fields and field windings
required to produce the lesser amount of magnetic flux necessary for
any given voltage.

12. MULTIPLE POLE DYNAMO.—Heretofore the text has treated
entirely of dynamos having but one N pole and one S pole. Such
machines having but the two poles are called bipolar. Another way of
increasing the e.m.f. is to increase the number of magnetic poles, and
a dynamo with more than two poles is called a multipolar dynamo.

Either the ring armature or the drum armature is adaptable for
use with a multipole magnetic field. In Fig. 18 is shown a ring

![Diagram of ring-wound armature in multipolar field](http://PRR.Railfan.net)
armature in a four-pole field. The conditions here are similar to those as explained for Fig. 11, except that there are now two N poles and two S poles. The e.m.f.'s induced in the conductors under the N pole are equal and opposite to the e.m.f.'s induced in the conductors under the S poles, when the armature is rotated in a uniform field; and hence no current will flow in the winding on the ring. If, however, brushes are placed at $aa$ and $bb$ the current generated will flow out of the armature winding though the $a$ brushes, and returning from an external circuit will flow into the winding through the $b$ brushes. The brushes, $aa$, are electrically connected together to form one positive terminal, and the brushes, $bb$, are similarly connected to form one negative terminal.

Fig. 19.

Diagrammatic arrangement of armature winding in: $a$, a two-pole field; $b$, a four-pole field; and $c$, a six-pole field.
With this arrangement it will be seen that there are two paths for
the current in the armature from each of the negative to each of the
positive brushes; that the current in each path is one fourth the total
current; and that the conductivity of the path between brushes is
one fourth the total conductivity of the armature, or one half of what
it would be in a similar two-pole machine of the same capacity output.

By reference to Fig. 19a, 19b, and 19c, the connections, direction of
current flow, and relative conductivity of internal circuit may be further
studied for a two-pole, a four-pole, and a six-pole machine.

In each of the diagrams R is the external resistance; T, the posi­
tive terminal; T', the negative terminal; d, the negative brushes; e, the
positive brushes; N, the north poles of the field magnets; and S, the south
poles of the field magnets. As the external connectors between the
brushes of like polarity, in Fig. 19b and 19c, are always of very heavy
copper cables or bars, their resistance may be neglected. If the total
conductivity of the armature is taken as one (1), then the relative
conductivity of the several coils which are in the winding between the
brushes will be as indicated by the fractions placed near the curved lines
which run from brush to brush, and which lines represent the turns of
wire in the armature winding. If the total current in the external
circuit also be represented by one (1), then the current in the several
wires will be as shown by the same small figures near the lines represent­
ing the wires and connections.

That which has been said in connection with ring armatures placed
in multipolar fields applies equally well to drum armatures placed in
the same kind of fields, the core and winding of the latter armature
differing from that of the former in the same respects as explained in
Sections 7 and 8.

13. HOMOPOLE DYNAMO.—Efforts have been made to construct
a dynamo with the characteristics of a machine having but one pole;
and while such machines have worked fairly satisfactorily in the
laboratory, no really commercial type has ever been perfected except
for very low voltages and even then the machine must be run at very
high speeds. Such a dynamo with the characteristic of but one pole is
called a unipole or homopole dynamo. The value in the use of such a
machine lies in the fact that a direct current may be obtained from
the same without the use of a commutator.
14. PRACTICAL DYNAMOS.—In order that the construction of a modern multipolar dynamo may be better understood, Fig. 20 is given in order to show as clearly as possible the various parts of a medium-sized machine. The names of the various parts are as follows: $a$ is called an eye bolt and is used for lifting the machine; $b b$ are lugs for bolting the upper half of the field yoke, $Y$, to the lower half of the field yoke, $Y'$; $c$ is a bolt holding the two halves of the yoke together; $d$ is the leading and $e$ the trailing pole tip when the direction of rotation is as shown by the arrow, $p$; $f$ is the air gap in the magnetic circuit between the armature and the pole face, $s$; at $g$ are shown slots in the armature core, $m$, to
receive the conductors of the armature winding as shown at h; i shows spokes of the armature spider; j is the shaft on which the spider is mounted; k is the key and keyway which keeps the spider from slipping when the shaft is revolved; l is the pole shoe; m' is a lamination, or punching, of the armature core; n, a commutator bar, or segment; and o, the insulation between the segments. In this particular diagram P_1 and P_2 are the field magnet cores on the lower yoke, of the negative, or S, pole and of the positive, or N, pole, respectively, while P and P' are the N and S poles, respectively, on the upper yoke. With the polarity as given above, the path of the magnetic flux or the magnetic paths would be as shown by the dash lines on which are the arrows marked r. F is a sectional view of a coil of copper wire, called the field coil, and F' is a field coil wound with cord to protect the insulation on the wire. The field coils are sometimes wound on insulating spools, called the field spools, and shown in side view at G and in section at G'. BB is called the base, and qq are bolts, called hold down bolts, used to fasten the machine to a foundation or other support.

In Fig. 21 is illustrated a small bipolar generator built some years ago by the Crocker-Wheeler Company. A modified type of this machine has been very largely used to generate current for use in telegraph work, and many of them are still in service at the various large telegraph offices, both commercial and railroad. Fig. 22 shows what is sometimes called an "exploded" view of a similar machine. Here the various parts which go to make up a complete machine are shown separately, and the names of the principal parts are enumerated at the side of the cut.

Fig. 23 illustrates the advance in the art of designing and building small generators. Machines of this general type are now used in place of the generators shown in Fig. 21 and 22. Such machines are built in sizes from about 200 watts up to five kilowatts, and for very low voltages, up to 500 volts. For larger sizes, multipolar machines are generally used and Fig. 24 shows an "exploded" view of a 20 K. W.
Fig. 22.

Small Bipolar Generator Displayed.
Fig. 23.
One Kilowatt Bipolar Generator Displayed.

1 Magnet Frame
2 Front Shield
3 Rear Shield
4 Pole Shoes
5 Pole Shoe Screws
6 Field Coils
7 Porcelain Bushings
8 Armature (includes 9 and 10)
9 Commutator
10 Shaft
11 Pulley Key
12 Pulley
13 Front Shield Cap Screws, with Washers
14 Rear Shield Cap Screws
15 Front Journal Box with Oil Ring
16 Rear Journal Box with Oil Ring
17 Journal Box Cap Screw
18 Oil Well Plugs
19 Brush and Terminal Studs
20) Brush Holders
21) Brush Holders
22 Brush and Terminal Studs
23 Brass Washers for Brush and Terminal Studs
24 Brush and Terminal Stud Nuts
25 Brushes
26 Name Plate
27 Name Plate Screws
<table>
<thead>
<tr>
<th></th>
<th>Component</th>
<th></th>
<th>Component</th>
<th></th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Magnet Frame</td>
<td>11</td>
<td>Oil Rings</td>
<td>21</td>
<td>Insulating Washers</td>
</tr>
<tr>
<td>2</td>
<td>Front Shield</td>
<td>12</td>
<td>Armature (includes 13 and 14)</td>
<td>22</td>
<td>Brush Stud Insulating Bushings</td>
</tr>
<tr>
<td>3</td>
<td>Rear Shield</td>
<td>13</td>
<td>Commutator</td>
<td>23</td>
<td>Brush Stud Nuts</td>
</tr>
<tr>
<td>4</td>
<td>Shield Cap Screws</td>
<td>14</td>
<td>Shaft</td>
<td>24</td>
<td>Brush Holders</td>
</tr>
<tr>
<td>5</td>
<td>Eye Bolt</td>
<td>15</td>
<td>Pulley</td>
<td>25</td>
<td>Brushes</td>
</tr>
<tr>
<td>6</td>
<td>Pole Shoe with Screws</td>
<td>16</td>
<td>Pulley Key</td>
<td>26</td>
<td>Connection Cable and Tips</td>
</tr>
<tr>
<td>7</td>
<td>Oil Hole Cover and Chain</td>
<td>17</td>
<td>Field Coils</td>
<td>27</td>
<td>Terminal Cable and Tips</td>
</tr>
<tr>
<td>8</td>
<td>Oil Gauges</td>
<td>18</td>
<td>Rocker (includes 19 and 20)</td>
<td>28</td>
<td>Shunt Cable and Tips</td>
</tr>
<tr>
<td>9</td>
<td>Journal Screws</td>
<td>19</td>
<td>Wing Screw</td>
<td>29</td>
<td>Shunt Field Connector</td>
</tr>
<tr>
<td>0</td>
<td>Journal Boxes</td>
<td>20</td>
<td>Brush Studs</td>
<td>30</td>
<td>Flats for connecting Series Fields</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Cable Tips</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Porcelain Bushing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Terminal Studs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Washers, plain brass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Terminal Stud Nuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Main and Series Labels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Ties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Name Plate and Screws</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Crocker-Wheeler generator with four poles, and arranged for belt drive. In this view note particularly the large number of band wires on the armature, so located that the armature conductors are firmly held in place. Such machines are built in sizes ranging from 3 K. W. to 45 K. W. Fig. 25 shows a side view of this same machine completely assembled and ready for service.

Small Multipolar Direct Current Generator—Crocker-Wheeler Co.

In Fig. 26 is shown a part of a similar type of machine as manu-

Generator Frame with Pole Pieces and Field Coils.
factured by the Westinghouse Electric and Manufacturing Company. This portrays very clearly the machining on the sides of the yoke, where the *end bells, or bearing brackets*, which support the bearings are fastened. A field coil such as would be used on this machine is shown in position on the pole piece in Fig. 27. Note the two long machine bolts which are used to bolt the pole piece to the yoke. Four such pieces are shown in place in Fig. 26.

A complete armature for such a machine is shown in Fig. 28. Here only two sets of band wires are used—one set at each end of the armature conductors. In the larger machines the armature conductors are...
wound on forms in such a shape that they are ready to be placed in the armature slots. They are then known as form wound and such windings are shown in Fig. 29. A complete shaft for the armature in Fig. 28 is shown in Fig. 30. The large part in the middle is to receive the armature spider and commutator, the smaller part at the left and the medium part at the right go in the bearings, while the part at the extreme right is to receive the pulley. A commutator for this armature is shown completely assembled in Fig. 31. The small part at the right in this cut is one of the copper segments partly formed.

Fig. 32 shows a brush holder so arranged that it may be clamped to a stud fastened in the rocker arm. The small wire at the right varies
the amount of tension placed on the brush and the flat spiral spring bearing on the top of the brush keeps the brush in close contact with the commutator. The heavy flexible copper shunt wires leading from the brush to the holder serve to increase the conductivity from one to the other and thus prevent undue heating.

In the smaller belted generators of this type some means must be employed to keep the belt tight so that it will not slip, thus causing undue friction which is a waste of energy. This trouble is prevented by placing the machine on slide rails as shown in Fig. 33. The rails are bolted to a foundation by means of bolts through the lugs on the side at the bottom. The bolts on the top of the rails go through the holes in the feet of the generator. By means of the long screw at the left the generator is slid along the rails so that the belt is kept under proper tension. The bolts through the feet may be made tight so that the machine is firmly held.

A typical installation of a type of multipolar generator, of which there are thousands in use, is shown in Fig. 34. Here the engine and
the generator are separate units, but are mounted together on a suitable heavy iron casting called a *bed plate*. The bed plate in turn is bolted down to a suitable foundation, usually of brick or concrete. Foundations for installations of this type should be quite massive so that the engine and generator will not vibrate when in operation.

In very large direct current generators the number of poles, and hence the number of brush holders and brushes, is greatly increased. Fig. 35 illustrates a machine of this type with twenty four poles and
the same number of brush holders, each of the latter holding eight brushes, making 192 brushes in all. As this machine is direct connected to a vertical engine it would be difficult to remove the field yoke if it were horizontally divided. Hence the yoke is vertically divided as shown, and so arranged that the two halves may be slid away from the armature so as to facilitate inspection and repairs to either the armature or the fields. In machines of this general type, but of somewhat smaller size, the armature is constructed similar to that shown in Fig. 36. Construction methods are such that band wires are unneces-

![Fig. 36.](image)

Armature for 250 K.W. 250-Volt Direct Current Engine Type Generator.

sary over the core and only one set is used, that being at the back end of the winding. These machines have massive pole pieces as shown by Fig. 37. This cut shows very clearly the laminations of the pole

![Fig. 37.](image)

Pole Piece of Direct Current Engine Type Generator.
piece and of the pole shoe, which in this case is formed from the same
punching as the pole core. Heavy pieces of metal are shown riveted to
the sides of the pole piece so as to hold the laminations tightly together.

15. LOSSES IN DYNAMOS.—In all the machines described there are
certain losses taking place continually so long as the machine is in
operation. These losses manifest themselves as heat in various parts
of the dynamo, and they may be divided into two general classes: viz.,
*mechanical losses* and *electrical losses*.

**MEchanical Losses**

16. FRICTION.—The *mechanical losses* are those produced by
mechanical means and are mainly independent of all losses in the
electrical parts of the machine. The main source of mechanical loss is
in the *friction* of the bearings, and of the brushes on the commutator.
This is not of much importance in small or medium-sized machines, but
in very large and heavy machines the power required to turn the arma­
ture, especially against bearing friction, may be considerable. This
loss may be reduced to a minimum by a careful design of the bearings
and by their proper lubrication. A hot bearing is a sure sign of undue
friction with its consequent mechanical loss, and should not be tolerated
longer than is absolutely necessary.

17. WINDAGE.—Another source of mechanical loss is known as
*windage*. This loss is caused by projections on the revolving armature
striking the air, thus setting up currents of air in the surrounding
atmosphere. Air cannot be set in motion and kept moving without
the expenditure of energy; thus the energy required to drive an armature
against windage is a loss.

In small machines or in other machines with smooth armatures
that are practically solid, the windage loss may be very little, but in
very large machines with openly constructed armatures, the loss may be
relatively large. If these currents of air thus set up served no useful
purpose, the energy necessary to produce them would be a total loss.
Fortunately, however, these air currents in passing through and over
various parts of the machine, carry off the heat generated due to certain
electrical losses, the dissipation of this heat being necessary in order
that the parts may not become too hot. In well-designed machines
of the larger sizes, special provision is made to purposely set columns of
air in motion in order to properly ventilate the machine.
ELECTRICAL LOSSES

18. COPPER LOSS.—In a well-designed dynamo the most serious electrical loss which takes place is the copper loss in the field windings and armature windings. It has been stated in E-2 that the copper loss in a line is that energy which is consumed by the conductors and is dissipated as heat. Similarly the copper loss in a dynamo is that energy which is consumed in the field windings and armature windings. The magnitude of this loss may be ascertained from the equation, \[ W = IR, \]
in which \( W \) is the loss in watts, \( R \) is the resistance of the armature winding or of the field winding, and \( I \) is the current flowing through either of them. It will be seen that if either \( I \) or \( R \) increases, the copper loss will increase directly as \( R \), and directly as the square of \( I \). In a practical machine the conductors are always made reasonably large to keep \( R \) as small as possible. The density of the current is thus kept down and this is particularly desirable as the positive temperature coefficient* of the copper—of which the conductors are composed—causes the resistance to rise as the temperature rises. Hence it is very desirable to keep the temperature of the windings as low as possible for the reasons stated above, and also to prevent damage to the insulation surrounding the conductors—this insulation usually consisting of more or less combustible materials.

19. EDDY CURRENTS.—It was stated that the early armature cores were made of solid iron, and in the case of the Gramme ring, it was at one time made of a coil of iron wire. Such a core revolving in a magnetic field is nothing less than a conductor cutting lines of force and hence e.m.f.'s will be generated tending to send current through the metal of the core. These local currents are called eddy currents, because they eddy uselessly through the core, their behavior resembling the currents in a stream of water having eddies. They are sometimes called Foucault currents, after the French scientist by that name who investigated the generation of electric currents in large masses of metal. These eddy currents thus induced in the core flow around in the iron somewhat as shown in Fig. 38 which illustrates a section of a solid, drum

*The temperature coefficient of resistivity is that property of a metal whereby it changes its electrical resistance with changes in temperature. When the resistance increases with the temperature, the coefficient is said to be positive; when the resistance decreases as the temperature increases, the coefficient is said to be negative; and when the resistance remains constant as the temperature changes, the metal is said to have a zero temperature coefficient. Most of the pure metals have about the same temperature coefficient which is positive, and for practical purposes it may be assumed that for every 2.5 degrees Centigrade rise in temperature there is a rise of one per cent. in the value of the resistance. Some materials, such as carbon, have a negative coefficient, while in some alloys the coefficient is so small that it may be neglected. In ordinary calculations the coefficient of resistivity need not be considered. (See also Pamphlet E-2.)
type, iron core revolving between the poles of an electromagnet. The
currents may not be very large, but their continual flow will cause
the core to become hot, and this heat must also be dissipated into
the air. The eddy currents also cause a magnetic drag on the arma­
ture, and power is required to overcome this drag. This power is
converted into heat in the armature, and is thus wasted.

To overcome the trouble and loss due to eddy currents the armature
core is laminated, as previously mentioned; that is, it is made up of a
large number of thin sheet iron disks insulated from each other by
thin sheets of paper, or by coatings of japan or shellac. As oxide of
iron (common iron rust) is a fairly good insulator, the sheets are some­
times permitted to rust before they are assembled in the core. The core
thus laminated does not restrict the flow of magnetic flux across the
armature from side to side, but does prevent to a large extent the flow
of eddy, or local, currents through it.

20. Hysteresis.—The larger part of power lost in an armature core
and converted into heat is caused by a sort of magnetic friction between
the molecules of iron in the core when it is made to revolve in a magnetic
field. Each molecule continually tries to align itself parallel to the
lines of force passing from the N pole to the S pole of the electromagnetic
circuit of the dynamo. As each molecule rotates with the armature
and passes successively under the influence of the different pole pieces
it can be seen that it must assume many different positions in each
revolution of the armature. In order to cause the molecules to so align
themselves considerable power must be expended, which is turned into
heat by the friction; and this loss is not lessened by the use of lamina­
tions. This effect is called hysteresis. The losses occasioned by hysteresis,
and eddy currents, are called the core losses. In a modern dynamo these losses should not be more than two per cent of the total power input at full load.

The amount of energy lost and the heat produced due to hysteresis depends upon four quantities: viz., the quality of the iron in the core, the amount of iron in which the effect takes place, the number of revolutions per minute, the number of poles, and the density of the lines of force through which the core passes. In Pamphlet E-3 it was stated that the molecules of hard iron or steel are difficult to align, hence the loss due to hysteresis would be less in a core made of soft iron. For this reason armature cores are usually made of very soft wrought iron or steel which has been thoroughly annealed.

21. OTHER LOSSES.—Besides the I^2R loss in the field winding, already mentioned, there is a small loss in the field core due to the distortion of the lines of force where they enter and leave the pole faces, caused when an armature with a slotted core is used. The teeth of the core passing before the pole faces cause eddy currents to be generated in the pole pieces, and in order to keep these currents at a minimum the pole pieces are also usually laminated.

In generators having very large armature conductors local e.m.f.'s are sometimes set up within the conductors themselves caused by the adjacent edges of any one conductor cutting the same line of force at different times or at different rates of speed. The e.m.f.'s thus generated cause eddy currents to flow within the several armature conductors, and while no one current is very great, in the aggregate they sometimes cause considerable heating in the armature, and are useless because they do not flow into the external circuit.

In connection with Fig. 9, it was stated that the lines of force between the N and S poles pass through the iron core of the armature. In a well-designed machine with either type of armature core and with different arrangements of pole pieces the great majority of the lines so pass, but there are a few which do not pass through the core and hence are not cut by the armature conductors. These lines constitute what is known as the stray field, or magnetic leakage, and are the ones responsible for magnetizing a watch when brought near a direct-current dynamo-electric machine. In order to produce these lines some energy must be expended and as they serve no useful purpose this energy is a total loss. Some idea of the magnitude of this loss for different types of machines may be gained by reference to Table No. 1.
<table>
<thead>
<tr>
<th>CAPACITY IN KILOWATTS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upright Horseshoe Type</td>
<td>Inverted Horseshoe Type</td>
<td>Horizontal Horseshoe Type</td>
<td>Single Magnet Type</td>
<td>Vertical Double Magnet Type</td>
<td>Horizontal Double Magnet Type</td>
<td>Bipolar Ironclad Type</td>
<td>Vertical Double Horseshoe Type</td>
<td>Horizontal Double Horseshoe Type</td>
<td>Four-pole Ironclad Type</td>
<td>Single Magnet Multipolar Type</td>
<td>Inner Pole Type</td>
<td>Radial Multipolar Type</td>
<td>Tangential Multipolar Type</td>
<td>Axial Multipolar Type</td>
</tr>
<tr>
<td>.1</td>
<td>2.00</td>
<td>1.75</td>
<td>1.90</td>
<td>1.50</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.25</td>
<td>1.80</td>
<td>1.60</td>
<td>1.75</td>
<td>2.00</td>
<td>1.40</td>
<td>1.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.5</td>
<td>1.70</td>
<td>1.50</td>
<td>2.00</td>
<td>1.65</td>
<td>1.90</td>
<td>1.35</td>
<td>1.35</td>
<td>1.80</td>
<td>1.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.65</td>
<td>1.45</td>
<td>1.90</td>
<td>1.60</td>
<td>1.80</td>
<td>1.30</td>
<td>1.30</td>
<td>1.70</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>1.60</td>
<td>1.40</td>
<td>1.80</td>
<td>1.55</td>
<td>1.70</td>
<td>1.28</td>
<td>1.28</td>
<td>1.60</td>
<td>1.65</td>
<td>1.75</td>
<td>1.60</td>
<td>1.40</td>
<td>1.50</td>
<td>1.90</td>
<td>2.00</td>
</tr>
<tr>
<td>5.0</td>
<td>1.55</td>
<td>1.35</td>
<td>1.75</td>
<td>1.50</td>
<td>1.65</td>
<td>1.25</td>
<td>1.25</td>
<td>1.55</td>
<td>1.60</td>
<td>1.65</td>
<td>1.50</td>
<td>1.35</td>
<td>1.40</td>
<td>1.80</td>
<td>1.90</td>
</tr>
<tr>
<td>7.5</td>
<td>1.50</td>
<td>1.30</td>
<td>1.70</td>
<td>1.45</td>
<td>1.60</td>
<td>1.22</td>
<td>1.22</td>
<td>1.50</td>
<td>1.55</td>
<td>1.60</td>
<td>1.45</td>
<td>1.32</td>
<td>1.35</td>
<td>1.70</td>
<td>1.80</td>
</tr>
<tr>
<td>10.0</td>
<td>1.45</td>
<td>1.28</td>
<td>1.65</td>
<td>1.40</td>
<td>1.55</td>
<td>1.20</td>
<td>1.20</td>
<td>1.45</td>
<td>1.50</td>
<td>1.55</td>
<td>1.40</td>
<td>1.30</td>
<td>1.32</td>
<td>1.65</td>
<td>1.70</td>
</tr>
<tr>
<td>25.0</td>
<td>1.40</td>
<td>1.25</td>
<td>1.60</td>
<td>1.35</td>
<td>1.50</td>
<td>1.18</td>
<td>1.18</td>
<td>1.40</td>
<td>1.45</td>
<td>1.50</td>
<td>1.35</td>
<td>1.28</td>
<td>1.30</td>
<td>1.60</td>
<td>1.65</td>
</tr>
<tr>
<td>50.0</td>
<td>1.35</td>
<td>1.22</td>
<td>1.55</td>
<td>1.32</td>
<td>1.45</td>
<td>1.15</td>
<td>1.15</td>
<td>1.35</td>
<td>1.40</td>
<td>1.45</td>
<td>1.30</td>
<td>1.25</td>
<td>1.28</td>
<td>1.55</td>
<td>1.60</td>
</tr>
<tr>
<td>100.0</td>
<td>1.30</td>
<td>1.20</td>
<td>1.50</td>
<td>1.30</td>
<td>1.40</td>
<td>1.12</td>
<td>1.12</td>
<td>1.30</td>
<td>1.35</td>
<td>1.40</td>
<td>1.25</td>
<td>1.22</td>
<td>1.25</td>
<td>1.50</td>
<td>1.55</td>
</tr>
<tr>
<td>200.0</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From actual leakage factors of 200 practical dynamos, and researches of Hopkinson, Lahmeyer, Corsepius, Reson, Wedding, Ives, Edser, and Puffer.
In this table the small cuts at the top show the arrangement of the pole pieces and the position of the armature, while the decimal part of the numbers in the columns below the cuts are equivalent to the percentage of lines of force lost due to magnetic leakage.* It will be noticed that for the larger sizes, the machines shown in columns 12 and 13 have the smallest leakage, and partly on this account most of the modern machines have magnetic fields of this general shape.

22. EFFICIENCY.—In any dynamo the mechanical power required to drive it is always greater than the electrical power obtained from it. This is due to the fact that the machine itself absorbs some of the power and turns it into heat, due to the effects of friction, windage, eddy currents, hysteresis, and the I^2R losses in the armature and field windings.† The ratio of the power taken from a machine to the power put into it is called its efficiency. Expressed as an equation:

\[
\text{Efficiency} = \frac{\text{Power taken from machine}}{\text{Power put into machine}},
\]

the power being expressed in like terms. When the losses are high the efficiency is necessarily low and vice versa. Owing to the losses described above, the efficiency of any machine is always less than unity, but in all calculations it is always expressed as a percentage of 100 per cent.

---

* The leakage factor in any dynamo having a smooth core can be expressed as the quotient of the total joint permanence of the system by the permanence of the useful path. Or, expressed as an equation, \( \lambda = \frac{\text{Joint permanence of useful and stray paths}}{\text{Permanence of useful path}} \).

† The magnetic leakage is not considered in this connection, as it really has to do only with the efficiency of the magnetic circuit.
PROBLEMS

Note.—These problems should be answered one or more complete
lessons at a time. Where the answer requires calculations show all the
work.

First Lesson

1.—(a) What is a dynamo? (b) What is an electric generator?
2.—Upon what principle is the construction of a generator based?
3.—What are the essentials of a generator?
4.—Why is it that the construction shown in Fig. 8, Pamphlet
E-5, does not form a practical generator?
5.—Make a sketch of a simple generator and describe how and
why it causes current to flow?
6.—What are collector rings?
7.—At what point of rotation in the Fig. of problem 5 is the volt­
age at a maximum? Why? At what point is it at a mini­
mum? Why?
8.—What is the advantage of using a rotary motion in electric
generators?
9.—Why can not large currents be obtained from the generator
of Fig. 4?
10.—How could the generator of Fig. 4 be improved so that it
would be a practical machine?

Second Lesson

11.—What is the objection to the use of curved poles? Why is this
an objection?
12.—How may this objection be overcome?
13.—What is an armature core?
14.—What is a rectified current?
15.—What is a commutator?
16.—What is the action of a commutator?
17.—Of what use is a dynamo armature?
18.—What is a field magnet?
19.—What is a field winding?
20.—What is a field yoke?
THIRD LESSON

21.—How could the voltage of the machine shown in Fig. 4 be increased?

22.—Suppose this generator was constructed with a single coil of 30 turns of wire arranged to rotate in such a magnetic field that each conductor cuts 1,500,000 lines in each half revolution. If the machine runs at 1200 revolutions per minute, what voltage may be obtained at the terminals? (Hint: A conductor cutting 100,000,000 lines of force per second produces one volt.) Ans. 36 volts.

23.—What is a Gramme ring?

24.—How does the current flow through a ring armature?

25.—How is a practically uniform voltage obtained from a generator?

26.—What is a commutator segment?

27.—In Fig. 12 suppose each full turn on the armature represents a coil of wire having 10 turns in it. If the number of these coils be doubled and the armature rotated in a field, having a strength of 2,000,000 lines, and at a speed of 720 revolutions per minute, what pressure will be developed? (Hint: In this armature there are two paths between the brushes for the current, and hence but half the coils are in series.) Ans. 76.8 volts.

28.—(a) What is a brush? (b) Describe its function.

29.—What is the neutral brush position?

30.—(a) What is armature reaction? (b) What effect does it have on the position of the brushes?

FOURTH LESSON

31.—What are some of the disadvantages of ring armatures?

32.—(a) What are active conductors? (b) Waste conductors?

33.—Describe a Siemens armature.

34.—How does the winding of a drum armature differ from that of a ring armature?

35.—(a) What is a smooth core armature? (b) What is its disadvantage and how is it overcome?

36.—Suppose a certain generator developed 50 volts at its terminals at a speed of 500 r.p.m. Show mathematically how 60 volts could be obtained without changing the windings of the machine? Give a reason for the answer.
37.—What is a multiple pole generator?
38.—Why are multiple pole machines used in preference to bipolar machines?
39.—What is a homopole dynamo?
40.—(a) What is the air gap? (b) The pole shoe? (c) The leading pole tip? (d) The trailing pole tip? (e) The armature spider?

**FIFTH LESSON**

41.—(a) What is a pole face? (b) What are the magnet cores? (c) What is the magnetic path of a generator? (d) What is a lamination?
42.—Why are laminated armature cores used?
43.—What is an eddy current?
44.—Name the principal mechanical losses in a dynamo.
45.—Where does the copper loss take place in a generator? Is this loss constant?
46.—The armature of a dynamo has a resistance of 0.012 ohm. What will be the copper loss when 100 amperes are flowing? Ans. 120 watts.
47.—If the fields of this same machine permit 4 amperes to flow through them when 100 volts are impressed at the terminals, what is the copper loss in the field windings? Ans. 400 watts.
48.—What is hysteresis loss?
49.—How can the amount of it be kept low?
50.—What would excessive heating in any part of a generator indicate?

**SIXTH LESSON**

51.—What is the objection to the use of solid pole pieces?
52.—What losses besides the I^2R losses occur in the armature conductor, and what is the cause?
53.—What is magnetic leakage?
54.—How could excessive magnetic leakage be detected?
55.—What effect has a large air gap and poor joints in the magnetic circuit, on the reluctance and magnetic leakage?
56.—What is a toothed armature?
57.—Name several advantages obtained from the use of a toothed armature?

58.—What is meant by the efficiency of a generator?

59.—Instruments placed on a certain generator show that it is developing at the terminals, 1400 amperes at 240 volts, and that 500 horsepower is being required to drive the armature shaft. What is the commercial efficiency of this machine? Ans. 90 per cent.

60.—Make a sketch of each of the machines shown in columns 5 and 7 respectively, Table No. 1. Place the field windings on each, and show the direction of current through the field winding, the direction of magnetic flux, and mark the north and south poles of the machine.