A TEXTBOOK

ON

MINING ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

DYNAMOS AND MOTORS
ELECTRIC HOISTING AND HAULAGE
ELECTRIC PUMPING, SIGNALING, AND LIGHTING
ELECTRIC COAL-CUTTING MACHINERY

WITH PRACTICAL QUESTIONS AND EXAMPLES

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DYNAMOS AND MOTORS.

(PART 1.)

INTRODUCTION.

1. Electricity is the name given to the cause of all electrical phenomena. The word is 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 two physical properties in common with material substances, namely, **indestructibility** and **elasticity**; 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 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.

2. 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.

3. 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.

4. 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.

5. 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 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. 1. 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.

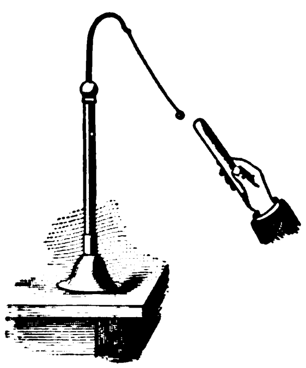

FIG. 1.

But the charges 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.

6. 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.

7. 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.

8. 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, Copper, Other Metals, Charcoal, Ordinary Water, The Body.	CONDUCTORS.
Paper. Oils, Porcelain, Wood.	NON-CONDUCTORS OR INSULATORS.

Silk, Resins, Gutta-percha, Shellac, Ebonite, Paraffin, Glass, Dry Air, etc.	NON-CONDUCTORS OR INSULATORS.

ELECTRODYNAMICS.

9. 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.

10. 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.

11. 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.

12. A **simple voltaic,** or **galvanic, cell,** Fig. 2, 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.**

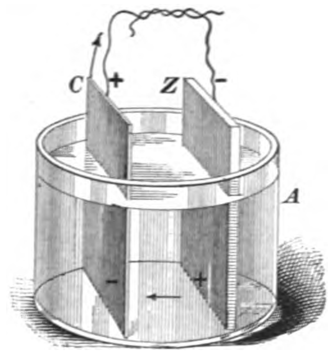

FIG. 2.

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.

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.

13. 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 example, 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.

14. 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. 3. 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 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 any other *high* resistance circuit.

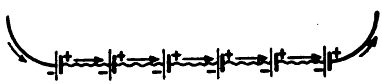

FIG. 3.

15. 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 shown by the diagram, Fig. 4. 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 electroplating.

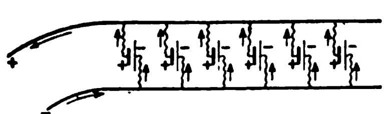

FIG. 4.

16. Cells are connected in **multiple-series** by arranging them in several groups, each group being composed

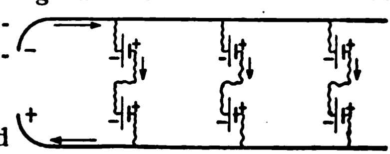

FIG. 5.

of several cells connected in series, and then connecting all the groups together in parallel, or multiple-arc, as shown in the diagram, Fig. 5. 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.

17. 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.

18. Conductors are said to be connected **in series** when they are so joined together as to allow the current to pass consecutively through each. For example, Fig. 6 represents a *closed* circuit consisting of a simple voltaic cell *B* and four conductors *a*, *b*, *c*, and *d*, connected *in series.*

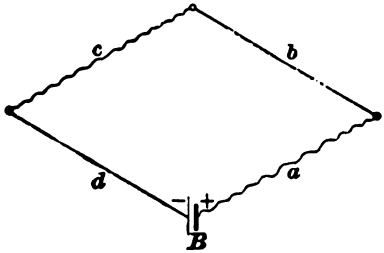

FIG. 6.

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. 7. 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.

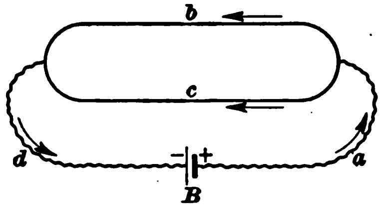

FIG. 7.

MAGNETISM.

19. 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. 8.

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. 8, 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.

20. 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. 9.) That part of the magnet where there is no 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 called the **axis of magnetism.**

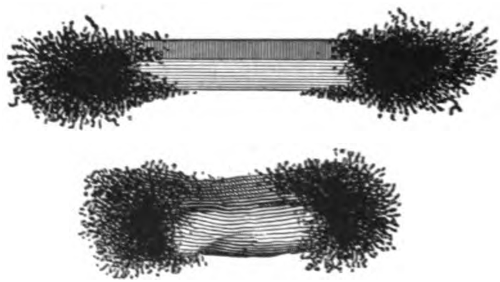

FIG. 9.

A **compass** consists of a magnetized steel needle, Fig. 10, resting upon a fine point, so as to turn freely in a horizontal plane. 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-**

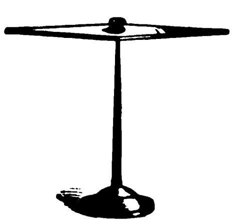

FIG. 10.

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.

21. 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.**

22. 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

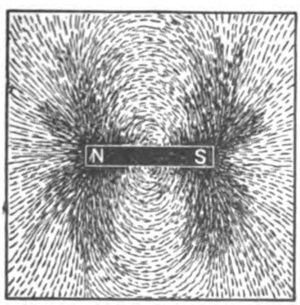

FIG. 11.

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. 11. 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. 12.

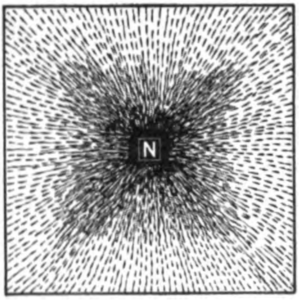

FIG. 12.

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

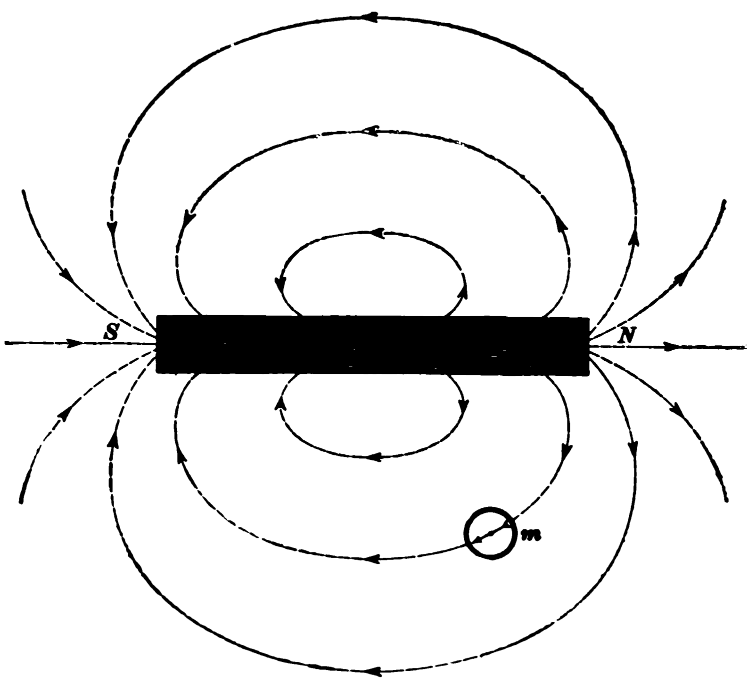

FIG. 13.

north pole again, as shown in Fig. 13. This is called the *direction of the lines of force*, and the path which they take is called the *magnetic circuit.*

23. 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. 13. The north pole of the needle will always point in the direction of the lines 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.

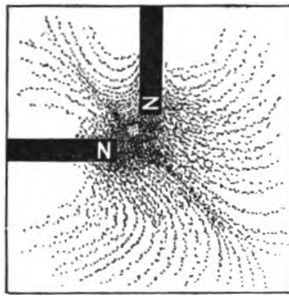

FIG. 14.

NOTE.—In all diagrams, the *direction of the lines of force* will be represented by arrow-heads upon dotted lines.

Lines of force can never intersect each other; when two opposing magnetic fields are brought together, as indicated by the iron filings in Fig. 14 and Fig. 15, 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.**

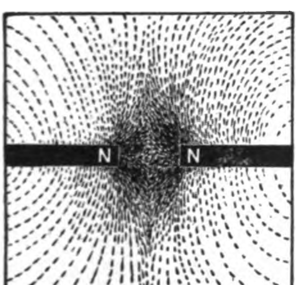

FIG. 15.

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.

24. 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.

25. If a conductor be placed parallel to the magnetic axis of a compass needle, and a current passed through the

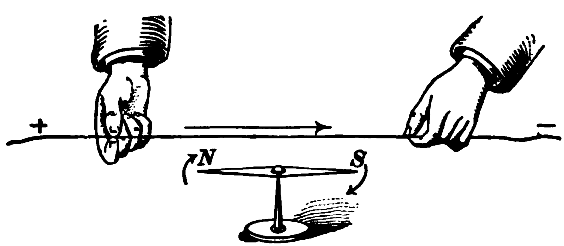

FIG. 16.

conductor in either direction, the needle will tend to place itself at right angles to the conductor, as shown by arrows in Fig. 16; or, in general, an electric current and a magnet exert a mutual force upon each other. From the definition given in Art. **22**, 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 conductor, as represented in Fig. 17. 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. 18.)

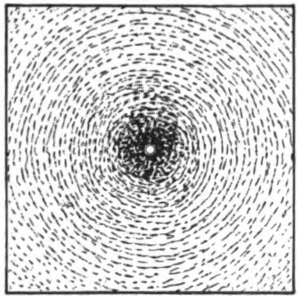

FIG. 17.

26. If the current in a horizontal conductor is flowing *towards* the *north*, and a compass is placed *under* the conductor, Fig. 19, the north pole of the needle will be deflected towards the *west;* by placing the compass *over* the wire, Fig. 20, 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.

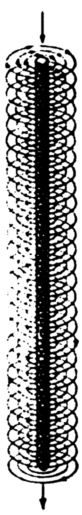

FIG. 18.

If the conductor is placed *over* the needle, and then bent back *under* it, forming a loop as shown in Fig. 21, 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.

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.*

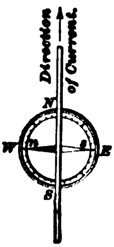

FIG. 19.

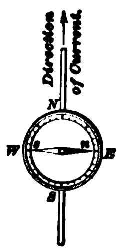

FIG. 20.

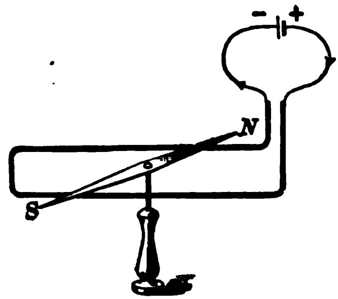

FIG. 21.

The direction of the lines of force around a conductor is indicated in Fig. 22 where the current is assumed to be flowing downwards, that is, piercing the paper.

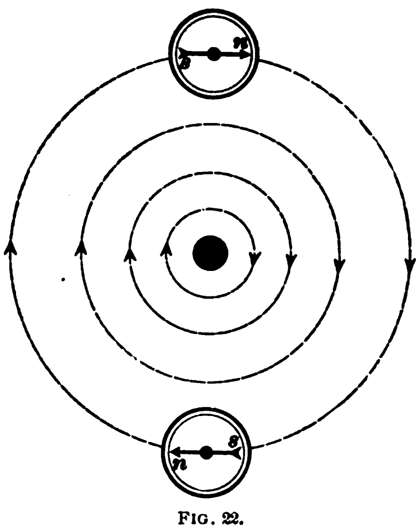

FIG. 22.

27. 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. 23, the lines of force will tend to surround both conductors and contract, thus *attracting* the conductors. If, however, the currents are flowing in opposite directions, as in Fig. 24, the lines of force lying between the conductors will have the same direction, and therefore *repel* the conductors.

28. If the conductor carrying the current is bent into the form of a loop, as in Fig. 25, 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 *helix*

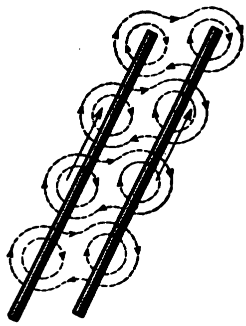

FIG. 23.

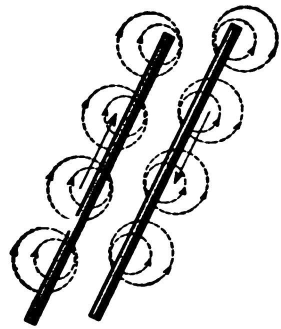

FIG. 24.

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.

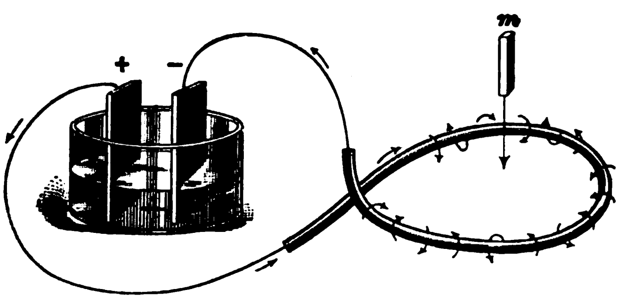

FIG. 25.

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.**

29. 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. 26 represents a conductor coiled in a right-handed 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.*

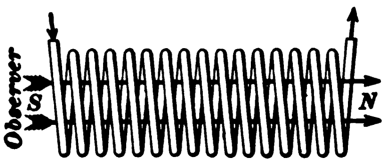

FIG. 26.

The polarity of a solenoid can be changed by reversing the direction of the current in the conductor.

30. In Art. **24** 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.

31. A magnet produced by inserting a magnetic substance into the magnetic circuit of a solenoid is an **electromagnet,** and the magnetic substance around which the current circulates is called the **core.** (See Fig. 27.) The solenoid is generally termed the **magnetizing coil.**

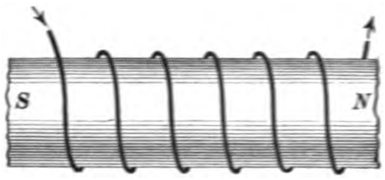

FIG. 27.

In the ordinary form of electromagnet, 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 electromagnet 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. 28.

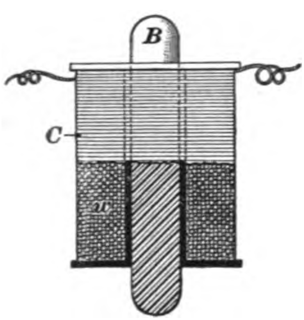

FIG. 28.

The rule for determining the polarity of a solenoid, Art. **29,** is the same for an electromagnet. 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.

32. The most convenient form of electromagnet for a great variety of uses is the *horseshoe*, or U-*shaped*, electromagnet, Fig. 30. 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 electromagnet 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. 29. In looking at the free ends of the two cores, Fig. 30, the current should circulate around 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

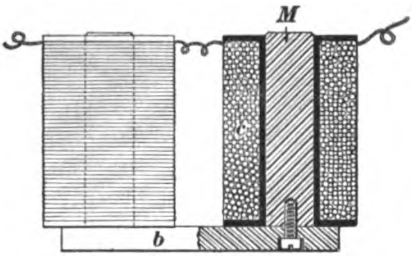

FIG. 29.

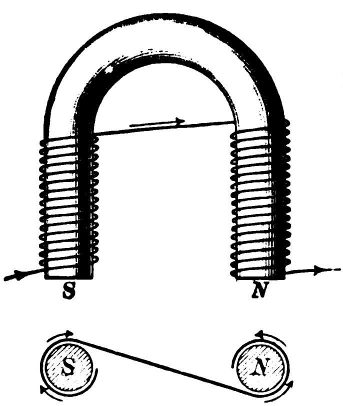

FIG. 30.

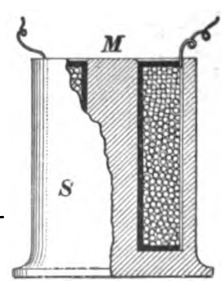

FIG. 31.

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.

Another common form of electromagnet is known as the **iron-clad** electromagnet. In its simplest form, Fig. 31, 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.

33. 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 of 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.**

34. 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 the 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 wili 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.

35. 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.

The *international ampere* is defined as the strength of an unvarying current, which, when passed through a solution of nitrate of silver and water, deposits silver at the rate of .01725 grain per second.

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.

36. The principal effects produced by an electric current are given in Art. **3**; of these, the one most generally used for measuring is the action of the current upon a magnetic needle, as shown in Art. **25.** 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. **25,** 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. 32. 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. 32; and in the more sensitive galvanometers, Fig. 33, 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.

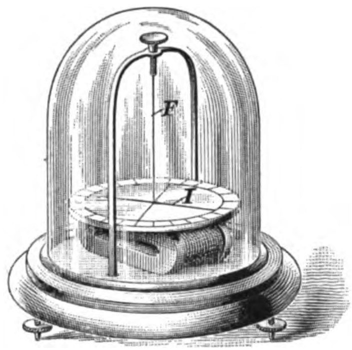

FIG. 32.

In any of these galvanometers, when no current is flowing in the coils, the needle should point in a direction parallel to the length of the coil, Fig. 34. The measuring of

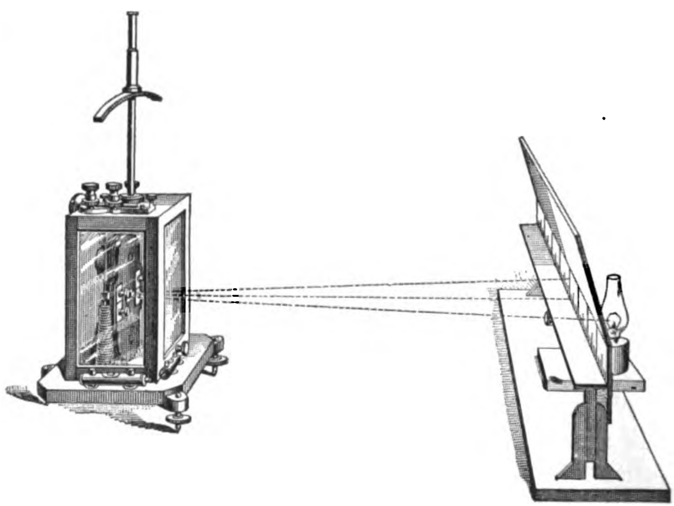

FIG. 33.

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. **25,** while the tendency of the earth's 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.

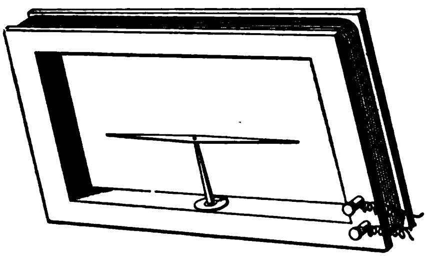

FIG. 34.

37. 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. 35 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-posts *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.

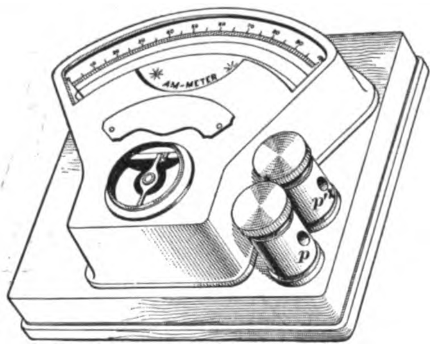

FIG. 35.

38. The Ohm, or the Unit of Resistance.—In Art. **8** 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.

39. 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.*

40. 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:

$$r_2 = \frac{r_1 l_2}{l_1}. \qquad \textbf{(1.)}$$

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 **1**, the required resistance $r_2 = \frac{.013 \times 5{,}280}{10} =$ 6.864 ohms. Ans.

41. 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:

$$r_2 = \frac{r_1 a_1}{a_2}, \qquad (2.)$$

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 **2**, 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 **2**, the resistance $r_2 = \frac{1 \times .01}{.001} = 10$ ohms. Ans.

42. When comparing resistances of round copper wires the following formula is used:

$$r_2 = \frac{r_1 D^2}{d^2}, \qquad (3.)$$

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 = diameter^2 × .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 **3**, 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 **3**,

$$r_2 = \frac{12.6 \times .125^2}{.0625^2} = 50.4 \text{ ohms. Ans.}$$

43. The resistance of two or more conductors connected in *series* (Art. **14**) 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.

44. The **microhm** is a unit of resistance devised to facilitate calculations and measurements of exceedingly small resistances, and is equal to *one millionth* $\left(\frac{1}{1,000,000}\right)$ 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.

45. 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.

46. 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 1 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 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,

$$r_2 = r_1 (1 + t\,k). \qquad (4.)$$

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 1);
$t = 52 - 32 = 20$ degrees.

By formula **4**, the required resistance $r_2 = r_1 (1 + t\,k) = 40 (1 + 20 \times .002155) = 40 \times 1.0431 = 41.724$ ohms. Ans.

47. 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, $r_2 = \dfrac{r_1}{1 + t\,k}$. **(5.)**

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 1);
$t = 22°$ F.

By formula **5**, the required resistance

$$r_2 = \frac{r_1}{1 + tk} = \frac{16}{1 + 22 \times .000244} = \frac{16}{1.005368} = 15.9145 \text{ ohms. Ans.}$$

48. 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 ot 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 1, in the order of their relative resistances, beginning with silver, which offers 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 **1**, 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. 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. 1.8244 ohms.

EXAMPLE.—Find the resistance in ohms of 1 mile of square iron wire (annealed) .1" on a side. Ans. 24.2852 ohms.

TABLE 1.

Name of Metal.	Resistance, Microhms per Cu. In.	Relative Resistance.	Temperature Coefficient.
Silver, annealed	.5921	1.000	.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	2.2150	3.741	.002028
Platinum, annealed	3.5650	6.022	
Iron, annealed	3.8250	6.460	
Nickel, annealed	4.9070	8.285	
Tin, pressed	5.2020	8.784	.002028
Lead, pressed	7.7280	13.050	.002150
German Silver	8.2400	13.920	.000244
Antimony, pressed	13.9800	23.600	.002161
Mercury	37.1500	62.730	.000400
Bismuth, pressed	51.6500	87.230	.001967

49. 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.

50. 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 a 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. 36.

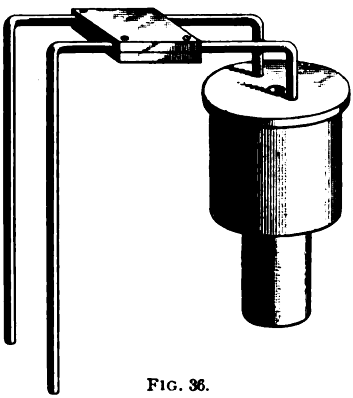

FIG. 36.

51. 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.

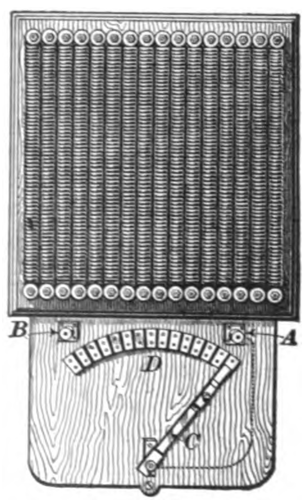

FIG. 37.

Fig. 37 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. 38. 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 passes through the remaining coils only.

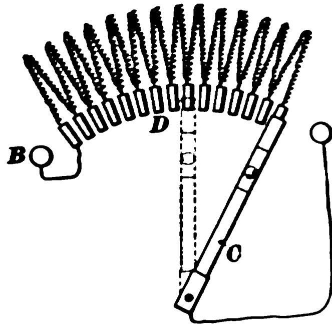

FIG. 38.

52. 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. 39, the separate coils offering resistances from one ohm up to 5,000 ohms. The operation of adjusting the resistance by means of the removable plugs can be seen from the diagram in Fig. 40. 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 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*.

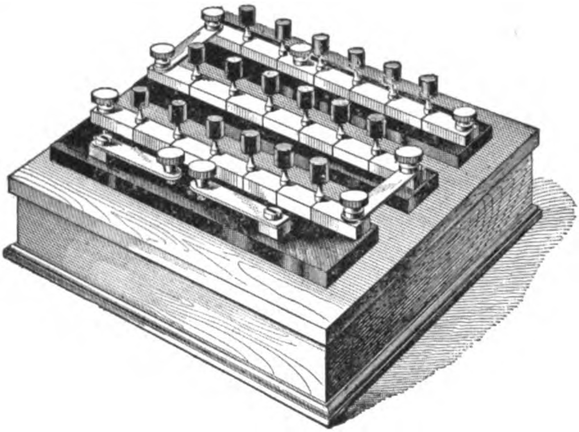

FIG. 39.

and *6* to the terminal *B*. The total resistance of the rheostat can be lowered by inserting the plug *P* between the

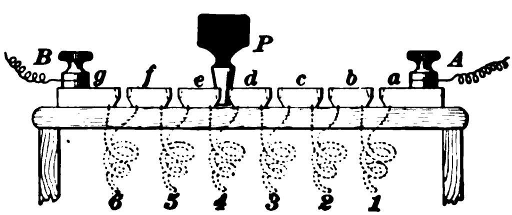

FIG. 40.

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.

53. Electrical resistance may be measured by an apparatus called a **Wheatstone 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. 41.

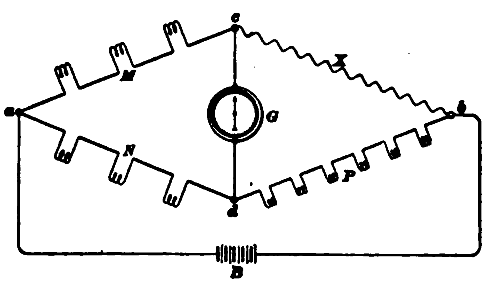

FIG. 41.

M 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 *a*, part of it flowing through resistances M and X, and the rest through N and P. 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 arm 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

$$X = \frac{M}{N} \times P = \frac{1}{100} \times 112 = 1.12 \text{ ohms.}$$

54. The actual various forms of resistance-boxes used with the bridges differ widely from the diagram, but all are

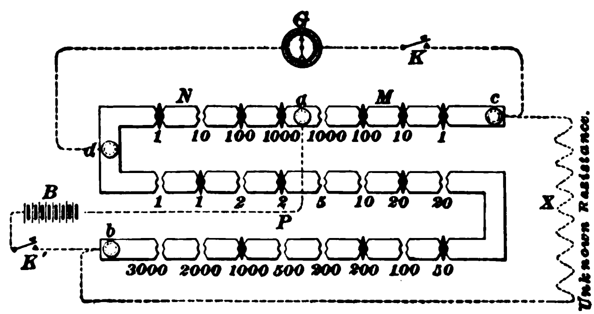

FIG. 42.

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. 42. 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 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 $X = \frac{M}{N} \times P = \frac{1{,}000}{10} \times 5{,}838 = 583{,}800$ ohms.

Fig. 43 shows a special pattern of resistance-box for a Wheatstone bridge, in which the coils of the adjustable

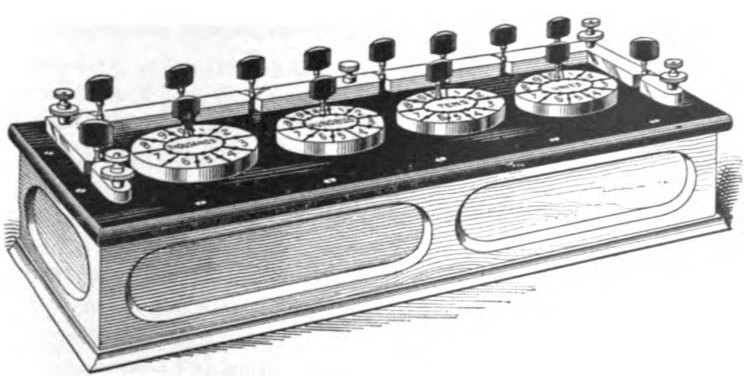

FIG. 43.

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.

EXAMPLE.—The diagram in Fig. 44 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,

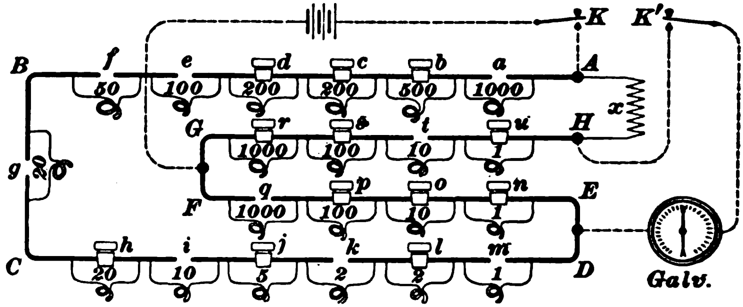

FIG. 44.

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 $G\,H$ represent the upper balance arm M of the bridge; that the coils in the line $E\,F$ represent the lower balance arm N, and that the coils in the lines $A\,B$ and $C\,D$ represent the adjustable arm P. From the fundamental equation of the Wheatstone 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, $P = 1,000 + 100 + 50 + 20 + 10 + 2 + 1 = 1,183$ ohms. Substituting these values in the fundamental equation gives $X = \frac{M}{N} \times P = \frac{10}{1,000} \times 1,183 = 11.83$ ohms. Ans.

55. 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. **34**; for, by transposing, $E = C R$.

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, $E = C R = 2 \times 1.2 = 2.4$ 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.

56. 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, therefore, $1.5 \times 12 = 18$ 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.

57. 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. 45, 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 the wire will 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.

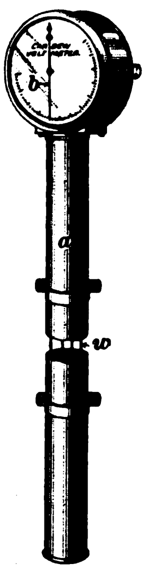

FIG. 45.

58. The **Weston** voltmeter, Fig. 46, is based upon the same principles as the Weston ammeter, and in appearance is quite similar to it. 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 voltmeter is exceedingly small. For example, in the instrument described above, when indicating 150 volts, the current, by Ohm's law, is only 150 ÷ 19,000 = .0079 ampere. All voltmeters are provided with at least two terminals, or binding-posts, such as *p* and *p'*, Fig. 46. Connections are made by two separate conductors, called *voltmeter leads*, from

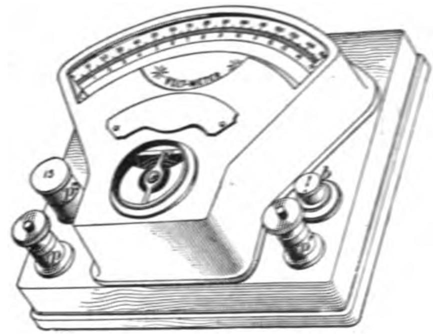

FIG. 46.

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.

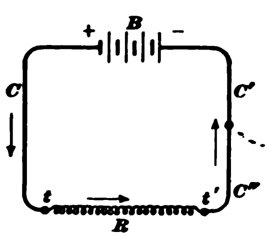

FIG. 47.

59. 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 four cells connected in series are connected 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. 47 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.

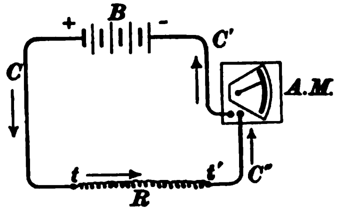

FIG. 48.

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. 48, 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. 49, 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 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.

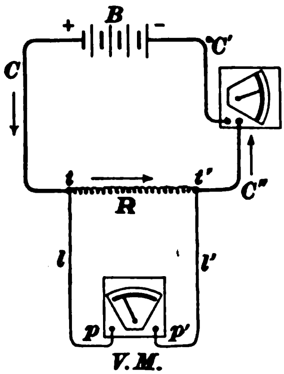

FIG. 49.

APPLICATIONS OF OHM'S LAW.

TO CLOSED CIRCUITS.

60. 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.*

61. 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:

$$C = \frac{E}{R}, \qquad (6.)$$

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 **6**, the current

$$C = \frac{E}{R} = \frac{1.75}{6.6} = .265 \text{ ampere. Ans.}$$

62. 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:

$$R = \frac{E}{C}, \qquad (7.)$$

the letters having the same significance as in formula **6.** By formula **7** 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 **7** the resistance

$$R = \frac{E}{C} = \frac{1.8}{.6} = 3 \text{ ohms. Ans.}$$

63. 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:

$$E = C R. \qquad \textbf{(8.)}$$

The letters have the same meaning as in formulas **6** and **7**. 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 **8**, the electromotive force $E = C R = .4 \times 5 = 2.0$ volts. Ans.

TO DROP, OR LOSS, OF POTENTIAL.

64. Referring again to water flowing in a pipe, it is evident that although 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 **8.** 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 **6** and **7.**

EXAMPLE.—Fig. 50 represents part of a circuit in which a current of 3 amperes is flowing. The resistance 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*.

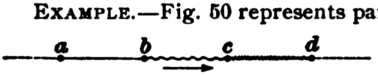

FIG. 50.

SOLUTION.—Since, by formula **8**, $E' = C R'$, 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.

65. 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*) find 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 **7**, $R' = \frac{E'}{C} = \frac{12}{5} = 2.4$ ohms. Ans.

(*b*) The resistance per foot of the conductor is found by formula **1.** 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.

66. 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.

67. 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 = $C r_i$, and the available electromotive force,

$$E' = E - C r_i. \qquad \textbf{(9.)}$$

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 **9**,

$$E' = E - C r_i = 2.2 - (1.2 \times .8) = 1.24 \text{ volts. Ans.}$$

TO DERIVED CIRCUITS.

68. 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 one-half; 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 one-quarter.

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.

69. Fig. 51 represents a derived circuit of 2 branches.

Let r_1 and r_2 = the separate resistances of the two branches; 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 the two branches; thus, if a current of 2 amperes is flowing in the main circuit, one ampere will flow through each branch.

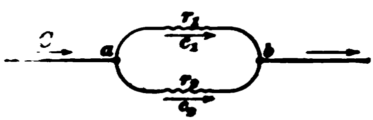

FIG. 51.

When the resistances of the two branches are unequal, the current will divide between them in inverse proportion to their respective resistances. In Fig. 51 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:

For the first branch, $$c_1 = \frac{C r_2}{r_1 + r_2}. \qquad \textbf{(10.)}$$

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.*

For the second branch, $$c_2 = \frac{C r_1}{r_1 + r_2}. \qquad \textbf{(11.)}$$

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 **10,** 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 **11,** which will give

$$c_2 = \frac{C r_1}{r_1 + r_2} = \frac{60 \times 2}{2 + 3} = \frac{120}{5} = 24 \text{ amperes. Ans.}$$

70. 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.

71. 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. 51, the conductivities of the branches are $\frac{1}{r_1}$ and $\frac{1}{r_2}$. 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

$$R'' = \frac{r_1 r_2}{r_1 + r_2}. \qquad \textbf{(12.)}$$

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. 51, given $r_1 = 2$ ohms and $r_2 = 3$ ohms; find their joint resistance in parallel.

Solution.—From formula **12**, 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.

72. Fig. 52 represents a divided circuit of three branches. Let r_1, r_2, and r_3 be the separate resistances of those branches, respectively. Then, $\frac{1}{r_1}$, $\frac{1}{r_2}$, and $\frac{1}{r_3}$ 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

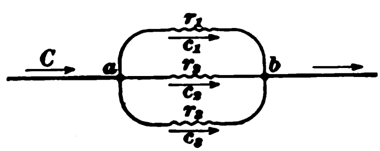

Fig. 52.

$$1 \div \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3} = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}.$$

Hence, the joint resistance of three branches in parallel

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}. \qquad \textbf{(13.)}$$

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. 52, 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 **13**, their joint resistance

$$R''' = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2} = \frac{5 \times 10 \times 20}{10 \times 20 + 5 \times 20 + 5 \times 10} = \frac{1{,}000}{350} = \frac{20}{7}$$

$= 2\frac{6}{7}$ ohms. Ans.

73. 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. **34.**

For example, if the currents in the three branches, Fig. 52, 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.

74. 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. 52, assume that the separate resistances of the three branches are 5, 10, and 20 ohms, respectively, 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.

75. The separate resistances 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. 52, 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. 53 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.

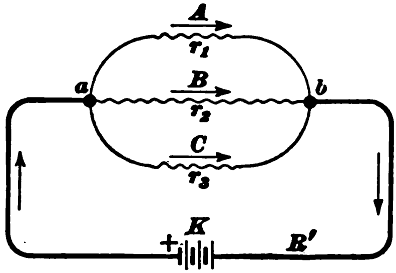

FIG. 53.

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 **8**, $E = C R$, 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 **13**, 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.

76. 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 will pass in one second through a circuit in which the strength of current is one ampere.

As stated in Art. **35,** 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 two 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.

$$\text{Then, } Q = C\,t. \qquad \textbf{(14.)}$$

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 formula **14,** $Q = C\,t = 12 \times 5{,}400 = 64{,}800$ coulombs. Ans.

ELECTRICAL WORK.

77. 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 potentials differing by *one volt.*

The unit of electrical work is, therefore, the *volt-coulomb,* and is called the **joule.**

1 *joule* = .7373 foot-pound.

78. 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,

$$J = CEt. \qquad (15.)$$

When the current and resistance are known,

$$J = C^2 R t. \qquad \textbf{(16.)}$$

When the resistance and electromotive force are known,

$$J = \frac{E^2 t}{R}. \qquad \textbf{(17.)}$$

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 ½ 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 **16,** the electrical work done

$$J = 15 \times 15 \times 2 \times 1{,}800 = 810{,}000 \text{ joules. Ans.}$$

79. When the work in joules is known, the work in foot-pounds

$$\text{F. P.} = .7373 J. \qquad \textbf{(18.)}$$

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 potentials differing by 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 **15,** the electrical work done $= J = 8 \times 10 \times 7{,}200 = 576{,}000$ joules. Expressed in foot-pounds, this will be, by formula **18,**

$$\text{F. P.} = .7373 \times 576{,}000 = 424{,}684.8 \text{ foot-pounds. Ans.}$$

ELECTRICAL POWER.

80. 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 **15**, the amount of electrical work $J = C E t$. Then,

$$W = \frac{C E t}{t} = C E. \qquad \textbf{(19.)}$$

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 potentials differing by 25 volts?

SOLUTION.— $E = 25$ volts and $C = 12$ amperes. Hence, by formula **19**,

$$W = C E = 12 \times 25 = 300 \text{ watts. Ans.}$$

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 **16**,

$$W = \frac{C^2 R t}{t} = C^2 R. \qquad \textbf{(20.)}$$

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 **20**,

$$W = C^2 R = 30^2 \times 3 = 2{,}700 \text{ watts. Ans.}$$

By derivation from formula **17**,

$$W = \frac{E^2 t}{R t} = \frac{E^2}{R}. \qquad \textbf{(21.)}$$

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 **21**,

$$W = \frac{E^2}{R} = \frac{20^2}{10} = 40 \text{ watts.} \quad \text{Ans.}$$

81. One watt equals $\frac{1}{746}$ of a horsepower; or, one horsepower equals 746 watts.

If H. P. = horsepower,

$$\text{H. P.} = \frac{W}{746}. \qquad \textbf{(22.)}$$

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 **19**, **20**, **21**, viz.:

$$\text{H. P.} = \frac{E\,C}{746}; \ \text{H. P.} = \frac{C^2 R}{746}; \text{ and H. P.} = \frac{E^2}{746\,R}.$$

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, $\text{H. P.} = \frac{E\,C}{746} = \frac{250 \times 50}{746} = 16.756$ 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,

$$\text{H. P.} = \frac{C^2 R}{746} = \frac{25^2 \times 14.92}{746} = 12.5 \text{ horsepower.} \quad \text{Ans.}$$

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, $\text{H. P.} = \frac{E^2}{746\,R} = \frac{110^2}{746 \times 4} = 4.055$ horsepower. Ans.

82. To express the power in watts when the horsepower is known, use the following formula:

$$W = \text{H. P.} \times 746. \qquad \textbf{(23.)}$$

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 **23**, the electrical power $W = 4.35 \times 746 = 3{,}245.1$ watts. Ans.

83. The watt is too small a unit for convenient use in expressing the output of large dynamos, so the *kilowatt* is generally used. One kilowatt is equal to 1,000 watts, or about 1⅓ horsepower. For example, if a dynamo were rated at 75 kilowatts, it would have an output of 75,000 watts or, roughly, about 100 horsepower.

The *kilowatt-hour* is a unit of *work* commonly used in connection with electrical measurements. It is the amount of work done when 1 kilowatt is expended for 1 hour, or ½ kilowatt for 2 hours, etc. The kilowatt-hours are therefore found by multiplying the average number of kilowatts by the number of hours during which the kilowatts were expended. Since 1 kilowatt = 1,000 watts, 1 kilowatt-hour = 1,000 watt-hours. Now, 1 watt expended for 1 second is equal to 1 joule; hence, 1 kilowatt-hour = $1{,}000 \times 3{,}600 = 3{,}600{,}000$ joules, or $3{,}600{,}000 \times .7373 = 2{,}654{,}280$ foot-pounds. The kilowatt-hour represents a definite amount of work, whereas the kilowatt expresses the rate at which work is done and is, therefore, a unit of power.

DYNAMOS AND MOTORS.

(PART 2.)

ELECTROMAGNETIC INDUCTION.

1. 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. 1 represents such a coil around which a current is flowing from the battery *B*. Suppose the battery is disconnected from 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. 2, 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

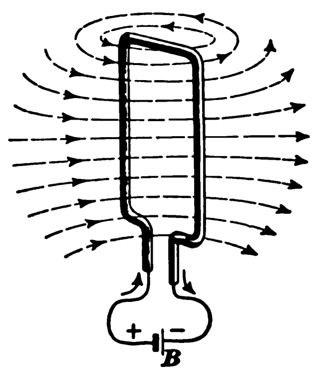

FIG. 1.

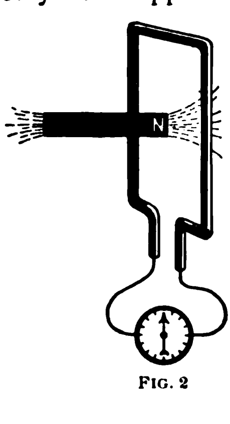

FIG. 2

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.

2. In place of a small magnetic pole, imagine the coil to be suddenly inserted into a large uniform magnetic

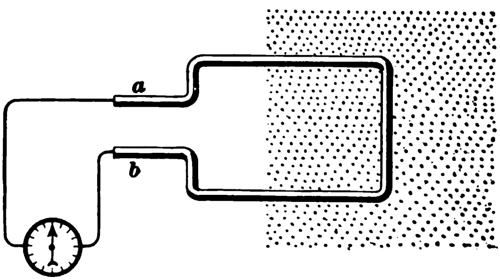

FIG. 3.

field where all the lines of force are parallel to one another. The diagram, Fig. 3, 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. 4, 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. 5, 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.*

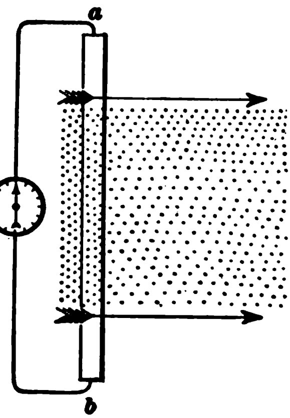

FIG. 4.

3. In reality, currents generated in a conductor *cutting* lines of force, and those *induced* in a coiled conductor by a change in the 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. 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. 6 the heavy loop *C. C.* represents a closed coil, and the light loop *L. F.* represents four

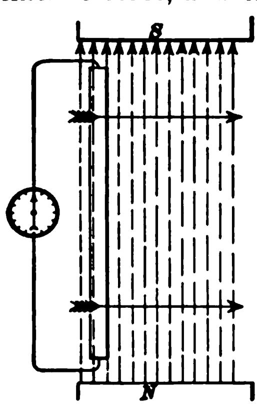

FIG. 5.

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, 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.

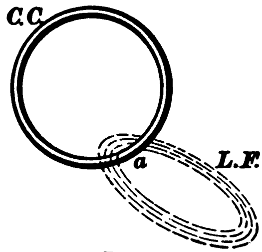

FIG. 6.

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.

4. There are three methods of producing an electromotive force by induction in a coiled conductor; namely, by *electromagnetic induction*, by *self-induction*, and by *mutual induction*.

In **electromagnetic 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.

5. 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.

6. 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. 7, where the current circulates around the coil *P* when the circuit is closed at key *b*. The coil *P* is called 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.

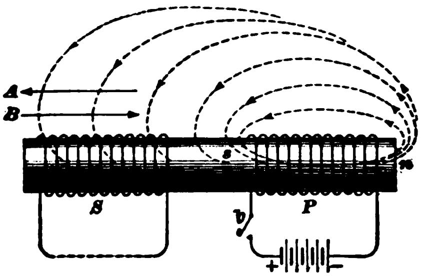

FIG. 7.

To make this clear, in Fig. 7, suppose the current in the primary coil to be suddenly established by closing the switch at *b*. The lines of force will surround the conductors and spread out in all directions. The lines of force spreading out in the direction of arrow A cut the conductors of the secondary coil. The resulting current in the secondary would have the same direction were the lines of force stationary, as shown, and the coil S moved along the core in the direction of arrow B. Then, according to the thumb-and-finger rule, Art. **8,** the current will flow in the secondary coil as indicated by the arrows, or opposite to that in the primary. Similar reasoning will show that when the primary circuit is broken and the lines of force collapse, the direction of the current in the secondary coil S will be the *same* as that which existed in the primary.

7. 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. 3, 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.

8. 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. 4, 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. 8, 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, in the direction towards which the middle finger is pointing.

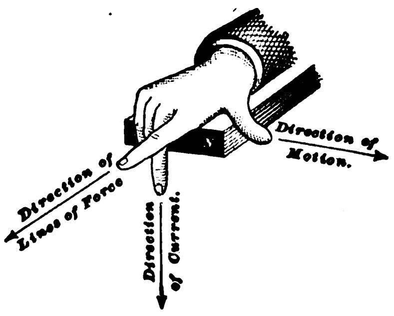

FIG. 8.

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.

9. In Fig. 9, 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 the direction indicated by the curved arrows. As the coil starts to rotate, its sides *c d* and *e f* 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. **8**, 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.

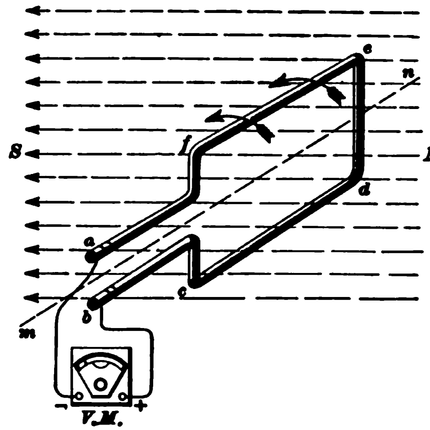

FIG. 9.

10. The diagram, Fig. 10, 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 position *1* to position *2* can be graphically shown by means of cross-section paper, Fig. 11. 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 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. 10, it has consumed one-third of the time; hence, at this instant the E. M. F. that is being generated

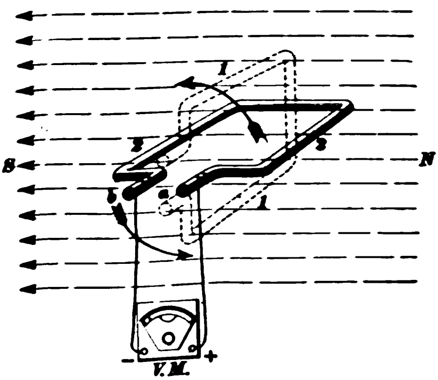

FIG. 10.

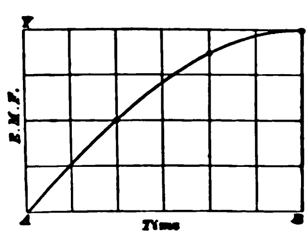

FIG. 11.

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.

11. 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. 12. The sum of the divisions between *A* and *C* represents 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. 10, which corresponds to *B*, Fig. 12. In this position the plane of the coil lies parallel to the lines of force, and its

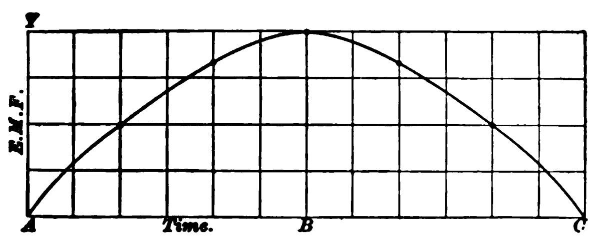

FIG. 12.

sides, corresponding to *c d* and *e f*, Fig. 9, 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: *The E. M. F. generated in a moving conductor cutting lines of* *force at right angles is directly proportional to the rate of cutting.* Suppose, 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.

12. Fig. 13 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* cut a few lines of force, 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 tends to flow during the first half of the revolution. For, by applying the rule in Art. **8**, 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 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.

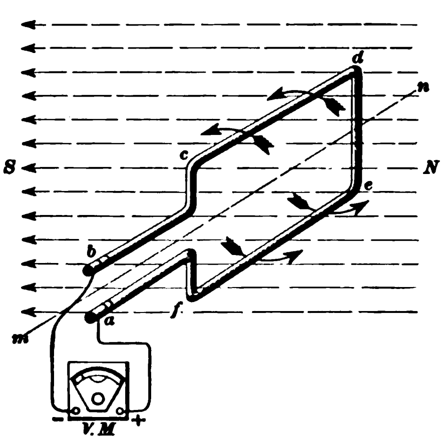

FIG. 13.

The E. M. F. that 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

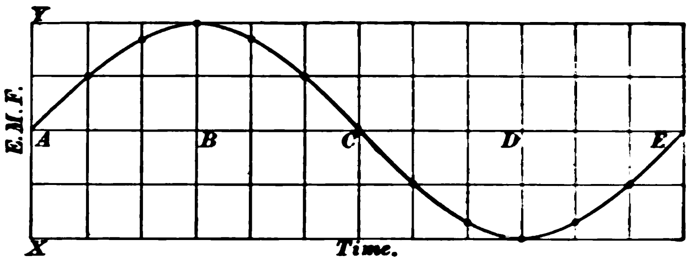

FIG. 14.

coil reaches a vertical position. In Fig. 14, 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* represent 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 *A E*, 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 *A E*. For convenience, let the direction in which the E. M. F. tends to act in the first half of the revolution be called the **positive (+) direction,** and in the last half the **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.

13. In Fig. 15, instead of connecting the external circuit directly to the ends of the coil, suppose the wires *o* and *p* to be brought to two brushes *r* and *s*, which lie in a

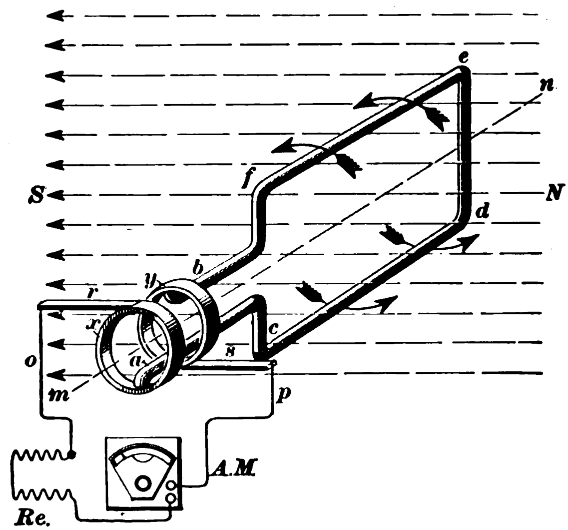

FIG. 15.

horizontal position and bear on the two *collector rings* *x* and *y*, respectively. These collector rings, it will be seen, are connected to the two ends of the coil; *x* to *a* and *y* to *b*.

The resistance of the entire circuit, including the coil, ammeter, collector rings, and brushes, 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. **5**, 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. 16

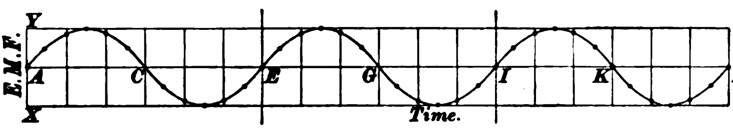

FIG. 16.

represents 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.**

14. The next step is to demonstrate the principle of changing, or *commuting*, this alternating current into a *continuous*, or *direct*, current; that is, a current which always flows in the same direction through the external circuit. In Fig. 17, 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

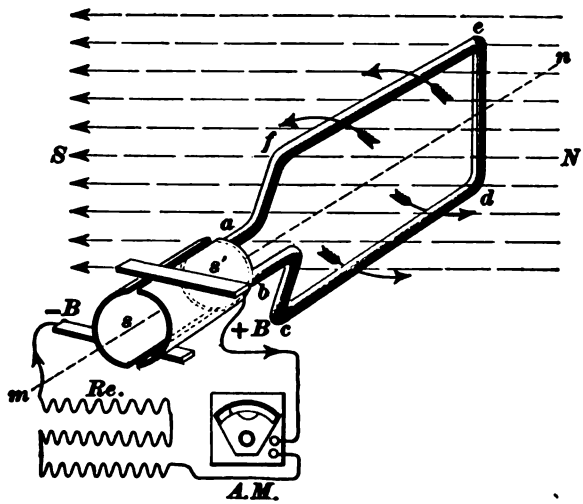

FIG. 17.

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 ammeter *A. M.* and the resistance *Re* 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 always in the same direction. The effect is graphically shown in Fig. 18 by the use

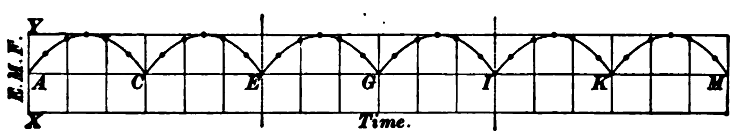

FIG. 18.

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.

A consideration of the preceding paragraphs will show the student that direct-current dynamos require commutators, while alternating-current dynamos employ only collector rings.

15. In Fig. 19, two separate coils are placed in a magnetic field at right angles to each other. Four metallic

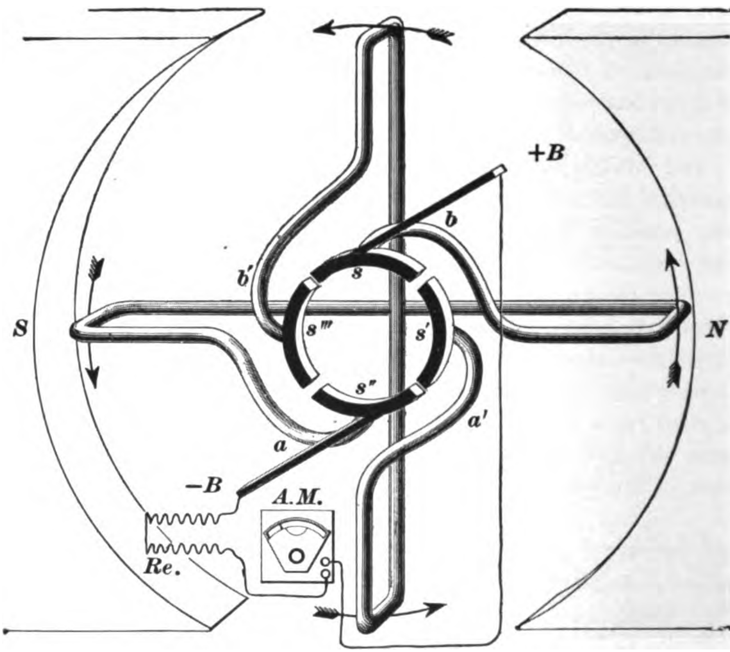

FIG. 19.

segments s, s', s'', and s''' are cut from a cylindrical ring to 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 *Re*. 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. 20, the divisions between the base line *A M* 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

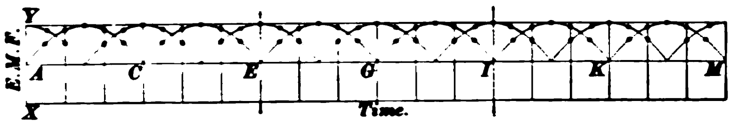

FIG. 20.

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. A continuous current of uniform strength is known as a constant current.

16. In Art. **30,** Part 1, 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. 21, the number of lines of force passing through the coils is increased, and the E. M. F. that is generated is greater, since, Art. **11,** 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

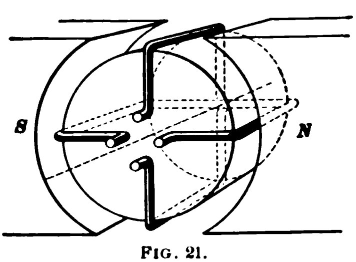

FIG. 21.

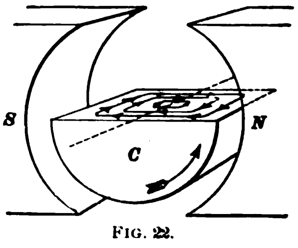

FIG. 22.

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 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 core can be formed from Fig. 22. *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. 23. 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. A core made in this way is said to be **laminated.**

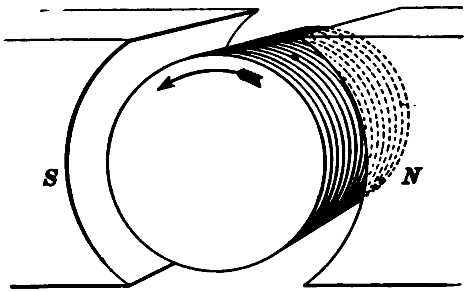

FIG. 23.

17. Iron cores are generally made in two styles: **drum or ring.**

A drum core may be defined as a laminated cylinder, the length being generally greater than the diameter, such as shown in Fig. 23.

A ring core may be defined as a laminated rim of rectangular cross-section, such as *R* in Fig. 24.

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 example, in Fig. 24, an iron ring *R* is placed between the poles *N* and *S* of

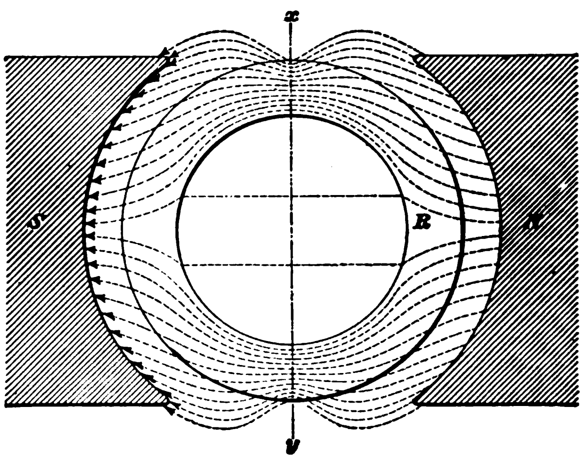

FIG. 24.

a magnet; the lines of force pass out from the north 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 *x y*, 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. 25, if a loop of insulated wire *a b c d* is wound around the iron ring, and the ring and loop are rotated on a central axis *m n* like the rim of a fly-wheel, only that part of the loop from *a* to *b* is cutting lines of force; 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

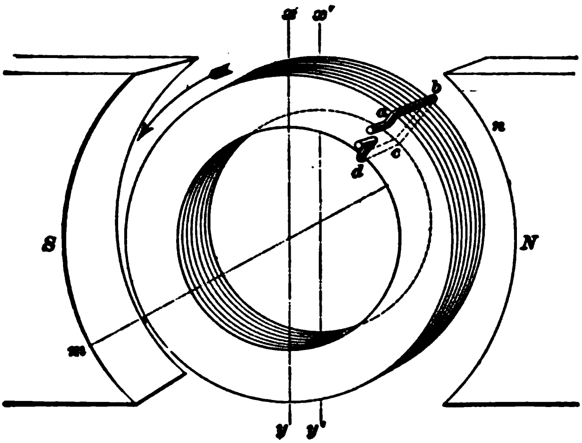

FIG. 25.

given in Art. **8**, it will be seen that the E. M. F. generated in the side *a b* of the loop tends to send a current from *b* to *a* during the first half of the revolution from *y y'* to *x x'*, and in the opposite direction during the last half.

18. 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 *m n* 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 generated in the two parts tend to oppose each other; that is, the E. M. F. generated between *a* and *b* tends to act

A drum core may be defined as a
length being generally greater than
shown in Fig. 23.

A ring core may be defined as a
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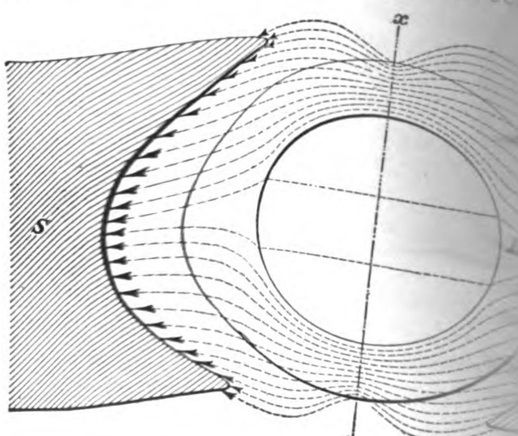

Fig. 24.

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be cutting the lines of force as they pass
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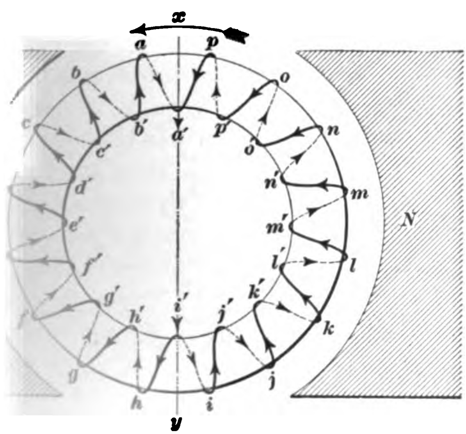

. 27.

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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

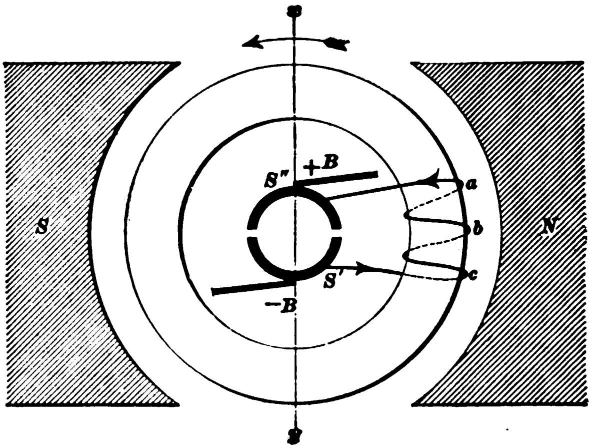


FIG. 26.

Fig. 26, and the ends of the coil connected to two metallic segments S' and S''. By applying the rule in Art. **8**, 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. **14**. 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. 27. This is known as a *ring* winding, or one in which the conductors are wound in the form of a helix

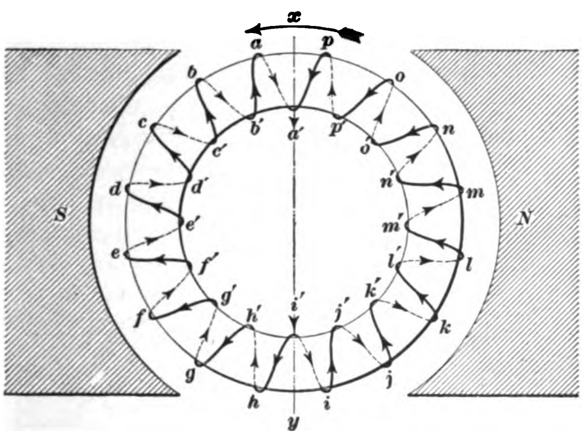


FIG. 27.

on a ring core. 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 arrow-heads 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 *i′*.

19. 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. 27, 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 of potential will always be found between any two turns situated diametrically opposite one another when they pass through the vertical diameter $x\,y$. 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

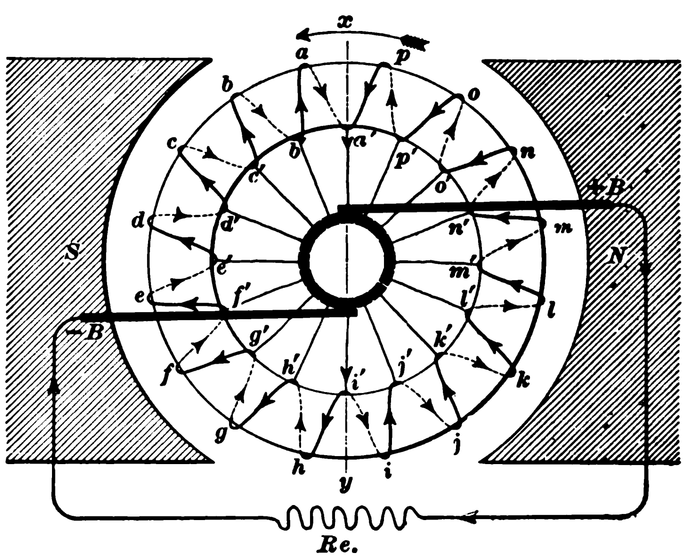


FIG. 28

allowing two brushes to rub against the commutator at two points diametrically opposite each other on the vertical diameter $x\,y$, Fig. 28. 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 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. 29, 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. **56**, Part 1, the total E. M. F. of the above battery is equal to the E. M. F. of either of the two sets 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.

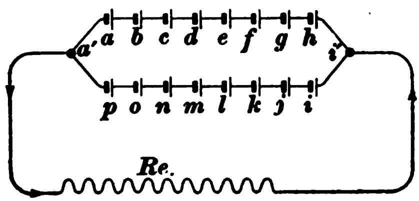


FIG. 29.

If a comparatively large number of turns and segments is used, the current flowing from $+B$, Fig. 28, 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.

20. A conductor wound upon a core in the manner shown in Figs. 27 and 28 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. 19 and 26, the winding is termed an **open-coil** winding.

21. A *closed-coil winding* can be applied to a cylindrical drum core as described in Art. **16**, and a continuous non-pulsating current obtained from the brushes, as in the case of the ring core. The method of winding is somewhat

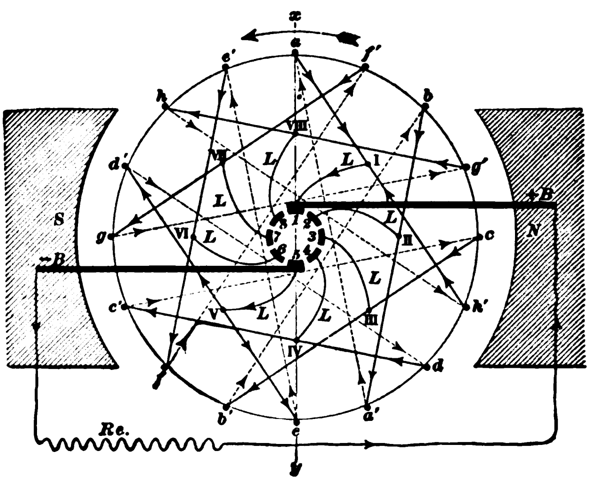


FIG. 30.

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. 30. This is known as a drum winding, or one in which the conductors are wound longitudinally upon the surface of a drum core. A drum winding may also be applied to a ring core, as will be seen. 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 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'*, *c*, *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. 30, the two neutral points lie opposite each other on the commutator along the vertical diameter *x y*. 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. **8**, 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.

22. 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, *rate of cutting* $= \frac{N}{t}$, where 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 $E = \frac{N S}{10^8 t}$, 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 $E = \frac{N S}{10^8 t} = \frac{4{,}500{,}000 \times 8}{100{,}000{,}000 \times 1.5} =$ .24 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, $E = \frac{(N n t) S}{10^8 t} =$

$$\frac{202{,}500{,}000 \times 8}{100{,}000{,}000 \times 1.5} = 10.8 \text{ volts.}$$

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, $E = \frac{(N n t) S}{10^8 t}$, the two t's cancel one another, leaving the equation, $E = \frac{N S n}{10^8}$. 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. 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 make the demonstration clearer by using a specific value for t.

23. The equation $E = \frac{N S n}{10^8}$ can now be applied with some modifications to the closed-coil conductor wound upon either the ring or drum core. The ring core, Fig. 28, 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

$$E = \frac{2 N S n}{10^8}. \qquad (1.)$$

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. 28, 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. Substituting the values in the formula gives $E = \frac{2 N S n}{10^8} = \frac{2 \times 3{,}000{,}000 \times 8 \times 35}{100{,}000{,}000} = 16.8$ 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. 30. 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.

24. 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 electromagnet, 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.

25. 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. 31 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

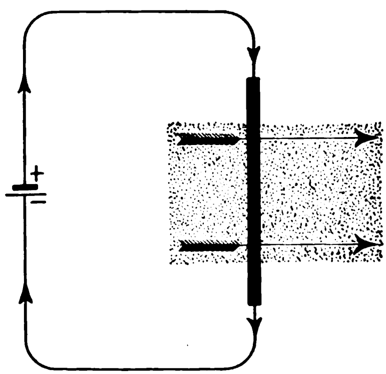


FIG. 31.

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.

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. 31 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.

26. 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 **8**, 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.*

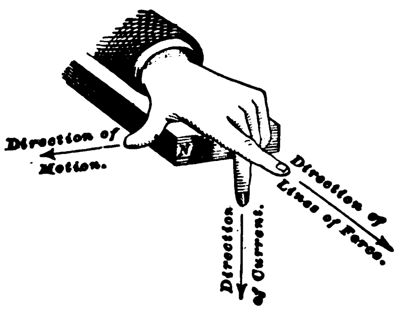


FIG. 32.

For example, in Fig. 32, 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.

27. Comparing the rule in Art. 8 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. 33. 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 by the small arrow-heads, according to the rule given in Art. **8.** 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 lengths of the arrows.

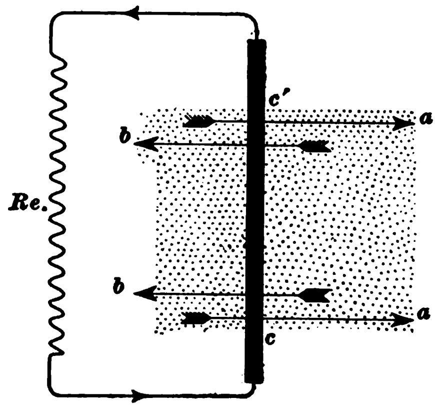


FIG. 33.

28. 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 will be 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.

29. 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. 34, the current is flowing through the armature coil in the same direction as represented in

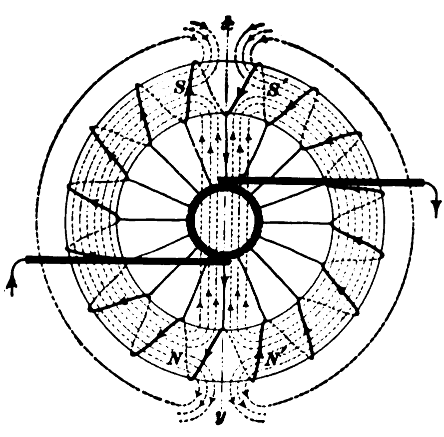


FIG. 34.

Fig. 28. The current circulating around the armature coil in two directions acts as a magnetizing force upon the core and produces two electromagnets. 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. 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. 35 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 $x\,y$. As the positions of the neutral points on the commutator depend upon the positions of the neutral spaces on the core, they are also shifted

forwards in the direction of rotation when the current flows through the armature; hence, the brushes must be moved

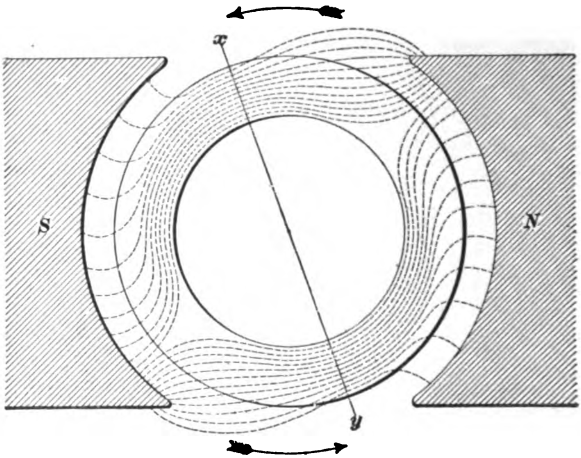


FIG. 35.

forward 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.

30. 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. 30. 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. 36, and downwards in front of the south pole, as represented by the solid circles. The 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. 36. The direction of the lines of force around the conductors in which the current is flowing downwards corresponds with the movements of the hands of

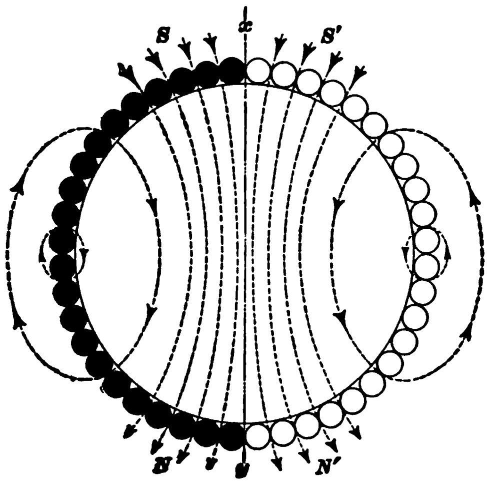


FIG. 36.

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.

31. 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.

32. In Art. **24** it was stated that the magnetic field in all dynamos is produced from either a permanent magnet or an electromagnet. 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 pattern, of hard steel, and with a recess bored out between the ends of the poles to admit the armature, as shown in the diagram, Fig. 37.

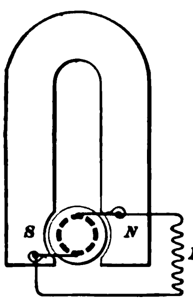


FIG. 37.

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. 38. The alternating current is obtained from two brushes, one rubbing against

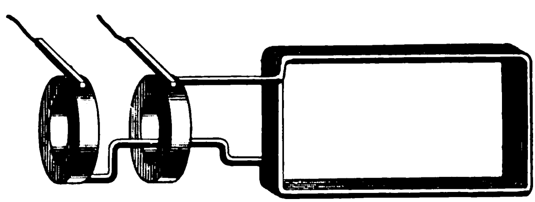


FIG. 38.

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 instant. By comparing this coil with that in Fig. 13, it will be seen that the current obtained from the two brushes flows in two directions during every revolution.

33. In nearly all dynamos furnishing current for lamps, power, and other commercial purposes, the magnetic field is produced by an electromagnet. This class of dynamos is divided into various types, depending upon the manner in which the current is obtained to excite the field-magnets.

34. 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. 39. 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

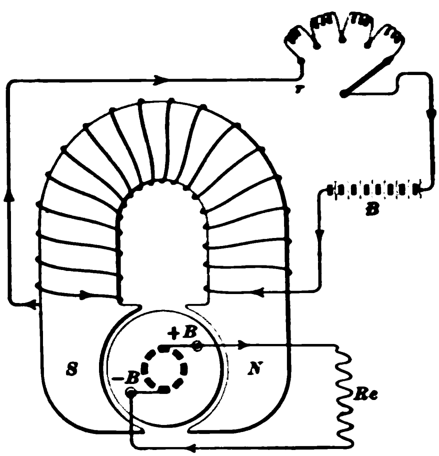


FIG. 39.

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.

35. 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 electromagnet 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 upon both 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.

36. The second class of machines with an electromagnet 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

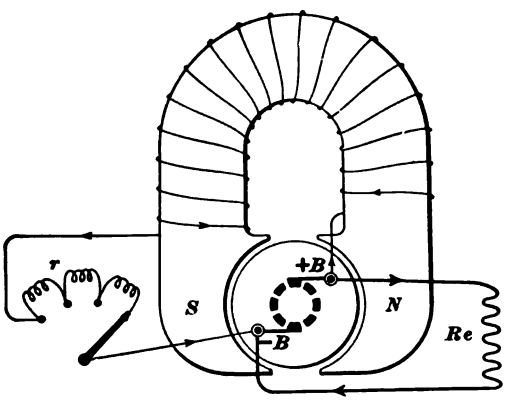


FIG. 40.

field coils being connected in *shunt* with the external circuit from the brushes. In Fig. 40, 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 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.

37. 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.

38. 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.

39. 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. 41. The current 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

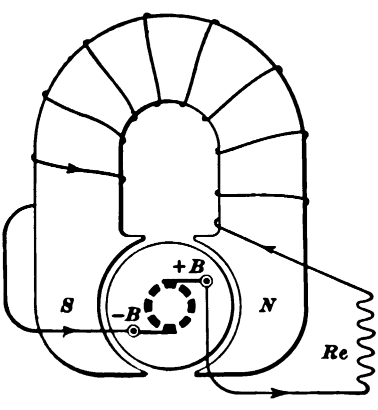


FIG. 41.

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 degree of magnetization, since that is proportional to the *ampere-turns*.

40. 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. 42. *S F* represents the magnetizing coils. *A* is a contact arm which travels in either direction along the line *x y*, 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 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.

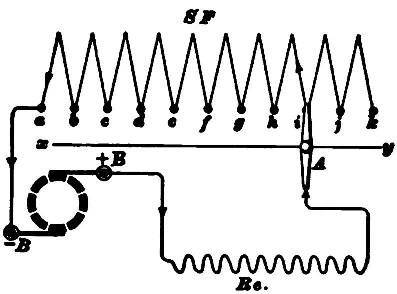


FIG. 42.

41. 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.

This effect is accomplished by connecting a resistance *R*, Fig. 43, 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

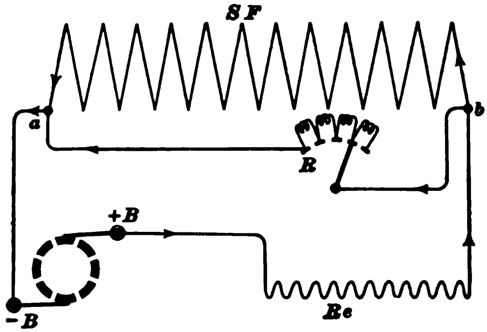


FIG. 43.

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.

42. 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

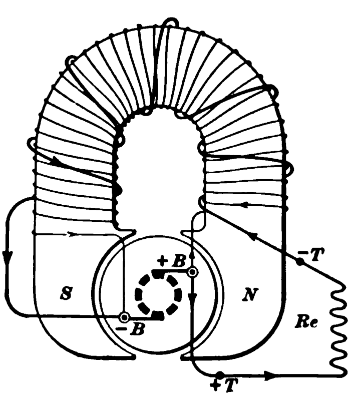
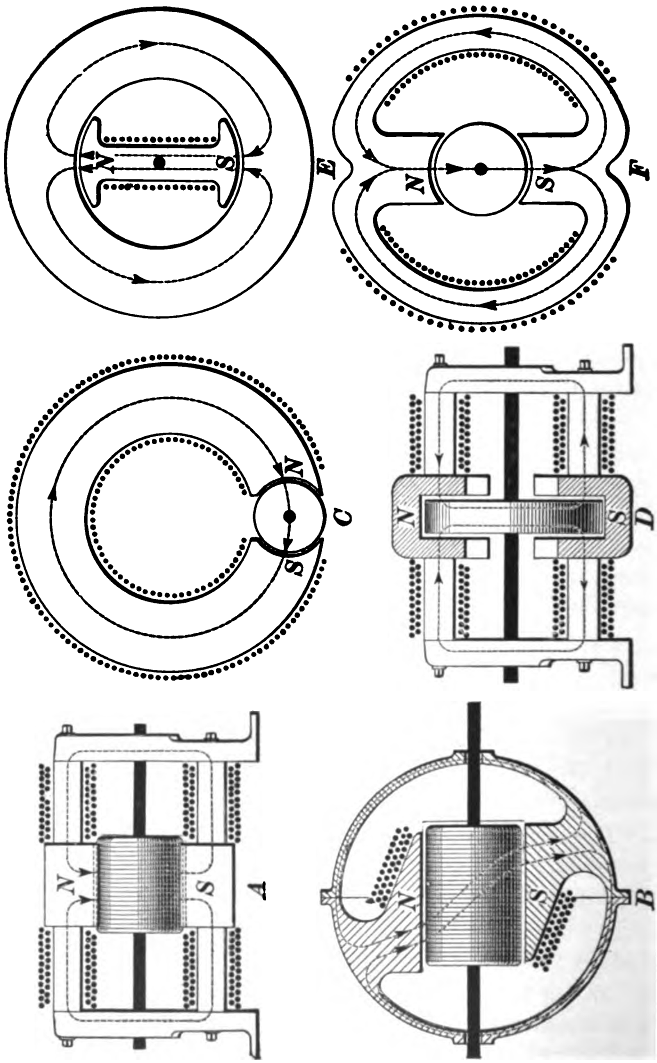


FIG. 44.

Fig. 44, 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 action 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. 44, 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-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

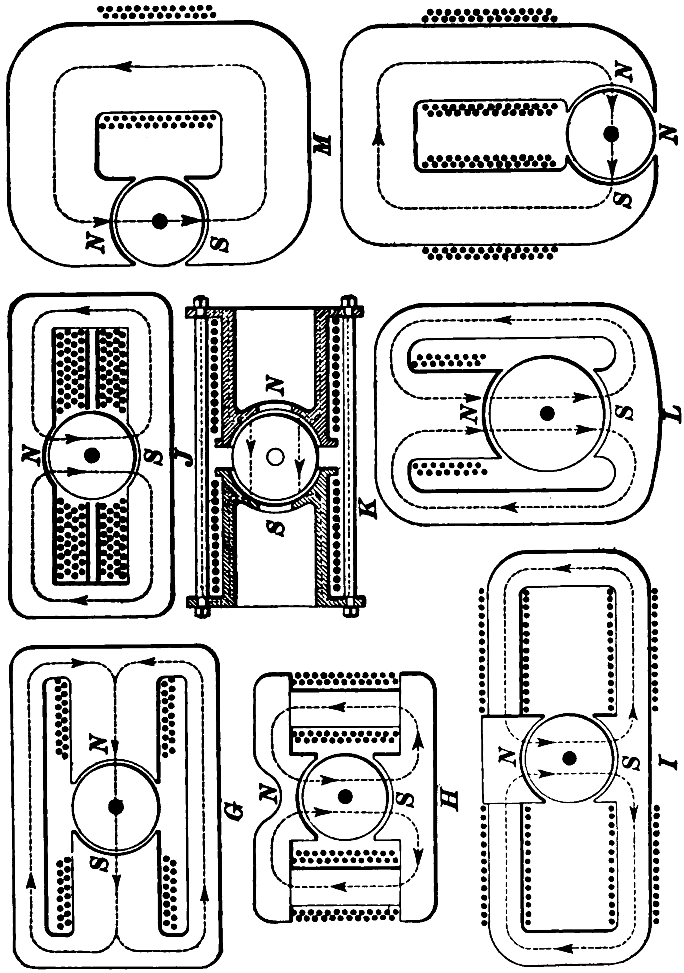


FIG. 45.

field outside the series coils; that is, in Fig. 44, 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.

43. The various types of field-magnets for dynamos in which the armature revolves between only one pair of poles are shown in Fig. 45. 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 separate 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.

Field poles are distinguished as follows with respect to the coils producing them: (*a*) **Salient poles**; (*b*) **Consequent poles.**

In all cases where a single coil is used, or where, if two coils are used, they are wound so as to produce unlike poles at their free ends, the poles are called salient poles. When two coils are used and wound so as to make their adjacent poles similar, the resultant poles are called consequent poles.

Referring to Fig. 45, salient poles exist in fields *B*, *C*, *G*, *J*, *K*, *L*, *M*, *N*, and consequent poles in *A*, *D*, *E*, *F*, *H*, *I*. The adjacent coils in *A*, Fig. 45, have their adjacent poles at *N* and *S* similar. Were these poles opposite, the magnetic flux would circulate around the magnets without passing through the armature.

TYPES OF DYNAMOS.

44. 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 and 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 and whose E. M. F. is constant. In ordinary alternating-current dynamos the reversals average generally either 7,200 or 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.

45. 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. 46, 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

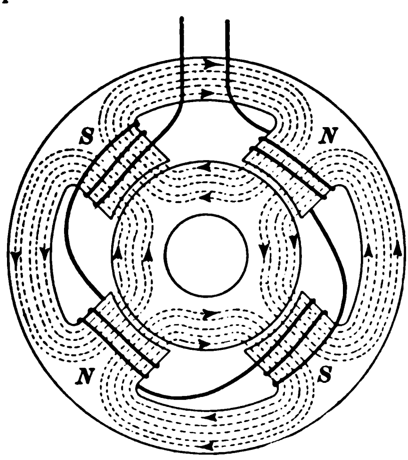


FIG. 46.

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 diagram. 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 magnetic circuits, in the armature and in the field yoke.

46. The process of generating an E. M. F. is similar to that in bipolar machines, but there are some points which

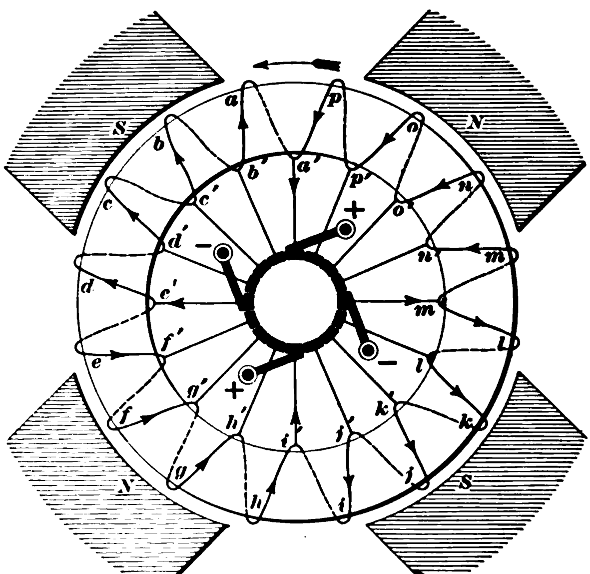


FIG. 47.

should be understood. Consider first the case of a ring core with a closed-coil winding as shown in the diagram, Fig. 47. 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. 48. 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 potential between the positive and negative brushes in Fig. 47, 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.

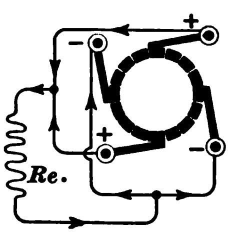


FIG. 48.

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, winding,** since the current divides into as many circuits in parallel as there are poles in the field-magnet.

47. It is possible, however, to connect and group the conductors in an armature for a multipolar dynamo so that

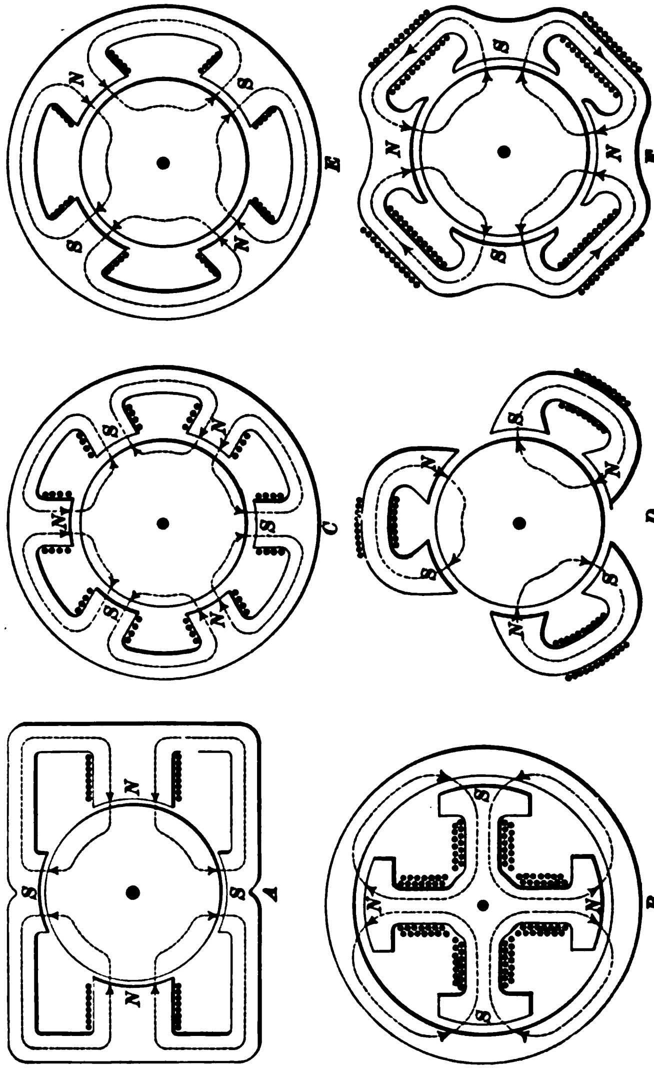


FIG. 49.

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.

48. 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, whichever is more expedient.

49. Types of Multipolar Field-Magnets.—The various types of multipolar field-magnets are shown in Fig. 49. 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.

50. Mechanical Construction.—Heretofore, only the principles of a dynamo have been considered; its mechanical 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

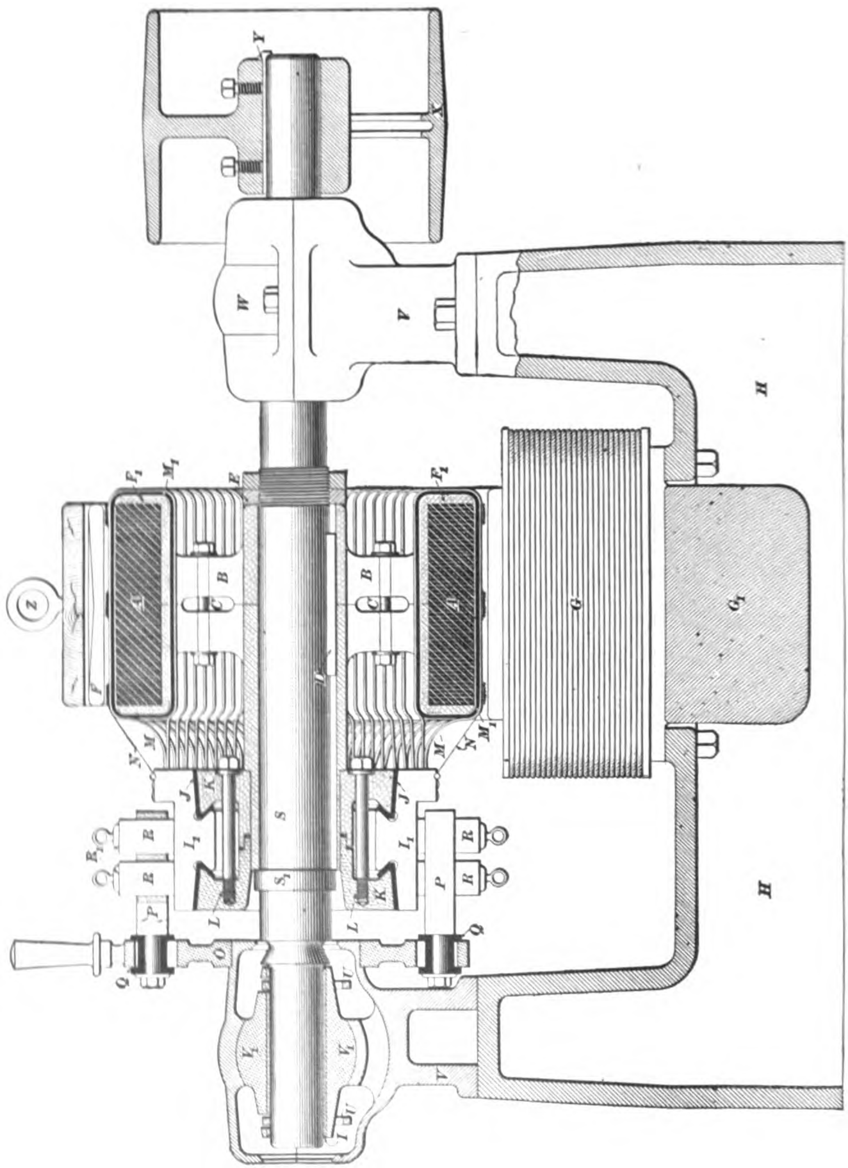


FIG. 50.

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. 50, 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 lock-nut.
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.

T = Bearing or brass. U = Oil-rings. V = Standard. W = Cap for standard.	Complete outfit called pillow-block.

X = Pulley.
Y = Key for pulley.
Z = Eye-bolt.

51. Frame.—The frame is made up of two castings; the upper one 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.

52. Armature.—As generally used, the word **armature** includes the wound core and commutator mounted on the shaft ready for operating. In Fig. 50, 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.

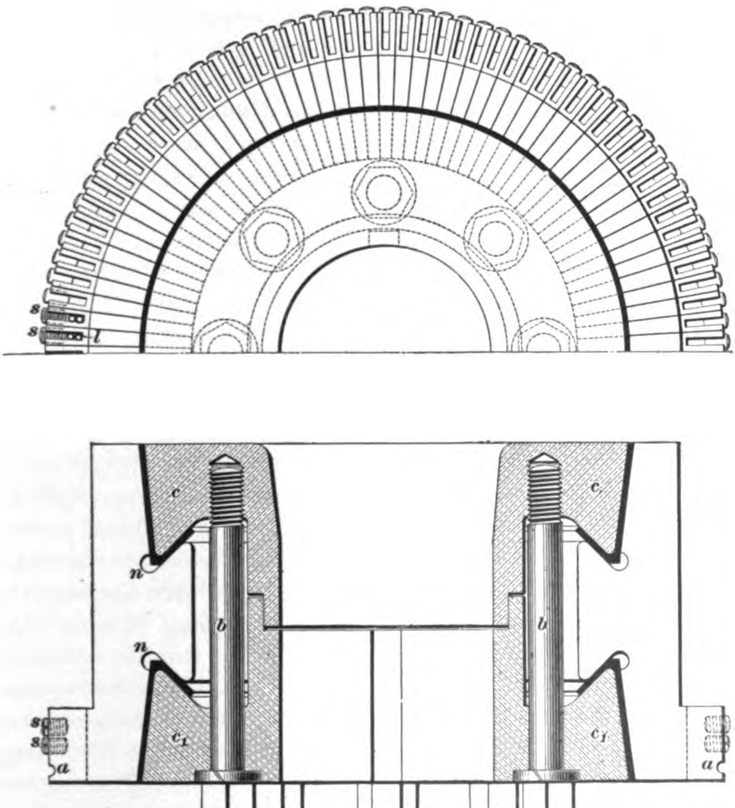


FIG. 51.

53. Commutator.—Every maker of dynamos has a special design of commutator, but all embody the same general construction. Fig. 51 shows two enlarged views of a commutator such as is shown in place in Fig. 50. 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 *l*. 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.

54. Brushes and Brush Holders.—In the cut of the machine in Fig. 50, 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.

55. 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. 50 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 large 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. 50. 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.

56. 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.

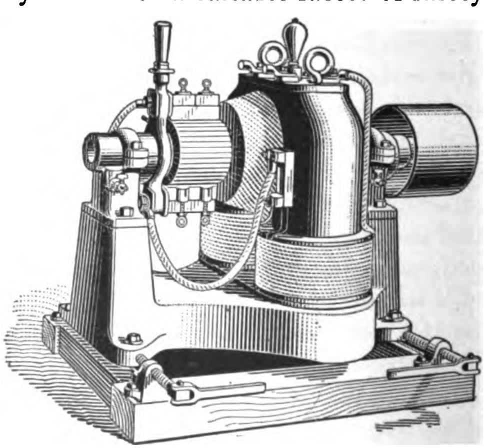


FIG. 52.

57. A perspective view of the bipolar dynamo just described is shown in Fig. 52. In the cut the machine is 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 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.**

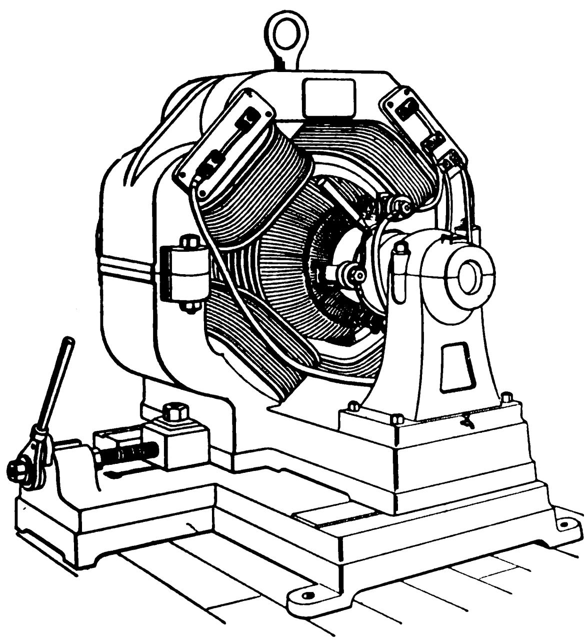


FIG. 53.

58. A multipolar dynamo for developing a constant potential and ready for operating is shown in Fig. 53. 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.

59. 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* of 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.

60. 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

$$\mathsf{E} = \frac{100 \times O}{I}. \qquad (2.)$$

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 **2**,

$$\mathsf{E} = \frac{100 \times 13,428}{14,920} = 90 \text{ per cent.}$$

61. 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 formula

$$L = \frac{100\ (I - O)}{I}. \qquad \textbf{(3.)}$$

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 **2**, the efficiency

$$E = \frac{100 \times 6,341}{7,460} = 85 \text{ per cent. Ans.}$$

(*b*) By formula **3**, 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 efficiency. 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 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.

62. When the output of a dynamo and its corresponding efficiency are given, the input necessary may be found by the formula

$$I = \frac{100 \times O}{E}. \qquad (4.)$$

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 **4**, 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.

63. When the input of a dynamo and its corresponding efficiency are given, the output may be found by the formula

$$O = \frac{I E}{100}. \qquad (5.)$$

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 **5**, the output of the dynamo under these conditions, $O = \frac{26,110 \times 89.5}{100} = 23,368.45$ watts. Ans.

64. 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 **4**, 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.

65. 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. **16**; 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 electromagnet 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 electromagnet 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 electromagnet 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.

66. 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 **20**, Part 1. 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.

67. 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. **36,** 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 **19,** Part 1, the power in watts, $W = CE$; 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 **20** or **21**, Part 1.

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.

68. 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 $\frac{4400}{220} = 20$ 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 $W_s = E_e \times C_s = 220 \times .8 = 176$ 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.

69. 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.

70. 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 **20**, Part 1), 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 **20,** Part 1, 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 to 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.

71. 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.

72. 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.

73. 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 out, 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 can not 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.

74. When a dynamo is first started, it is at about the same temperature as the air, so that when the conductors in the armature begin to generate heat, this heat can not 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 boiling-point 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 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.

75. 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° 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 the 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 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 the rise of the armature; i. e., it is usually limited to about 80° F above the temperature of the air.

76. 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 *sparking*. Referring to Fig. 28, 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. 5) 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. 28) 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.

77. It has been shown (Art. **29**) 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 any amount of shifting of the brushes will not afford sparkless commutation.

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.

78. 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 farther 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. On account of the increased resistance of contact, 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.

79. 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 of 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 the reason, therefore, that they are of higher resistance, 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.

(PART 3.)

CONSTANT-CURRENT DYNAMOS.

1. 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.

2. 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. **75,** Part 2), 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.

3. 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. (Art. **1**), 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.

4. The second method has been described in Arts. **40** and **41**, Part 2, 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. **35**, Part 2), 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.

5. The third method is almost universally used in this type of machines. It has been pointed out (Art. **19**, Part 2) 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. 28, Part 2.

6. 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. **79,** Part 2.)

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. 34, Part 2) 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: Electromagnets 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.

7. Wood Dynamos.—These machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *A*, Fig. 45, Part 2, 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. 1 (*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

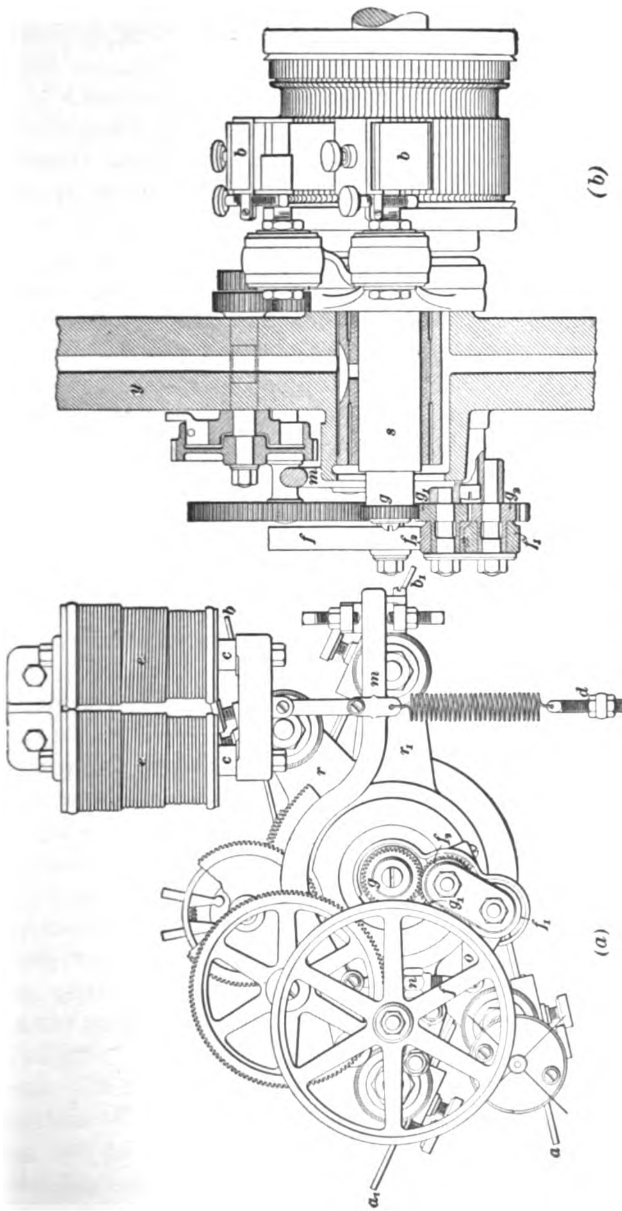


FIG. 1.

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 electromagnet *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 electromagnet 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 electromagnet 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. 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 of these machines, the friction-rollers 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. These regulators are simple and reliable in action.

8. Standard Dynamos.—These machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *H*, Fig. 45, Part 2. 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. This mechanism 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, and 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.

9. Western Electric Dynamos.—In the smaller sizes these machines have bipolar, consequent-pole, series-wound field-magnets of the type illustrated at *I*, Fig. 45, Part 2, 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.

10. 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. 45, Part 2, 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, thus reducing 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. **4** and **5.**

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.

11. Ball Dynamos.—These machines are of a very peculiar construction. The magnetic circuit is represented in Fig. 2, 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;

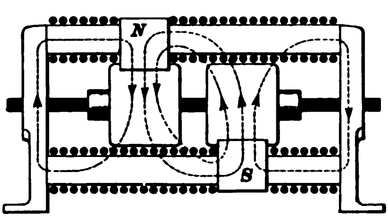


FIG. 2.

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 figure. The armatures are ring wound, and may each be used separately or connected in series.

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.

12. 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. **20**, Part 2.)

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.

13. 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. 3, which represents the field-magnet as seen from the top. This type of field-magnet is what that shown at *D*, Fig. 45, Part 2, would become if that part of each pole-piece which covers the cylindrical face of the ring were removed.

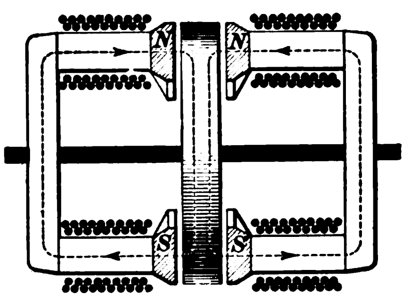


FIG. 3.

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.

14. 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. **15,** Part 2, and illustrated in Fig. 19, Part 2; 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 $\frac{1}{3}$ 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. 4, *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 during a part of each half revolution.

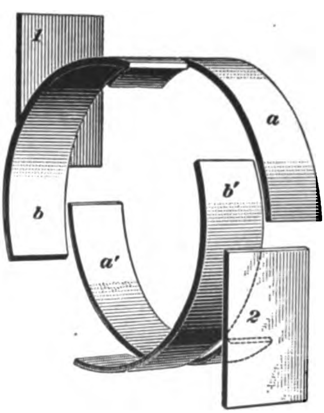


FIG. 4.

If this form of commutator with overlapping segments be applied to Fig. 19, Part 2, 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, and this 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.

15. As stated, the Brush armature winding is made up of two or more separate windings, the action of each being as already described.

Fig. 5 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. 3. 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 circumferences.

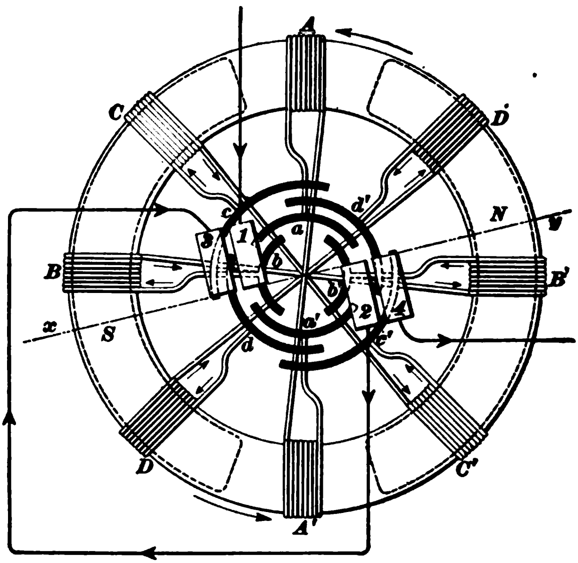


FIG. 5.

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 *x y* of the coils. 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 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 $\frac{1}{8}$ 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. 20, Part 2, 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. 5) of one winding with the negative (*3*, Fig. 5) of the other, the external circuit being connected between the two remaining brushes (*1* and *4*, Fig. 5).

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.

16. 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. **41**, Part 2, and Fig. 43, Part 2.)

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.

17. Westinghouse Dynamos. — These machines, which are comparatively new, use a multipolar field-magnet with six salient poles, of the type illustrated at *C*, Fig. 49, Part 2. 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.

18. A diagram showing the connections of the armature winding to the commutator of the Westinghouse machine is given in Fig. 6. As in Fig. 5, 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'*

Applying the statement made in Art. **17** to Fig. 6, it will be seen that coils *A* and *A'* are in the position of least

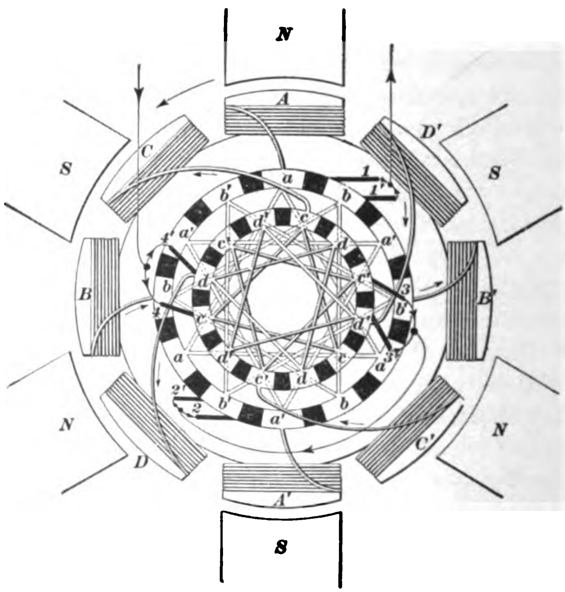


FIG. 6.

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 arrow.

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.

19. Thomson-Houston Dynamos.—These machines have bipolar, series-wound, salient-pole field-magnets, of the type illustrated at *K*, Fig. 45, Part 2. 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 $\frac{1}{6}$ the circumference, when the machine is giving its greatest E. M. F.

20. A diagram of the connections, etc., of the drum-wound armature is shown in Fig. 7. *A A'*, *B B'*, and *C C'*

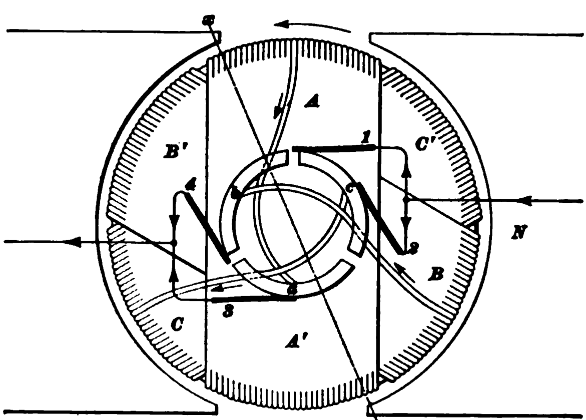


FIG. 7.

are the three coils, wound on the core $\frac{1}{3}$ of the circumference apart. One end of each of the coils is joined to a metal ring (not represented in the figure) 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. 7) 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 *x y*. 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. 7) 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. **14**, 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.

21. 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 figure (Fig. 7), 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.

22. Fig. 8 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, and contact is made at B, 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 regulating 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^2, and the resistance r to the line. If the resistance were not there, the

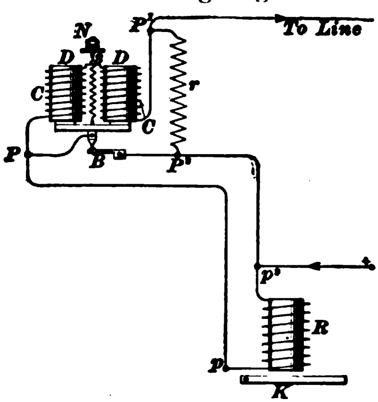


FIG. 8.

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.

23. 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 farther. 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 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. and output which can be obtained, and, conversely, an increase in the speed will increase the possible output.

ALTERNATING-CURRENT DYNAMOS.

DEFINITIONS.

24. The definition of an alternating current is given in Art. **13**, Part 2. 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. **12** and **13,** Part 2, 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 *A E* in Fig. 14, Part 2, 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.

25. 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. 38, Part 2.)

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. **21**, Part 2), there will be two points in each revolution where a part of the coil is under *each* pole-piece, as represented in Fig. 9. Under these circumstances, the E. M. F. generated in that part of the coil under 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.

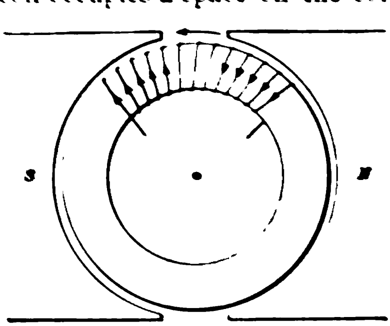


FIG. 9.

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. **12**, Part 2.

26. 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. 10 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.

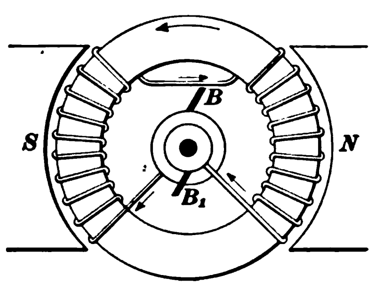


FIG. 10.

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

$$\frac{1,500}{60} \times \frac{10}{2} = 125.$$

27. For these multipolar machines, ring windings are seldom used in this country. One of the commonest types of alternators is shown in Fig. 11. This machine is provided with eight radial poles and eight coils on the armature, giving a style of winding in common use for machines used on lighting circuits. In Fig. 11, the coils C are shown bedded in the slots p on the periphery of the iron core P, which is built up of thin iron stampings. These coils are heavily taped and insulated and are secured in place by hardwood wedges w. This makes a style of armature not easily injured, and the use of the dovetailed slots and wooden wedges does away with the necessity of band wires. It is necessary that the space between the two halves of any one coil be made about equal to the width of the field, as represented in Fig. 11; for, if this were not the case, a part of

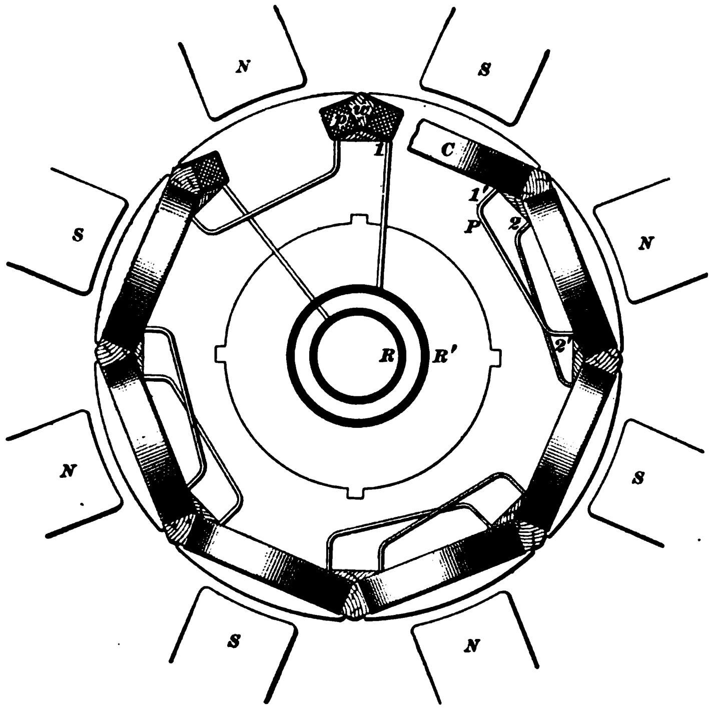


FIG. 11.

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.

28. Alternators are generally required to furnish a high voltage, and, in consequence, the armature coils are usually connected in series. Care must be taken, in connecting up such windings, to see that the coils are so connected that the E. M. F.'s do not oppose one another. By laying out a diagram of the winding, the manner in which the coils must be connected will be easily seen. This has been done in Fig. 12, which shows diagrammatically the winding of the armature in Fig. 11. The coils are represented by the heavy sector-shaped figures, and the connections between

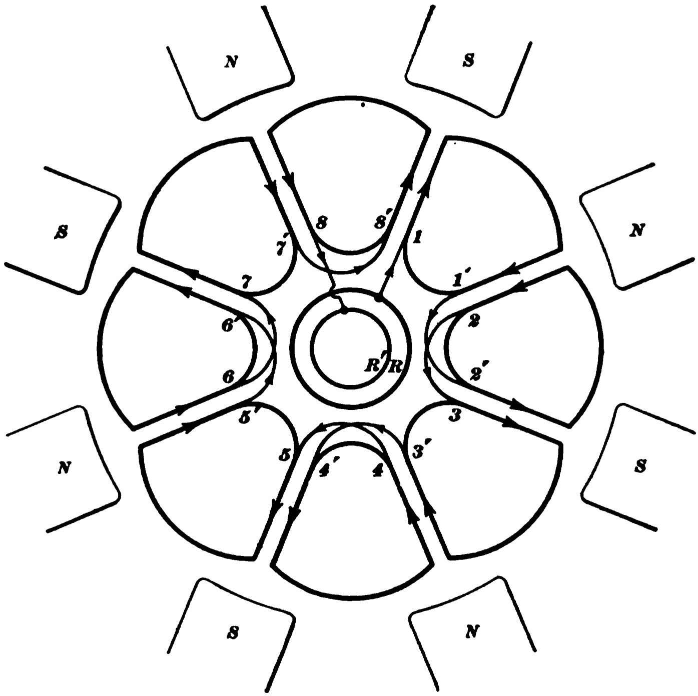


FIG. 12.

them by the lighter lines. The circles in the center represent the collector rings of the machine, and the radial lines that part of the coil which lies in the slot, that is, the part in which the E. M. F. is generated. The circular arcs joining the ends of the radial lines represent the ends of the coils which project beyond the laminated armature core. The drawing is made to show the coils at the instant the conductors in the slots are opposite the centers of the pole-pieces. At this instant, the E. M. F. will be assumed to be at its maximum value, and we will suppose that the direction of rotation is such that the conductors under the north poles have their E. M. F.'s directed from the back of the armature towards the front. These E. M. F.'s will be denoted by an arrow-head pointing towards the center of the circle, since the inner end of the radial lines represents the front or collector-ring end of the armature. The E. M. F.'s in the conductors under the south poles must be in the opposite direction, or pointing away from the center. After having marked the direction of these E. M. F.'s, it only remains to connect the coils up so that the current will flow in accordance with the arrows. Starting from the collector ring *R* and passing through the coils in the direction of the arrows, it is seen that the connections of every other coil must be reversed; i. e., if *1*, *1'*, *2*, *2'*, etc., represent the terminals of the coils, *1'* and *2'* must be connected together, also *2* and *3*, and so on. The end *8* is connected to the other collector ring, and the winding thus completed. The connections of such a winding are quite simple; but if not connected with regard to the direction of the E. M. F.'s, as shown above, the armature will fail to work properly. For example, if *1'* were connected to *2*, *2'* to *3*, and so on around the armature, the even-numbered coils would exactly counterbalance the odd-numbered ones, and no voltage would be obtained between the collector rings. Of course, in this case, all the coils are supposed to be wound in the same direction, as is nearly always done in practice. The connections in the diagram, Fig. 12, are shown between the coils in Fig. 11. It should be noted that this constitutes an open-circuit winding; that is, the winding is not closed on itself, like that of a continuous-current drum or ring armature. A large number of alternator windings are of the open-circuit type, which is better adapted for the production of high voltages, because it admits of a larger number of turns being connected up in series.

29. 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. **14**, Part 2.

30. 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, in addition to providing a means for varying the degree of compounding of the series field. In some machines, a revolving shunt is connected across the terminals of the rectifier, thus cutting down the current to be rectified and thereby decreasing sparking.

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 winding about half way between the ends which are connected to the collector rings is usually taken.

This is represented in Fig. 13, 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

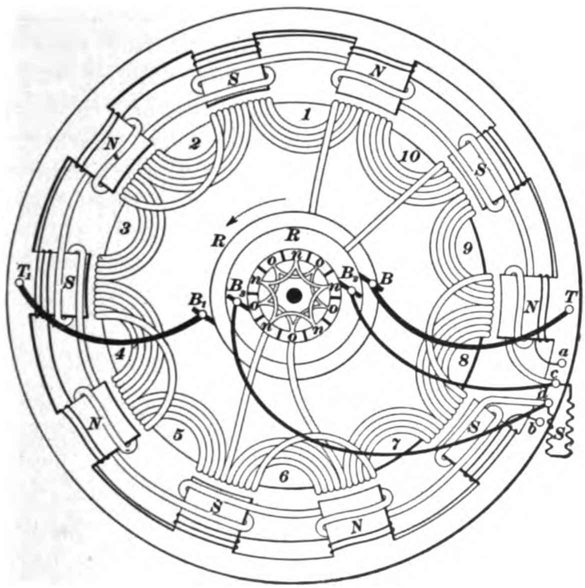


FIG. 13.

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_2 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_3 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.

31. 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. **24.**) 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.

32. 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 **polyphase** or **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.

Two-phase armatures can be considered as the windings of two single-phase machines mounted on one core, the two windings being separated 90° in the case of a two-pole machine. That is, when a coil of one winding would be directly under a pole, the corresponding coil in the second winding would be midway between that pole and the next.

The two currents can be collected in two ways, namely: (1) by means of four collector rings, and (2) by means of three collector rings. To illustrate the former case, Fig. 14 may be referred to. This represents the two windings of a

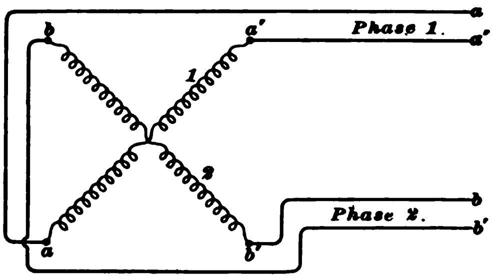
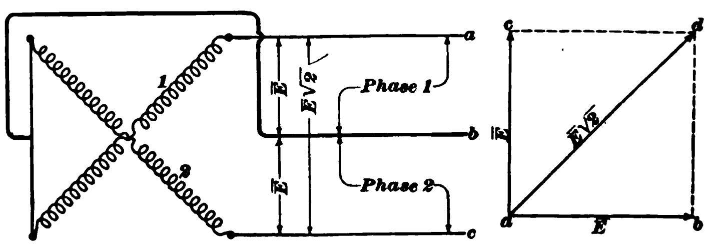


FIG. 14.

two-phase machine in a two-pole field. A displacement of 90° between the two currents calls for a similar mechanical displacement between the two windings. If four wires are used, the two circuits are independent of each other. The windings are represented by coils *1* and *2*, connected to the collector rings *a*, *a'* and *b*, *b'*. These windings, as was stated, have no electrical connection with each other and connect to two distinct circuits.

33. Sometimes, instead of using two distinct circuits with four collector rings, a common-return wire is employed,



(a) FIG. 15. (b)

as indicated in (*a*), Fig. 15. Here one end of each of the phases is joined to a common-return wire, and but three collector rings are necessary. If $\bar{E}$ represents the E. M. F. generated per phase, the voltage between *a b* and *b c* will be $\bar{E}$, while that between *a c* will be $\bar{E}\sqrt{2}$. This will be understood by referring to (*b*), Fig. 15, the E. M. F. between *a* and *c* being the resultant of the two E. M. F.'s $\bar{E}$ at right angles to each other.

34. In some two-phase machines, the armature is wound with the equivalent of a series-path continuous-current winding, and four collector rings and independent circuits are then required to avoid short-circuiting portions of the armature. If a closed-coil continuous-current winding, as is represented in Fig. 16, is used in a two-pole field, a single-phase alternating current can be obtained by connecting two collector rings to opposite points of the winding, as at *1* and *3*. Connecting two *opposite* points will give the highest E. M. F. that can be obtained in this manner. If on the same armature we make connection to two other opposite points *2* and *4*, situated midway between *1* and *3*, we shall have in circuit *2'–4'* a single-phase alternating current differing in phase by 90° from that in circuit *1'–3'*. To obtain a three-wire two-phase circuit from this sort of winding, it is evident that there could be no combination of the indicated circuits made, as a portion of the winding would be short-circuited thereby. Instead, three of the four wires are used, as *1'*, *2'*, and *3'*. In this case, the two phases are *1* and *2* and *2* and *3*. Taking the E. M. F. per phase in the first instance to be E, in the latter case its value would be $\frac{E}{\sqrt{2}}$. The E. M. F. across the two outside wires *1* and *3* would be equal to E. The current in the common-return wire making connection at *2* will be $\sqrt{2}$ times that in each of the outer wires.

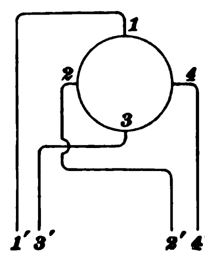


FIG. 16.

The graphical representation of these two currents shows that their sum at any instant is never as much as twice the maximum of one of the currents; this is represented in Fig. 17.

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

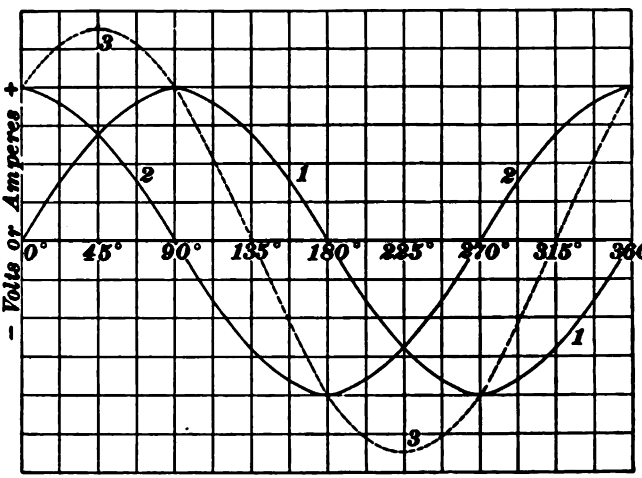


FIG. 17.

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.

35. In three-phase machines, three windings are used, giving three separate currents differing 120° in phase;

these are graphically represented in Fig. 18. It will be seen from this diagram that at any instant *the amount of 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

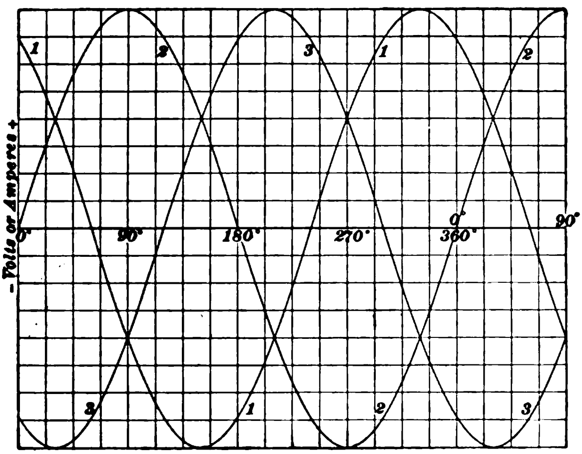


FIG. 18.

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. 19, the latter in the diagram, Fig. 20. 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 to which are connected the three armature windings *1*, *2*, and *3*. In Fig. 19, 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. 20, windings *1*, *2*, and *3* are respectively connected between rings R, R_1, and R_2, and a common junction c. The method of connection shown in Fig. 19 is known as the Δ (delta) or mesh connection. That shown in Fig. 20 is known as the Y or star connection.

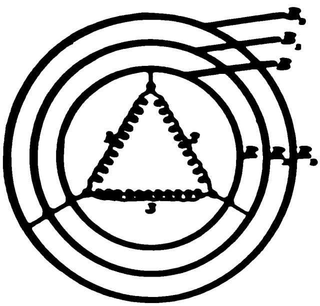


FIG. 19.

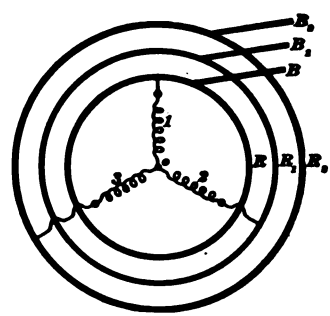


FIG. 20.

It should be understood that the above representations (Figs. 19 and 20) are merely *diagrammatic;* the separate windings are actually wound on the core in the same manner as illustrated in Fig. 12; 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. 20 is the same as is used in the Thomson-Houston constant-current open-coil dynamo (see Art. **20**), collector rings being here substituted for the commutator segments of that machine.

PROPERTIES OF THE ALTERNATING CURRENT.

36. It has been pointed out (Art. **70,** Part 2) 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* or *average* 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. 17 and 18, as is usually the case, the effective current is equal to (very nearly) .707 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 (.707 of the maximum) is meant, unless otherwise stated.

37. 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., C does not equal $\frac{E}{R}$, if E represents the applied E. M. F. as in the case of direct currents. 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 *applied* E. M. F. which is sending the current through the circuit at any instant is equal to the *difference between* the *actual* E. M. F. used in overcoming resistance and the *counter* E. M. F. (that due to self-induction) at the same instant. The difference is here taken because the counter E. M. F. of self-induction is in itself negative, i. e., it tends to prevent the current from changing. If we considered the E. M. F. necessary to *overcome* self-induction (the equal and opposite of the E. M. F. of self-induction), then the *applied* E. M. F. would be equal at each instant to the *sum* of the E. M. F. necessary to send the current through the resistance and that necessary to *overcome* the self-induction. This will be understood from the curves in Fig. 21.

38. 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 E. M. F. required to overcome resistance 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.

39. If the instantaneous values of the current and the resulting E. M. F. of self-induction are graphically repre-

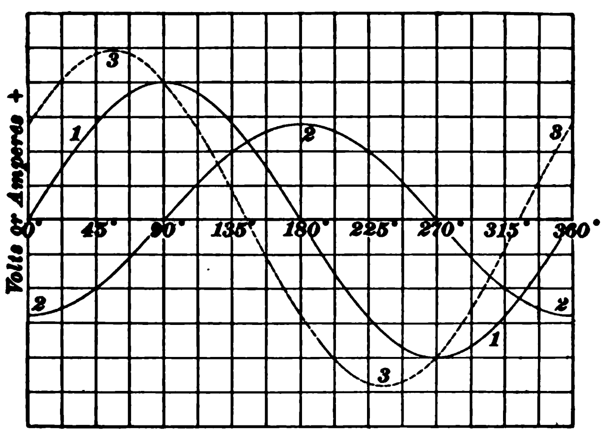


FIG. 21.

sented, 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. **31**) between the two curves is 90°.

This is represented in Fig. 21, 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. required to send the current through the resistance 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. 21) may also represent the curve of this *actual* E. M. F.

Considering this to be the case in Fig. 21, 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. **38.**

This applied E. M. F. curve, so constructed, is represented by curve *3*, Fig. 21.

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. **37,** 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. 21, 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.

40. 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. **6,** Part 2.

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.**

41. 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 lines 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 the secondary will be $\frac{100}{1000} = \frac{1}{10}$ 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 choking-back effect of the primary coil, and 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.

42. Fig. 22 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, 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

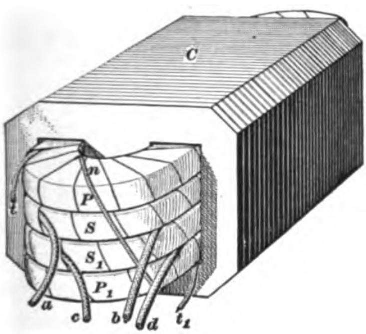


FIG. 22.

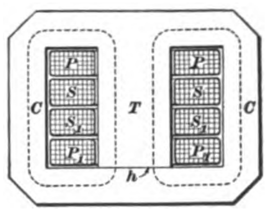


FIG. 23.

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. 23 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 $P\,P$, $S\,S$, $S_1\,S_1$, 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*.

43. 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.

44. It is often necessary to change direct current to alternating, and *vice versa*, and machines for accomplishing this are known as **rotary transformers.** The transformation might be effected by having an alternating-current motor coupled to a direct-current generator, simply using the alternating current to drive the generator. An arrangement of two machines is, however, not usually necessary, although such motor-generator sets are used to some extent. Rotary transformers are largely used for changing alternating current to direct for the operation of street railways, electrolytic plants, etc.

45. Suppose an ordinary Gramme ring armature to be revolved in a two-pole field, as shown in Fig. 24; a continuous E. M. F. will be generated and a continuous current obtained by attaching a circuit to the brushes *a*, *a'*. If, instead of the commutator, two collector rings were attached to opposite points of the winding, an alternating current would be obtained in a circuit connected to *b*, *b'*. If the machine be equipped with both commutator and collector rings, the armature may be revolved by means of direct current led in at the brushes *a*, *a'*, thus running it as a motor instead of it being driven by a belt. The conductors on the revolving armature will be cutting lines of force just as much as they were when the machine was driven by a belt;

therefore an alternating current will be obtained from the rings *b*, *b'*. In other words, the machine acts as a transformer, changing the direct current into a single-phase alternating current. If the operation be reversed and the machine be run as an alternating-current motor, the alternating current will be transformed into a direct one.

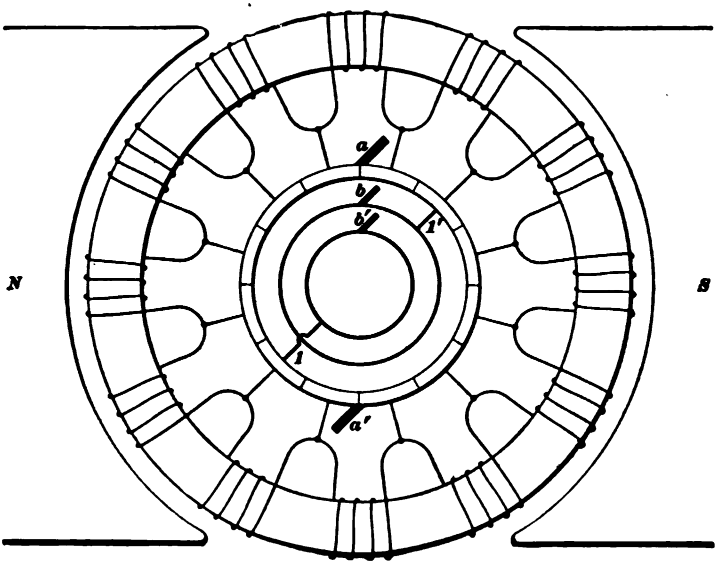


FIG. 24.

In the above single-phase rotary transformer, it is evident that the maximum value of the alternating E. M. F. occurs when the points *1*, *1'* to which the rings are connected are directly under the brushes *a*, *a'*; that is, the maximum value of the alternating E. M. F. is equal to the continuous E. M. F. For example, if the continuous E. M. F., were 100 volts, the *effective* volts on the alternating-current side would be 70.7, because the effective value is .707 times the maximum value. Therefore, if $\bar{E}$ is the alternating voltage and V the direct, we may write for a single-phase rotary transformer,

$$\bar{E} = .707\, V. \qquad \textbf{(1.)}$$

46. By connecting four equidistant points of a winding (similar to that described in Art. **45**), as in Fig. 17, to four collector rings, we would have a two-phase rotary transformer. The two phases would be related as shown in Fig. 17, and the E. M. F. of each phase would be determined in exactly the same way as in the case of a single-phase rotary transformer, such as described in Art. **45.**

47. By connecting three equidistant points of a winding, such as that described in connection with single-phase rotary transformers (Art. **45**), a three-phase transformer is obtained. Since all direct-current, constant-potential armatures have closed circuit windings, it follows that the connections on the alternating side of a three-phase rotary transformer are always Δ, the **Y** connection not being practicable. If $\overline{E}$ be the effective voltage between the lines on the alternating side of a three-phase rotary transformer and V the voltage of the continuous-current side,

$$\overline{E} = .612\,V. \qquad \textbf{(2.)}$$

48. In the rotary transformers, whose principles were just shown, the ratio of transformation is fixed, and the only way by which the transformed E. M. F. can be raised or lowered is to raise or lower the primary voltage, or the voltage of the current supplied to the machine. It would appear at first sight that a variation in field strength would cause a variation in the speed of a rotary transformer. This is true when *direct current* is supplied to the machine, the secondary voltage being alternating. However, when the primary voltage is *alternating*, the machine operates as an alternating-current motor, and a variation in field strength in no wise affects the speed at which the armature rotates. The reason for this will be seen when the subject of synchronous motors is taken up.

When the primary voltage is continuous, the speed would need to be varied in possibly only one case. That would be to synchronize the secondary alternating E. M. F. with a corresponding alternating-current circuit with which the rotary transformer is to operate in multiple.

When the primary voltage is alternating, a variation in the secondary (continuous) E. M. F. is secured by varying the number of turns in the secondary of the transformer supplying the rotary transformer.

49. In order that the speed of rotary transformers may not be too high, it is usually necessary to make them with more than two poles. In fact, in general appearance, they are very similar to ordinary multipolar direct-current generators with the addition of the collector rings to one end of the armature. Fig. 25 shows one of these machines and

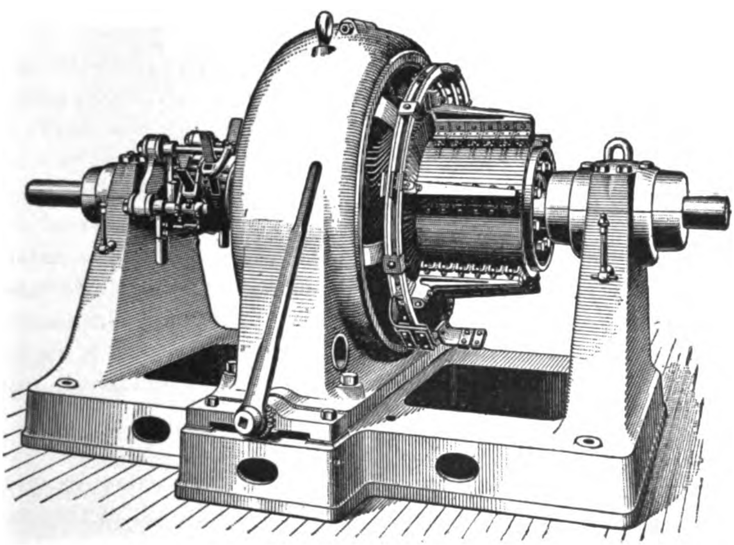


FIG. 25.

gives a very good idea as to the construction usually adopted. In this machine, the collector rings may be seen at the left-hand side of the machine. This particular machine is intended for electrolytic work calling for a large current output, and, for this reason, the commutator is larger than usual in order to obtain ample contact surface.

ELECTRIC MOTORS.

PRINCIPLES.

50. The principle upon which all electric motors operate is that given in Art. **25,** Part 2, namely, *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 electromagnet.

Their difference can be summed up as follows: In the case of a dynamo, the mechanical energy delivered at the pulley rotates the armature in a magnetic field, and this results in the generation of an E. M. F. in the armature. In the case of a motor, an electric current is sent through the armature, and this results in a reaction between the armature conductors and the field, producing a rotation of the motor armature. The essential difference, therefore, between a dynamo and a motor is that in the case of the former, mechanical energy is transformed into electrical energy, while in the case of the latter, electrical energy is transformed into mechanical energy.

51. 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.

52. 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. 26, so that the current enters at the brush $+B$, and passing through the winding in the direction indicated by the arrow-heads, leaves at

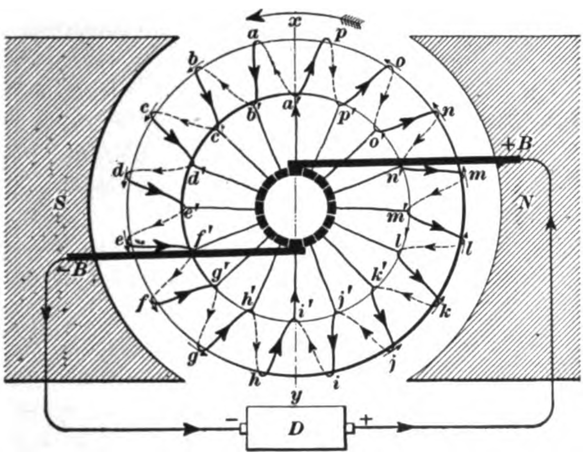


FIG. 26.

brush $-B$, it will be found by applying the thumb-and-finger rule given in Art. **26**, Part 2, that all the conductors under the *S* pole face, *b*, *c*, *d*, *e*, *f*, and *g*, will tend to move *downwards*, and all those under the *N* pole face, *j*, *k*, *l*, *m*, *n*, and *o*, will tend to move *upwards*, as indicated by the small arrows.

These forces combine to produce a tendency of the armature to rotate about its axis, as indicated by the large arrows, which tendency is called the **torque** of the motor. The amount of this torque—which is usually expressed in **pound-feet**, that is, a certain number of pounds acting at a radius of a certain number (usually 1) of feet—depends upon (1) the strength of the field, (2) the number of conductors, (3) their mean distance from the axis of the armature, and (4) the amperes in each conductor. In any given machine, the second and third conditions are constant, so that the torque depends upon the strength of the field and of the current.

53. If the armature is stationary, the E. M. F. required to send the current through the winding is only that necessary to overcome the drop, which is due to the resistance of the winding. If the torque exerted by this current is greater than 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. **8**, Part 2, to Fig. 26.

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.

54. 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 losses and core losses in the motor itself, which are of the same nature and effect as the similar dynamo losses (see Arts. **64** and **65,** Part 2), and also in overcoming the resistance to motion of whatever external apparatus is 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%.

55. 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. **52**).

56. 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. **35**, Part 2), 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 expended only 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.

57. 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 used only 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, and this 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.

58. Fig. 27 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.

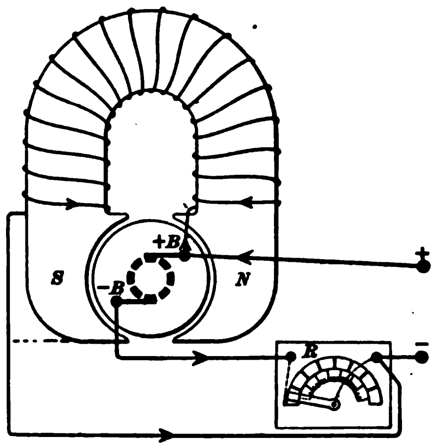


FIG. 27.

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.

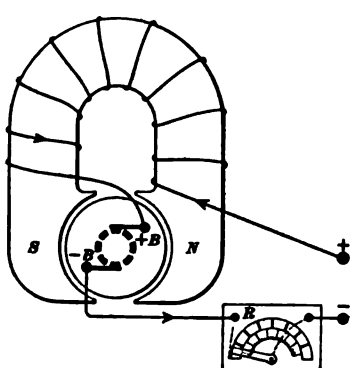


FIG. 28.

59. 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. 28 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.

To reverse the direction of rotation of a motor, it is necessary to reverse *either* the polarity of the field or the direction of the current through the armature. (See Art. **26**, Part 2.) 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. 29 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.

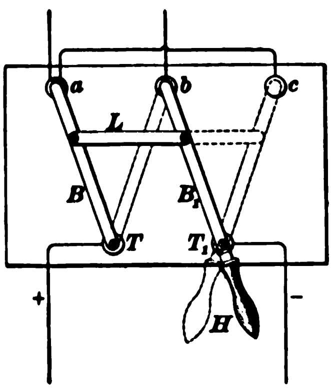


FIG. 29.

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. 30 represents the connection for a reversing shunt motor (*a*) and a reversing-series motor (*b*); + and – are the line terminals; *R*, the starting resistance; *B* and B_1

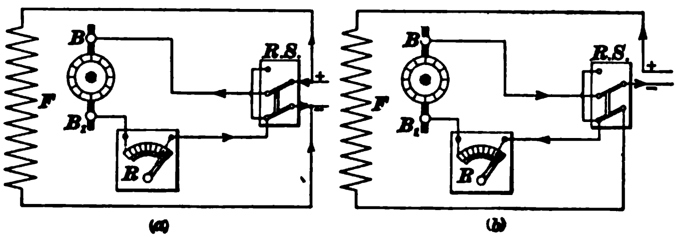


FIG. 30.

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.

60. 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 bases, known as **fuse boxes** or **cut-outs,** 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.

61. To illustrate the manner in which these various apparatus are connected, the following example in connecting a 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. 31 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

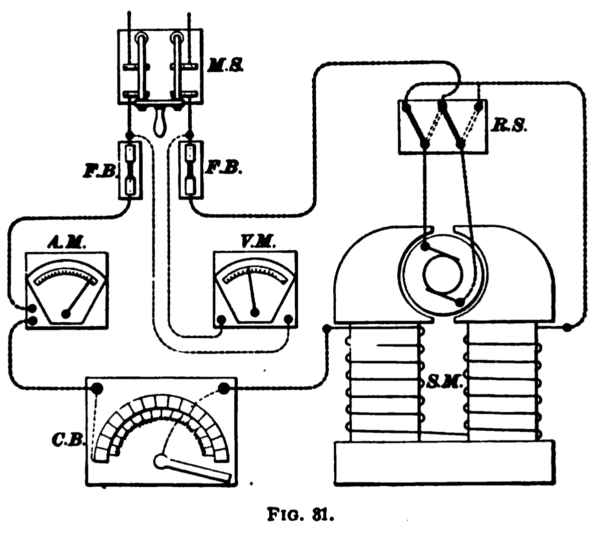


FIG. 31.

motor circuit, just inside the main switch. The voltmeter *V. M.* is connected to each side of the circuit just above the 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.

62. 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 × the diameter of the circle, or to 2 × 3.1416 × 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. **52.**

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 horse-power, 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

$$\text{H. P.} = \frac{2 \times 3.1416\, TS}{33{,}000} = .0001904\, TS. \qquad \textbf{(3.)}$$

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 the final 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:

$$S = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, T} = \frac{\text{H. P.}}{.0001904\, T}. \qquad \textbf{(4.)}$$

Or, if the H. P. and the number of revolutions per minute are known, the torque may be found from the formula

$$T = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, S} = \frac{\text{H. P.}}{.0001904 S}. \qquad \textbf{(5.)}$$

63. Fig. 32 illustrates a method of measuring the torque of a motor by means of a **Prony brake.**

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 *pound-feet.*

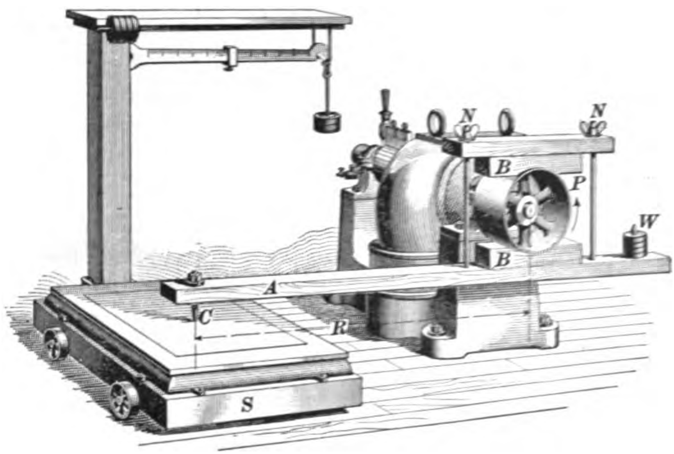


FIG. 32.

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 **3.** 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 **2,** Part 2.)

64. 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. 32. 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. 32) being 30 in., or $2\frac{1}{2}$ ft., and the pressure on the scales being 24 lb., the torque of the motor is $24 \times 2\frac{1}{2} = 60$ pound-feet. Substituting this value for T, and 800 for S, in formula **3**, gives $\text{H. P.} = \frac{2 \times 3.1416 \times 60 \times 800}{33,000} = \frac{301,593.6}{33,000}$.

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 1.

Then, $\frac{301,600}{33,000} = 9.1393$, or 9.139 H. P. is the output of the motor. Ans.

The input is $35 \times 230 = 8,050$ watts. Reducing 9.139 H. P. to watts gives $9.139 \times 746 = 6,817.694$, or 6,818 watts.

Then, by formula **2**, Part 2, the efficiency $E = \frac{6,818 \times 100}{8,050} =$ 84.7 per cent. Ans.

65. 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^2R, 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^2R 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 **2,** Part 2, the efficiency $\mathbf{E} = \frac{4188}{5000} = .837$, 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. 26 with Fig. 28, Part 2. See also Art. **29,** Part 2.) Consequently the brushes of a motor must be shifted *backwards* as the load increases.

THE CONSTRUCTION OF CONSTANT-POTENTIAL MOTORS.

66. 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. 45 and 49, Part 2.)

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*) 5.193%.

4. After the test made in Art. **64** 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.

67. 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.

ALTERNATING-CURRENT MOTORS.

SYNCHRONOUS MOTORS.

68. Single-Phase Synchronous Motors.—If an alternating-current generator has its fields excited from some source of direct current, 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 opposite *in phase* to 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. **27.**)

69. When the counter E. M. F. of the motor is exactly opposite in phase to 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 of a spring, as represented in Fig. 33, 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.

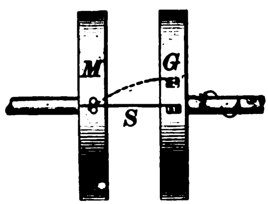


FIG. 33.

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.

70. If a single-phase generator is used as a motor, it will not be self-starting. Single-phase synchronous motors are manufactured by the Fort Wayne Electric Works, which are self-starting, with or without load. One of these machines is illustrated in Fig. 34, and a brief description will serve to explain the principle employed in starting.

The general appearance of the machine can be seen from Fig. 34, which is quite similar in appearance to a multipolar direct-current machine.

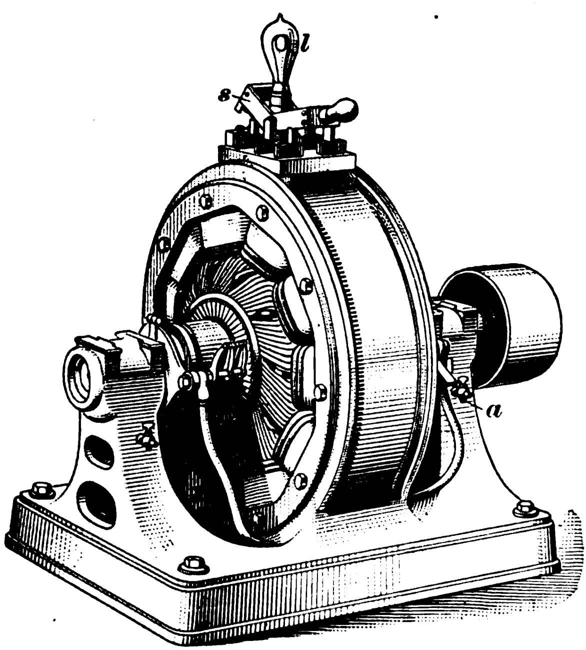


FIG. 34.

The laminated field in the machine illustrated has ten poles. These are provided with two windings. One of these is composed of a few turns per pole of comparatively heavy wire, and another of a large number of turns of light wire. The former is used in starting and the latter serves to supply the field excitation after the machine has been brought to speed.

The armature is provided with two windings, one an ordinary distributed winding connected to the commutator shown at the left end of the machine, and the other a shuttle winding, concentrating a number of distinct and regularly alternating poles around the armature. The two ends of this latter winding are connected to two collector rings at the pulley end of the machine. Bearing on these rings are two brushes, one of which can be seen at *a*.

The operation of the machine can be summed up as follows: In starting, the heavy field winding and distributed armature winding are connected in series. These connections to the circuit are made by means of the special knife switch mounted on top of the machine. Its starting position is that shown in the figure. The alternating current reverses its direction in the armature and field simultaneously, producing a torque in one direction. This brings the machine rapidly up to synchronous speed, which is indicated by the illumination of a lamp *l* connected to the shuttle winding on the armature. When this speed has been reached, the handle of the switch is lifted and the shuttle armature winding thereby directly connected to the alternating supply circuit. The field requiring direct current receives its excitation from the fine wire winding, which is, by means of the switch, connected to the distributed armature winding through the brushes and commutator shown at the left end of the machine.

71. Polyphase Synchronous Motors.—Synchronous motors for polyphase circuits are similar in construction to polyphase generators. With regard to their construction, these machines can be divided into two general classes: (1) those with internally revolving fields; (2) those with internally revolving armatures.

Machines of the first class are those used for such purposes as driving arc-light dynamos, frequency changes, etc. The external stationary member is made of laminated soft-iron disks, with inwardly projecting radial teeth. The winding is similar to that of the stationary member of a polyphase induction motor, as will soon be described. The effect of the polyphase currents (either two or three phase) is to cause a rotating magnetic field.

In starting, a current is induced in the internal field, which has radial poles. When the machine is working at synchronous speed, the internal field is energized by a continuous current, and the motor is now capable of furnishing power. Fig. 35 shows a three-phase machine with stationary armature and internally revolving field. The field is supplied with its exciting current by the two collector rings shown. Such a machine could be operated either as a three-phase generator or a three-phase synchronous motor.

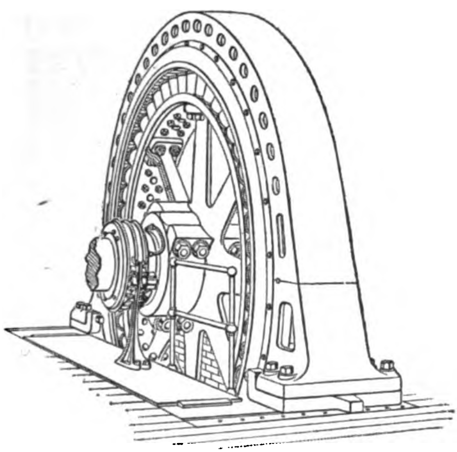


FIG. 35.

Machines belonging to the second class, as divided above, are used principally as rotary converters. Here the winding on the armature causes a rotating magnetic field in that member. The reaction between its field and that caused by the current induced in the stationary winding is sufficient to start the machines.

Several other methods of starting polyphase synchronous motors can be employed. The first of these necessitates the use of a polyphase induction motor, belted to the shaft of the synchronous motor. It will be seen farther on that induction motors are self-starting, and a machine of this type and of small capacity can be used for the purpose mentioned. When the synchronous motor is running at full speed, it is synchronized with the supply circuit as any alternator would be, and the belt from the induction motor is then thrown off.

Another method of starting a synchronous motor, which is employed only in case the motor forms part of a rotary transformer, involves the employment of the direct-current side of the machine. The latter winding enables the machine to be run as a direct-current motor, enabling the alternating side to be synchronized with the supply circuit, as before. From the foregoing it will be seen that polyphase synchronous motors are not to be used where machines requiring a large starting torque are required. Their essential quality of operating at absolutely constant speed (supposing the frequency of the supply circuit to be constant) makes their use in many cases indispensable.

INDUCTION MOTORS.

72. Single-Phase Motors.—The lack of the power of self-starting under load in synchronous motors led to the development of a type of motor known under the above head. Induction motors, in the same way as synchronous motors, can be divided into two general classes: (1) single-phase, and (2) polyphase.

The operation of an induction motor, whether single or polyphase, rests essentially on the existence or assumption of a rotating magnetic field.

Until a few years ago, a single-phase, self-starting induction motor was practically unknown in commercial work.

In discussing induction motors, some writers employ the terms *field* and *armature* in the same relation to the supply circuit that exists in a direct-current machine. To avoid confusion, however, we shall refer to the *armature* as the *revolving* member and the *field* as the *stationary* member, irrespective of line connections.

73. The field of a single-phase induction motor is wound exactly the same, in principle, as that of a direct-current machine. The field core, as well as the armature core, is laminated instead of being solid, and is so made to reduce loss from hysteresis and eddy currents.

The armature of a single-phase induction motor is, in most cases, the same as that employed in polyphase induction motors. By referring to Fig. 36, an idea of its construction can be obtained. There is a laminated core provided with a number of slots. In these slots are placed copper bars *b*, *b*, *b*, insulated from the core by means of insulating

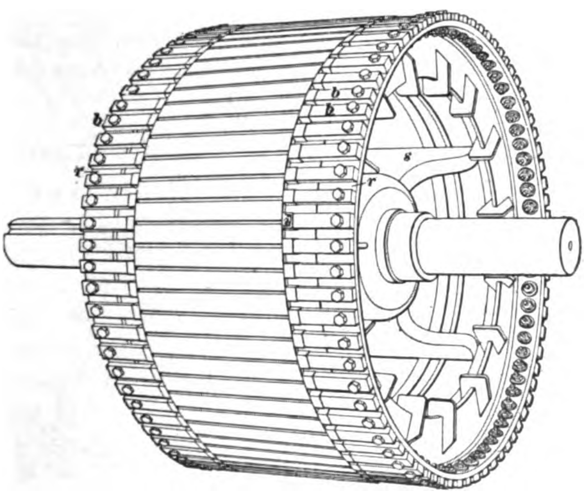


FIG. 36.

troughs *i*. The ends of the copper bars are connected together by means of the copper rings *r*, *r*. The whole construction resembles a squirrel cage, and this form of winding is therefore known as the *squirrel-cage winding*. The alternating magnetism in the field sets up current in the armature, and the reaction between the two causes a repulsion. This does not evince itself as useful torque, as the forces are balanced. If, however, the armature is given a start (by hand) *in either direction*, it will increase in speed till such a speed is reached that the slip is just sufficient to allow the proper working current to be induced in the armature. An increase in load will cause the armature to drop slightly in speed.

74. It has been said that a motor with an armature of this type is not self-starting. As far as practical requirements are concerned, a motor of this type would do little towards supplying the demand.

The motor shown in Fig. 37 is one made by the Wagner Electric Manufacturing Company, and has the property of self-starting. The field is of the usual type, described as follows: The armature is provided with a distributed winding. In

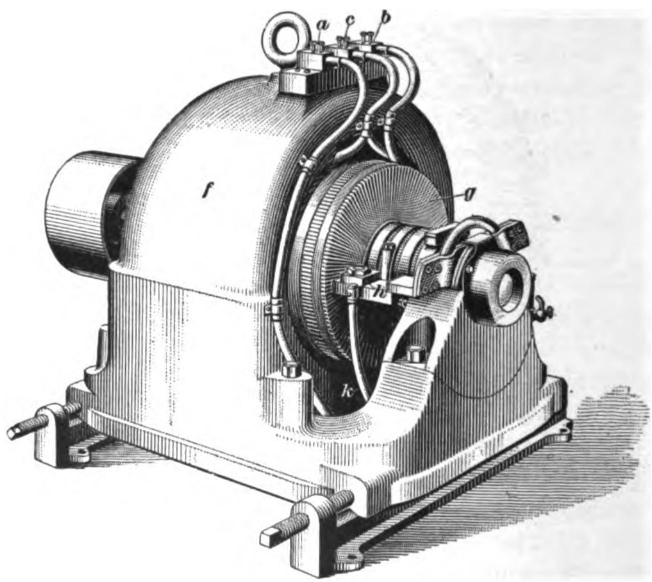


FIG. 37.

starting, the field is connected to the supply circuit, and the induced currents in the armature, instead of being allowed to circulate at will, as in the squirrel-cage type, are controlled by means of short-circuited brushes, one of which can be seen at *h*, Fig. 37. The reaction between armature and field causes a repulsion as before, one component of which acts tangentially on the armature, causing it to revolve with considerable torque. When the proper speed has been reached, a pair of centrifugal weights concentric with the shaft lift the brushes from the commutator and introduce at the same time a copper ring into the center of the commutator, completely short-circuiting the latter. By this means the armature winding is converted into one of the squirrel-cage type, and the machine, therefore, continues to operate. This machine can be made to start with even more than full-load torque by cutting out part of the field winding. This is done by connecting the line-wires to binding-posts *a* and *c*, in place of *a* and *b*.

The direction of rotation in a Wagner single-phase induction motor can be changed by shifting the brushes a slight amount forwards or backwards.

POLYPHASE INDUCTION MOTORS.

75. In a great many cases it is necessary to have an alternating-current motor which will not only start up of its own accord, but one which will start with a strong torque. This is a necessity in all cases where the motor has to start up under load. It is also necessary that the motor be such that it may be started and stopped frequently, and in general be used in the same way as a direct-current motor. These requirements are fulfilled by *polyphase induction motors*, which have come largely into use, especially in sizes up to about 100 or 150 H. P.

76. Polyphase induction motors are usually made for operation on two or three phase circuits, although they are sometimes operated on single-phase circuits, as explained later. They always consist of two essential parts, namely, the *primary*, or field, to which the line is connected, and the *secondary*, or armature, in which currents are induced by the action of the primary. Either of these parts may be the revolving member, but we will suppose in the following that the field is stationary and the armature revolving. In a synchronous motor or direct-current motor, the current is led into the armature from the line, and these currents reacting upon a fixed field provided by the stationary field-magnet produce the motion. In the induction motor, however, two or more currents differing in phase are led into the field, thus producing a magnetic field which is constantly changing and which *induces* currents in the coils of the armature in the same way that currents are induced in the secondary coils of transformers. These induced currents react on the field and produce the motion of the armature. It is on account of this action that these machines are called induction motors.

FIELD WINDING.

77. The winding on the field of an induction motor is almost exactly the same as that on the armature of a syn-

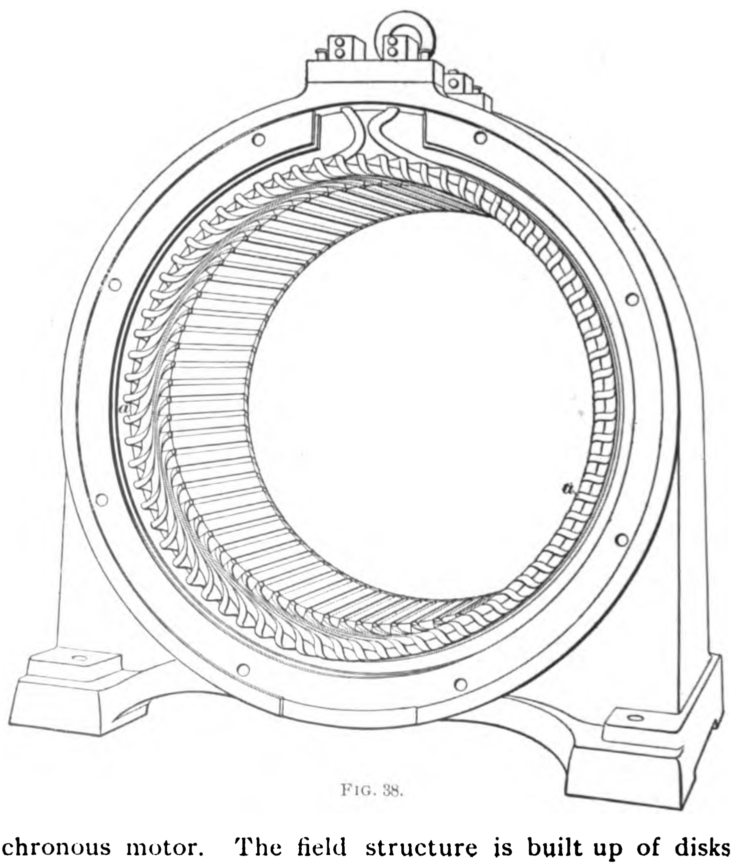


FIG. 38.

chronous motor. The field structure is built up of disks with teeth on their inner circumference, which form slots when the core is assembled. The coils are placed in these slots, forming a winding like that on the surface of a polyphase armature. Distributed windings are usually employed; that is, there is generally more than one coil per pole per phase, and the winding when completed resembles very much the evenly distributed arrangement of coils on a continuous-current armature. Fig. 38 shows a finished field for an induction motor. The coils are seen at *a*, *a* distributed evenly around the inner circumference.

78. The action of the out-of-phase currents in producing a changing field will be understood by taking the case

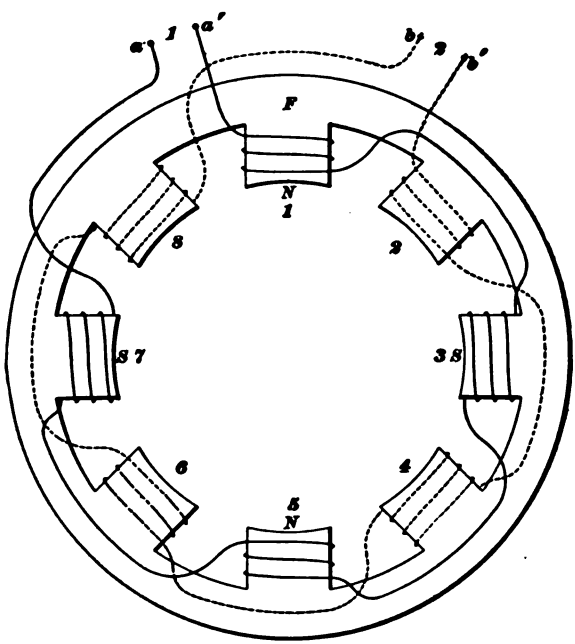


FIG. 39.

of a simple two-phase field, as shown in Fig. 39. In order to make the action clearer, we will suppose that the coils are wound on projecting poles instead of being sunk in slots.

The field *F* composed of laminations has eight polar projections, four poles for each phase. Each projection is wound with a coil, and alternate coils belong to the same phase, the winding constituting phase *1* being shown full and phase *2* dotted. The winding is such that if a current is sent through either of the windings, the poles formed are alternately north and south; for example, *1*, *3*, *5*, *7* would be *N* and *S*, as shown. If such a field were connected to a two-phase alternator, currents would be induced in each of the circuits, differing in phase by 90° and continually reversing in direction. The effect of this is that as the magnetism in, say, pole *1* dies out, it increases in pole *2*, and so on, thus producing the effect of a field continually shifting around or revolving. In fact, the field produced by the field coils shifts around in the same way that the field is made to shift around the armature of the alternator by its rotation in the field produced by the separately excited field-magnets. This gives, then, the effect of a four-pole revolving field; the speed at which it revolves would depend upon the frequency of the alternator. In this case, if the frequency were 60, the field would make $S = \frac{2 \times 60}{4} = 30$ rev. per sec., or 1,800 R. P. M. The effect of the distributed winding in Fig. 38 is more uniform than that in the simple motor shown above, and causes the motor to exert a more even torque.

79. Suppose an armature having also eight polar projections to be placed inside the field of Fig. 39. Each of these projections is wound with a coil *c*, Fig. 40, and these coils form independent closed circuits, since their two terminals are united at the points *d*. When a current is sent through the field, a varying magnetic flux is set up through the armature coils, thus generating an E. M. F. in them. Since the coils form closed circuits, the induced E. M. F. causes currents to be set up in them, and this causes the armature to rotate by the reaction of these currents on the field. If the armature were held from turning, the coils on the armature would act like the secondary of an ordinary transformer, and heavy currents would be set up in them. However, as the armature comes up to speed, the relative motion between the revolving field and armature becomes less, and the induced E. M. F.'s and currents become smaller, because the secondary turns do not cut as many lines of force as before. If the armature were running exactly in synchronism with the field, there would be no cutting of lines whatever, no currents would be induced, and

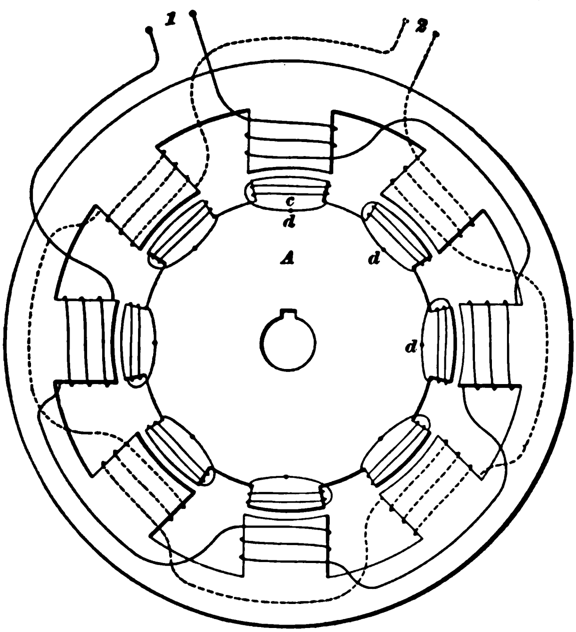


FIG. 40.

the motor would exert no torque. Therefore, in order to have any induced currents, there must be a difference in speed between the armature and the revolving field, and the greater the current and consequent torque or effort, the greater must be this difference. When the load is very light, the motor runs almost exactly in synchronism, but the speed drops off as the load is increased. This difference between the speed of the armature and that of the field for any given load is called the **slip.** The slip in well-designed motors does not require to be very great, because the armatures are made of such low resistance that a small secondary E. M. F. causes the necessary current to flow. In well-designed machines it varies from 2 to 5% of the synchronous speed, depending upon the size. A 20-H. P. motor at full load might drop about 5% in speed, while a 75-H. P. motor might fall off about $2\frac{1}{2}$%. For example, if an 8-pole motor were supplied with current at a frequency of 60, its field would revolve $\frac{60}{4} = 15$ rev. per sec., or 900 R. P. M., and its no-load speed would be very nearly 900. At full load the slip might be 5%, so that the speed would then be 855 R. P. M. It is thus seen that as far as speed regulation goes, induction motors are fully equal to direct-current shunt machines.

That member of an induction motor to which the working current is led and in which the rotating field is produced is by some writers called the field, irrespective of its use as a stationary or rotating member of the motor. In single-phase induction motors, the field is invariably the stationary member, or, as it is sometimes called, the *stator*. In regard to polyphase induction motors, we have thus far considered only that type in which the rotating field is produced in the stationary member. In another type, in which the armature is wound similarly to that of a polyphase alternator, current is delivered to the winding by means of collector rings. In this type of machine, the relation between the rotating field produced in the armature and the consequent direction of rotation differs somewhat from that in the type heretofore considered, in which the rotating field is produced in the stator. In the second type of machine just mentioned, the rotating member is sometimes referred to as the *field*, for the reason that the rotating field is produced in it. To avoid confusion in the application of the terms *field* and *armature*, it is sometimes well to refer to the rotating member as the *rotor* and the stationary member as the *stator*, as mentioned before. In a polyphase induction motor, the winding in which the rotating field is produced encloses, or is enclosed by, another winding, whose conductors will be cut by the lines of force of the rotating 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 rotating field is produced in the rotor, and the latter is held stationary and the external conductors are free to move, they will revolve in the *same* direction that the field moves; while if, in the same case, the stator is fixed and the rotor is free to move, the armature will rotate in the opposite direction to that in which the field moves.

ARMATURE WINDING.

80. A form of armature winding for polyphase induction motors was described in Art. **73** and illustrated in Fig. 36. In some cases, especially in the larger motors, it is best to have the armature winding so arranged that a resistance may be inserted in series with it while the motor is starting up, and cut out when full speed is attained. If this is not done, there will be a large rush of current at starting, because when the motor is standing still it is in the condition of a transformer with its secondary short-circuited, and since the armature is stationary with regard to the field, a fairly high E. M. F. may be induced, thus causing a very heavy current to flow through the low-resistance secondary winding. This would cause a large current to flow in the primary, and would therefore be objectionable. Moreover, this large secondary current reacts on the field produced by the primary so as to greatly weaken it, and results in a very small starting torque. If the armature were so designed as to have a fairly high resistance in itself, in order to limit the starting current and procure a good starting torque, the motor would be inefficient and would give bad speed regulation. It is therefore best to have a resistance which may be placed temporarily in the circuit and then cut out. This may be done by supplying the secondary with a regular winding similar to that of the field and bringing the terminals to collector rings. By means of these, connection may be made to a resistance-box, and resistance cut in or out in much the same way as is done in starting up direct-current motors. In the General Electric Company's motors, the use of collector rings is avoided by mounting the resistance on the armature spider, and cutting it out by a switch operated by a sliding collar on the shaft.

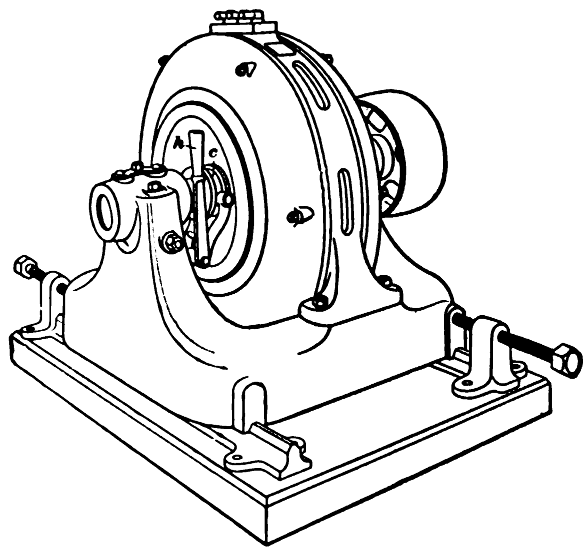


FIG. 41.

This enables the motor to be built without any moving contacts whatever. Fig. 41 shows one of the above motors with adjustable resistance in the secondary, the handle *h* shown in the figure being used to operate the sliding collar *c*. It also shows the arrangement of the parts of a motor with stationary field and revolving armature.

81. In cases where it is necessary to have induction motors run at variable speeds, it is usual to supply them with collector rings connected to an adjustable rheostat, a method often used where such motors are intended for operating hoists, etc.

The direction of rotation of the revolving field produced in a polyphase induction motor can be changed by reversing one of the phase connections.

82. Induction motors are always constructed with a multipolar field, so as to keep down the speed of rotation. The number of poles employed increases with the output, and the speed is correspondingly decreased. The following table gives the relation between poles, output, and speed for some of the standard sizes of induction motors (60 cycle).

Poles.	H. P.	Speed.
4	1	1,800
6	5	1,200
6	10	1,200
8	10	900
8	20	900
10	50	720
12	75	600

PHASE SPLITTING.

83. Motors are sometimes operated from single-phase circuits by splitting the phase; that is, the original single-phase current may be split up into other currents which are out of phase, and thus suitable for starting up a motor. A simple arrangement of this kind is shown in Fig. 42. The motor is supplied with two windings, which are connected to the mains, one in series with a resistance R and the other in series with an inductance L. It is evident that the current in circuit B will lag behind that in A, and the motor will therefore be supplied with two currents suitable for starting. After the motor has run up to speed, R and L are usually cut out and the machine runs as a synchronous motor. A number of starting devices are in use for operating motors from single-phase machines; but where a really satisfactory motor is required, the multiphase induction or synchronous motors are used. The latter are especially

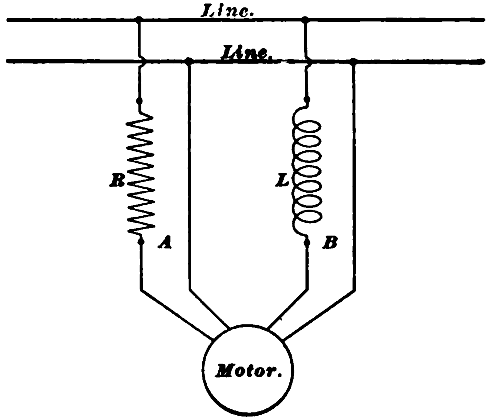


FIG. 42.

valuable for large power-transmission plants, where lagging currents are objectionable.

OUTPUT.

84. 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. **62.** As stated in Art. **39,** 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. **68**). 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.

85. Dynamo-electric machinery should always be located in a dry place, where the air is cool (see Art. **75,** Part 2), 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 machine should be supported on a wooden subbase, resting on the foundation or floor, which should be about 8 inches high. This subbase 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 subbase. The subbase 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 subbase, extending from one of the bolts which holds the subbase to the foundation to one of the bolts fastening the dynamo base to the subbase. 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 subbase and large enough to catch whatever oil may drip from the bearings, thereby preventing it from soaking into the floor.

86. 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. 52 and 53, Part 2.) The machine is not, then, bolted directly to the subbase, but may be fastened down on the bed-plate which is bolted to the subbase.

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 inch 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 ⅔ the width of a single belt to transmit the same power. Dynamo and motor belts should have cemented or riveted joints, to insure smooth running. Laced belts should not be used.

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 formula $N = \frac{d\,n}{D}$. 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 or their representatives.

87. 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 subbase should first be prepared, then the bed-plate set in position on the subbase, 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 headroom, 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 2 or 3 inches, instead of more than half its diameter, as would be the case with standards cast solid with the base.

88. After cleaning up the bearings and joints, the lower half of the machine should be set up in position on the bedplate, 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.

89. 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. 43, *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.

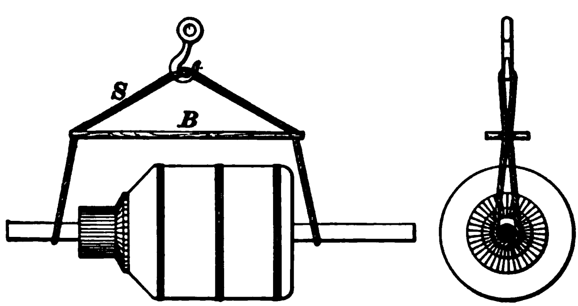


FIG. 43.

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 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 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.

90. 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 subbase. 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, and 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. **86.**)

91. 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 relocate 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.

92. 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. **37**, Part 2); 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. **53**, Part 1) 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.

93. This method of testing is represented by the diagram, Fig. 44; *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 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*.

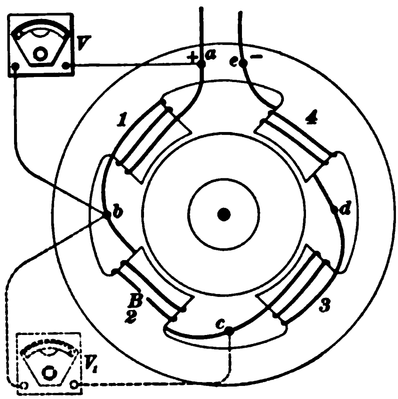


FIG. 44.

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.

94. 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, screwdriver, 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, set 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.

95. 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 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 rewound or the short circuit otherwise removed.

96. 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 number 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. 45 illustrates a form of water rheostat, in which *T* is the

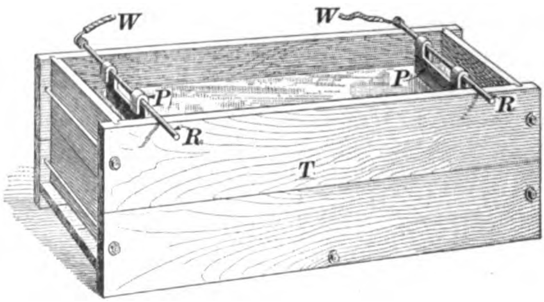


FIG. 45.

wooden tank, which should be about 7 feet long and about 2½ feet square, inside measurements, made of 1½-inch or 2-inch 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 figure.

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 3½ 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 (¼-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 pounds 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 one-quarter 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.

97. 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 resolder 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 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. Resin dissolved in alcohol makes a very convenient flux for this kind of work.

If the break is such that it can not be readily 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. **91** and **94.** 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.

98. 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.

99. 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 screw-driver 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. **94.**) 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.

100. 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. 46, 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.

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_1, and *vice versa*. If the needle shows a deflection

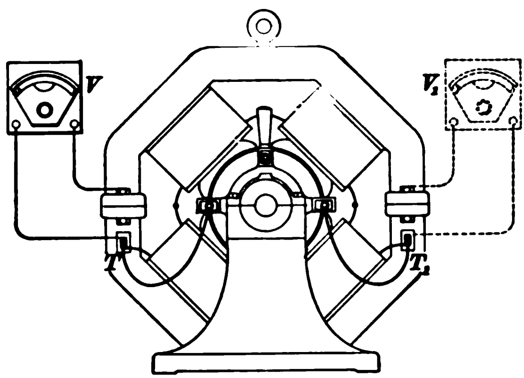


FIG. 46.

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.

101. 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. 47.

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. 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.

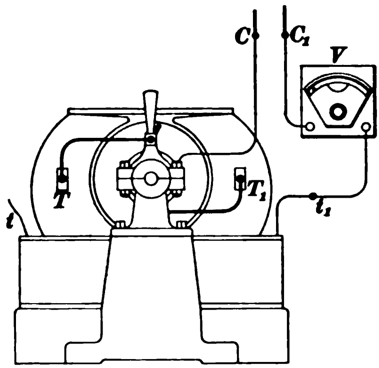


FIG. 47.

102. 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. **75**, Part 2.)

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.

103. 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 screw-driver 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. **92** and **93**. 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. **63**.

CARE OF DIRECT-CURRENT MACHINERY.

104. 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, 3 or 4 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.

105. 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 heat it to redness and plunge it in lubricating oil. This practice is to be recommended, as there will then be no liability of getting too much oil on the commutator, and enforced inattention will not be the cause of a poor commutator.

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. **91.**)

106. 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. **94, 97,** 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. **60**), 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. **93.**)

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. **95**). With short-circuited field coils, it is the *good* coil that burns out (see Art. **99**), 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.

107. 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 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.

108. 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. **101**, 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.

109. 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 ⅛ to ⅜ inch wide on the upper edge and 12 to 18 inches 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.

110. All 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 $\frac{1}{2}$ inch 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.

111. Alternators require no special directions for setting up, other than those given for constant-potential machines. The way in which the exciter (see Art. **29**) 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. **94**). 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. **29**). 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. **17** and **30**. 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. 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.

112. 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. **80**) 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.

113. 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.

114. 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 hardwood 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 $\frac{3}{4}$ inch to 2 inches 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 2 feet from any wall, so as to give a space for examining and making alterations in the wiring. A clear space of at least 2 feet should also be left between the bottom of the board and the floor.

SWITCHBOARDS FOR ARC-LIGHTING CIRCUITS.

115. 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 up on 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

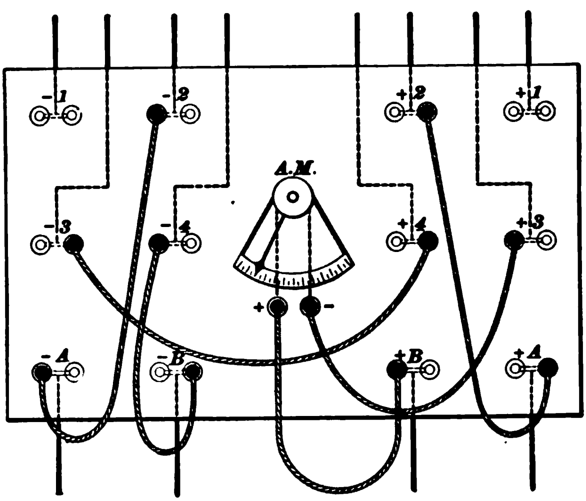


FIG. 48.

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 insure firm contact, and often a spring latch is added to hold the plug in place when inserted.

Fig. 48 represents one form of this sort of board, arranged for two dynamos and four circuits. Each terminal is double, 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.

116. 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 foregoing 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.

117. 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. 49 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."

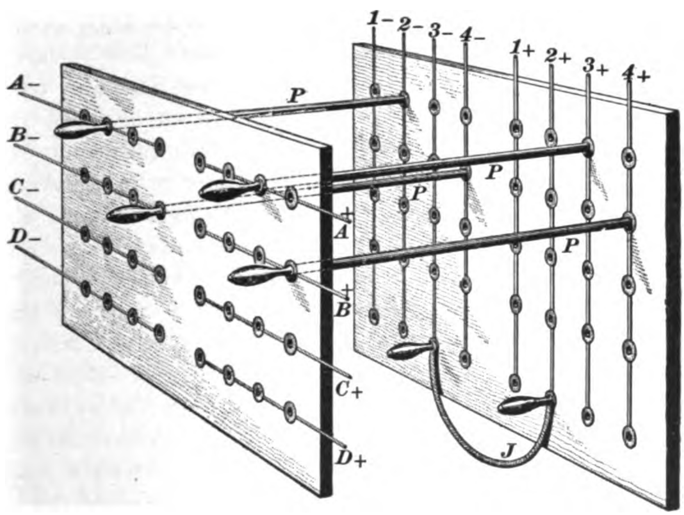


FIG. 49.

The method of connecting from one circuit to another, etc., will be evident from an inspection of the diagram, Fig. 49.

118. 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.

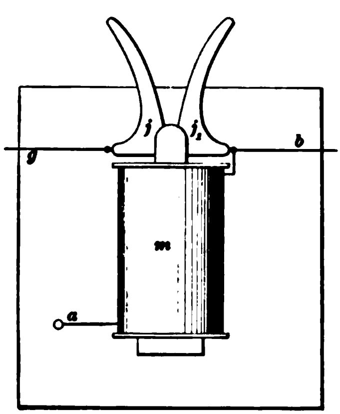


FIG. 50.

This arrester is illustrated in Fig. 50. The spark gap across which the lightning charge jumps exists between the 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 electromagnet *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 can not follow it, and the arc is therefore "blown out," or ruptured.

119. The windings of the electromagnet 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. & 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 inch iron pipe at least

10 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.

120. 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. **116.**)

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. **32,** Part 2), 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.

121. 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 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. 51, 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. 51, where *d* represents the dynamo which

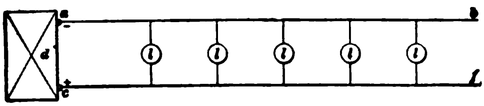


FIG. 51.

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. 52, 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, and either of the other two that the lamps or groups of lamps are connected in parallel, as shown.

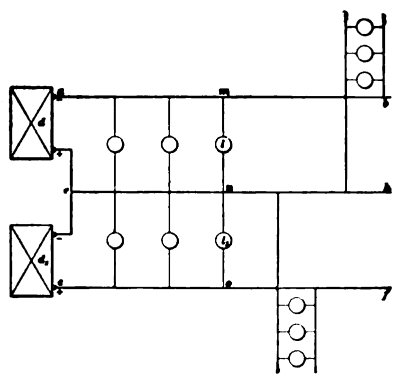


FIG. 52.

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 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. 53 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. 53), 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.

124. 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 2 or 3 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.

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.

123. Switches.—Switches for incandescent work are usually of the *jack-knife* type, illustrated in Fig. 53. 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

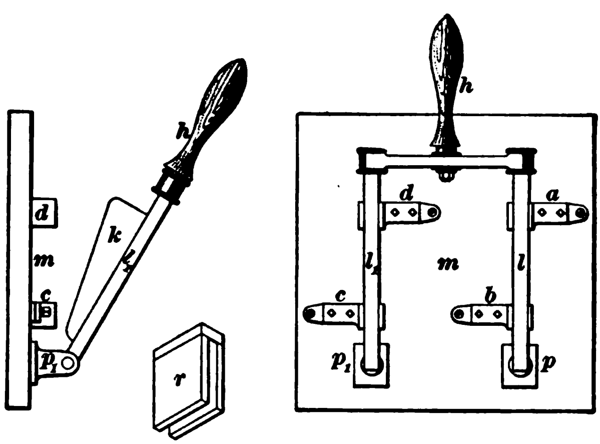


FIG. 53.

switches are provided with one, two, or three blades and sets of contacts, each insulated from the others, and are 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. 53 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. 53), 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.

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125. 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 **voltmeter 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. **100.**

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.

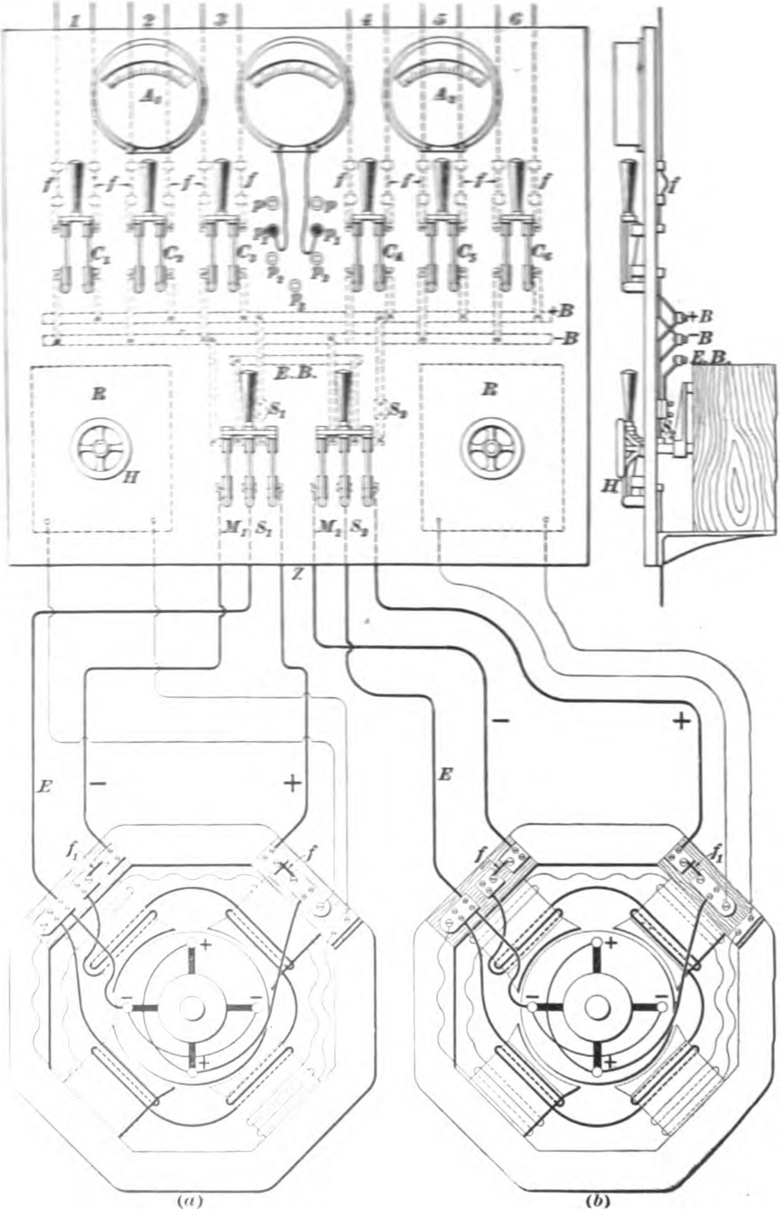

1
2
3
4
5
6
A_1
A_2
f
C_1
C_2
C_3
C_4
C_5
C_6
p
P_1
P_2
P_3
+B
-B
E.B.
R
H
S_1
S_2
M_1
M_2
Z
E
−
+
f_1
(a)
(b)

FIG. 54.

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.

126. Safety Devices.—To prevent the possible damage to dynamos and circuits, due to an excessive flow of current from any cause, fuses (see Art. **60**) 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.

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.

127. 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

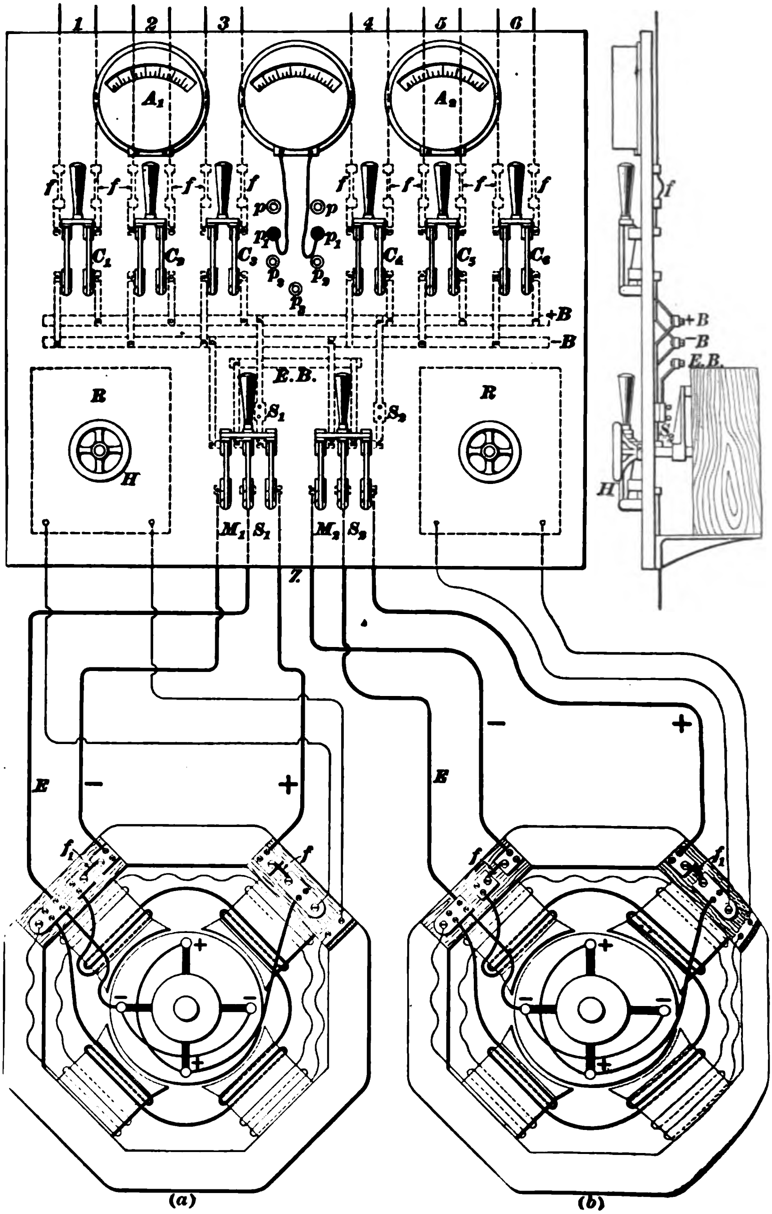


FIG. 54.

127.

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. 54 shows a switchboard embracing the features previously described, and showing the equalizing connection for running the two compound-wound dynamos in parallel. In this figure 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 *E B*. 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.

128. Referring again to Fig. 54, *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 figure) 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 the current from one machine does not always pass through the — lead, on account of the equalizing connection. (See Art. **127.**) 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. (Art. **125.**)

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.

129. The foregoing figure 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.

130. 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. **40**) located at various points near where the lights are to be used.

This distribution being at a constant potential, the switchboard 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. **69**). 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.

131. 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. 54.

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 to be 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.

132. 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.

ELECTRIC HOISTING AND HAULAGE.

POWER TRANSMISSION AT MINES.

GENERAL CONSIDERATION.

1. In the operation of a mine, one of the most important considerations is the choice of the method of distributing power to operate the various apparatus employed. Whether this power can be transmitted to the best advantage by means of electricity, steam, compressed air, or water power, will depend largely on local conditions.

In a general way, it may be said that the advantages of electricity increase with the distance and the number of points to which power is to be delivered.

With both steam and compressed air the cost of installation and the loss of power (as well as the danger of breakdown) increases rapidly as the system is extended. These systems are also affected in efficiency by changes of temperature, which have no appreciable effect on electrical distribution. Moreover, by reason of their flexibility, electrical conductors are not so generally liable to injury and breakage by floods or shifting ground as are the rigid pipes conveying steam or compressed air.

Up to within a few years, a serious drawback to the use of electricity was the limited application of motors to the different forms of mining machinery, and also the lack of reliability in their operation. Recent advances, however, have been so great that this form of power is rapidly coming to the foreground for mine haulage, hoisting, pumping, lighting, surface traction, and the operation of machine shops.

2. Long-Distance Transmission.—Electricity may be said to excel other methods where water power is available within a reasonable distance, say up to 40 or 50 miles (depending on the relative cost of fuel), when the local conditions require the use of power at scattered points, or where the mine is off the line of railroad and the haulage of fuel involves heavy expense. In this latter case, the placing of an electric generating station at some central point and the transmission of current to the various places where power is used, both on the surface and underground, will generally effect considerable saving.

3. Relative Advantages of Electricity and Steam or Compressed Air.—Where the bulk of power is used for drilling and pumping near the boiler plant, steam and compressed air have an advantage, as the reciprocating motion of the steam and compressed-air cylinder is more advantageous in these operations than the rotary motion of the electric motor. On the other hand, a more extended use of hoisting, hauling, and ventilating machinery will generally favor the use of electricity, especially in view of the added advantage of its use for lighting and the greater flexibility of the installation.

4. Haulage. — With long hauls and small tonnage, wagon haulage is undoubtedly the most economical where roads of reasonable quality and grade are available. As the distance shortens or the tonnage increases, the use of a track becomes advisable, and ultimately on this track the locomotive or cable replaces the mule or horse in economy. Again, the limitation in the use of locomotives to grades not exceeding 4% to 5% where they are long or continuous will often decide in favor of the hoisting drum and cable or the overhead cable with buckets. Then, again, for short distances and large tonnage, the use of conveyer belt or bucket must receive consideration.

In connection with the use of tramways, it is interesting to know that whereas the pulling power (or direct pull) required to haul 1 ton on rails at the rate of 3 miles per hour ranges from 4 to 12 pounds, the power required for macadam road is from 45 to 65, and for an ordinary dirt road it is over 200 pounds.

In any case the form of power to be used will depend largely upon the question which form can be used to the most advantage for the largest number of purposes. Each system has its advocates, and caution should be observed in accepting the data and comparisons used in trade catalogues by manufacturers anxious to sell their own wares.

ELECTRICAL TRANSMISSION.

5. In the event of the selection of electricity, the choice of the system must be determined—whether direct (continuous), simple, alternating, or polyphase current machines shall be used, or possibly a combination of two of these systems. The voltage of the direct-current machine is limited in practice to about 600 volts, due to complications in insulation and to increasing the number of segments of the commutator for higher voltages.

For these reasons, direct-current generating apparatus can not be used to advantage when the power is to be transmitted for long distances. Roughly speaking, a wire of a certain cross-section will carry a given number of amperes of current without undue heating. As the *power* or watts carried is the product of the amperes multiplied by the volts, twice as much power can be transmitted over the same wire by doubling the voltage, and so on in the same ratio.

This law is to be compared to the capacity of piping, carrying water under varying pressures, except that with water the friction increases with the speed of flow. As a general statement, it may be said that in the electrical transmission of power a loss of over 10%, at most 15, in the line is not permissible, even where the source of power is water.

A more detailed explanation of this statement will not be amiss. Taking, for example, a case where an abundant water power is available: at first sight it would seem that as the prime energy is secured at a nominal cost, the loss of even 25% and over, caused by the use of small wires in transmission, would be more than offset by the saving in cost of copper. This expense for conductors for distances of over 25 miles may amount to more than one-half the total cost of installation. Several causes combine to effect this; among them are:

1. It is difficult to regulate the voltage at the point of using the electric current when there are constant variations of load, as the potential will decrease rapidly as the load increases, and *vice versa*. This fluctuation changes the speed of motors and the brilliancy of lights. (There would, of course, be little drop under no load.)

2. The interest on the increased cost of installing the larger water-wheels or turbines, dynamos, and fittings largely offsets the expense of larger conductors.

CHOICE OF SYSTEM.

6. For the transmission of energy for short distances (not exceeding say 2 miles) where it is to be used chiefly for power and incidentally for lighting, the choice will rest between

(*a*) The direct current, not exceeding 600 volts for surface, 500 volts for underground, and

(*b*) The multiphase-alternating current with either induction or synchronous motors, with the addition, where electric locomotives are to be used, of rotary transformers to supply direct current to them.

7. For the transmission of energy for lighting, with incidental use for power, the monocyclic system or two-phase three-wire system is preferable. With the monocyclic system the lighting current is conducted by two wires, a third wire brought from an intermediate point in the wiring of the dynamo being added for power use.

8. Long-distance transmission requires some form of alternating current, as the cost of conductors for the low-potential direct current would be prohibitive.

With the use of electricity, the greatest freedom is permitted in selecting a site for the power plant. Instead of being arbitrarily located at or in the immediate vicinity of the mine shaft or mill, it may be placed with due reference to the cheap delivery of fuel, and also due regard to a satisfactory supply of water for the boiler and condensing engine.

Moreover, where power is used at several scattered shafts or works, one generating plant only will be necessary, in which efficient, large unit boilers and engines can be installed.

PRACTICAL EXAMPLES.

9. Metropolitan Railway Company of New York City.—This plant furnishes a good example of the economy effected by the centralization of plant, and may be described as follows:

The power station supplies current for the widely scattered electric-car lines of the Metropolitan system, and is located between Ninety-fifth and Ninety-sixth Streets, First Avenue and the East River. Although this location can not be called a central point of distribution, the greater facility with which coal and ashes can be handled and the unlimited supply of water from the river for condensing purposes, in addition to the much lower cost of land, governed the selection.

10. The building is a steel-frame structure with brick walls. The ground plan is 200′ × 280′. The boiler room will contain 87 Babcock & Wilcox water-tube boilers in three tiers, each boiler having a rated capacity of 250 H. P., capable of being forced to 400. An engine room of about 100′ × 200′

will contain 11 vertical cross-compound condensing Allis engines of 4,500 indicated H. P. each at their maximum efficiency, but capable of running continuously at 6,000 H. P., and for a short time at 7,000. To these engines will be coupled 3,500-kilowatt generators of the General Electric Company (approximately 4,700 H. P.). The generators will run at 75 revolutions per minute.

The entire floor above the boilers will be occupied by the steel coal-bins, with a capacity of 9,000 tons. The chimney is the largest in the world, being 353 feet high, with a 22-foot core. As the ground was very poor for the foundation, over 1,200 piles were driven, and these were topped with a solid block of concrete 85 feet square and 20 feet deep. The chimney built upon this block contains over 3,500,000 bricks.

11. At Fiftieth Street and Sixth Avenue, nearly 2½ miles away, a substation with a capacity of over 6,500 H. P. will convert the high-pressure three-phase current (6,000 volts) to the necessary 550 volts direct current for use on the conduit-trolley line, by means of rotary transformers. At One Hundred and Forty-sixth Street, also about 2½ miles away, another substation will be located with a capacity of 5,300 H. P. Three and one-half miles away, in Twenty-fifth Street, there will be one of 6,300 H. P., and at Houston Street, 5 miles away, one of the same capacity. The farthest, located at the lower extreme of the city, 7 miles away, will be of 4,000 H. P. Two additional stations will probably be located in the lower end of the city at a later date.

This plant with its 45,000 H. P. capacity forms one of the most interesting examples of the extensive transmission of electric power where the current is used almost exclusively for street-railway work and where all wires have to be placed underground. The main cables are insulated with rubber and woven braid and covered on the outside with heavy lead tubing. This is then drawn through vitrified brick conduits adjoining in most cases the tracks of the company.

12. Southern California Power Company's Plant.—Ordinarily a distance of 50 miles is the practical limit of electrical-power transmission, but in localities where fuel is expensive and large amounts of power are required, a much greater distance is practicable, especially where water power may be obtained. This case is well illustrated by the plant under consideration, which may be described as follows:

13. In the mountains 83 miles from Los Angeles, water power under a head of 700 feet is used to drive (Pelton) water-wheels coupled direct to three-phase generators of 750 volts pressure. This current is transformed in three sets of static transformers to 1,900 volts, giving a working pressure on the line of 3,300 volts. Four 1,000 H. P. dynamos are now operated and six additional machines of the same size are being installed. The current is used at Los Angeles for lighting, street-railway, and other power purposes. For the trolley service, the necessary direct current is secured by means of rotary transformers. In mines favorably located below the source of water power, water-wheels and hydraulic motors can be utilized direct for hoisting and pumping; but for one such case there are a score where the water is located below the point where it is required, with hills intervening, or too far away to be piped.

TRANSMISSION LINE.

14. Having determined the location of the power plant and the electric system to be employed, the next consideration is the construction of the transmitting line.

(For methods of installing dynamos and wiring switchboard and station connections, see *Dynamos and Motors.*)

15. Line Construction.—Whether a high or low tension system is used, it is advisable to construct the pole line in the most substantial manner. Twenty-five to thirty-five foot poles of not less than 5 inches in diameter at the top should be used. These should be set at least 4 feet in the ground, preferably 5. The pole hole should be dug large enough to permit the butt of the pole being dropped straight in without forcing and should be filled in slowly with dirt, tamped with iron rods to insure thorough packing of the earth. Poles used at corners or angles should be preferably of 7 inches top diameter when heavy wires are carried, and sufficiently long to permit of their being set 5 feet 6 inches in the ground. Where the ground is moist, it is well to smear the butt end of poles with pitch or tar and have this extend at least 2 feet above the ground line. The proper distance between poles will depend on the character of the ground and the weight and physical strength of the wire. One hundred feet interval is perhaps the best for general conditions, and a distance of 125 feet should never be exceeded, except with the use of aluminum conductors. This metal is only about half the weight of copper for equal conductivity and equal breaking strain, so that a much longer span is permissible. For every 5 feet added to the length of the pole, it should be set an additional 6 inches in the ground.

16. Insulation.—There are two methods of insulating conductors carrying electricity at high pressure—continuous insulation and interval insulation. In the former, the wire or cable is covered or coated throughout its length with rubber or other insulating material. In the latter, bare wire is supported at intervals on glass, porcelain, or composition insulators. In the aerial transmission of very high pressure currents, complete reliance must be placed on the quality of pole insulators and on the mechanical strength of the wire and line construction.

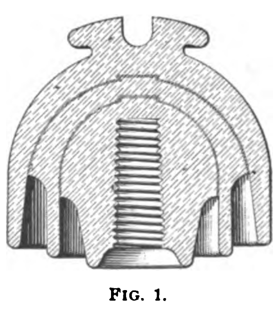


FIG. 1.

Figs. 1 and 2 show double-petticoated porcelain insulators, such as are used in high-tension work. The shaded lines show that it is made in sections and melted together by the vitrifying furnace. Where high-tension wires cross telephone or telegraph lines, it is best to place the high-tension wires above, or if below, to protect them by guard wires to prevent the grounding of the system in the event of the breaking of the lighter wires.

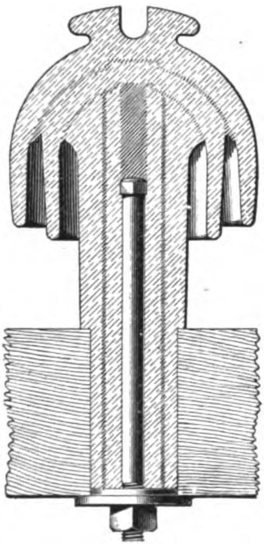


FIG. 2.

17. Lightning-Arresters.—In high altitudes and exposed country, the line should be protected by occasional lightning-arresters. Several different forms are effective. They are connected to the line at the terminals and at exposed points. One side is connected to the line by heavy wire or cable, the other to the earth, and it is essential that the latter section should be carried to moist ground in order to be effective. One type consists of series of cylinders of so-called non-arcing metal, placed parallel and close to each other, with little gaps between, which the lightning will jump across, but which could not be spanned by the relatively low tension of the service current.

The term non-arcing metal is used for the reason that the gases formed by the burning metal due to the passage of the lightning discharge do not form a conducting path for the current of the line, as is the case with the majority of the metals. In another type the lightning jumps a small air-gap between two horns spreading out from each other, and there is placed a strong magnet whose lines of magnetic force pass across this gap with the effect of counteracting the arc, or, as it is expressed, "blowing it out." A third form consists of two large disks of metal placed with a small interval between them and with a sufficient surface to radiate the heat so rapidly that the arc or center of heat is dissipated.

18. Interior and Underground Wiring. — The electric current may be carried at high potential to the entrance of a building or mine and with carefully insulated cables at pressures up to 1,000 volts to central distributing points in mine or building, there to be converted to a pressure not to exceed 500 volts. This voltage is not sufficiently high to seriously injure any healthy person who may accidentally handle the bare conductors or connections of a machine. The method of running the wire cables down a shaft will depend on the available space, or whether it is "wet," and on the voltage of the current.

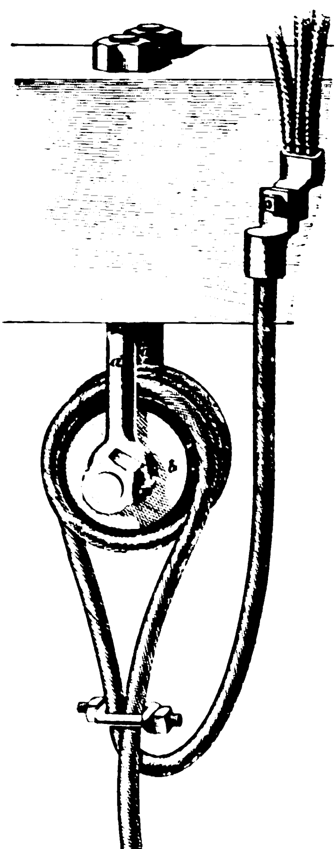


FIG. 3.

19. An ingenious device is shown in Fig. 3, by means of which cables may be suspended in vertical shafts. This device consists of a pulley with heavy bolts for attaching to the beam at the head of the shaft and projecting downwards. The large hardwood rollers are soaked in paraffin or paint and covered with soft rubber. The ends of the cable are carried around these pulleys two or three times, and then down the shaft, where they should be firmly attached to the side of the shaft on insulators at frequent intervals. The upper ends are connected to the outside feeders by heavy brass couplings which permit of being disconnected at will.

20. Where the current is to be used for underground locomotive traction, bare wire must be used along the haulageways. This wire is attached to the roof of the tunnel or gallery, between or over one of the rails, according to the character of the roof or the location of the trolley-pole on the electric locomotive. The trolley supports may be placed at from 25 to 40 feet apart.

21. Hangers.—Where the entry is timbered overhead, the hangers and insulators supporting the trolley-wires can be attached to these, otherwise special supports will be necessary. They must be strong enough to hold the weight of the wire and to withstand the constant jar and vibration to which it is subjected. Where the roof is good and its height uniform, the supports can be attached directly to it. Fig. 4 shows a good form of hanger and insulator. The insulating substance *a* is protected from injury by accidental blows by a metal hood-shaped covering *b*. The insulating material in the center has steel studs insulated from each other, projecting upwards and downwards. The upper one is fastened to the iron hood which has arms *c* for attaching to the roof. To the lower stud *e* is fastened the clamp *d* for holding the trolley-wire. This clamp consists of two jaws of bronze, hinged to an interlocking pin which passes through the head of the stud-bolt. The clamping effect is secured by screwing the cone-shaped nut down on the stud-bolt; this spreads the upper part of the jaws apart and tightens the grip on the wire. The clamp *d* can be loosened at any time for readjustment by turning the nut *e*.

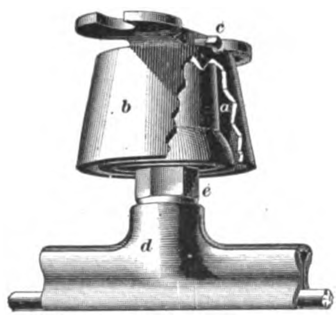


FIG. 4.

22. Fig. 5 shows a trolley hanger and the method of suspending it from the roof. A hole is drilled in the top rock, and a bolt with its upper end made wedge shape and larger than the diameter of its stem is placed in the hole. A short piece of gas-pipe which is split at its upper end is also placed in the hole and over the bolt. A hole is then bored in a piece of 4" × 3" timber, just large enough to admit the bolt and prevent the gas-pipe from entering it when the piece of timber is put over the bolt and up against the roof, and the nut on the end of the bolt is tightened up. It can be seen that as this nut is screwed up the widened portion of the bolt is wedged tightly into the gas-pipe, which is in turn forced against the side of the hole. The block of wood is supported in this manner at two points, and the insulated hanger is screwed into it. This device serves very well where the roof is approximately the proper height for the trolley-wire, but where the roof is high, it is a good plan to drill two holes about 2 inches in diameter and 10 inches deep, and about 12 inches apart, crosswise over one of the rails. Wooden plugs are then driven into the holes and sawed off the proper height above the rails, and a piece of $1\frac{1}{2}'' \times 4'' \times 14''$ timber nailed on to the ends of the plugs by using three twentypenny spikes in each.

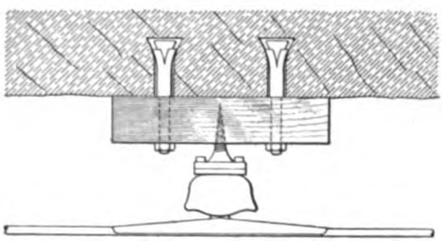


FIG. 5.

Malleable-iron pins are also made in two halves, one having projections, the other smooth. The half with projections is first placed in the drilled hole in the roof and the other or smooth half is then driven up beside it. This form is very satisfactory with a good roof.

23. Frogs.—Fig. 6 shows a frog used at junction points. It is similar to those used in street-railway practice. Being placed just forwards of the switch in the track, the trolley arm before reaching it has received an inclination in the direction the locomotive is taking and automatically shifts to the correct overhead wire.

24. Return Circuit.—In mine traction as in surface traction, the rails, properly bonded, are generally used for the return circuit. That is so say, the current passes from the bare trolley-wire, through the trolley arm to the starting resistance and motor, and through the frame of the motor and wheels to the rails, and so back to the generator. The conductivity of iron being low and the fish-plates connecting the different lengths of rails being liable to rust (which

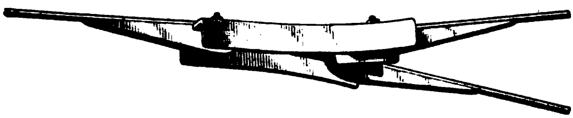


FIG. 6.

largely destroys its conductivity), the path for the return current is assisted by "bonding," which consists in connecting the rails together with copper wire by wedging or soldering the ends of a short piece of heavy copper wire into the web of adjoining rails. Cross connections between opposite rails should be made not less than every 150 feet. The method of bonding, by winding copper wire around the bolts before the fish-plates are put on, is not to be recommended.

25. Arrangement and Protection of Conductors.—From the end of the rails to the power house it is well to use a cable for the return circuit. Where the current is to be used exclusively for other purposes than traction, bare wires exposed for their entire length are not essential, and insulated cables may be used with the alternating system (single, two, or three phase) up to 1,000 volts potential. Current can be conveyed to central points at this pressure and converted at substations in the mine to the working voltage by means of static transformers. However, this would be done only where the distance from the mine shaft was considerable or where a large amount of current was used, making the cost of copper for conveying at 500 volts, without too great loss, a serious item of expense. The wires or cable should be placed at one side of the gallery, as much out of the way as possible, to avoid injury to miner or mule (stock) from accidental contact. It is wise to conduct the current in any case through mains or feeders, and to have the system divided into sections with switches, so that the shutting down of one portion for repair or extension need not affect the balance. Where the wires cross main gangways, it is wise to protect them thoroughly against chance contact or mechanical injury; this may be done by covering them with split rubber hose and binding it at intervals with rubber tape.

26. Carrying Capacity of Wires.—The safe carrying capacity of wires is given in the following tables for bare wire and wire enclosed in moldings or conduits. The reason for the great difference in capacity is due to the fact that in one case the heat can radiate and in the other it accumulates.

TABLE I.

SAFE CARRYING CAPACITY OF BARE WIRES.

Brown & Sharpe. Gauge Number.	Safe Carrying Capacity. Current in Amperes.
0000	300
000	245
00	215
0	190
1	160
2	135
3	115
4	100
5	90
6	80
7	67
8	60

TABLE II.

CARRYING CAPACITY OF WIRES WHEN ENCLOSED.

Brown & Sharpe. Gauge Number.	Amperes.
0000	175
000	145
00	120
0	100
1	95
2	70
3	60
4	50
5	45
6	35
7	30
8	25

27. Danger of Injury from Shock.—It is not wise to touch a bare conductor carrying current at a pressure of over 110 volts, unless you are provided with gloves made of rubber or standing upon some dry insulating material. This fact should be remembered by persons traveling along headings where the conductors may be touched by some part of the body. A person wearing dry rubber boots or standing on dry wood may touch a single conductor through which a current of high voltage is passing without injury, provided he does not make contact with the negative conductor (generally the earth) with some exposed part of the body.

A dynamo or motor may become "charged" by injury to the wiring or on account of some loose coils touching the body of the machine. In such a case it is exceedingly dangerous to touch any part of the machine, for it will discharge through your body into the earth. It is a wise precaution to connect the frames of pumps and other machines run by electricity to the earth to prevent their becoming charged and inflicting possible injury to those handling them.

ELECTRIC HOISTING.

GENERAL CONSIDERATION.

28. The electric motor is an ideal form of power engine for hoisting. Having a rotary motion, the intervention of a crank with its varying power at different positions is not necessary, as is the case with the use of steam or compressed air. Hoisting-engines used in mining are frequently located quite a distance from the boilers, necessitating great length of pipe for delivery of steam. In addition to the losses from condensation, there is constant danger of blowing out the cylinder-head from having water collected in it. As hoisting-engines are used intermittently, this will be a very serious source of trouble unless the engine and pipes are carefully drained before starting. In cold weather, ice may also form in the pipe and engine and cause accident. The electric-motor hoist reduces dangers from careless handling to a minimum.

PRACTICAL EXAMPLES.

29. Fig. 7 shows a direct-current electric mining hoist. The motor is one of the armored railway type built by the General Electric Company. It is enclosed as shown, the case *a* forming part of the field magnet and protecting the machine from dust and dirt as well as mechanical injury. The controller *b* is of the street-car type, and is mounted so as to be convenient for the operator to observe the necessary signals. The current is regulated by the lever *c*, and reversed when necessary by the lever *d*. The pinion upon the axis of the armature gears with the spur-wheel upon the shaft *e*. These gear-wheels are enclosed in the case *f*, which not only protects them from dust and dirt, but also furnishes a receptacle for oil, which insures continuous and perfect lubrication. On the right-hand end of the shaft *e* there is a pinion that gears with the large spur-wheel *h*,

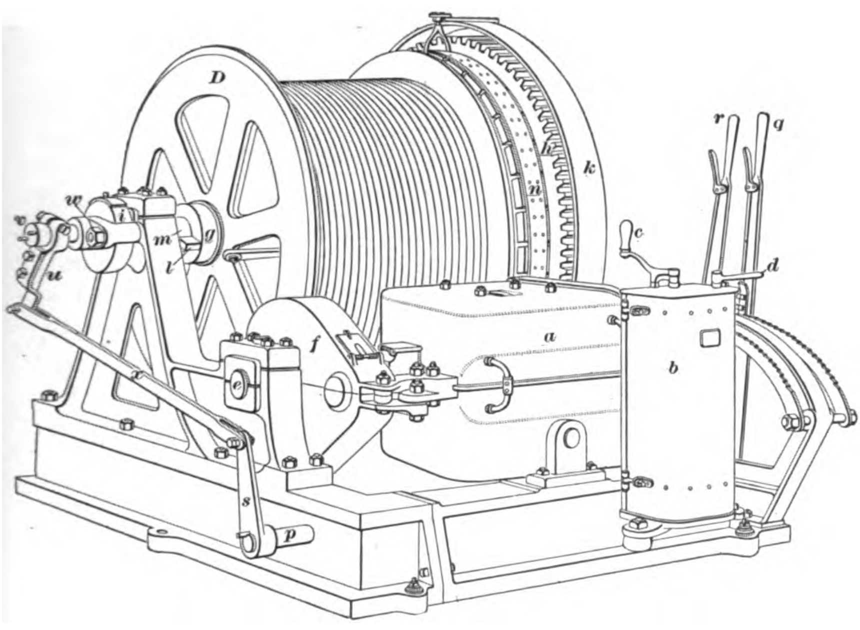


FIG. 7.

which is covered by the protective band *k*. The gear-wheel *h* is fixed rigidly to the drum shaft *m*, while the drum runs loosely upon it. The band brake *n*, which consists of a flat iron band having a number of wooden blocks attached to its inner side by means of wood-screws, engages with the drum and is applied or released by the lever *r*. The lever *q* operates the patent friction-clutch through the

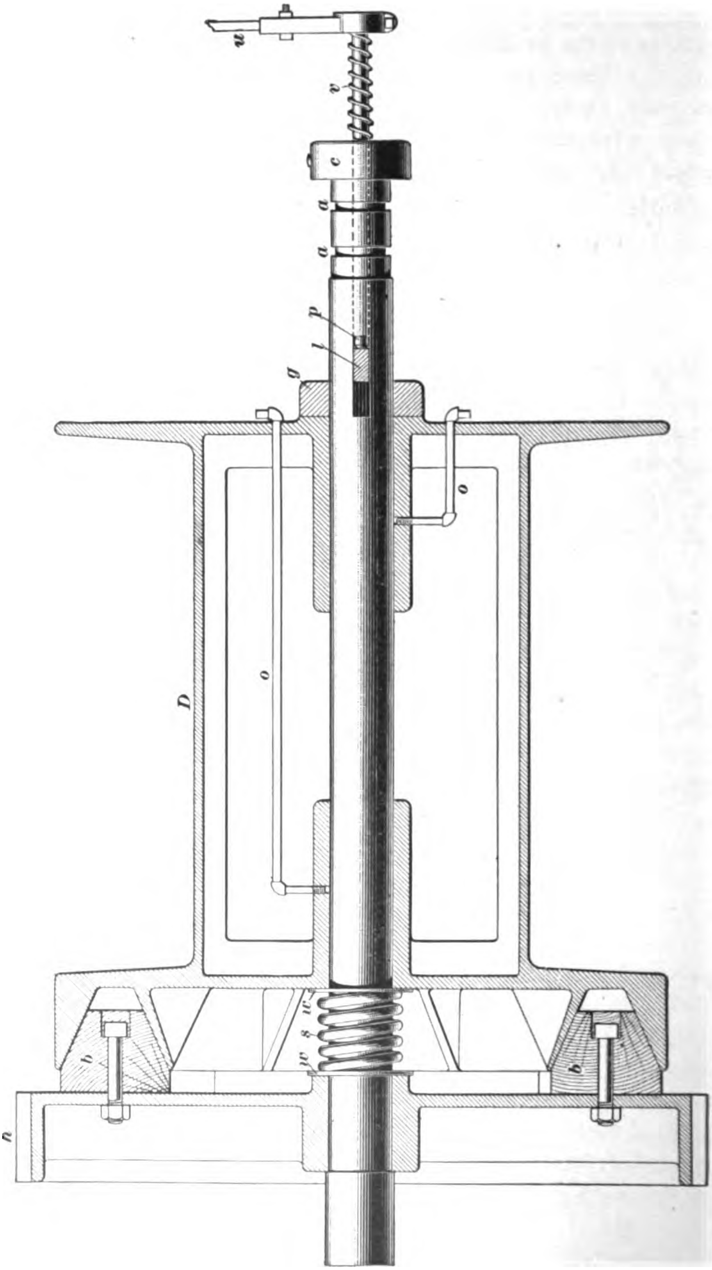


Fig. 8.

horizontal shaft *p*, the lever *s*, the link *x*, and the lever *u*. When the screw *v* is slightly turned by this system of levers, it is forced into the nut *w* and against the end of a concentric steel pin which passes through the shaft *m* to the cross-key *l*. This key then forces the washer *g* against the drum, which is pushed to the right and engages with the friction-clutch. The bearing between the end of the concentric pin and the screw is kept well lubricated by means of the oil case *i*.

30. Fig. 8 shows a section of the drum *D*, Fig. 7, illustrating the construction and action of the Beekman patent friction-clutch as built by the Lidgerwood Manufacturing Company, of New York. Large wooden blocks *b* are bolted to the side of the spur-wheel *h*, and they are made of suitable shape to conform to the V-shaped groove in the side of the drum *D*. The steel spring *s* between the two steel washers *w*, *w* disengages the brake as soon as the pressure is relieved from the opposite side of the drum. It can be clearly seen from the figure that, as was previously stated, when the lever *u* (Fig. 7) is turned, the screw *v* is forced against the end of the concentric steel pin *p*, which in turn presses the cross-key *l* against the collar *g*. This collar presses the side of the drum, which then frictionally engages with the large spur-wheel *h*. The drum shaft is prevented from moving longitudinally by means of the grooves *a*, *a* and the screw collar *c*. The wide bearings of the drum on its shaft are lubricated by means of the pipes *o*, *o*.

31. This hoist is provided with separate resistance to regulate the speed of the armature when the motor is working under different loads; it is especially suitable for a single shaft, for the friction-clutch can be used while hoisting the cage and the band brake used in lowering it, provided it is not necessary to reverse the current and use the power. The rope may coil upon the drum in several layers, unless the hoist is used to raise material out of two adjacent shafts or a double shaft, in which case both ropes are attached to the middle of the drum and wind upon it towards the ends; or, better still, one rope may be attached at the middle and the other at the side of the drum, so that the stress will be placed more equally upon the bearings of the drum shaft. With this arrangement, the ropes can not be accurately or conveniently adjusted to make the rails on the cage at the top, and those on the cage at the bottom fall in line with the rails of the roads at the top and bottom.

32. After considerable use, the ropes vary in length, and rather than attempt to adjust one or the other of them, blocks are sometimes bolted to one end of the drum to increase its circumference and thereby take up the required amount of rope to land the cage properly and prevent undue jars and stresses when starting to hoist. In many large mining hoists, the ropes are adjusted by means of internal positive clutches. This arrangement is very convenient where the shafts are deep and the ropes necessarily long.

33. When two ropes are attached to a single drum, the length of rope is limited to the width of drum, as not more than one layer of rope can be wound upon the drum, while if double drums or single drums with one rope are used, several layers of rope may be coiled upon the drum. This, however, is not good practice in hoisting, although in haulage practice the rope usually winds upon itself. Hoisting drums are generally provided with spiral grooves, which guide the rope and furnish a good bed for it.

34. The hoist shown in Fig. 7 weighs about 24,000 pounds and can hoist 6,000 pounds (gross load) at a speed of 500 feet per minute. The drum has a 36-inch face and is 60 inches in diameter. The motor makes 700 revolutions per minute and is rated at 110 horsepower. Hoists of this type and size are used at small mines and for auxiliary hoisting at large mines. Motors are used to run large double drums instead of the steam-engine, but the conditions at the majority of mines are such as to make it uneconomical; for it would not be good policy to incur the double cost of transforming the steam energy into electrical energy when steam can be used directly and near where it is generated.

35. Fig. 9 shows a direct-current electric mining hoist quite similar to that shown in Fig. 7, except that it has a

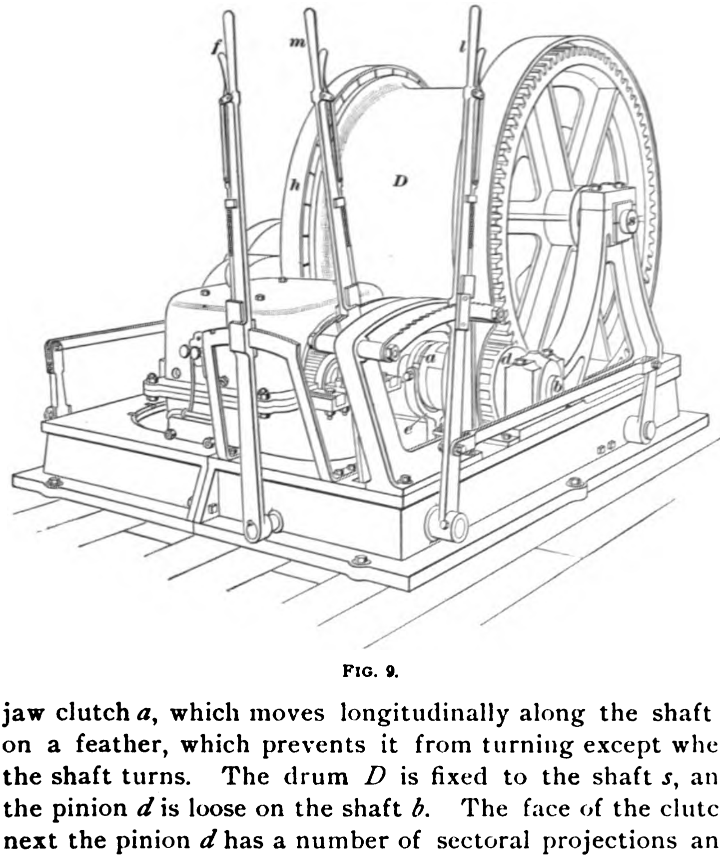


FIG. 9.

jaw clutch *a*, which moves longitudinally along the shaft *b* on a feather, which prevents it from turning except when the shaft turns. The drum *D* is fixed to the shaft *s*, and the pinion *d* is loose on the shaft *b*. The face of the clutch next the pinion *d* has a number of sectoral projections and recesses which fit into corresponding recesses and projections on the adjacent side of the pinion. The clutch is thrown in or out of gear by the bifurcated upright *c* which is operated by the hand lever *f*. The bifurcated ends of the upright have suitable projections bolted to them, which run in the annular groove in the clutch *a*. This form of clutch is positive and can not be thrown in gear when the motor is running at any considerable speed unless the projections

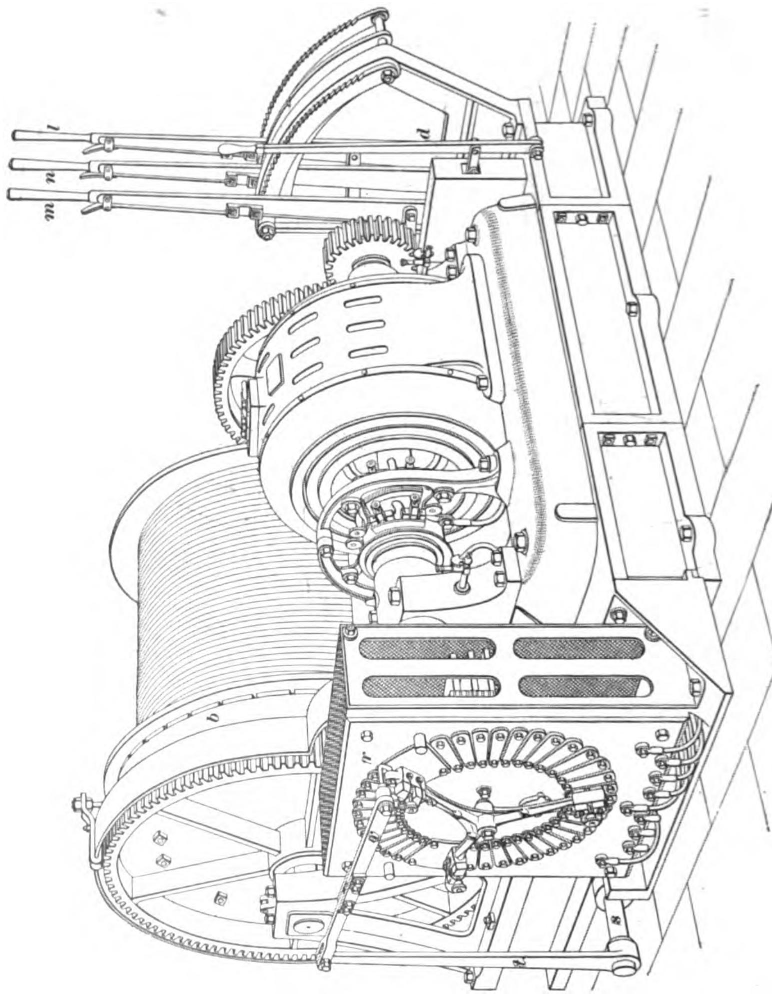


Fig. 10.

and recesses have considerable play, in which case the entire hoist is subject to great stresses if the gear is thrown in while the motor is running.

The cage may be lowered by throwing the clutch out of gear and using the band brake *h*, which is operated by the hand lever *l*. The motor and the resistance are controlled by the hand lever *m*. This hoist is built to raise 6,000 pounds with current supplied at a voltage of from 250 to 500, and it is especially suitable for local hoisting in wet places. The face of the drum is smooth and the rope may wind upon itself.

36. Fig. 10 shows an induction-motor mining hoist provided with a patent friction drum operated by the lever *l* and a band brake *b* operated by the lever *m*. The motor is of the three-phase induction type and is provided with a resistance in the armature circuit and external contacts for varying the same. The motor may be wound for a voltage of from 110 to 500, and can be adapted for use on two or three phased systems. The controller is so constructed that a speed varying from maximum to zero can be obtained as readily as if a steam-engine were used. The external contact arms *c* are placed upon the resistance box *r*, and are operated by the hand lever *n*, through the horizontal shaft *s*, lever *t*, and link *v*. The current is reversed by the lever *d*.

37. Fig. 11 shows an electric hoist made by the Lambert Hoisting Engine Company, of Newark, New Jersey. The armored continuous-current motor *M* is connected to the pinion *n*, which gears with the spur-wheel *w*, on whose shaft there is a pinion that gears with the large spur-wheel *s*. The current is regulated by the small crank *a* on the controller *C*. This hoist is provided with a patent friction-clutch that is operated by the lever *l*; also the band brake *b*, operated by the lever *p*. The gear-wheels are covered with bands *e* and *f*, in order to prevent anything from falling between them.

38. Fig. 12 shows a double independent drum hoist having an induction motor *M* and controller *C*, which are similar to those shown in Fig. 10. The levers for controlling the patent friction-clutches and band brakes and the lever on the controller are all placed so as to be convenient for the operator, who stands upon a platform above the floor

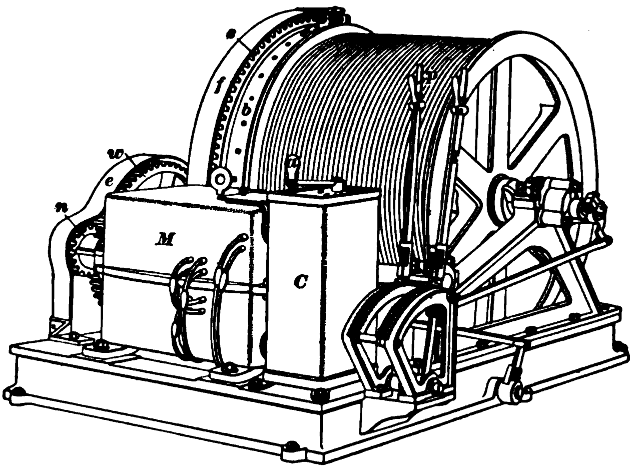


FIG. 11.

in order to get a clear view over the top of the hoist. Each friction drum is driven through a single-reduction gearing

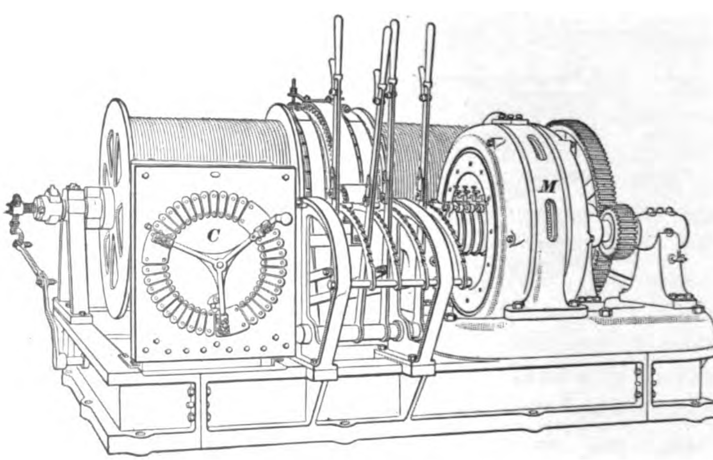


FIG. 12.

by a 100-volt 12-pole induction motor of 30 horsepower running at 600 revolutions per minute. Each drum is independent and of 42 inches diameter, has a 40-inch face, and will wind about 420 feet of $\frac{7}{8}$-inch rope. The maximum hoisting speed is 300 feet per minute and the weight hoisted, including load, car, and cage, is 2,100 pounds. The depth from which the load is hoisted is 400 feet from the surface.

ELECTRIC HAULAGE.

39. General Consideration.—Electric motors may be employed for operating drums for tail-rope, endless-rope, or other haulage systems, but these could not properly be called systems of electric haulage, as the electric motors can be replaced by engines without affecting the means of drawing the cars. In the present treatment of the subject, electric haulage is taken to mean a system by means of which the motors are placed upon electric locomotives and travel with the cars.

40. Haulage in mines is usually accomplished in two divisions. The cars are hauled between the shaft bottom or outside landing, and the turnout near the working places in the mine by means of the main system, and between the turnout and the different working places by means of mules or horses. These divisions are called the general and the local haulage, respectively. The former is done in large trips and the latter in small trips of from one to ten cars, and consists in hauling the empty cars in and the loaded ones from the working places. In some mines the local haulage, which is often termed **gathering,** is partially done by electric locomotives; but in such cases, electricity is used for running the mining machines, the trolley-wire being also used to conduct the current to the machines. Gathering with locomotives operated by a trolley has not been entirely successful. The storage-battery locomotive is now being experimented with and bids fair to prove successful in this work.

41. Advantages of the Electric Locomotive.— The compactness of the electric locomotive and the fact that it can run in lower entries than either the steam locomotive or the mule make it specially advantageous for mine operations. The mechanism can also be better protected from injury and is more readily accessible for repair. All working parts, with the exception of the controlling mechanism, are practically enclosed in a heavy, rigid, cast-iron frame, and heavy metal or wooden doors on the top of the frame secure the parts from damage by water or falling rock from the roof.

42. Construction and Arrangement of Mine Locomotives.—Motors constructed for mine locomotives are generally of the iron-clad, single-reduction-gear type, with the gearing running in tight cases containing oil. The motors are controlled by either the rheostat (resistance method) or by a series-parallel controller. In the latter, the current passes, on the first movement of the lever, through a temporary resistance, then through each motor in series. The resistance is then cut out, either by the next position of the lever or in successive steps. The motors are then thrown in parallel, that is, the current passes through each one separately with an added resistance; the final step cuts out this resistance. It is evident that with 500 volts on the line when the motors are placed in series, each one gets the equivalent of 250 volts, and when in parallel, each has the benefit of the 500 volts on the line. It is very essential that the resistance used with the controller should be of sufficient carrying capacity not to overheat if the operator carelessly allows the motors to run with the controller in such position as to include it.

43. Apparatus for mines should be constructed with a view to running without chance of breakdown under the most unfavorable conditions rather than under proper ones. Among careless mechanics and operators there is always temptation to neglect the apparatus as long as it will run. Too much stress can not be laid upon the importance of constant inspection and attention.

44. Speeds.—Electric locomotives for mines are generally designed to run at speeds of from 5 to 10 miles an hour, and most of the standard makes are designed to run at 6 miles an hour at their maximum power.

45. Electric Locomotives vs. The Mule.—Often a single electric locomotive can handle the entire haulage of a mine and replace the work of many mules. The latter constantly block each other in main gangways when material is collected from many galleries, and as the output of a mine is often limited by the amount of material that can be hauled out through the main passage, the greater speed of the locomotive and its ability to haul in one load many times the number of cars that a mule is capable of will frequently greatly increase the output of a mine and materially cheapen the general cost of production. Then, again, where the seam or vein is thin, the locomotive can operate with a headroom of 3 feet 6 inches to 4 feet, while the mule will require over 5 feet. Another advantage is that the locomotive can work for 24 hours, if necessary, without getting tired, while several shifts of mules would be required, with the consequent trouble of feeding and accommodating a large number of animals underground or occasioning delay in hoisting them to the surface.

46. Electric vs. Rope Haulage.—It is a difficult matter to compare the relative advantages of rope and locomotive haulage, for this question will depend upon so many minor details; but it is certain that locomotive haulage will not be available where there are grades of over 5%, as the traction-engine can haul on this grade only about one-tenth of the capacity which it can haul on a level track. The energy expended in overcoming the weight of the locomotive and cars takes the major part of this capacity. With rope haulage, the load factor of the cars is the only one which is to be considered.

47. Size and Capacity of Electric Locomotives.—Electric locomotives are always operated by direct-current

TABLE III.

LIMITING DIMENSIONS OF DOUBLE-END BALDWIN-WESTINGHOUSE MINE LOCOMOTIVES.

LOCOMOTIVES HAVING OUTSIDE FRAMES.

Class.	Min. Gauge. Inches.	Diam. of Drivers. Inches.	Wheel-Base.		Height Exclusive of Trolley. Inches.	Minimum Width. Inches.	Max. Gauge for Min. Width. Inches.	Length Excluding Bumpers.	Weight. Pounds.
			Motors Tandem. Inches.	Motors Central. Inches.					
$4\frac{2}{6}$ C	20	20	30	38	24	37	20	10′ 8″	4,000
$4\frac{2}{10}$ C	24	24	40	46	32	43	25	11′ 4″	7,500
$4\frac{2}{10}$ C	30	28	40	50	34	50	32	11′ 6″	7,500
$4\frac{2}{15}$ C	30	28	44	52	34	51	32	11′ 10″	10,000
$4\frac{2}{25}$ C	30	30	44	54	36	52	32	12′ 0″	15,000
$4\frac{2}{35}$ C	35	30	48	56	38	58	40	12′ 0″	20,000
$4\frac{2}{50}$ C	35	30	48	56	38	59	40	12′ 0″	26,000

LOCOMOTIVES HAVING INSIDE FRAMES.

Class.	Min. Gauge. Inches.	Diam. of Drivers. Inches.	Wheel-Base.		Height Exclusive of Trolley. Inches.	Minimum Width. Inches.	Max. Gauge for Min. Width Inches.	Length Excluding Bumpers.	Weight. Pounds.
			Motors Tandem. Inches.	Motors Central. Inches.					
$4\frac{2}{6}$ C	29	20	30	38	24	35	29	10′ 8″	4,000
$4\frac{2}{10}$ C	34	24	40	46	32	41	35	11′ 4″	7,500
$4\frac{2}{10}$ C	40	28	40	50	34	48	42	11′ 6″	7,500
$4\frac{2}{15}$ C	41	28	44	52	34	49	43	11′ 10″	10,000
$4\frac{2}{25}$ C	42	30	44	54	36	50	44	12′ 0″	15,000
$4\frac{2}{35}$ C	48	30	48	56	38	56	50	12′ 0″	20,000
$4\frac{2}{50}$ C	49	30	48	56	38	57	51	12′ 0″	26,000

TABLE IV.

JEFFREY ELECTRIC LOCOMOTIVES.

Type.	Class.	Drawbar Pull. Pounds.	Speed in Miles per Hour.	Number of Motors.	H. P. of each Motor.	Weight of Locomotive. Pounds.	Minimum Gauge. Inches.	Min. Gauge with Outside Wheels. Inches.	Width over all with Inside Wheels. Minimum Gauge. Inches.	Width over all with Outside Wheels. Minimum Gauge. Inches.	Height over all Excluding Trolley. Inches.	Length over all Excluding Bumpers.	Wheel-Base. Inches.	Diam. of Wheels. Inches.	Lightest Steel Rail To Be Used. Pounds.
S M	10	500	6 to 10	1	10	4,000	22	34	40	40	36	7′ 4″	30	24	8
"	20	1,000	"	1	20	8,000	36	48	55	55	39	7′ 9″	35	28	12
D M	20	1,000	"	2	10	8,000	18	30	37	36	36	9′ 3″	36	24	12
"	30	1,500	"	2	20	12,000	28½	45½	48½	51½	39	9′ 4″	40	28	16
"	40	2,000	"	2	25	14,000	28½	45½	48½	51½	39	9′ 4″	40	28	20
"	50	2,500	"	2	30	16,000	36	53	56	59	39	9′ 4″	40	28	25
"	60	3,000	"	2	35	18,000	36	53	56	59	39	9′ 4″	40	28	30
"	70	3,500	"	2	40	20,000	36	53	56	59	39	9′ 4″	40	28	30
"	100	4,500	"	2	50	24,000	40	57	60	63	43½	10′ 10″	40	28	40
T M	110	5,500	"	3	35	30,000	39	53	59	59	46	11′ 8″	62	28	40

motors. Up to the present time no system has been devised to utilize the alternating current to advantage. Electric mine locomotives are now made in sizes ranging from 4,000 pounds in weight with a drawbar pull of 500 pounds and running at a speed of 6 to 10 miles per hour, to 30,000 pounds in weight, 5,500 pounds drawbar pull. They are made in two forms, with outside and inside wheels; that is, the wheels are located inside the heavy cast-iron frame in one case, outside in the other. The minimum gauge is 18 inches, but tracks of this width are not to be recommended.

Outside dimensions range from 34 inches up. The preceding tables give the prevailing dimensions.

48. Effect of Grade Upon Capacity.—In modern steam-railway practice, a ton weight of train can be hauled

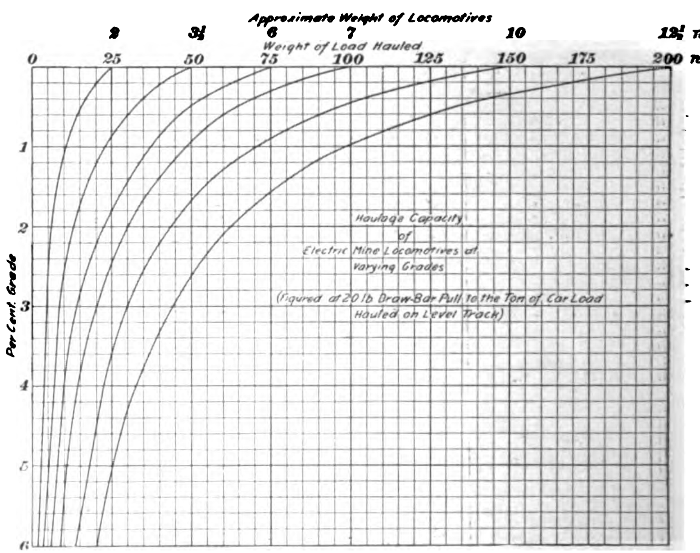


FIG. 18.

at 20 miles an hour over 80 to 100 pound rails with good roadbed for every $3\frac{1}{2}$ pounds of drawbar pull exerted by the locomotive. With old-style light rails used twenty years ago on the large railroads, a drawbar pull of from 6 to 8 pounds per ton was required. In mine haulage, at least 20 pounds must be figured on, and with careless construction and badly oiled and adjusted car axles, this will run to 75 pounds and over. Attention is called to the diagram, Fig. 13, showing the rapidly decreasing capacity of locomotives with increase of grade. This is figured on the basis of 20 pounds drawbar pull to the ton, on level track, which can only be accomplished with rolling stock in good condition.

49. Curves offer a large increase of resistance to the locomotive and cars, and consequently they very rapidly decrease the hauling capacity with the shortening of the radius. Of course, the combination of grade and curve will effect the economic operation of the entire road. Under any circumstances, labor expended in keeping the track and journal-bearings in the best of condition will be amply repaid by the greater efficiency and capacity secured.

ADVANTAGE OF HEAVY RAILS.

50. In locomotive mine haulage, too much stress can not be laid upon the necessity of having the rails of sufficient size and weight so that they will not give under the weight of the locomotive and cars; also, for permanent working, the wisdom of having the best possible track construction.

The running of a locomotive or of heavily loaded cars with flat wheels over light rails will often effect a permanent set in the rail which will greatly increase the frictional loss and add to the wear and tear on rolling stock.

The following table gives the minimum weight of steel **T** rails admissible for the different weights of locomotives. These figures are the minimum allowable, and greater economy in operation is effected by a liberal increase in these weights.

TABLE V.

Tons.	Pounds per Yard.
4	10
5	16
7½	20
10	25
13	30

EXAMPLES OF ELECTRIC LOCOMOTIVES.

51. Fig. 14 shows an electric locomotive made by the General Electric Company. It is of 40 horsepower and has a drawbar pull of 1,500 pounds. The track upon which this machine runs is made of 30-pound rails tied together with heavy fish-plates and laid on 6-inch square ties. The trolley-pole, which is held against the trolley-wire through all its variations of height by means of a spring, is placed to one side in order to have the overhead wire near the side of the entry. This form of trolley-pole does not need to be changed in position in order to run the locomotive either way. The controller is of the street-car type, and sufficient resistance is provided to prevent damage on starting the load. A magnetic blowout is used to avoid serious arcing at the contacts.

There are two motors, one for each pair of drivers. They have single-reduction gearing, and each is suspended by two bearings on the axle, which are kept well lubricated, and by an attachment to the front of the frame, which permits a slight lateral and endwise movement in case the main frame moves with respect to the axles. With this method of suspending the motors, one end of each supporting frame is practically suspended on springs, for it is attached to the main frame which rests upon helical springs placed upon the journal boxes, and the other end rests upon the axles and keeps the pinion on the armature shaft always in perfect gear with the spur-wheel on the driver shaft, no matter how much the front end of the frame supporting the motor may be moved up and down while the locomotive is running. The frame is made of very heavy cast-iron side and end pieces for the purpose of obtaining great weight in order that the locomotive will have sufficient adhesion to the rails. The journal boxes are provided with bronze bearings and oil-wells for

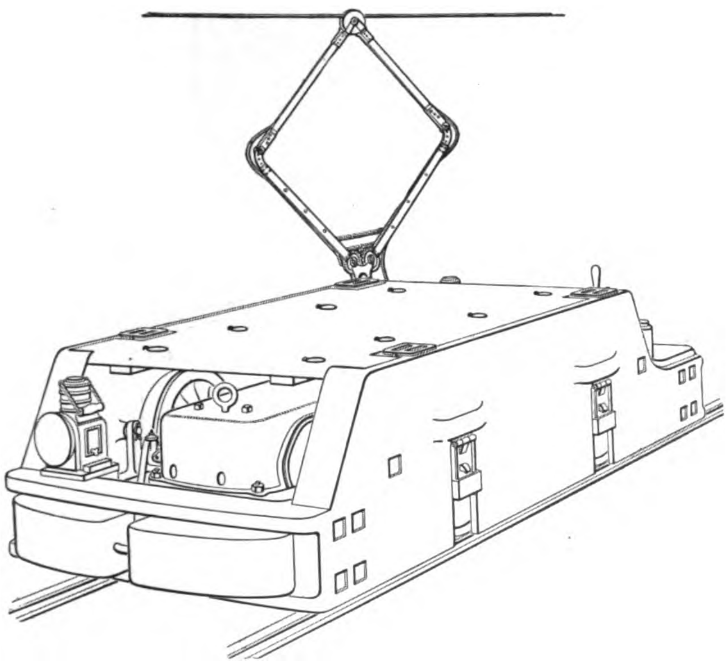


FIG. 14.

holding the saturated cotton waste. The massive frame is supported on helical springs resting upon the journal boxes. The use of the springs is to relieve the machine and rails from destructive shocks, and consequently prevent much wear and tear to both. This locomotive, in general with other types, is provided with a headlight, sand boxes, and a good brake. The speed varies from 6 to 10 miles per hour, depending upon the weight of the load and the grades.

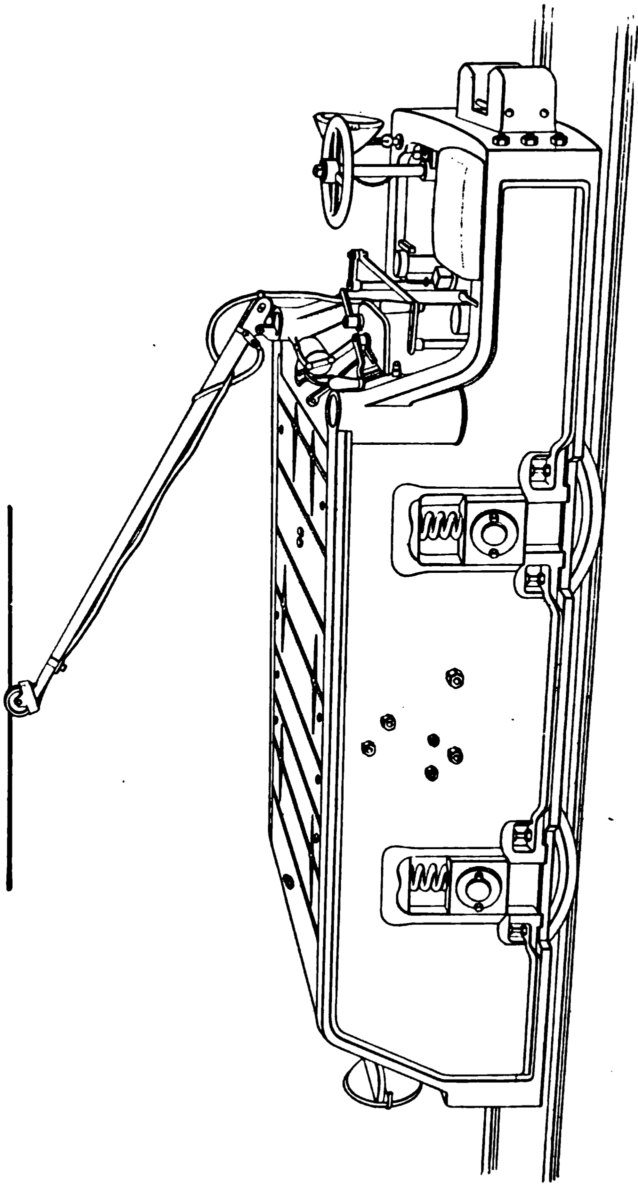


Fig. 15

52. Fig. 15 shows an electric mine locomotive built by the Baldwin-Westinghouse Electric and Manufacturing Company. They are built in sizes from 20 to 150 horsepower, to run at an average speed of 8 miles per hour. They vary in weight from 7,000 to 34,000 pounds.

53. Mine locomotives are also manufactured so arranged that the operator sits in the center of the frame between the two axles, being surrounded by the heavy casting, and thus protected from injury in case of a collision with anything standing on the track. This style of locomotive is manufactured quite extensively by the Jeffrey Manufacturing Company, of Columbus, Ohio.

54. Mine locomotives have generally been made with two pairs of wheels, with a motor mounted on each of the two axles. A recent type, however, has six wheels, each pair with its separate motor, attached by single-reduction gearing. It is claimed that in this design the weight is distributed better over the track, causing less strain to it, and that the additional pair of drivers gives a largely increased traction. To enable this six-wheel locomotive, with its longer wheel-base, to operate on short-radius curves, the center pair of wheels are made without flanges, that is, with smooth face.

ELECTRIC PUMPING, SIGNALING, AND LIGHTING.

PUMPING.

1. The **drainage of mines** is one of the most difficult problems in mining operations. Even if not encountered at the start, water-bearing ground is likely to be met with as the work progresses. The pumping plant should always have a large reserve capacity, since the extension of operations is likely to bring with it a larger amount of water to be handled. Where other mines have been operated in the neighborhood to greater depth, some light may be thrown on the probable requirements. Whether the water should be collected in the lowest level or pumped from each level separately depends on the question whether economy or simplicity is the main object, and this may be decided by the amount of flow.

2. Conditions.—The operation of a shaft mine in which water collects depends upon the ability to keep the working parts free from the accumulation of any large amount of water, and the pumps should be constructed and arranged so as to offer the smallest possible chance of failure. They should be capable of running a long time without requiring packing or repair, and the sinking-pumps and those located in the lowest level should be capable of running under water. Where acid water is encountered or where there is much grit in the water, the pump should be capable of handling it without too rapid wear.

The operation of pumps is influenced by many conditions, such as the length and size of the suction-pipe, the number of angles or turns in the pipe, the barometric pressure, temperature of the water, and altitude at which plant is located. The smoothness of the inside of the pipe and the diameter will also greatly affect the capacity and efficiency.

3. Comparison of Systems of Pumping.—The various styles of pumps and the arrangement of parts have been quite fully described in *Hydromechanics and Pumping.* The advantages of inside and outside packing, of direct-acting and fly-wheel pumps, and other facts regarding pumping machinery are there thoroughly treated. For the present we have to deal with electric pumps only; but it may not be amiss to state under what conditions the electric system is superior to the other systems. If there is but a limited amount of pumping to be done, it is not advisable to install any very expensive plant, as the interest on the cost might exceed the operating expense, and hence for such cases the water may be removed by means of water buckets, water cars, or pumps driven by steam or compressed air.

4. Steam Consumption of Steam-Pumps.—The duty of steam-pumps is approximately as follows: For small sizes, the consumption of steam is from 130 pounds to 200 pounds per horsepower per hour when operating in the workings of a mine at some distance from the boiler. For larger sizes of simple steam-pumps, the consumption is from 80 pounds to 130 pounds of steam per horsepower per hour. Compound condensing pumps, such as are commonly employed at stations in mines, consume from 40 pounds to 70 pounds of steam per horsepower per hour, while triple-expansion, condensing, high-class pumping-engines consume from 24 pounds to 26 pounds of steam per horsepower per hour. From these figures, it will be seen that, especially in the case of dipping pumps, which throw water to the main sump of a mine, the steam consumption is very great indeed.

5. Steam Consumption of Electric Pumps.—The duty of electrically driven pumps may be taken as follows: When a compound condensing engine is employed upon the surface operating electric pumps underground, the steam consumption per horsepower per hour for the smaller sizes would be about 40 pounds per horsepower per hour, for medium-sized electric pumps about 30 pounds per horsepower per hour, and for larger sizes from 20 to 30 pounds per horsepower per hour. It will be seen from these figures that for pumping from isolated portions of the mine, electric pumps are much more efficient than steam-pumps.

6. Advantages of Electric Pumping. — When steam-pumps are employed underground, the pipes are very objectionable in the mine, owing to the heat which they impart to the workings. It is also difficult to dispose of the exhaust-steam, and the entire system is liable to injuries. In case of accident, as, for instance, the sudden breaking into the mine of a considerable flow of water, it is difficult to assemble the pumps or rearrange them so as to meet the new conditions, on account of the fact that it takes some time to couple up the necessary steam or air pipes. The objections in regard to heat do not apply to compressed-air pumps, but the objections in regard to flexibility of system apply equally. With electric pumps, the system is always semiportable, owing to the fact that the conductors can be strung easily and quickly and the pump moved with ease and rapidity. Then, too, when either steam or compressed air is employed, there is a great loss in the transmission line, owing to the fact that the air can not, as a rule, be reheated previous to use and that there is a great condensation in the steam line. In the case of electric pumping, the power can be furnished by a generator directly connected to an engine on the surface, thus affording the most efficient power-generation plant possible. If the mine contains many small pumps, the total efficiency of the system when driven by electricity will be very much above that of a mine provided with a high-class pumping-engine at the foot of the shaft and several compressed-air or steam-driven pumps throughout the workings. Another advantage is that the electrically driven pumps need very little attention, it being possible to place them in charge of some one who simply visits them occasionally to see if they are working properly and to oil them. In mines where electricity is used for lighting, electric traction, or other power purposes, the pumping system fits in to the electric system already installed, and hence the whole may form a very efficient arrangement. One very important point in connection with electric pumping is that electric motors can be arranged to run at a uniform speed through a considerable range of load, so that if the pump were to work on air at times it would not result in any serious damage to the machinery; while if this occurs with a direct-connected steam-pump, there is danger of serious hammering or breaking of the pump, owing to the fact that the ram or piston jumps forwards on account of the air and strikes a destructive blow upon the water. This point is very important in the case of pumps placed in isolated portions of the mine to throw water to the main sump, as these pumps are frequently left to take care of themselves for a whole day at a time.

7. Centrifugal Pumps.—Centrifugal pumps may be driven by electricity, but they are only suitable for short lifts, the maximum efficiency being attained for a lift of approximately 17 feet. Another disadvantage of the centrifugal pump lies in the fact that it is only efficient when driven at the speed for which it is designed to work and when operating against the head for which it is designed, and any change of speed or head reduces the efficiency very rapidly. One advantage of the centrifugal pump is that it can safely pass gritty water or even small stones without damage.

8. General Construction and Form of Packing Employed.—Electricity may be used to operate either piston or plunger pumps, but for mine work piston-pumps are not efficient and are rarely used except in isolated cases for dipping from stopes which are below the general drainage level of the mine, the objection to the piston-pumps being the rapid wear and consequent leakage from one side of the piston to the other. Ordinarily, electric pumps are of the plunger type having outside packing, and may be arranged as duplex or triplex pumps, i. e., two or three cylinders placed side by side and so arranged that their cranks stand at angles of 90° for the duplex and 120° for the triplex. One advantage claimed for the steam and compressed-air pumps is that with their use the reciprocating motion can be obtained without the intervention of gearing, which is necessary in all electric pumps; but the loss due to this cause is much less than the loss in the steam or air cylinder due to the large amount of clearance in all pumps using these mediums which are not provided with fly-wheels.

9. Gearing.—The rotative motion of the motor is transformed into a reciprocating motion of the pump by means of a series of gears, this being necessary on account of the fact that efficient motors can not be manufactured which can be run at a sufficiently slow speed so that they may be attached to the crank-shaft of the pump. The reciprocating motion may be obtained by either single or double reduction gearing. In the former case, a pinion is attached to the armature of the motor, which engages a large gear on the crank-shaft. The latter case is illustrated by Fig. 1, and in this case a pinion on the armature shaft drives the large gear *c* upon the shaft *a*. The gear *b* is also placed on the shaft *a* and drives the large gear *d* upon the crank-shaft. In the double-reduction gearing, a high-speed motor is employed, and an efficiency of from 65% to 70% of the power delivered to the electric motor is obtained in the horsepower output of the water. With the single-reduction gearing, an efficiency of from 70% to 75% can be obtained for lifts of over 300 feet, below which height the efficiency drops very rapidly, becoming 60% or less for 100 feet. Of course the water is thrown from the mine to the surface at a less expense per gallon from the shallow opening than from the deep opening, but, as has been stated, the total efficiency expressed in foot-pounds is less. The discovery of this fact has led more and more to the doing away with the station pumps in the shafts and

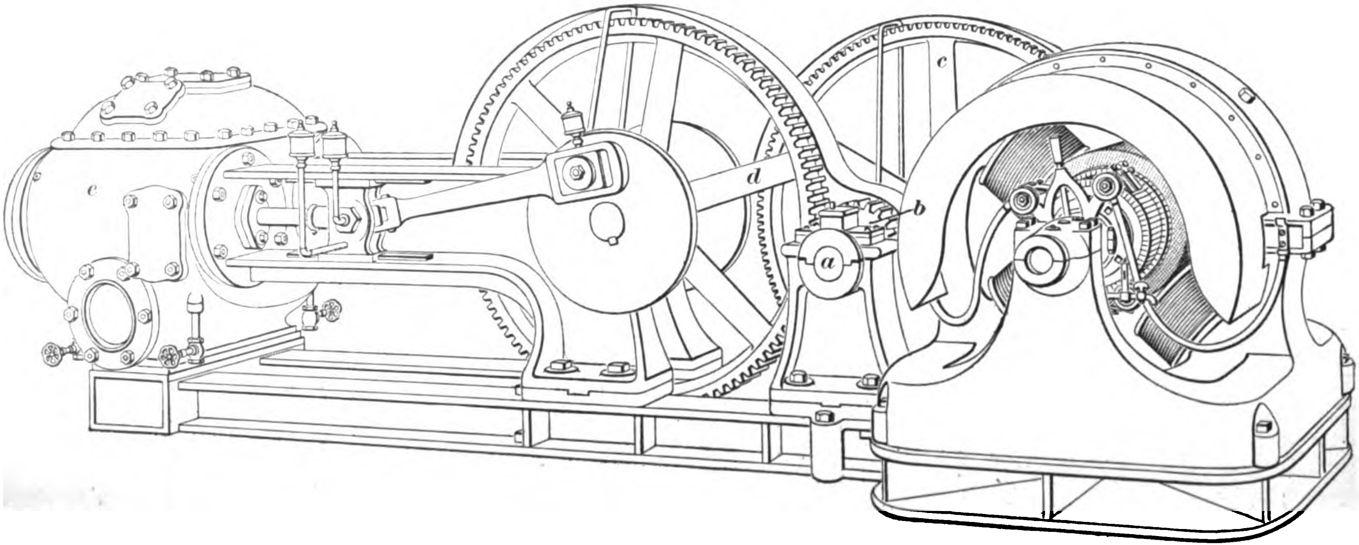


FIG. 1.

has been influential in increasing the practice of throwing the water to the surface at one lift, even when this is as great as 1,300 or 1,400 feet.

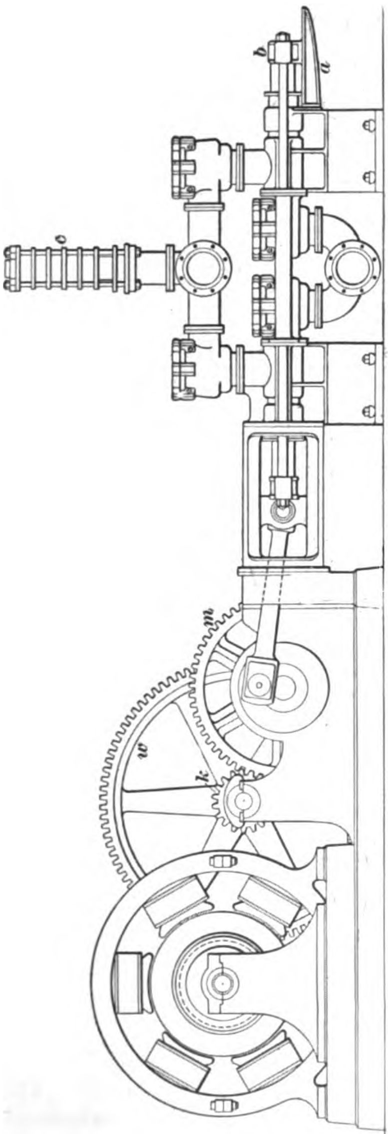


FIG. 2.

10. The pump shown in Fig. 1 is a Knowles double-reduction pump driven by a 4-pole direct-current motor, which is mounted upon an extension of the pump bed-plate, as shown at the right of the drawing. At the left of the drawing, cylinders *e* are shown. There are two of these cylinders, arranged with their cranks at 90°, both taking water from a common suction and discharging into a common discharge. This pump is fitted with inside-packed pistons, and hence not suited for gritty waters, though it may be somewhat cheaper than the plunger type.

11. Triplex Outside-Packed Pump.—Fig. 2 illustrates a mine pump manufactured by the Janesville Iron Works Company, having a large 6-pole motor mounted upon a bed-plate, as shown to the left of the illustration. This motor

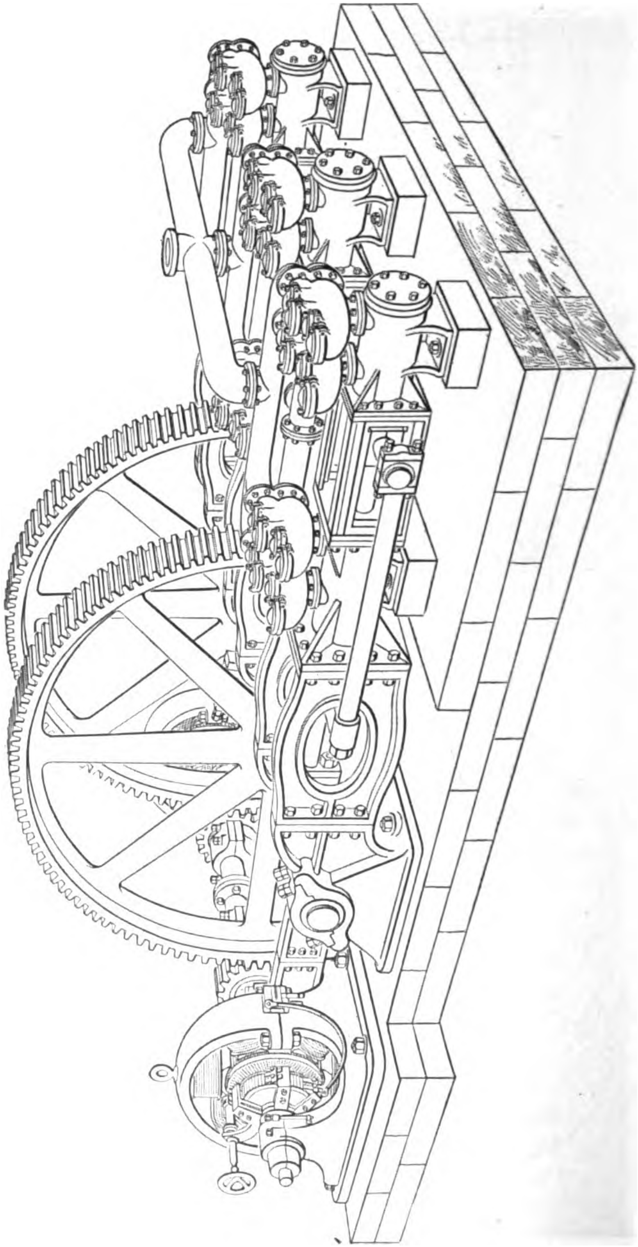


FIG. 8.

has a pinion upon its armature shaft which engages the large gear-wheel *w* upon the same shaft with the pinion *k*. The pinion *k* drives the gear *m* upon the crank-shaft of the pump. There are three cranks, placed at an angle of 120°, and the pump has six single-acting, outside-packed plungers, three at each end. The cross-heads for working the back plungers operate upon tail supports *a*, as shown at *b*. These cross-heads *b* are driven by means of parallel rods, which pass from the main cross-heads to the rear cross-heads on each side of the pump frame. This pump is intended for lifting 1,200 gallons per minute to a height of 1,100 feet. No air-cylinder is employed, on account of the fact that the large number of diplacements causes a practically continuous flow; but to guard against accidents from the stoppage of the column pipe, spring relief-valves are placed as shown at *c*.

12. Center-Packed Pumps.—A slightly different form of triplex electric pump is illustrated by Fig. 3, which is a Worthington pump. The capacity of this pump is 1,000 gallons per minute against a head of 1,000 feet, requiring over 250 actual horsepower. The water end consists of six single-acting, outside-packed plungers arranged in pairs, so that the packing comes between the adjacent cylinder-heads in place of at the outside ends of the cylinder-heads. This makes the packing a little harder to inspect than when it is placed at the outer ends of the cylinders, but at the same time does away with the tail rods and tail-rod supports, thus simplifying the machine. Both plungers are driven from the ends of the parallel rods, and each plunger really acts as a tail rod to support the other, thus doing away with the necessity of any guides between the adjacent cylinder-heads. The motive power is furnished by two electric motors coupled directly to the countershaft and driving the pump through a double set of single-reduction gears. The cranks operating the cross-heads and plungers are set at an angle of 120°.

13. Triplex Pump Without Tail-Rod Supports.—A design of pump intended for comparatively small

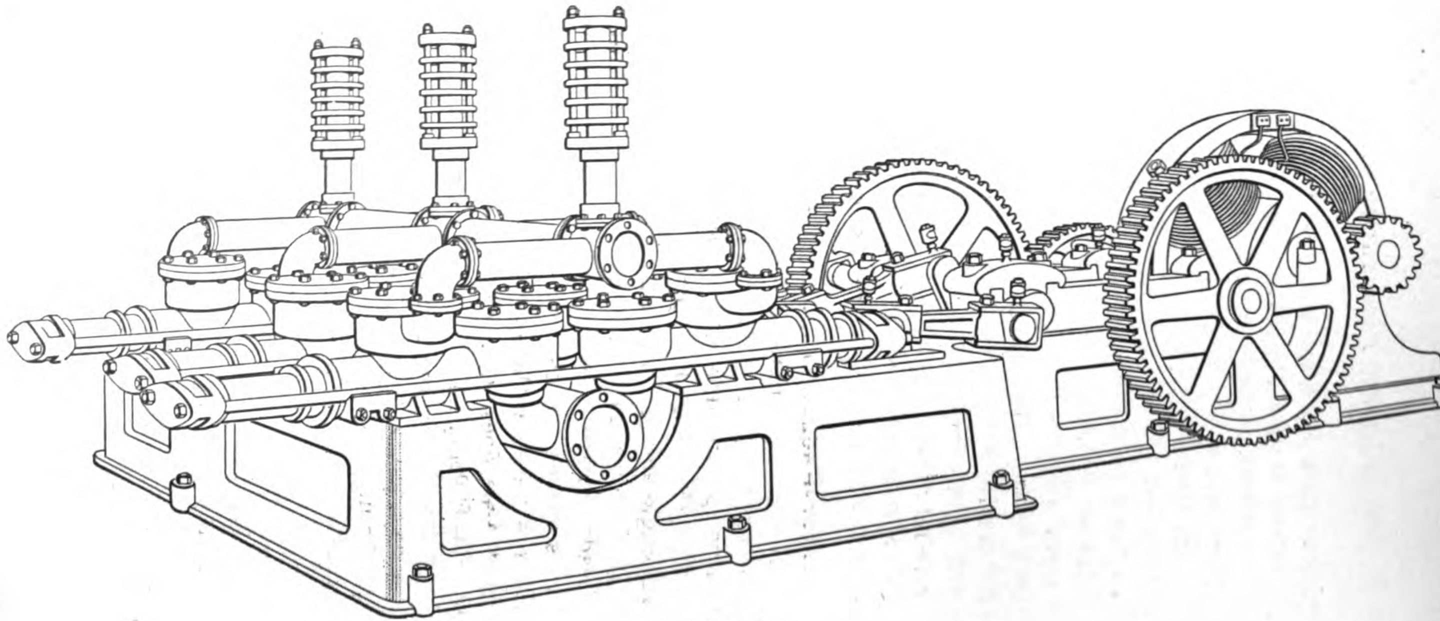


FIG. 4.

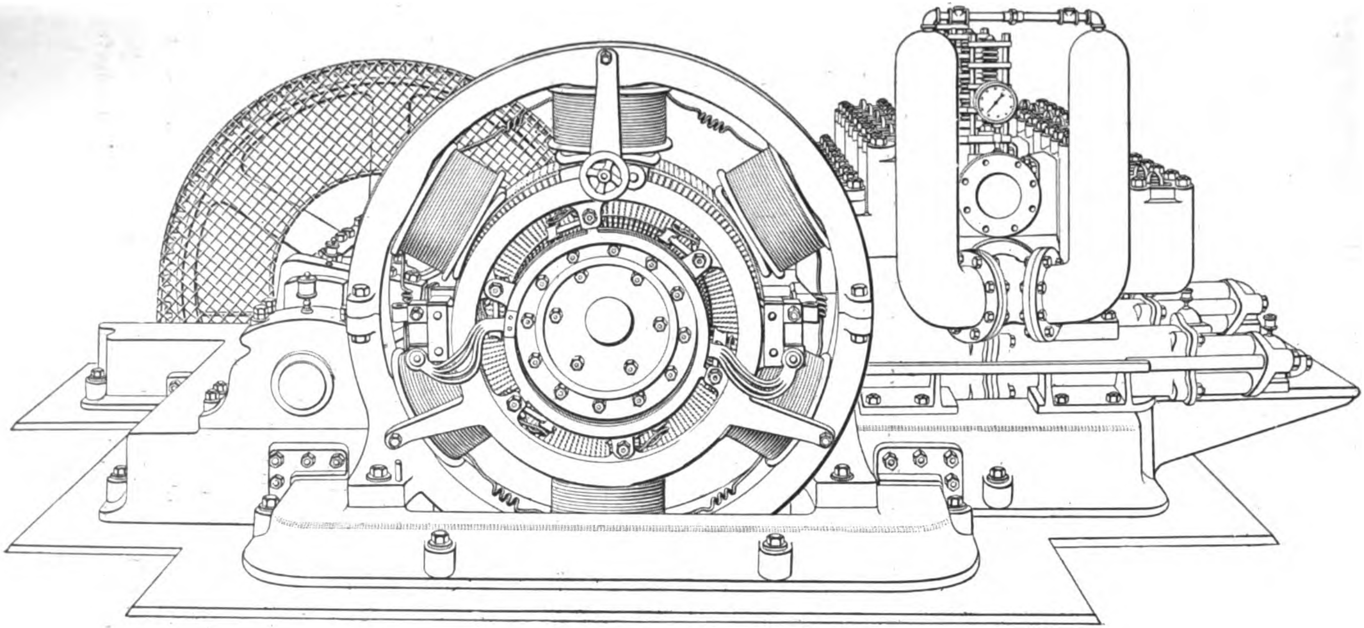


FIG. 5.

installations is shown in Fig. 4. Pumps of this style are built having a capacity ranging from 300 to 3,000 gallons against heads up to 600 feet. Spring relief-valves are employed, as in the form shown in Fig. 2. The gearing is also similar to the form illustrated in Fig. 2, but it will be noticed that the rams are not provided with any cross-heads or tail-rod supports at the left of the illustration, the packing bushings being made very long and depended upon as guides. The parallel rods for transmitting motion from the front to the back rams are shown very plainly, one of them being shown for its entire length along the sides of the pump-cylinder.

14. Single-Reduction Geared Pump.—Fig. 5 illustrates a Knowles double-acting, outside-packed plunger-pump which is driven by the General Electric Company slow-speed motor and a single-reduction gearing. The capacity of this pump is 500 gallons per minute against a head of 650 feet. It will be noticed that this pump is provided with spring relief-valves and with tail-rod supports for the plungers. The gearing is also enclosed in a casing, so as to protect the pump runner from injury. The manner of placing the motor makes the arrangement very compact.

15. Partially Enclosed Sinking-Pump. — Fig. 6 shows an electric sinking-pump provided with a 20-horse-power enclosed induction motor *m*. As this type of motor has no commutator or brushes, it can be encased to keep out water, and therefore the pump can be worked under water as well as above it. The armature shaft and the starting lever *l* pass through stuffing-boxes. This pump is of the duplex, double-acting type, and the power is transferred from the motor to the pump by means of double-reduction spur-gears, the arrangement of which can easily be understood by referring to the figure. The pump is suspended in the shaft by a cable attached to the eye-bolts *a*, and fixed in place by the supporting shoulders *b*. The suction-pipe *s* leads to the sump and the discharge-pipe *d* to the top of the shaft, or, in the case of deep shafts, to a force-pump placed at some point in the shaft. The three cables *c*, which are used to conduct the alternating current to the induction motor, are well insulated and also made waterproof. The air-chamber *h* makes the discharge more uniform and prevents shocks due to sudden changes in the velocity of the column of water in the discharge-pipe.

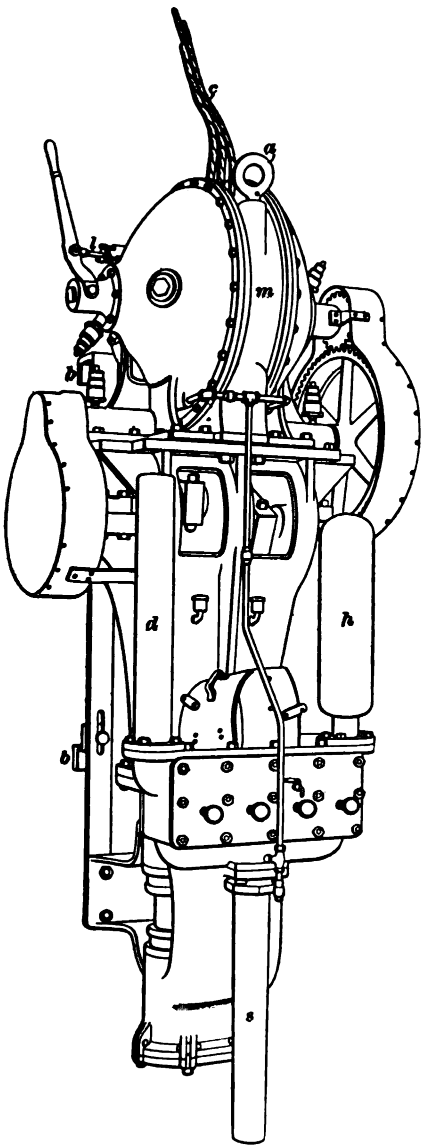


FIG. 6.

16. Enclosed Sinking-Pump.—Another electric mine sinking-pump is shown in Fig. 7. It is of the double-acting, outside-packed plunger type, and is protected against damage from water, moisture, and hard usage. The entire operating mechanism is enclosed in the case *c*, making it possible, with properly insulated cables, for the pump to work quite as well under water as above it. The motor, which is specially designed for the purpose, is further enclosed in a waterproof chamber, so that if anything should happen to the outside casing *c*, the pump would still be capable of working when submerged. The only moving parts that are visible are portions of the piston *p* and plunger *q*, yet all wearing parts are easily accessible for repair. The pump is raised or lowered by a cable attached to the eye-bolt *e*, and it is fixed in place by engaging the supports *s* with suitable timbers in the shaft. An air-chamber *a* is placed on the water chest *w*, into which the pump discharges and out of which the water is forced to the surface

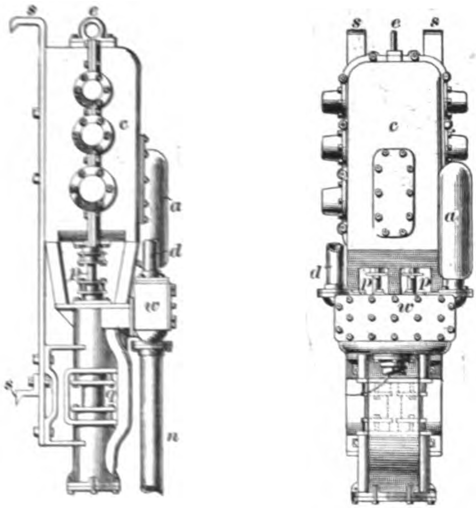


FIG. 7.

through the pipe *d*. The water is drawn from the sump at the bottom of the shaft through the suction-pipe *n*. One of these pumps with a 20-horsepower motor will discharge 250 gallons per minute at ordinary speed against a head of 100 feet. The plungers have a stroke of 8 inches and are 6½ inches in diameter, and the suction and discharge are 6 and 5 inches in diameter, respectively. The dimensions of the pump over all are 30" × 45" × 114", and its weight is 7,000 pounds.

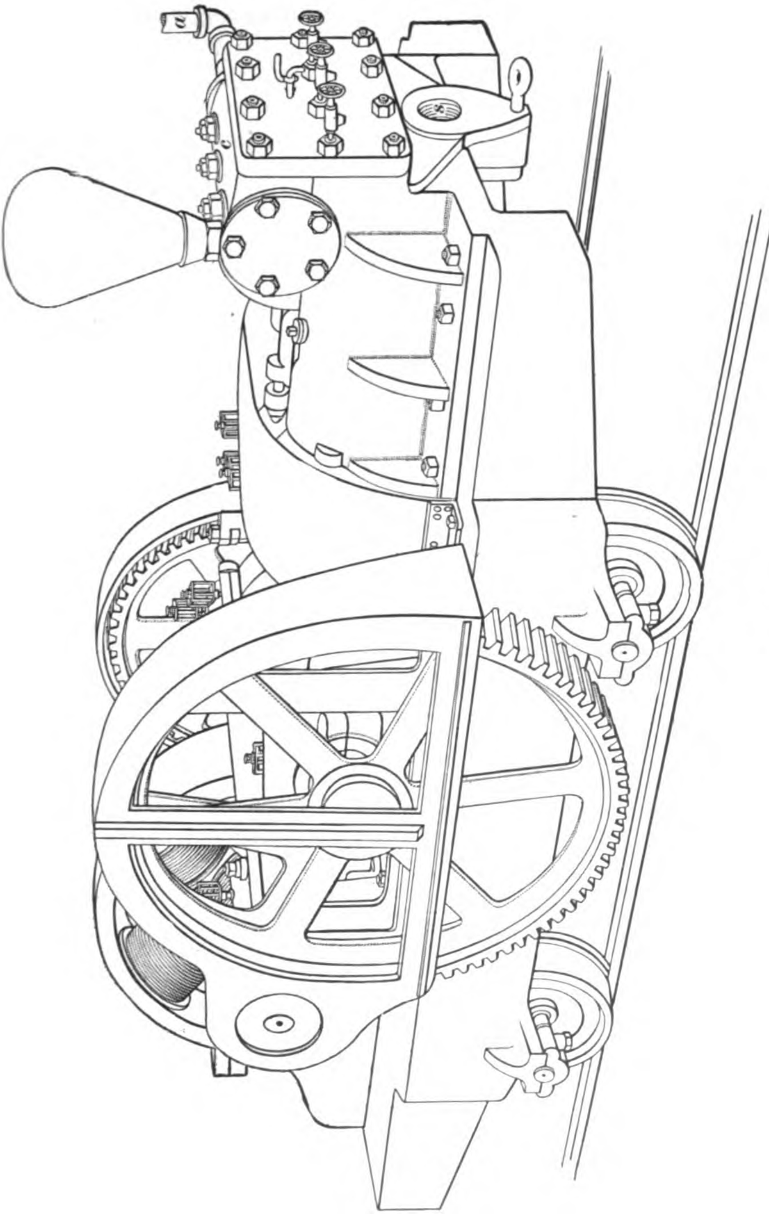


FIG. 8.

17. Portable Pump.—In some mines it is necessary to have auxiliary pumps to drain certain portions of the mine which are below the level of the main sump. For these local or auxiliary pumps, electric power is especially suitable. In driving wet dip headings, it is necessary to have some mechanical means of keeping the water away from the working-face. This is often accomplished by bailing the water into a water car and hauling it away, or by using hand-pumps. Both methods are expensive and often inefficient. With the use of electricity, however, such work can be done by the use of portable electric pumps, a horizontal triplex type of which is shown in Fig. 8. This pump is mounted on an iron truck, which can not be affected by moisture and which always maintains the accurate alinement of the pump and motor. The pump is made for a capacity of from 80 to 208 gallons per minute against a head of 300 feet. Such pumps require little attention, as they will not, if equipped with proper motors, run beyond a certain speed, even if working on air. Thus, if it is being used to drain the face of an entry passing a local dip, all the attention it will require will be an occasional oiling.

When in use, pumps of this type are generally switched off the main road into the neck of a room or break-through. The pipe leading to the sump at the working-face or to the body of water to be removed is connected to the pump at the opening *s* and the delivery-pipe to the opening at either side of the water chest *c*, as at ***a***.

18. Precautions.—It is not wise to touch bare conductors carrying current at a pressure of over 110 volts, though serious harm is not apt to result from less than 300 volts if you are provided with gloves made of rubber or stand upon some dry insulating material. This fact should be remembered by persons traveling along headings where the conductors may be touched by some part of the body. A person wearing dry rubber boots or standing on dry wood may touch a single conductor through which a current is passing, without injury, provided he does not make contact with the other side of the circuit with some exposed part of the body.

A dynamo or motor may become "charged" by injury to the wiring or by some loose coils touching the body of the machine. In such a case, it is exceedingly dangerous to touch any part of the machine, for it will discharge through the body into the earth. It is a wise precaution to connect the frames of pumps and other machines run by electricity to the earth, to prevent their inflicting possible injury to those handling them.

19. Selection of Pump.—In selecting the pump for any given duty, the first cost as well as the efficiency should be taken into account, as should also the location in which it is to be used. In some cases, especially in coal-mines, it is practically impossible to obtain headroom, and hence a low pump must be employed, while in some metal mines it is much easier to install a high machine than one that extends over considerable area. For this latter purpose, vertical duplex or triplex pumps driven by electric motors are frequently employed, especially where a comparatively small amount of water has to be handled. The simple fact that a pump is very efficient when it is one of a number driven by a carefully made generator of large capacity does not imply that it will be efficient for a small installation, and for this reason, if only one or two small pumps are required in the mine, it is generally much cheaper, both in first cost and in running expense, to install simply a boiler plant on the surface and use one or two steam-pumps underground, or to use compressed-air pumps and obtain air from the same system that drives the rock-drills. Then, too, the additional advantage of the improvement of the ventilation by the exhaust air from the pumps may have an important bearing upon the selection of compressed air as a motive power. As a general rule, it may be said that electric pumps should be used only where large installations are to be made, so that a number of small pumps or one or two large pumps may be supplied with power from a large generator driven by a very efficient engine or where the current can be derived from generators driven by water-wheels. Another case in which electric pumps can be used to advantage is where the current can be obtained from some power company at an advantageous rate. This case really comes under the former, on account of the fact that a power company is able to furnish the power at a low figure, because it sells a great deal of it to its different customers, and hence large generators of high efficiency may be employed.

ELECTRIC SIGNALING IN MINES.

SIGNALING WITH BELLS.

20. A system of signaling is necessary in all mines having a shaft or slope or in which mechanical haulage is employed. The most primitive method used to any large extent is that of an iron or steel plate, which is struck by a hammer operated by a wire supported at intervals along the haulage road or in the shaft. The wire is pulled by a lever situated at either end of the haul or lift. This mechanical method, although in use in many mines today, is rapidly being replaced by electric systems of signaling, which are instantaneous and which best meet the various requirements of modern haulage and hoisting.

Electric signals are made by bells, lights, telephones, or a combination of these. The power for operating these signals is generally an electric battery consisting of a number of primary cells.

21. The different methods of placing the bells on the circuit are shown in Fig. 9. In Fig. 9 (*x*) three bells *a*, *b*, *c* are shown in series in the circuit. With this arrangement, it is impossible to get the makes and breaks at the different bells to properly synchronize, and the result is that the bells ring with a weak sound if all the bells are allowed to make and break the circuit. One method of overcoming this difficulty is to cut out the make-and-break contact on all the bells but one, so that this one bell will be the only one interrupting the current in the circuit. The other bells will then be compelled to work in unison with the one doing the making and breaking of the circuit. Another method of overcoming this objection somewhat is by bridging the bells, so that a certain portion of the current will pass through them irrespective of the position of the hammers. This is shown in Fig. 9 (*y*), where the bells are put in parallel, and in order that each may ring with the same degree of sound,

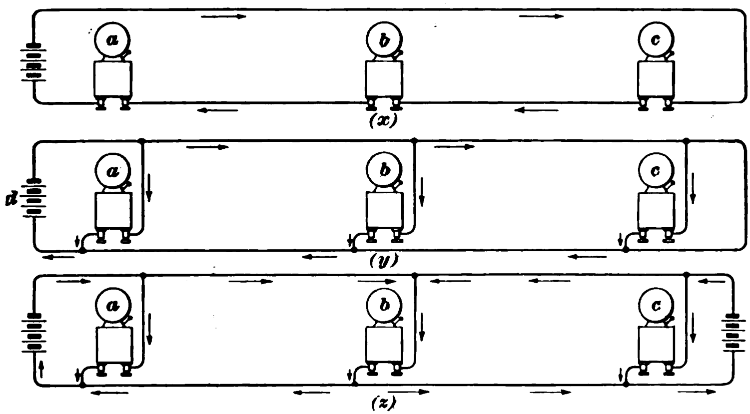


FIG. 9.

it is necessary that resistances should be put in series with each bell, except the one farthest away from the battery *d*. The resistances should be so arranged and proportioned as to cause the same current to flow through each bell. In the arrangement shown in Fig. 9 (*z*) there are two batteries forming two circuits that have a common path through the bell *b*. As a portion of the current from each battery passes through the bell *b*, which is the farthest away from the source of the power, it is seldom necessary to introduce resistance at the bells *a* and *c*.

22. It is well to have the bells placed in parallel for signaling in mines, as in this way the bells are not only independent of each other, but can be supplied with more current from a given battery, and therefore are more reliable and work more satisfactorily than bells coupled up in series.

23. The method of obtaining the reciprocating motion of the bell hammer is shown in Fig. 10. A soft iron core is placed within a solenoid or coil of insulated wire, forming an electromagnet *s*, and an armature or piece of soft iron *a* is

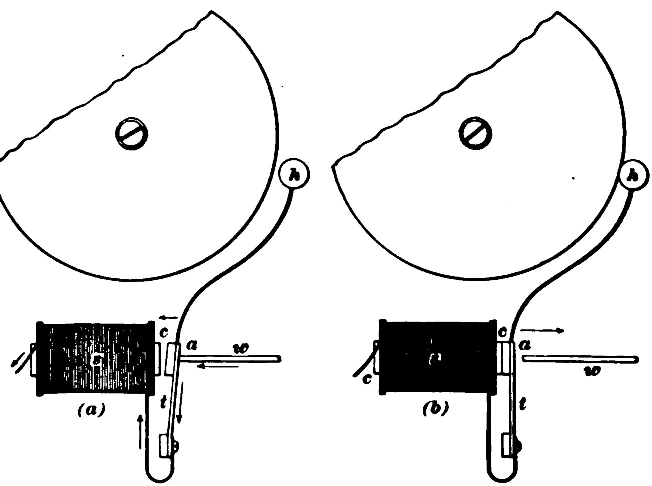


FIG. 10.

held between the end of the contact point *w* and the core *c* by means of a strip of steel, which acts as a spring. In (*a*) the current flows through the wire *w*, the spring *t*, thence into the solenoid *s*, and back to the battery. The core *c* becomes magnetized and attracts the armature to it. In doing so, however, the electric circuit is broken (*b*) and the core *c* loses its magnetism, allowing the spring to carry the armature *a* back till it rests against *w*, when magnetization recurs, and so on indefinitely, the hammer *h* striking the bell each time, and it is therefore caused to move in the same manner and strike the bell with a rapid succession of blows.

24. Fig. 11 shows an electric bell which has two electromagnets *m* for the purpose of giving the core the approximate shape of a horseshoe magnet, whereby greater strength is obtained. The wire handle of the hammer *h* is attached to the upper end of the armature *a*. The adjustable contact screw *s* is tipped with platinum in order to prevent oxidation and burning from sparks during the makes and breaks of the circuit. The battery terminals are connected to the bell by the contact screws *t*, and the mechanism is placed in a box to keep out the dust and dirt. The bell *b* and the hammer *h* which strikes it are, of course, not enclosed, and for this reason it is impossible to keep out dust entirely, consequently the box should be removed occasionally and the mechanism thoroughly cleaned. The bells shown in Figs. 10 and 11 are of the vibrating or continuous-ringing type; i. e., so long as the bell is connected to the battery by depressing the push-button it will continue to ring. For some purposes, it is desirable to use **single-stroke** bells, which will give only one ring when the push is depressed. All that is necessary to convert a vibrating bell into a single-stroke bell is to connect the terminals of the magnet coil directly to the binding-posts of the bell, so that the current does not have to pass through the armature and contact points. When this is done, the magnet holds the armature so long as the push remains depressed, and each time the push is pressed the bell gives one stroke, thus making it specially applicable for signaling purposes.

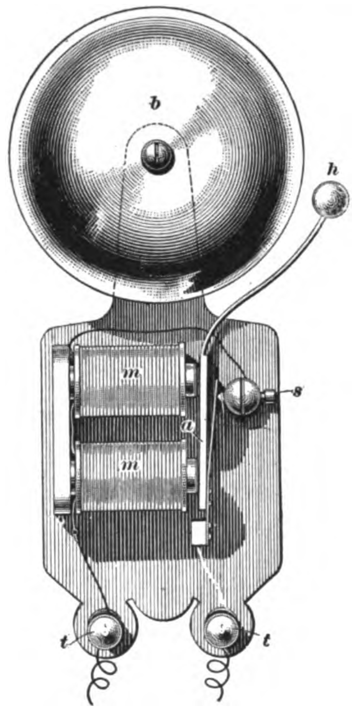


FIG. 11.

25. It is necessary to have circuit-closers, or **push-buttons,** as they are called, at different points in an electric-signal system. One form of push-button is illustrated in Fig. 12. The ends of the line-wire are brought up through a hole in the wooden base *a* and held under the screws on the brass contact springs *b*, *c*. The cap *d* when screwed in place holds the button *e*, which on being pressed down forces the two springs together and completes the circuit, causing the bell to ring. This type of push-button is operated by a single finger, and is not frequently employed for inside

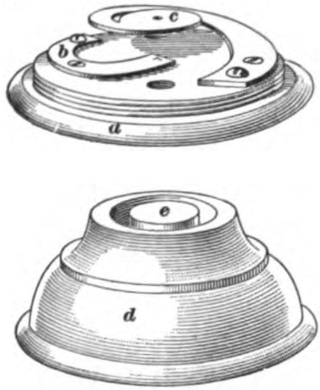


FIG. 12.

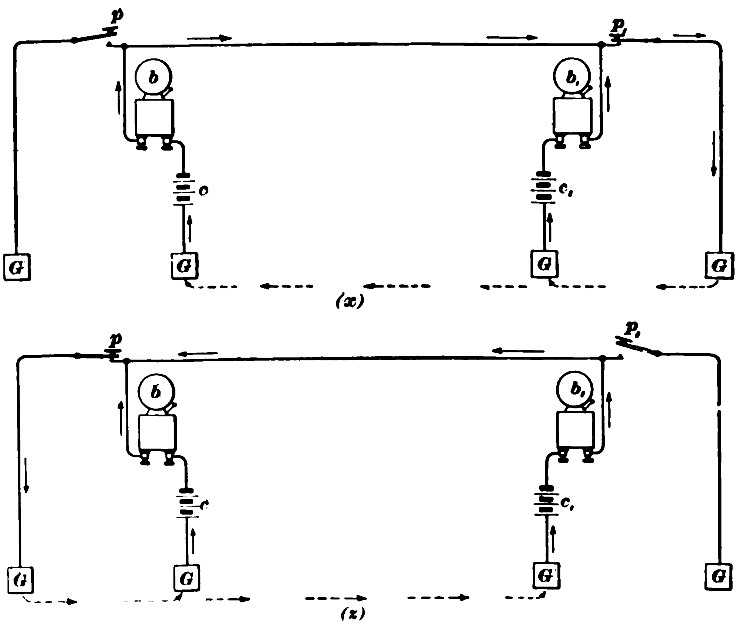


FIG. 13.

mine work. For this latter purpose, a larger type, which can be operated by the palm of the hand, is used.

26. Signal With Ground-Connection.—The construction of a circuit showing the relative positions of the batteries *c*, c_1, bells *b*, b_1, and push-buttons *p*, p_1 is shown in Fig. 13. The object of this arrangement is to allow the current from either battery to pass to the earth and have a complete circuit when either of the push-buttons is pressed down, while but one line-wire is used. The top view (*x*) shows the behavior of the current when the button p_1 is pressed down, and the bottom view (*z*) when the circuit is completed at the button *p*. The batteries should be connected with like poles to ground.

27. Signal Without Ground-Connection.—Where earth connections are poor, a return wire is used, as shown

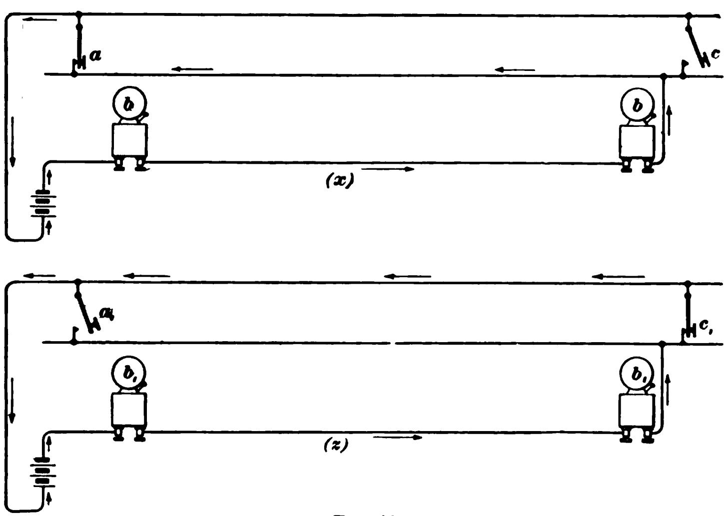


FIG. 14.

in Fig. 14. The bells *b*, *b* are in series, and in order to prevent both push-buttons from being on the same circuit, a third wire is necessary. In the top view (*x*) the button *a* is closed, leaving the top wire neutral, while in the bottom view (*z*) the button *c* is closed, leaving the center wire neutral. The object of having both bells ring when a signal is sent from either end is to assure the sender that everything is all right when he presses the button and the bell next him rings. On the other hand, if the bell does not ring he knows the signal has not been sent and that something is wrong.

28. Signals for Haulage Roads.—On haulage roads it is necessary to provide a system of signaling by which the trip rider can have the trip of cars stopped or started at any point. Such a system is shown in Fig. 15. Here two batteries c, c_1 and four ground-connections G are used. With the exception of the top wire, this system is the same as that shown in Fig. 13, and signals from either end of the line are given in exactly the same manner. The two wires which run along the roadside are only 6 or 8 inches apart and parallel to each other. The trip rider carries a short piece of

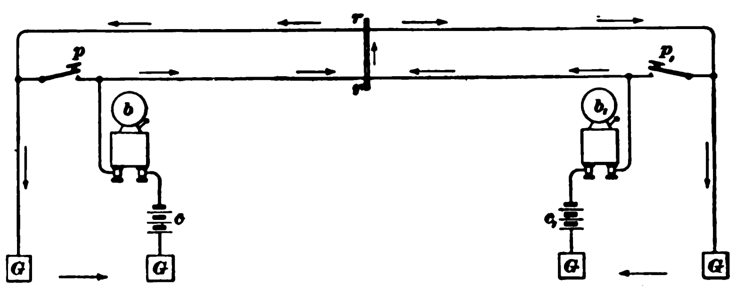


FIG. 15.

iron, which he places across the wires at any point where he desires to signal the engineer to either stop or start the trip. The iron r r is shown in contact with the wires, and from the flow of the currents, which is indicated by the arrows, it can be seen that both bells b, b_1 will ring. With this arrangement, it is not only possible to signal to stop or start the trip from any point, but also to signal to either end of the road for assistance in case of accident. It often happens that the trip rider while on a car that has been derailed must signal to the engineer to stop the trip. This he quickly does by reaching out and striking the wires with the iron which he holds in his hand. Thus it is seen how necessary it is to have the wires within the reach of the trip rider while on the moving trip. Two rings are generally used to start, and three to back up. Any other numbers may be used for other signals which may be found necessary for the safe and rapid operation of the haulage system in use.

29. The arrangement shown in Fig. 16 is the same as that shown in Fig. 15, except that the top wires are placed

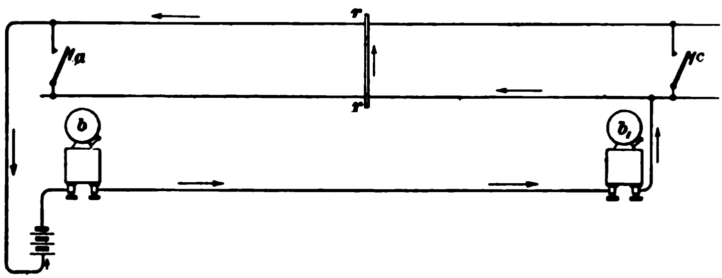


FIG. 16.

near and parallel to each other, so that contact can be made between them with the ringer or iron bar *r r*. This arrangement fulfils the same requirements as that shown in Fig. 15, but the bells are in series instead of being on independent circuits, and only one battery is used.

30. Where signals must be received from different parts of the mine, as, for instance, at the junction of several haulage roads where the engine is placed, the method of having a code for each road requires a great many rings, and is likely to confuse the engineer and cause accidents. Again, it is quite as unsatisfactory to have the same code for all

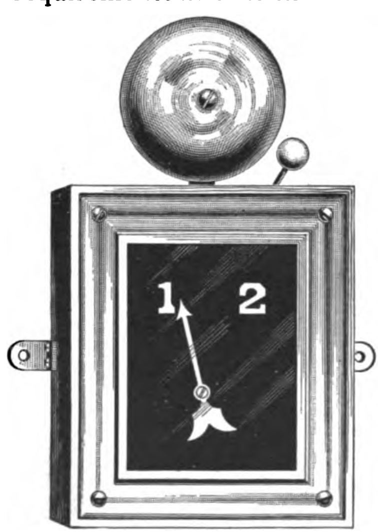
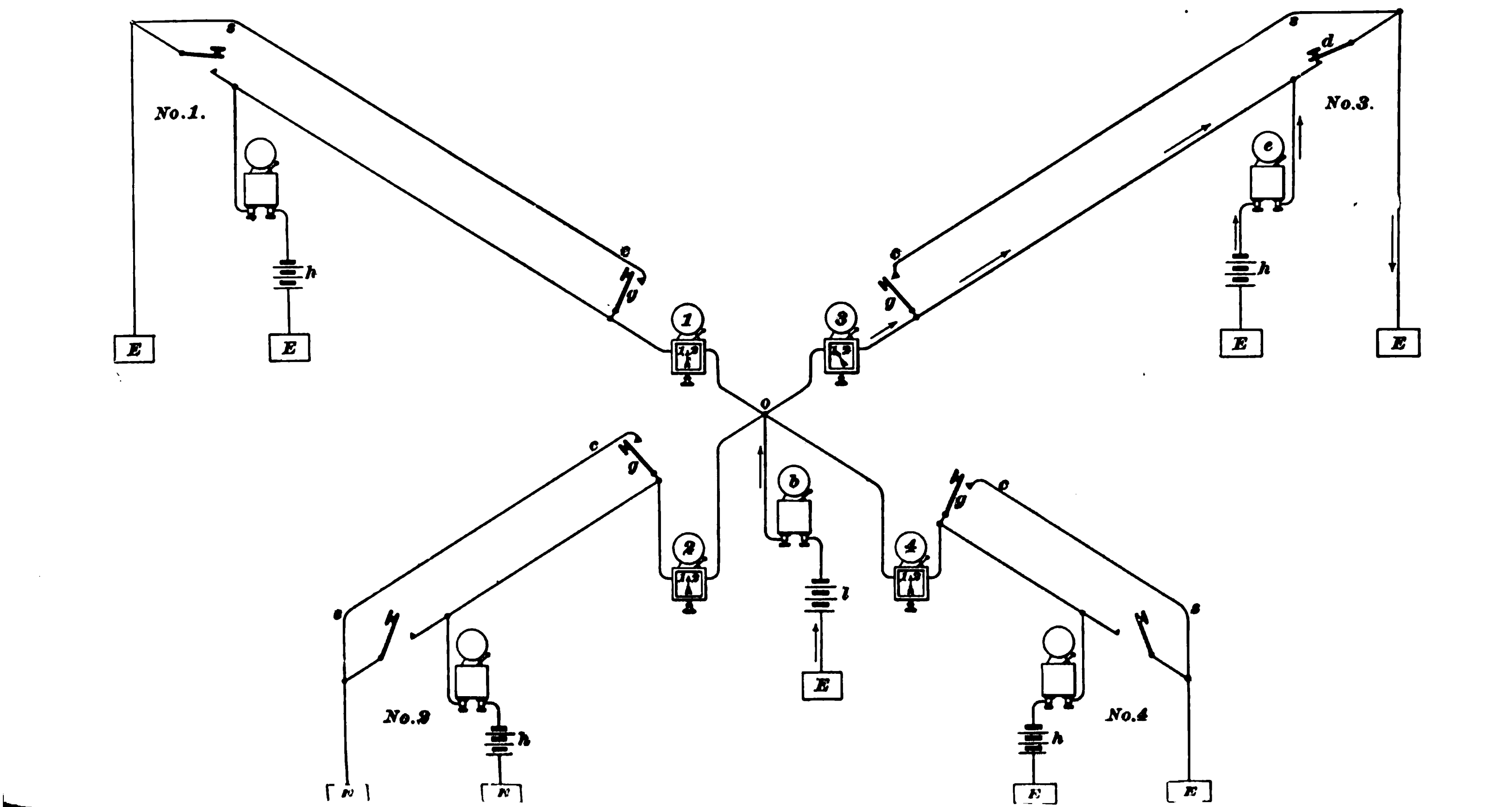


FIG. 17.

the roads and bells that have different sounds, because it is difficult to construct bells whose sounds are so distinctively


No.1.
No.3.
No.2
No.4
E
E
E
E
E
h
h
h
h
c
c
c
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g
g
g
s
s
s
s
d
e
b
l
o
1
2
3
4

different that no confusion or mistake will happen. These difficulties are largely overcome by the use of a signal code and an annunciator, Fig. 17. This annunciator is provided with a bell, the particular one shown indicating two places only. Where a signal has been given, the engineer can see immediately from which haulage road it has been sent by the pointer on the annunciator.

31. Fig. 18 shows in principle the arrangement of a system of signaling at the junction of four haulage roads. It is designed to avoid confusion on the part of the engineer, and thereby prevent accident or delay. The positive wires from the batteries *h* and the annunciator battery *l* all unite at *o*, and each is connected to the operating mechanism of a pointer on the annunciator. By the use of batteries at the end of the haulage road, a bell can be rung when the push-button is closed. This insures the sender that the signal has been given to the engineer. The wire *c s* makes it possible for a signal to be given by the trip rider at any point on the haulage road.

The figure shows the condition which exists when the push-button *d* at the end of *No. 3* entry is closed. From the direction of the current, which is shown by the arrows, it will be seen that the bells *c* and *b* will both ring, and that the pointer *3* will be deflected, showing the engineer from which road the signal has been sent. The instant the current ceases the pointer assumes its vertical position. It is, however, often advisable to have the pointer remain in its deflected position, for the engineer may be engaged in oiling or repairing his engine and be unable to see the annunciator at the moment the bell rings. In this case, it is necessary to have a convenient mechanical or electric method of allowing the pointers to assume their position whenever the engineer has seen the annunciator and operated the releasing apparatus.

In case a double call is received from different entries at the same time, the pointer will indicate it, and in order that the engineer will be sure of the proper number of rings from

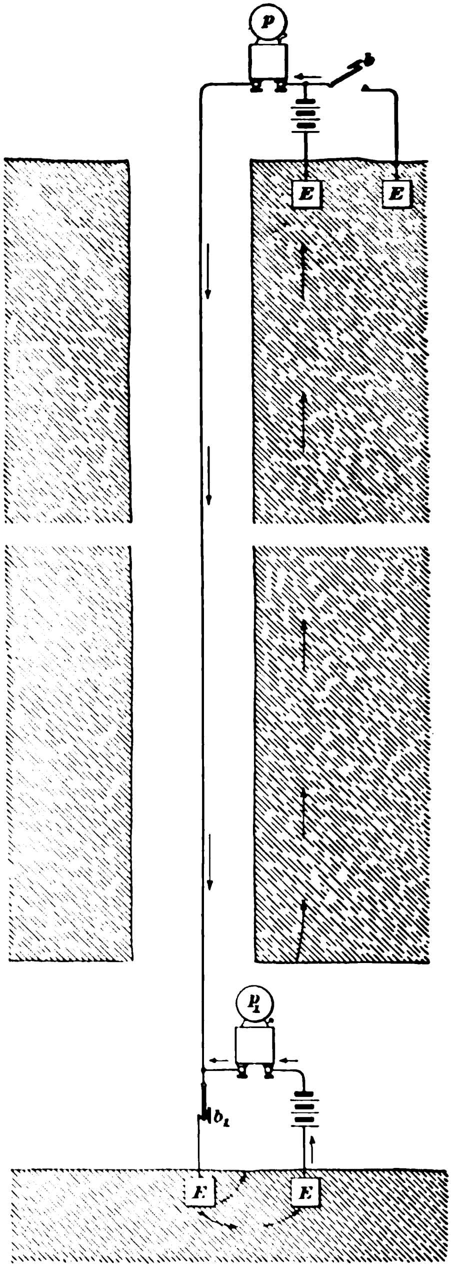


FIG. 19.

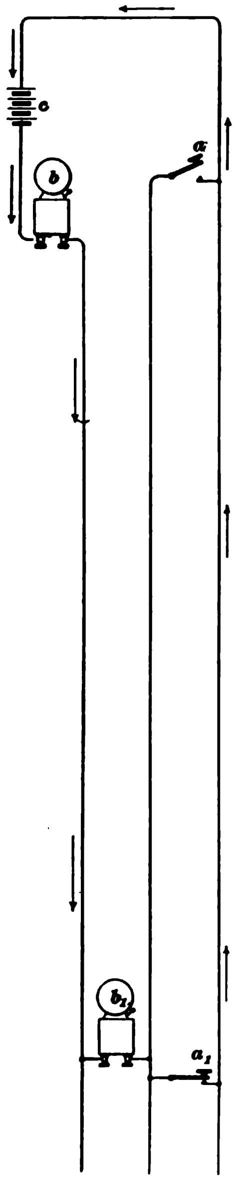


FIG. 20.

any one station, he must wait until he gets a complete signal in which but one pointer has been deflected. It is often necessary for the engineer to signal to the inside stations. This is accomplished by means of the push-buttons *g* which are placed on the different lines. It may be convenient to have the grades of the respective haulage roads roughly represented by broken lines on the annunciator. When this is done, each line is placed to one side of the corresponding pointer, so that the instant a signal is given the engineer can see the grades over which the trip must be hauled, and therefore be more likely to handle the engine in the best manner.

32. Signals in Shafts.—The method of signaling in shafts is quite similar to that used on haulage roads. Fig. 19 shows in principle the arrangement of a signaling system in a shaft. The positive wire passing down the shaft is well insulated and run through a small pipe for protection. The push-button b_1 is closed, and from the flow of the current it will be seen that both bells will ring. The operation of this arrangement can readily be understood from what has previously been said.

33. In order that the cage may be stopped at any point in the shaft where repairing of any kind is required, it is necessary to have a system of signaling from the cage to the engine room. There are a number of ways of accomplishing this, but the usual method is that in which trolleys are used. Two wires pass from the battery down the shaft, and they are supported at intervals with ordinary hangers. A trolley runs on each, in a manner like that of a street-car or an electric locomotive trolley. In this way current can be carried to the bell or telephone on the cage and signals given to the engineer by a man in the moving cage.

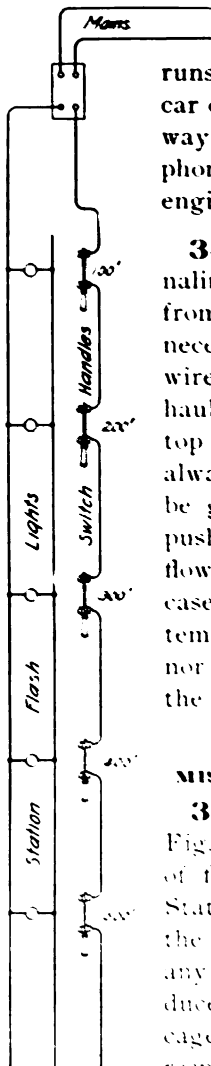


FIG. 21.

34. Fig. 20 shows another method of signaling in a shaft or slope. When signaling from intermediate points by this method, it is necessary to connect the middle wire and the wire a, a_1 by a ringer, precisely as is done in haulage systems. The bells b, b_1, placed at the top and bottom of the shaft, are in series and always ring, no matter where the signal may be given. But one battery c is used. The push-button a_1 is closed and the current is flowing in the outside wires, leaving, in this case, the center wire neutral. With this system, a telephone can not be used on the cage, nor is it an easy matter to send a signal from the cage when it is moving rapidly.

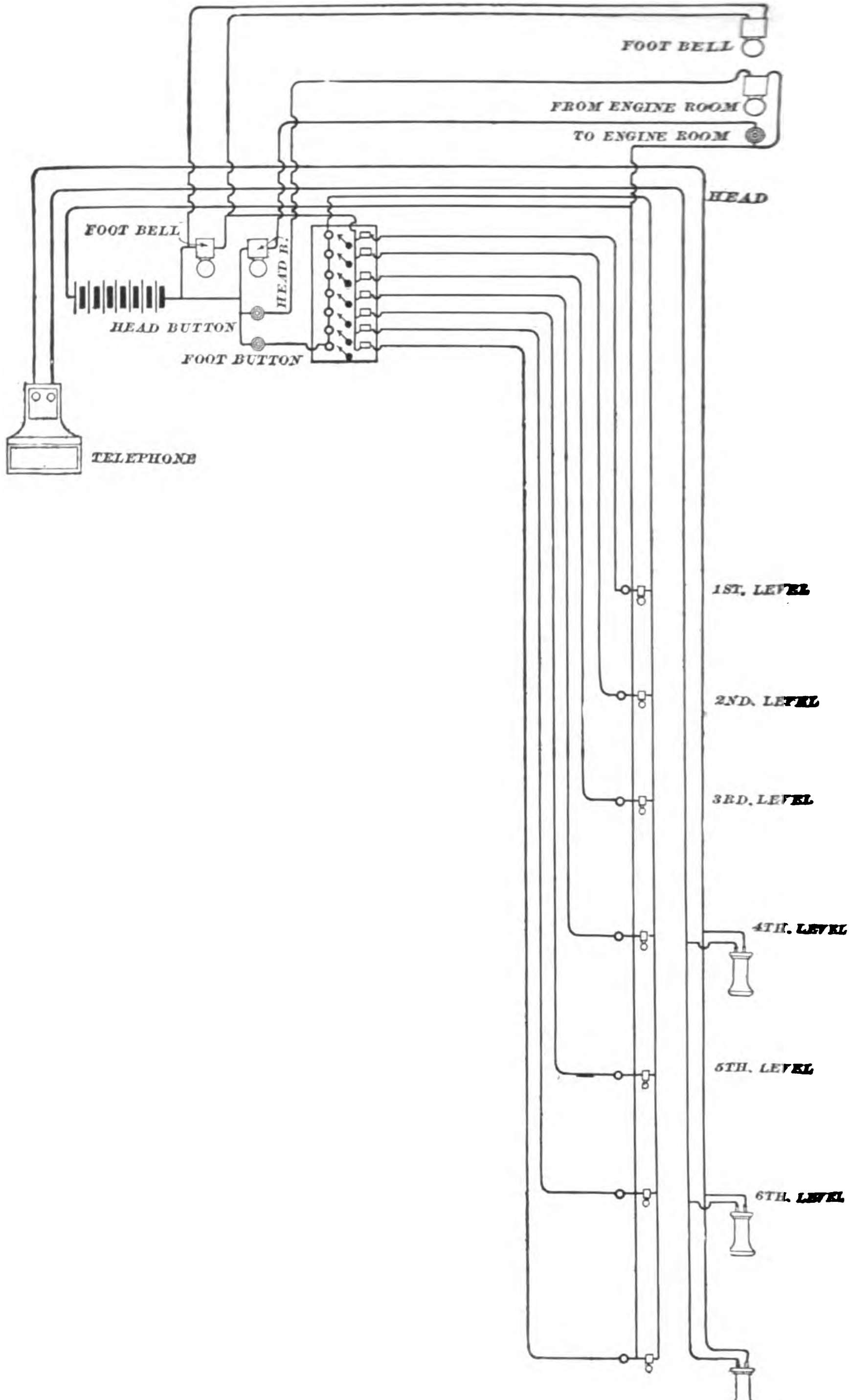
MISCELLANEOUS METHODS OF SIGNALING.

35. Signaling by Flash-Lights.—Fig. 21 shows a method of signaling by means of flash-lights, which is used in the Western States. It consists of a switch "cut in" to the main circuit at the different levels. When any switch is thrown out and in, a flash is produced in all the lamps on the circuit. If the cage is required at any level, the signal corresponding to that level can be given to the station tender, no matter what level he may be at, and he in turn will give the signal to the engineer.

This system is very simple and reliable. It has replaced largely the old-fashioned bell-rope and the electric bells and batteries,which give considerable trouble in deep, wet shafts. If lights are inserted in the circuit at different parts of the mine, the signals will be flashed throughout the mine, and in case it is necessary to signal to the various parts of the mine that an accident has occurred, it can easily and quickly be done from any switch. This is usually done by giving the accident signal, and then following it by the signal of the level on which the accident has occurred.

36. Signal System With Telephones.—A system of signaling in which the telephone supplements the bells and push-buttons is shown in Fig. 22. A high-grade bridging telephone is used, because loose contact in any telephone on the circuit does not affect the working of the others, and any defect in contact can be readily located and quickly fixed. The bells are of the skeleton-frame type with pivoted armatures. They are wound for different resistances, depending upon the work they have to do. When the circuits are well insulated, the ordinary open-circuit carbon-cylinder battery is used, because it is quite strong and easily and cheaply recharged. For circuits poorly insulated on account of water and grounds, the Gordon, Edison-Lalande, or similar type of battery is employed, because it does not polarize when the line is badly grounded and is less expensive to operate under such conditions than the ordinary open-circuit battery. On leaky circuits the Gordon batteries have worked for nearly two years without recharging, while the carbon batteries on the same circuits had to be recharged about every ten days.

37. The figure illustrates the arrangement of the signals at seven landings in a shaft. Each landing has a separate call to the engine room, which rings a bell at the same time at the head of the shaft. There is a separate call between the engineer and the head tender at the head of the shaft. A telephone is placed in the engine room and one at each landing in the shaft. The wires



FOOT BELL
FROM ENGINE ROOM
TO ENGINE ROOM
HEAD
FOOT BELL
HEAD B.
HEAD BUTTON
FOOT BUTTON
TELEPHONE
1ST. LEVEL
2ND. LEVEL
3RD. LEVEL
4TH. LEVEL
5TH. LEVEL
6TH. LEVEL

FIG. 22.

from the engine room to the shaft head and to the landings in the shaft are arranged in cables containing one No. 14 copper wire and as many No. 18 copper wires as are required. Each wire is insulated with paper and the wires properly stranded into a cable, which is well soaked in paraffin, wrapped with cotton, and then covered with lead $\frac{3}{32}$ inch thick, to make it waterproof. A layer of jute soaked in asphalt is laid over the lead, and the whole covered with a layer of No. 10 galvanized-iron wire armoring. That portion of the cable leading from the head of the shaft to the engineer's platform is carried through a 2-inch iron pipe. The end of the pipe at the head of the shaft terminates in a heavy oak box, and here the wires of the cable are separated and conducted to their proper places.

38. The telephones in the mine are each placed in a large wooden box and located in a dry spot, generally about 15 feet from the shaft. The box has a hinged door on front, with a small opening in it, opposite the telephone bells, and covered with a wire screen, so that the foot tender can hear the bell with the door closed. The return bell is fastened to the outside of the telephone box, which acts as a sounding-board, and the wires are brought out through the wood at the binding-posts of the bell. By this method the only wires exposed are at the terminals of the bells and buttons, and these are thoroughly taped. Heavy rubber-covered wire is used to make the connections between the cables and the bells and buttons and telephones.

To facilitate repairs, the wires in each junction-box are each designated by a thin copper tag giving the name of the wire. The No. 14 wire in each cable is the main-battery wire, and may be readily picked out by its size. This large wire lowers the resistance of each circuit, and it is the common-battery wire for all the call and reply circuits. The circuits are arranged as shown in the figure.

The main-battery wire runs to the bottom of shaft, and from it the button wires are tapped off at each landing, the current returning from the button by a separate wire to the annunciator in the engine room and onwards to the shaft bells, one being at the head of the shaft and the other at the annunciator.

The reply bells are connected by the main-battery wire in multiple to a common-return wire at the reply side of the annunciator.

Between the engineer and head tender there is a call-and-reply connection, as shown. The wires from the junction-box at the head of the shaft are arranged with the bells and buttons in the same way as for the other outlets.

39. The distinctive feature of this system is the annunciator, which indicates for 7 points that lie in a vertical line, and are named for the different veins they represent. Each point is located between two magnets, one wound for the call and the other for the reply from the engineer. The magnets in the reply circuit are connected in series, so that when the circuit is closed by the engineer, the current passes through all the magnets, throwing all the drops up to the "off" position and ringing all the reply bells on the line. The engineer can not throw up the drops except by ringing the reply bells, as the annunciator is completely enclosed.

All the bells are wound for 20 ohms resistance. The two bells in the engine room, besides being separated about 10 feet, are of entirely different sound, so that there is no possibility of any mistake about the rings. The bells at the head of the shaft are arranged in the same manner, one being the ordinary gong and the other a bell of the hand type.

The battery is located in a cupboard on the wall of the engine room, and the wires are carried from it to the rack in an iron pipe. It consists of 18 cells of a carbon-cylinder battery in series, and a space is left at the end of the box to receive the extra telephone wires that are used to connect the two shafts.

40. In the shaft, the foot tender has charge of all the inside bells, and no one is allowed to ring them without his consent. If he is working at a landing and any men wish to go up or down from another landing, they are required to call upon the telephone, and when the footman is ready he goes to that landing and sends the men to their destination, always staying in charge of the signals.

Should any one ring from one landing while the footman is working at another, the engineer can tell immediately by the annunciator that it was not the footman, and can see just where the ring has come from.

The telephone is used, however, as it is more satisfactory and safer, and does not cause any confusion in the signals.

The button wires for the engineer are run out through a small iron pipe from the rack to a convenient point for the engineer, and on the ends of these is fastened a plate on which are placed the two push-buttons for the engineer's use.

41. Haulage Block Signal.—A good system of signaling on a haulage road, common to two or more roads and used by several locomotives, is shown in Fig. 23. A switch

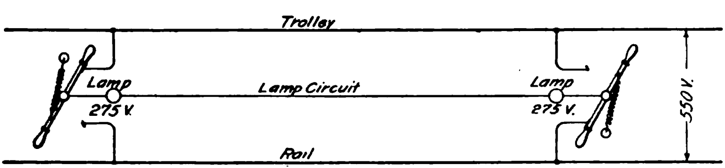
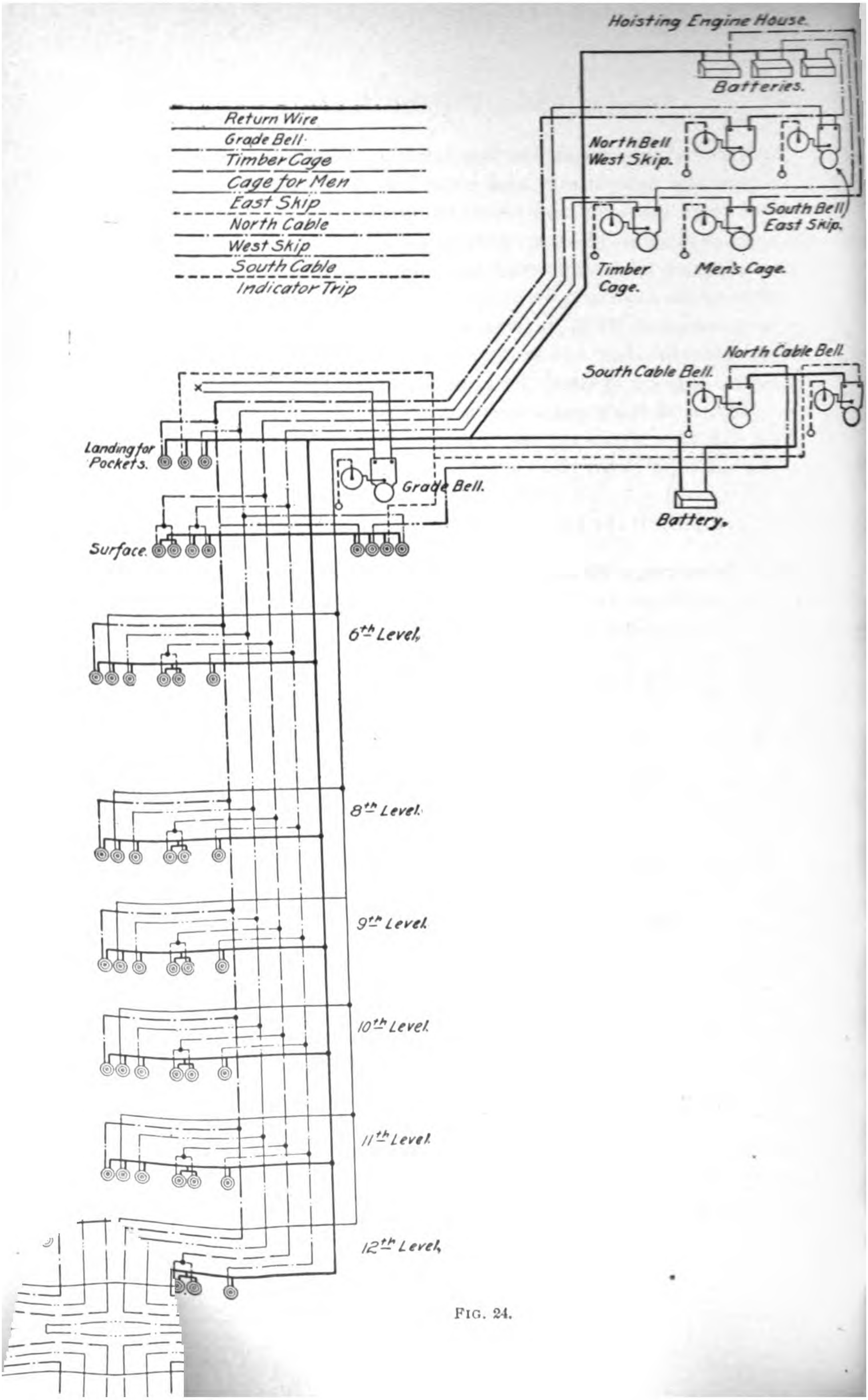


FIG. 23.

with a double-handle single-hinged lever is placed at either end of the road; one terminal of each switch is connected with the trolley-wire and the other with the rail, the center of the levers being connected by a wire, in which a lamp is inserted near each switch as shown. A spring is so attached to each lever that it will insure good contact for either position of the lever. Clear lights are used for clear tracks and darkness for occupied track. As one or the other of the ends of each lever is always in contact, a motorman approaching either end of the road can cut out the lamps by throwing the lever in the required direction to change the contact, and when he reaches the other end, he can change the contact again by throwing the lever of the other switch,



Hoisting Engine House.
Batteries.
Return Wire
Grade Bell
Timber Cage
Cage for Men
East Skip
North Cable
West Skip
South Cable
Indicator Trip
North Bell West Skip.
South Bell East Skip.
Timber Cage.
Men's Cage.
North Cable Bell.
South Cable Bell.
Landing for Pockets.
Grade Bell.
Battery.
Surface.
6th Level.
8th Level.
9th Level.
10th Level.
11th Level.
12th Level.

FIG. 24.

which cuts in the lamps again. The switches may be placed at any convenient place on the rib side or the roof, so that the motorman can operate the levers while the motor is going at full speed.

42. Special Shaft-Signal System.—As an example of wiring to cover the various requirements at a somewhat complicated shaft, Fig. 24 is given. The grade bell is intended for signaling the grade of ore to be hoisted, so as to facilitate the placing of it in its proper bin or pocket. The cable bells are intended for controlling the cables which operate the surface haulage plant at the shaft, while the other bells are employed in connection with the signals for the timber cage, the men's cage, and the ore skips. This system is in use at the West Vulcan mine in the Lake Superior region.

43. Six strands of wire are used in the shaft, as shown in Fig. 24. Five act as main wires and one as a return wire. The six wires are tied together every 5 feet, forming a cable. This is passed down through an iron pipe. The pipe is made tight by a tapered wooden plug, which is split and grooved to allow spaces for six wires. The plug is driven into the pipe and resin melted and run into the groove around the wires, sealing the wires in the pipe. To make sure that the wires will not draw through, a clamp is put on them above the plug. At each level the wires are brought out through a **T** in the pipe to connect with the buttons; then they are passed back through the **T** again and dropped to the next level below. After passing the wires back into the pipe, a plug similar to the one previously mentioned is inserted in the **T** and the wires sealed and clamped.

All connections are soldered, using the best blowpipe solder and powdered resin. After the connection is soldered, it is insulated with okonite tape and a heavy coat of Stockholm tar applied. Then a tight-fitting piece of rubber tubing about 4 inches long is slipped over the joint and bound at each end with a small copper wire. The connections made in this way have stood for the last four months and are in first-class condition. In the shaft house and the stations, for extra protection, a box-casing, painted inside and out, large enough for 12 wires, is used. As soon as the wires are put in, the cover, which fits snugly, is painted and driven into place, making the joints water-tight. This puts the wires out of harm's way and makes a neat appearance.

Fig. 24 shows the system of wiring, which includes seven main wires, on which are 47 buttons, and one return wire. The main wires each have an 8-inch single-stroke bell with indicator attached, and are operated by four batteries. Two of the main wires run only from the shaft house to the cable-engine house. The different wires are indicated as shown in the figure.

44. Owing to the fact that the shaft was very wet, special wooden casings had to be constructed for the protection of the push-button. In these cases, the button was so arranged that the plunger was pressed up against the button from below, as shown in Fig. 25. This rendered the casing self-draining and thoroughly protected it from moisture.

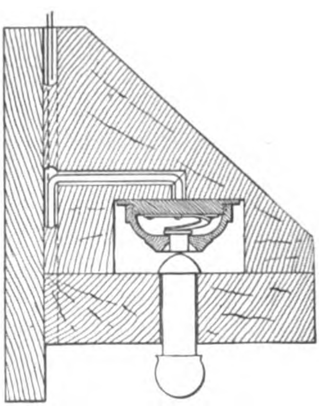


FIG. 25.

45. The heavy black line represents the return wire, which is connected to the negative pole of each battery and all the bells and buttons.

The main wire for the grade bell has a button on each level. By following the main wire from the positive pole of the battery in the cable-engine house to the grade bell in the shaft house, thence to one of the buttons in the mine, thence by the return wire to the negative pole, it will be seen that the grade bell will ring if any button on this line is pushed. The main wire for the timber-cage bell, which is in the hoisting-engine house, is shown as indicated. On the men's-cage wire there are two buttons at each station, one of which can be rung from the cage. The east-skip main wire and the west-skip main wire are also indicated. One battery is sufficient for these two lines, as the skips are run in balance and only one bell is rung at a time. The main wire for the south cable-engine bell is shown. One battery answers for the grade bell and both cable-engine bells, as they are never rung together. When the system was first put in, there were only two batteries, one in each engine house on the return wire. The result of putting the battery on the return wire is that if a button is pushed on two or more lines at a time, the electromotive force on each will be much less than when one line is in use, and the bells will not ring properly. If the batteries are distributed, the chance of all the lines giving out at once is practically eliminated.

The indicator was designed by Mr. E. Roberts, master mechanic of the Penn Iron Mining Company. The hand of the indicator is revolved by a ratchet connected by a rod to the armature of the bell. The case and hand are the same as used for steam-gauges, and the face is a clock dial. The hand stops when it reaches 11 and may be brought back to 0 by pulling a cord. It is adjusted to register if the armature makes a quarter of its stroke. The object of the indicator is to enable the men to see as well as hear the signal.

ELECTRIC LIGHTING IN MINES.

46. Where electricity is used in mining, it is generally found advantageous to use a portion of the current for lighting, both in the surface plant and the underground workings. The light is brighter than that given by the miner's oil lamp or candle, it has no exposed flame to set fire to mine gas, requires little or no attention, and can not be blown out by draft. Of course, it is not portable to the same extent as a candle or oil lamp, and is, therefore, not generally used at the working-face, but for landings, main gangways, turnouts, and where machines are located, it is very useful.

INCANDESCENT LAMPS.

47. The Incandescent Lamp.—Incandescent lamps give approximately the equivalent in light of one standard candle for every 3½ to 4 watts consumed. As there are 746 watts in a horsepower, this means over 200 candle-power per horsepower expended. The lamp most commonly employed is of 16 candle-power, but they are made in various sizes up to 100 candle-power. The light emitted by the incandescent lamp is due to the heating of a fine filament or thread of carbonized vegetable substance by the passage of the electric current. The filament is enclosed in a bulb from which the air has been exhausted to a high degree to prevent rapid oxidation.

48. Voltage of Lamps.—Incandescent lamps are nearly always operated in parallel, i. e., connected directly

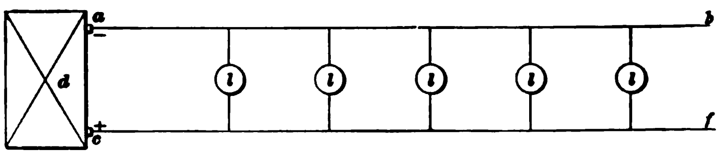


FIG. 26.

across the mains *b*, *f*, as shown in Fig. 26. The pressure maintained by the dynamo *d* is constant, no matter how many lights may be in operation, and as the lights *l* are turned on, the current delivered by the dynamo increases.

TABLE I.

Volts.	Candle-power.	Amperes.
52	16	1.0
52	32	2.0
52	100	6.0
110	16	.5
110	32	1.0
110	100	3.0

The pressure maintained between the lines is usually in the neighborhood of 100 volts. The usual voltage employed when lamps are operated on direct-current circuits is 110 volts. The current required for the operation of incandescent lamps of the sizes and voltages commonly met with is about as given in Table I.

The current required will vary according to the make of the lamp, as some lamps give more light per watt expended than others. About 3.5 watts per candle-power is a fair average, hence the current taken by a lamp may be obtained approximately from the formula

$$c = \frac{\text{c. p.} \times 3.5}{E}, \qquad \textbf{(1.)}$$

where E is the voltage at which the lamp is operated. The values given in the table are those generally employed in making calculations for lines supplying incandescent lamps.

ARC LAMPS.

49. Open-Arc Lamps.—Arc lamps are extensively used for outdoor lighting or in places where very large areas are to be illuminated—as, for example, around the entrance to shafts, etc. Fig. 27 shows the appearance of an ordinary arc. The carbon rods A, B are first touched together and then separated a short distance. A is connected to the positive pole of a dynamo and B to the negative, and when the carbons are separated, the current passes between them, forming the "arc." This causes the carbon-points to become heated to a very high temperature, and when direct current is used, the upper or positive carbon becomes much hotter than the lower. The lower carbon becomes pointed and the upper one has a small hollow, known as the *crater*, formed in its tip. This crater

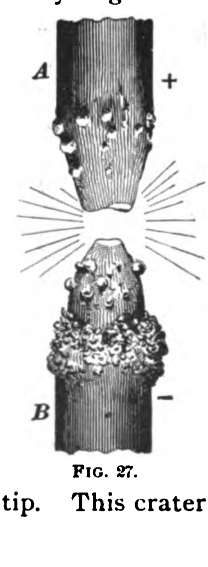


FIG. 27.

is the seat of the greater part of the light, and on this account the lamp throws the most intense illumination downwards at an angle of about 45°. When arc lamps are operated on alternating current, both carbons become pointed more nearly alike, and the light is thrown up more. On this account, alternating-current arc lamps should be provided with reflectors. Care should be taken in connecting up direct-current arc lamps to see that the upper carbon is connected to the positive side of the line, otherwise the lamp will burn "upside down," i. e., the crater will be formed in the lower carbon and the light thrown upwards. By allowing a lamp to burn for a short time, one can easily tell as to whether it is connected up correctly by noting the shape of the points. The lower carbon is nearly always fixed and the upper carbon fed down by means of a clutch or clockwork mechanism controlled by an electromagnet. These lamps are termed open-arc lamps, in order to distinguish them from the later style of enclosed-arc lamp, where the arc is enclosed in a small globe instead of being open to the air. An ordinary arc lamp of 1,200 nominal candle-power requires about 300 watts for its operation. A 2,000 nominal candle-power lamp requires about 450 watts, and the current is usually from 6.8 to 10 amperes. The ordinary 2,000 candle-power arc lamp requires a pressure of about 45 or 50 volts across its terminals in order to secure satisfactory operation.

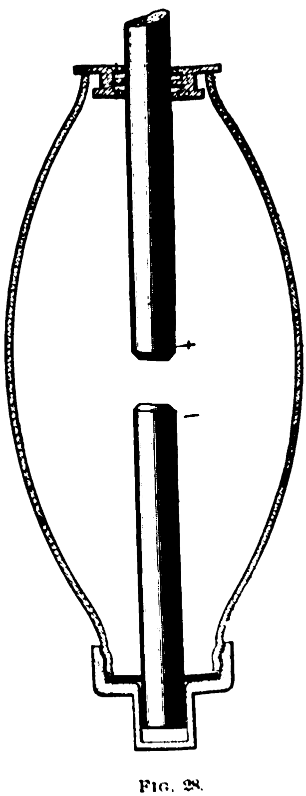


FIG. 28.

50. Enclosed-Arc Lamps.—In this style of lamp the arc is enclosed in a glass bulb, as shown in Fig. 28. The enclosed-arc lamp is coming very largely into use, because it gives a fine, steady light and the carbons are consumed at a very slow rate, on account of their being enclosed in a space where very little oxygen is present. As soon as the arc is started, the oxygen present in the enclosing globe is soon burnt out, and the gases become so heated that they expand and pass out through the top around the upper carbon rod, as the rod does not, of course, fit air-tight. The result is that the arc burns in a partial vacuum, and the rate of consumption is so slow that a lamp will burn 150 hours without retrimming. An ordinary arc lamp will only burn about 10 hours before new carbons are required. For enclosed-arc lamps a very high grade of carbon must be used, so that the decreased cost of trimming is offset to a slight extent by the increased cost of the carbons. These lamps take a smaller current (from 3 to 6.6 amperes) than the open arcs, and require a correspondingly higher voltage (from 75 to 85 volts across the arc). They burn with a long arc, because it is necessary to have the carbons separated considerably, in order to allow the light to be thrown out properly. The carbons burn with flat ends, and do not become pointed, as in the open arc.

LIGHTING SYSTEMS.

INCANDESCENT LIGHTING BY DIRECT CURRENT.

51. Most of the incandescent lamps used in mines are operated by means of direct current. Very often the lamps are run in connection with the mine-haulage or pumping system and are operated from the same dynamo. It is better practice, where possible, not to operate lamps on a mine-haulage system, because one side (the track) of such a system is always grounded, and if lamps are run on such circuits there is always danger of getting shocks. There is also more danger of fire, due to defective insulation, than if the lamps run on a circuit, both sides of which are insulated —as, for example, a regular power or lighting circuit.

52. As stated in Art. **48**, incandescent lamps are commonly connected in parallel, as shown in Fig. 26. If one lamp is put out, the others are not affected. For haulage or power circuits, the pressure used is usually 250 or 500 volts. If an ordinary 110-volt lamp were connected across such circuits, it would be at once burnt out; hence on 250-volt circuits, we must use two 125-volt lamps connected in series, as shown in Fig. 29. This is known as the **multiple-series** system. When 500 volts is used, five lamps would be

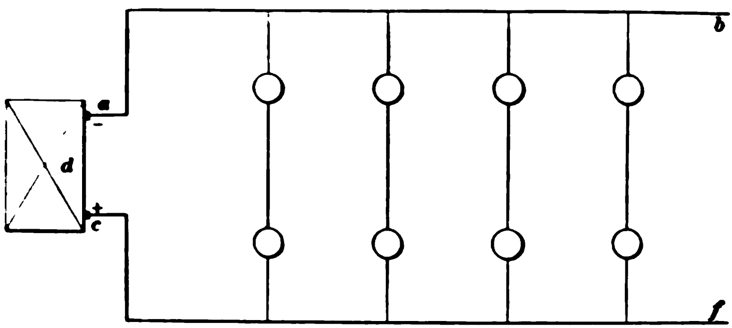


FIG. 29.

connected in series across the lines. Of course in the multiple-series system, when one lamp burns out, it puts out the others in series with it. With the lamps in multiple, as in Fig. 26, there will be ½ ampere delivered over the line for each 16 c. p. lamp connected. With two lamps in series, there will be ¼ ampere in the line for each 16 c. p. lamp, or ½ ampere for each pair of lamps, and with five lamps in series, there will be $\frac{1}{10}$ ampere per lamp, or ½ ampere for each group of five lamps. These current allowances per lamp will be found useful in estimating the size of wire necessary to carry current to a number of lamps.

INCANDESCENT LIGHTING WITH ALTERNATING CURRENT.

53. Where lights are widely scattered or where it is a long distance from the dynamo to the point where the light is used, alternating current is employed, because this current can be generated at high pressure and transmitted over the line to a point near where it is to be utilized. The pressure is then lowered by means of transformers to a pressure suited to the lamps and the local distribution carried out at low pressure. This arrangement is shown in Fig. 30, where *G* is the alternating-current dynamo supplying current at high pressure to the primary coils of the transformers *T*. The secondary coils are connected to the lamps and supply current at low pressure. The pressure generated by the dynamo is usually 1,000 or 2,000 volts, and on account of this high pressure, the primary wires should not be carried anywhere in the mine where there is any liability of their being a source of danger. The best plan is to carry the primary wires to **substations**, where the transformers are placed and where there will be no danger from the high E. M. F. The current may then be distributed at low pressure from these substations, and by adopting this method there is no more danger connected with the use of alternating current than with direct current. Alternating current is coming rapidly into favor for use in mines in connection with pumping, hoisting, etc., and if properly installed, it is equally effective for lighting purposes, allowing the light to be distributed over wide areas with comparatively small line-wires. In some installations these substations are located above ground, and no high-tension wires whatever are allowed in the mine. If, however, properly

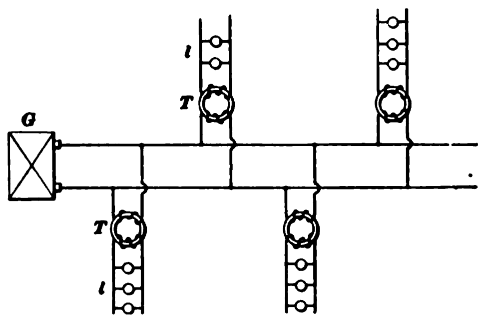


FIG. 30.

insulated high-tension cables are used, there is no reason why the current can not be carried safely to a substation located in the mine itself. The former is, however, the safer method, although it involves a somewhat greater expense for copper. With 1,000 volts on the primary circuit, about twenty 16 c. p. lamps can be operated per ampere delivered by the dynamo. With 2,000 volts, about forty lamps on the secondary will call for 1 ampere on the primary.

CONDUCTORS.

54. Material for Conductors.—Copper wire or cable is used almost exclusively, in connection with mine lighting, for conducting the current from the dynamo to the lamps. The lines are usually in the form of solid round copper wire, but when extra large conductors are required, stranded cables are used. The different sizes of copper wire are expressed according to gauge number, and the gauge most generally used in America to designate the different sizes of copper wire is the American, or Brown & Sharpe (B. & S.). The sizes as given by this gauge range from No. 0000, the largest, .460 inch diameter, to No. 40, the finest, .003 inch diameter. Wire drawn to the sizes given by this gauge is always more readily obtained than sizes according to other gauges; hence, in selecting line-wire for any purpose, it is always desirable, if possible, to give the size required as a wire of the B. & S. gauge. A wire can usually be selected from this gauge which will be very nearly that required for any specified case.

55. Estimation of Cross-Section of Wires.—The diameter of round wires is usually given in the tables in decimals of an inch, and the *area of cross-section* is given in terms of a unit called a **circular mil.** This is done simply for convenience in calculation, as it makes calculations of the cross-section much simpler than if the square inch were used as the unit area. A **mil** is $\frac{1}{1000}$ of an inch.

or .001 inch. A *circular mil* is the area (in decimals of a square inch) of a circle, the diameter of which is $\frac{1}{1000}$ inch, or 1 mil. The circular mil is therefore equal to $\frac{\pi}{4}(.001)^2 =$ .0000007854 square inch.

If the diameter of the conductor were 1 inch, its area would be .7854 square inch, and the number of circular mils in its area would be $\frac{.7854}{.0000007854} = 1,000,000$; but 1 inch = 1,000 mils and $(1,000)^2 = 1,000,000$; hence the following is true:

$$CM = d^2,$$

or the area of cross-section of a wire in circular mils is equal to the square of its diameter expressed in mils.

EXAMPLE.—A wire has a diameter of .101 inch. What is its area in circular mils?

$$.101 \text{ inch} = 101 \text{ mils.}$$

Henoe, $$CM = (101)^2 = 10,201.$$

Table II, inserted here for convenient reference, gives the dimensions, weight, and resistance of pure copper wire. The weights given are, of course, for bare wire. The first column gives the B. & S. gauge number, the second the diameter in mils. The diameter in inches would be the number as given in this column divided by 1,000. The third column gives the area in circular mils, the numbers in this column being equal to the squares of those in the second column. The safe carrying capacity is also given. Usually the wires are strung in the air in mining work, so that the column headed "Open" may be taken as the carrying capacity. No wires smaller than No. 14 should be used in connection with lighting work.

56. When wires larger than those given in Table II are required, stranded cables should be used, because they are much more flexible and easily handled. Table III gives some of the standard sizes of cables.

TABLE II.

PROPERTIES OF COPPER WIRE.—AMERICAN, OR BROWN & SHARPE, GAUGE.

Number B. & S. Gauge.	Diameter in Mils.	Area in Circular Mils. $CM = d^2$.	Weights.		Resistance per 1,000 Ft. International Ohms. 75° F.	Current Capacity (Amperes) National Board Fire Underwriters	
			Per 1,000 Ft.	Per Mile.		Open.	Concealed.
0000	460.0	211,600	641	3,382	.04966	312	218
000	409.6	167,805	509	2,687	.06251	262	181
00	364.8	133,079	403	2,129	.07887	220	150
0	324.8	105,534	320	1,688	.09948	185	125
1	289.3	83,694	253	1,335	.1258	156	105
2	257.6	66,373	202	1,064	.1579	131	88
3	229.4	52,634	159	838	.2004	110	75
4	204.3	41,742	126	665	.2525	92	63
5	181.9	33,102	100	529	.3172	77	53
6	162.0	26,250	79	419	.4104	65	45
7	144.2	20,816	63	331	.5067		
8	128.4	16,509	50	262	.6413	46	33
9	114.4	13,094	39	208	.8085		
10	101.8	10,381	32	166	1.010	32	25
11	90.7	8,234	25	132	1.269		
12	80.8	6,529	20	105	1.601	23	17
13	71.9	5,178	15.7	83	2.027		
14	64.0	4,106	12.4	65	2.565	16	12
15	57.0	3,256	9.8	52	3.234		
16	50.8	2,582	7.9	42	4.040	8	6
17	45.2	2,048	6.1	32	5.189		
18	40.3	1,624	4.8	25.6	6.567	5	3
19	35.8	1,288	3.9	20.7	8.108		
20	31.9	1,021	3.1	16.4	10.260		
21	28.5	810.1	2.5	13.0	12.940		
22	25.3	642.4	1.9	10.2	16.41		
23	22.6	509.4	1.5	8.2	20.57		
24	20.1	404.0	1.2	6.5	26.01		
25	17.9	320.4	.97	5.1	32.79		
26	15.9	254.1	.77	4.0	41.56		
27	14.2	201.5	.61	3.2	52.11		
28	12.6	159.8	.48	2.5	66.18		
29	11.3	126.7	.39	2.0	82.29		
30	10.0	100.5	.30	1.6	105.1		

TABLE III.

CARRYING CAPACITY OF CABLES.

Area Circular Mils.	Current Amperes.		Area Circular Mils.	Current Amperes.	
	Exposed.	Concealed.		Exposed.	Concealed.
200,000	299	200	1,200,000	1,147	715
300,000	405	272	1,300,000	1,217	756
400,000	503	336	1,400,000	1,287	796
500,000	595	393	1,500,000	1,356	835
600,000	682	445	1,600,000	1,423	873
700,000	765	494	1,700,000	1,489	910
800,000	846	541	1,800,000	1,554	946
900,000	924	586	1,900,000	1,618	981
1,000,000	1,000	630	2,000,000	1,681	1,015
1,100,000	1,075	673			

57. The wires used for supplying the current to lighting circuits in mines should be well supported on porcelain insulators. The wire itself is usually covered with a double or triple braiding of cotton soaked in insulating compound. Where extra good insulation is required, rubber-covered wire should be used.

58. Joints.—When it is necessary to make joints between wires, it is important to remember that the work can not be too well done. Under no circumstances should a joint be left unsoldered. When connecting a branch line to the main, the insulation is cut away as shown in Fig. 31; the cut should not be made straight down towards the wire with the edge of the knife, forming a sharp shoulder on the insulation,

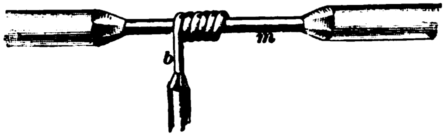


FIG. 31.

as the knife is very likely to make a nick in the wire, and subsequent bending might produce a crack at this point. Such a fault would increase the resistance locally and cause heating and, possibly, fire risk. In the illustration, the branch wire *b*, after being carefully bared of insulation and scraped clean, is wrapped over the main *m*, similarly exposed. This operation should be done with a pair of pliers of convenient size, and the turns of *b* should be close together. The joint should then be soldered, no acid being used, but resin only, as a flux, the reason being that it is impossible to clean off all the acid after the joint is finished, as some remains in the crevices and will eventually corrode the wire and break the electrical circuit. When the joint is cool, the wire is held firmly by the solder; all the exposed wire should then be covered by wrapping rubber insulating tape carefully over it, continuing across a short distance on the main insulation. It may here be remarked that it is not so easy to make a resin joint as one on which acid is used, which explains the disfavor in which the former is usually held by poor workers. Acid removes grease from the wire, such as a careless workman may have smeared on from his fingers, but when the wire is not handled after cleaning, resin will

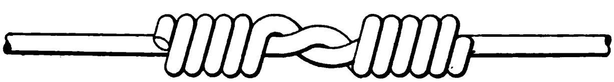


FIG. 32.

make a good joint. An alternative method is to tin both wires before wrapping, using acid as a flux; then wipe carefully, cleaning thoroughly, to remove all trace of acid, and wrap over, using pliers to bend the wire. The joint should then be completed with resin as a flux. When two wires are to be connected together to form a continuous conductor, the Western Union joint, Fig. 32, is employed, the wires being twisted one over the other, soldered, and taped.

CALCULATING SIZE OF WIRE FOR LIGHTING CIRCUITS.

59. The size of wire required to supply a given number of lamps situated a given distance from the dynamo will depend upon the amount of loss that is allowed in the line. The loss in the line due to its resistance causes a **drop** in pressure between the dynamo and the lamps. For example, if the resistance of the wire through which the current has to flow were R ohms and the current supplied C amperes, the pressure which would be used up in forcing the current through the line would be $C \times R$ volts. This pressure used up in driving the current through the wire is spoken of as the **drop,** because the pressure at the end of the line is less or drops off by this amount from the pressure at the dynamo. If we can afford to allow a large line drop, or, what is equivalent to the same thing, if we can afford to have a large loss in the line, it is evident that we may use a line having a large resistance. This means that the wire may be small and consequently cheap. For distributing from the dynamo to the different centers at which the lights are supplied, a drop anywhere from 5 to 15 per cent. of the lamp voltage is allowed. For local distribution on the branch circuits directly connected to the lamps, the drop should not exceed 2 or 3 per cent., because if it does the lamps will give a very poor light. The aim should be to keep the pressure at the different centers of distribution as constant as possible. If this is done and the drop in the lines running from the centers of distribution to the lamps is small, a good lighting service will result, and the life of the lamps will be much longer than it would be were the voltage regulation bad.

60. When the size of wire for supplying a number of lamps is to be estimated, the distance from the dynamo to the lamps must be known; the allowable amount of drop in the line and the current must also be known. The current can easily be estimated from the known number of lamps and their candle-power.

Let C = current supplied over the line;
L = total length of the line *in feet* (i. e., distance to lamps and return);
E = voltage at end of circuit where lights are located;

$\%$ = percentage drop (i. e., percentage of voltage at the lamps);

A = area of cross-section of wire in circular mils;

then, $$A = \frac{10.8 \times L \times C \times 100}{E \times \%}, \qquad (2.)$$

or $$A = \frac{10.8 \times L \times C}{\text{volts drop}}. \qquad (3.)$$

EXAMPLE.—A certain portion of a mine is to be lighted by fifty 16-candle-power, 110-volt lamps and ten 32-candle-power lamps. This portion of the mine is 1,000 feet from the dynamo room, and the drop is not to exceed 5% of the voltage at the lamps. Find the size of wire required.

SOLUTION.— 50 16 c.p. 110-volt lamps require 25 amperes.
10 32 c.p. " " " 10 amperes.
Total current, 35 amperes.

The total length of wire through which the current will flow will be $2 \times 1{,}000 = 2{,}000$ feet, because the current has to flow to the lamps and back again. Applying formula **2**, we have

$$A = \frac{10.8 \times 1{,}000 \times 2 \times 35 \times 100}{110 \times 5} = 137{,}454 \text{ circular mils. Ans.}$$

By looking up the wire table, we find that this corresponds to about a No. 00 B. & S. wire. It is very seldom that a wire will figure out so as to correspond exactly with any size given in the wire table. The next larger size is usually taken rather than the next smaller, unless the smaller size should be quite near the calculated value.

EXAMPLE.—Current is to be delivered to a mine 2 miles distant from the power station by means of alternating current at 2,000 volts. The drop in the line is not to exceed 10 per cent. Six hundred lamps are to be operated at the distant end from the secondaries of transformers. Calculate the size of the line-wire required.

SOLUTION.—Each ampere on the 2,000-volt primary lines is equivalent to 40 lamps on the secondary (see Art. **53**); hence the current will be approximately $\frac{600}{40} = 15$ amperes. The total length of line will be $5{,}280 \times 2 \times 2 = 21{,}120$ feet; hence we have

$$A = \frac{10.8 \times 21{,}120 \times 15 \times 100}{2{,}000 \times 10} = 17{,}107 \text{ circular mils. Ans.}$$

This lies between a No. 7 and No. 8 B. & S. No. 7 would probably be used, so as to allow a margin for additional lights that might be needed in the future.

ARC LAMPS ON CONSTANT-POTENTIAL CIRCUITS.

61. Arc lamps are frequently run on constant-potential or constant-pressure circuits in the same way as incandescent lamps. With the older types of arc lamps, it was necessary to connect two lamps in series across the 110-volt circuit, in order to take up the full pressure. It will be remembered that an ordinary open-arc lamp requires about 45 volts; hence if two are connected in series across the line, they will take up 90 volts, and the extra 20 volts must be taken up by a resistance *R*, as indicated in Fig. 33, where the arc lamps are

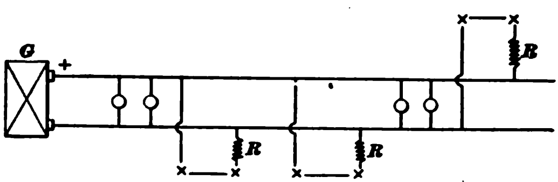


FIG. 33.

shown connected, two in series across a 110-volt circuit. This method of operating arc lamps is not, on the whole, very satisfactory, because the two lamps are apt to interfere with each other and not feed properly. This method of running open-arc lamps is being rapidly superseded by the use of the enclosed-arc lamp. As already stated, the enclosed arc requires from 75 to 85 volts for its operation and may be connected directly across a 100 or 110 volt circuit by the insertion of a small amount of resistance. Such lamps are very often convenient for use about mines, because they can be operated from the same dynamo and off the same mains that supply the incandescent lamps.

PROTECTION AGAINST SHORT CIRCUITS.

62. Before leaving the subject of lighting as carried out on constant-potential systems, it may be well to point out the necessity of protecting such systems from **short circuits.** It must be remembered that the pressure between the mains is maintained at a constant value by the dynamo. Compound-wound dynamos are generally used, and these machines maintain the pressure at a nearly uniform value, regardless of the amount of current they are called upon to furnish. From Ohm's law, $C = \frac{E}{R}$, it is at once seen that if E, the E. M. F., is kept constant, the current will depend upon the resistance between the two lines. If the resistance is high, the current will be small, but if the resistance is very low, the current may become dangerously large. If the two line-wires should be accidentally connected together, or, in other words, if a *short circuit* should be established between them, there would be a large rush of current, which might be sufficient to fuse the wire. Such short circuits are liable to occur, on account of accidents of various kinds, and it is necessary to provide some protection against them. In lighting work, this protection is generally provided for by means of fuses. These are usually in the form of a short piece of wire or strip made of a soft, fusible metal, which will melt and cut out the defective part of the circuit whenever the current reaches a dangerously high value.

63. The fuses are mounted in **fuse blocks** or **cut-outs,** and should be placed wherever a branch circuit is taken off the main line. A small fuse should also be placed in series with each individual lamp, especially if such lamp is hung from a drop cord.

Fig. 34 shows a cut-out of the kind referred to. It is called a rosette cut out and is principally used where a lamp drops from the supply wires. The figure shows the inside view of the two halves. They are both composed of porcelain, upon which metallic connection pieces are screwed. The half B is fastened in place through the holes h and h_1. The supply wires are connected to the binding-posts p and p_1, which are themselves connected to the two projecting elastic plates of metal c and d.

The half A has two projecting metallic pieces m and n, which hook in under c and d and make the connections when the two halves are put together. The side view of *m* or *n* is given at *f*. Upon each of these pieces at the end that rests against the porcelain is a binding-screw *s* or *x*. Two small metallic plates, each carrying a pair of binding-screws *t* and *v*, or *z* and *y*, are screwed upon the porcelain at diametrically opposite points, and the lamp conductors,

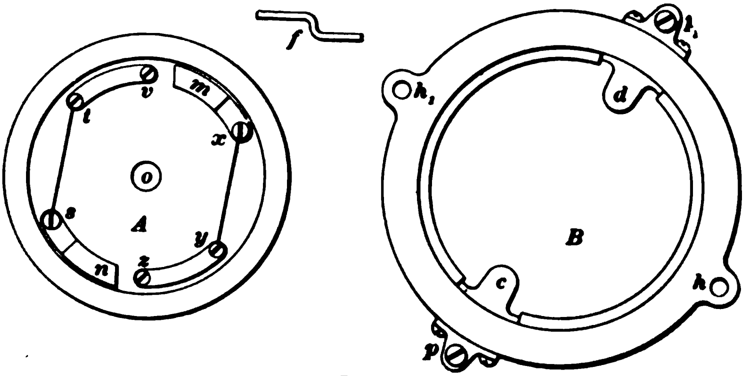


FIG. 34.

entering at hole *o*, are connected to *v* and *z*. If flexible cord is used, it should be knotted under the cap, in order to sustain the weight of the lamp. Between the two binding-screws *t* and *s*, as well as between *x* and *y*, are respectively connected two strips of a fusible alloy. This alloy melts and breaks the circuit when the current increases above a given value.

The current starts from one supply wire and flows through *d*, *m*, and the alloy or fuse wire *x y* to *z*. Then it flows through the lamp to *v*, through the fuse wire *t s* to *c*, and out to the other supply wire. The two halves are connected by a screwing motion, which rubs the contact pieces together.

64. The ordinary form of detachable fuse is shown in Fig. 35. The contact pieces *a* and *b* are made of sheet copper, and are intended to be clamped by screws to the terminals provided for them on the fuse blocks.

FIG. 35.

A strip *c* of fusible lead alloy is soldered to each contact piece, its cross-section being proportional to the maximum current to be carried, which is stamped on the copper ends. As a guide to the carrying capacity of fuses, the following table may be consulted, but it is to be pointed out that the fusing current depends upon the particular proportion of the metals used in the alloy and their selection, also on the length of fuse and the character of the terminals.

TABLE IV.

Diam. in Mils.	B. & S. Gauge (Approx.).	Amperes.
.017	25	3
.020	24	4
.032	20	7
.042	18–17	10
.056	15	15
.065	14	18
.075	13–12	25
.085	12–11	28
.096	11–10	31
.111	9	36
.130	8	50
.150	7–6	70

65. Fuse blocks are nearly always made of porcelain or slate and are of a great variety of styles, depending upon the use to which they are to be put, their current capacity, etc. Fig. 36 shows a **branch block** used where a branch circuit is to be taken off the main line. The mains may be connected at *m*, *m'*, the wires passing under the projecting ledges *l*, *l'*. The branch wires are secured

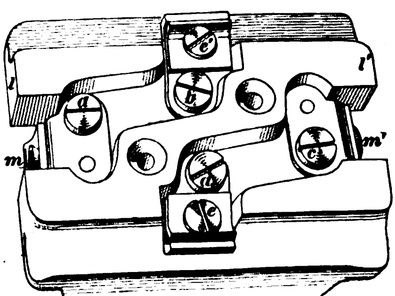


FIG. 36.

at *e*, *e'*. The fuses are held between the screws *a* and *b*, *c* and *d*. To prevent damage when a fuse "blows" or melts, a porcelain cover is fitted over the face of the block.

Fig. 37 shows a **main fuse block,** the wires from the point of supply being inserted at one end, as at *m*, *m*, and the line

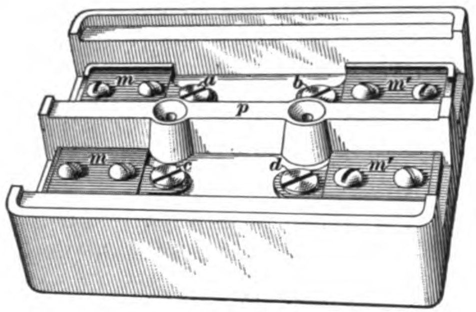


FIG. 37.

continued from the terminals *m'*, *m'* at the other end. The fuses are inserted between the screws *a* and *b* and between *c* and *d*. The two sides of the circuit are separated by the partition *p*, so that all danger of short circuit is eliminated. This fuse block is also provided with a porcelain cover not shown in the figure.

66. When fuse blocks are installed in mines, they should always be placed at some easily accessible point, so that they may be readily examined and fuses replaced when necessary. It is a good plan to place the blocks in a wooden box painted with waterproof paint and provided with a hinged door.

SWITCHES.

67. Switches used in connection with incandescent lighting may be of the **single-pole** or **double-pole** variety. In the former, one side only of the circuit is opened by the switch, while in the latter both sides are opened. Where small groups of lights are to be controlled, say 6 or 8 lights, a single-pole switch will answer; but where the number of lights is at all large, double-pole switches should be used.

The most durable type of switch is the knife-blade type described in Art. **123**, *Dynamos and Motors*, Part 3. Such switches, mounted in wooden boxes painted with weather-proof paint, make a very good arrangement for mining work. These switches are much more durable than the ordinary snap switches, such as are frequently used in connection with electric wiring. It is always well to mount the switches, no matter what kind is used, in a protecting box of some kind.

68. It must be said, in regard to most of the snap switches on the market, that they are very flimsy. Of course some of them are much better than others, but, as a general rule, they do not stand the hard usage they are liable to get in a mine. For this reason, a good substantial knife switch is to be preferred. We give, however, a couple of examples of typical snap switches which, if not abused, will give good service. They have one advantage in that they are more easily operated in the dark than a knife switch.

69. The style of switch shown in Fig. 38 is suitable for use on circuits where the current does not exceed 50 amperes.

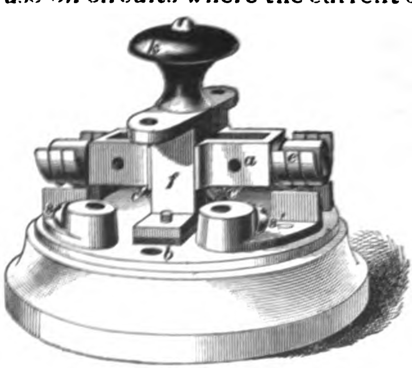


FIG. 38.

The positive and negative leads are brought up through the hole in the base *b* and connected one to each of the terminals shown by means of the screws *s*, *s'*. The leads for the lamps are connected in a similar manner to corresponding terminals on the other side of the switch, and the circuit is completed by forcing the arm *a* into contact with these terminals, thereby bridging over the gap between them. The knob *k* is fastened to a pin passing vertically through the frame *f* and secured to the springs *c*, *c'* at the lower end in such a way as to form a toggle-joint. When the knob is drawn upwards, the springs are compressed, and on passing the center, they suddenly force the contact arm downwards. In like manner, on pressing the knob down, contact is again broken.

70. Fig. 39 shows a double-pole switch for small currents. The cylinder *e*, made of china or other insulating substance, has brass contact plates *p* on opposite sides, against which press brass or copper springs when the cylinder is in the position indicated in the figure. Four terminals are provided, lettered *a*, *b*, *c*, *d*, and the wires for connection to them are brought up through the holes in the base, one of which is visible. The incoming wires, positive and negative, are connected to the terminals *b* and *d*, and the outgoing wires to *a* and *c*. The springs *a'*, *b'*, *c'*, *d'* are riveted to the terminals *a*, *b*, *c*, *d*, respectively, so that when the switch is turned to the position shown, the circuit is completed between terminals *a* and *b* and between *c* and *d*. A quarter-turn breaks the contact, for the springs then rest only on the china cylinder. A cover is provided to enclose the body of the switch, the handle alone projecting.

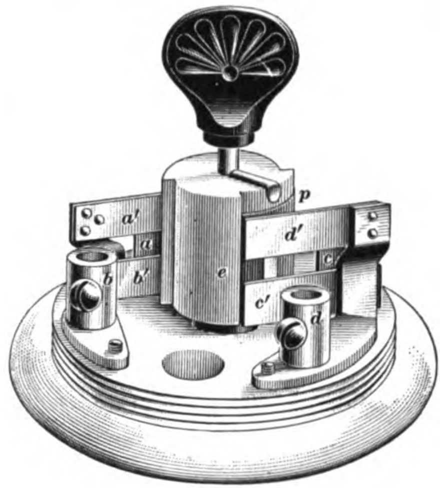


FIG. 39.

71. Sometimes it is very convenient to have switches arranged so that an incandescent lamp or group of lamps may be turned on or off from either of two points. This may be accomplished by using two "3-point" switches as shown in Fig. 40. *L*, *L* are the lamps to be controlled from the two stations *A* and *B*. The switches *A* and *B* have three points, since the contact plates *a*, *a'* are connected together and practically form a single terminal. The contact arm of the switch is thrown from the position shown to that indicated by the dotted line when the switch handle is turned.

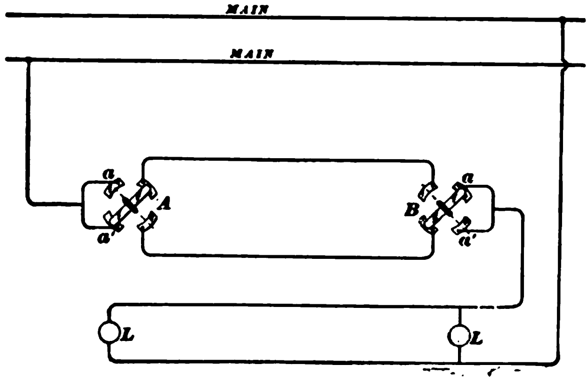


FIG. 40.

By tracing out the connections, it will readily be seen that the lamps may be turned on or off from either station without regard to the position of the switch at the other station.

72. By an extension of the arrangement just mentioned, lamps may be controlled from three or more stations.

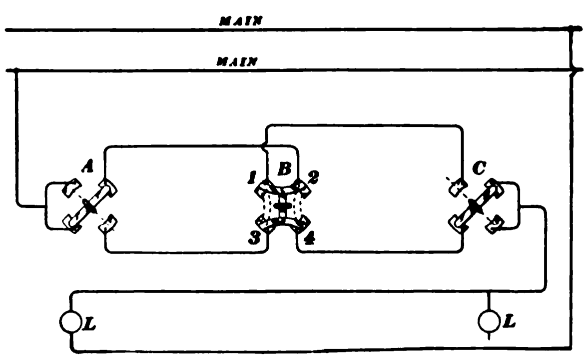


FIG. 41.

Fig. 41 shows how this is carried out for three stations by using two 3-point switches A and C, one for each end station, and one 4-point switch B for the center station. As shown in the figure, the points *1* and *2*, *3* and *4* of the 4-point switch are connected together. When the switch is turned, points *1* and *3*, *2* and *4* are connected, as shown by the dotted lines. By this arrangement, the lights may be turned on or off from any one of the three stations. This scheme can be extended to any number of stations by adding another 4-point switch for each additional intermediate station.

SERIES ARC-LIGHT SYSTEM.

73. All the lighting so far mentioned has been carried out on the constant-potential system, the lamps being connected in parallel. When a number of scattered arc lamps are to be operated, the **series system** is commonly used. In this case the lamps *l* are connected in series, as shown in Fig. 42. The same current flows through all the lamps, leaving generator *G* at the positive pole and flowing through each lamp in succession back to the negative pole. In a circuit of this kind, the current must be maintained at a constant value, because the current through the lamps must always remain at the same amount if the lamps are to operate in a satisfactory manner. If a large number of lights are burning, a high pressure must be generated by the dynamo (about 45 or 50 volts for each lamp in operation). If, on the other hand, most of the lamps are cut out, the pressure required will be small, and the E. M. F. generated by the dynamo must be cut down, in order that the current may remain constant. This is accomplished by providing the dynamo with an automatic regulator, which causes the E. M. F. generated to decrease whenever the load decreases, and *vice versa*. The size of line generally used for arc-light circuits is No. 6 or 8 B. & S.

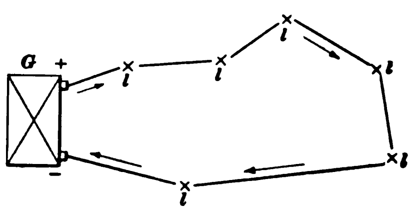


FIG. 42.

ELECTRIC COAL-CUTTING MACHINERY.

ELECTRIC COAL-CUTTING MACHINERY.

1. In the production of bituminous coal, the question of decreasing the cost has received much consideration, and the reductions in this respect, as in almost all others, have been made in large part by the use of labor-saving machinery. Another reason which has led to the introduction of coal-cutting machines is found in the fact that a greater output can be obtained from a limited territory with more certainty, steadiness, and reliability than can be depended upon when pick mining is used. As the most difficult and expensive operation in connection with the production of bituminous coal is the process of undercutting, the greatest development has been made in machinery for accomplishing this operation. This method of mining is confined to the bituminous fields, the anthracite coal being simply blown from the solid.

In order that the bituminous coal may be made into the best marketable form, it is first undercut and then blown down with as small a charge of powder as possible. Many machines have been designed and built to undercut coal; and machines for this purpose have reached such a degree of perfection that it can safely be said that a large, if not the greater, proportion of coal cutting will in the future be done by mechanical means. The flexibility and convenience of the electric system, together with many other advantages peculiar to existing conditions, makes it admirably adapted to the present bituminous fields throughout the world.

In many mines the conditions are more favorable to the use of machines operated by compressed air, and where such conditions exist there is but one alternative. There are three principal conditions which particularly favor compressed-air machines, these being bad roof, explosive gas in dangerous quantities, and frequent occurrence of pyrite or other hard substance which can be worked around with a pick machine which uses compressed air, but which would break the teeth or other parts of a chain-cutting machine. In mines where the roof is bad and it is necessary to place the props close to the face, requiring a machine which can be operated in very narrow places, the pick, or puncher, machine is the only one which can be used. Pick machines are usually operated by compressed air, but recently electricity has been successfully applied to machines of this type. Machines operated by alternating-current motors which are practically sparkless have been built and several plants installed, but this system has proved to be unsuitable for machinery designed for this class of work, principally on account of the danger to men and animals. The few plants that were installed are entirely abandoned. The continuous-current motor is consequently the only one being used.

TRANSMISSION OF ELECTRIC ENERGY TO MINING MACHINES.

2. The flexibility of the electric system of transmitting energy, together with its low cost and high efficiency, makes it especially suitable for undercutting machines, which are used at the working-faces of the entries and rooms. The current is carried through the main and cross entries by wires forming a complete circuit with a positive and negative side, the cross-section of wire used being determined by the amount of current required to be carried, this wire being supported on glass insulators, which are attached to timbers or props. From the entries the power is taken to the working-faces of the rooms by means of an insulated cable, these cables being of sufficient length to reach the face of the room when it has been worked to its greatest depth.

3. As it is more economical to transmit power at high than at low voltages, this feature in the transmission of electrical power has received much consideration where it is desired to carry power from a central plant to several mines which are situated a number of miles from the central station. By using high voltages, small wires can be used and a very great reduction in the cost of this portion of the plant can be made. In order to transmit power at high voltages, it is necessary to use the alternating-current system, and in order to adapt this to the direct-current motor on the machines or locomotives, it is necessary to transform it to a direct current of low voltage. That this may be done, it is necessary to employ a rotary transformer or motor generator. The advisability of using this system depends entirely upon local conditions, and should be determined upon the basis of comparative initial and operating expenses.

4. In constructing circuits about mines, care should be taken to place the wires as much out of the way of men and mules as possible. There is always danger connected with coming in contact with an electrical circuit, and those who are required to work in connection with construction of circuits should be provided with tools properly insulated, wear rubber gloves, and when working with the wire, stand upon some insulating material such as rubber or dry wood. Fatalities in mines due to contact with wires are rare and generally in connection with alternating-current machinery. The voltage used with direct-current machinery is so low that very little danger exists from contact with the wires. As some persons are more affected by an electric shock than others, it is best to caution all workmen of the danger of coming in contact with the wires.

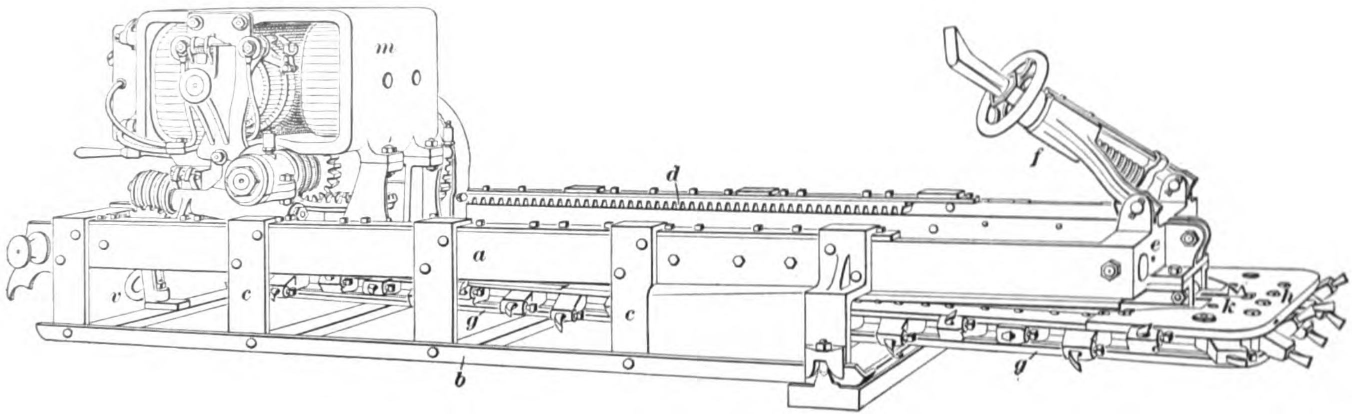


FIG. 1.

CHAIN COAL-CUTTING MACHINES.

5. Fig. 1 is an illustration of one of the leading types of electric chain coal-cutting machines. It consists of an outside or bed frame and inside or sliding frame and an electric motor. The outside or bed frame is made of two steel channel-bars *a* and two angle-bars *b* fastened together by means of heavy cast and forged steel cross-ties or braces *c*. The feed-racks *d*, which are made of the best rolled steel and have machine-cut involute teeth, are firmly bolted to the bed-frame. These racks are made up in sections, so that in case a tooth should be broken it can be replaced without renewing the entire rack. The rear end of the bed-frame is provided with hooks for moving the machine and a cross-bar on which rests the rear jack or the brace which passes to the roof to take the backward thrust of the machine. A heavy steel cross girt *e* joins the channel-bars at the front end of the bed-frame. The front jack *f* is mounted on the cross girt and the guides for the center rail of the sliding cutter frame are attached to the bottom of it. These guides consist of two adjustable bronze parts of extra length to give large wearing surface for the bearing of the center rails. As the floor of a mine is very uneven and would seldom be level enough to allow the machine to have a firm bearing, the outside frame is designed strong and rigid, so that there can be no bending due to irregularities in the floor. The rigidity of this frame does away with the friction caused by lighter and less rigid construction.

The inside or sliding frame is the shape of an isosceles triangle with the apex at the rear, and consists of a steel center rail, a cutter-head *h*, and two side chain guides *g*. This sliding frame is contained wholly, with the exception of the cutter-head, within the stationary bed-frame, which arrangement insures perfect protection to persons while it is in operation or when it is being moved from one place to another. As this frame comes in direct contact with the coal, it is made strong and has large wearing surfaces, and since its shape is triangular, only three wheels are required for the cutter chain, two sheaves or idlers in the cutter-head and one a driving sprocket at the apex of the frame. The center rail is secured to the sliding carriage on which the electric motor is placed by means of a steel step casting. A holder *k* is placed in the center of the cutter-head to take a portion of the side thrust of the chain when cutting coal. The driving mechanism consists of two steel spur-wheels and two steel bevel-gears, while the feed and pull-back mechanism consists of a system of worms and wheels.

The motor *m* is of the multipolar iron-clad type. The field frame is of cast steel and so proportioned as to make a compact and symmetrical appearance. The commutator is of high-grade hard-drawn copper. The frame of the motor surrounds the field coils and armature in such a manner that they are thoroughly protected from injury by falls of roof or dripping of water. The feed mechanism is automatically thrown out at the end of the cut and the cutter frame travels back from the face until it reaches a point where it automatically throws out the clutch and stops. The machine makes a cut 6 feet deep in about 3½ minutes and backs out or withdraws from the cut in about 40 seconds. Machines of this type are built to undercut from 5 to 7 feet deep, 39 to 44 inches wide, and about 4 inches high.

6. Fig. 2 shows a chain cutter which is constructed in a somewhat different manner than the one shown in Fig. 1. This difference exists principally in the construction of the stationary frame, which is much lighter, and in the position of the armature, which is vertical instead of horizontal. This machine weighs about 3,000 pounds and will advance while making a cut in the coal in about 4 minutes, and return in about 1 minute. On either of the above machines the time of feed or return can be changed by substituting different gears, the ratio of the gearing depending upon the quality of the coal in which the machine is working. The total length of the machine of this type which will undercut to a depth of 6 feet is about 10 feet over all, the height being about 29 inches over all. The width of the machine at the cutter-head is 42 inches over the chain and 45 inches over the bits or cutters, these not being shown in the figure. The width across the bed-frame is 24 inches. This enables the machine to be loaded on a truck which will run on a track having a gauge as narrow as 28 inches. The motor is of the multipolar type with internal fields. The armature is of the toothed Gramme ring type with the coils wound in slots

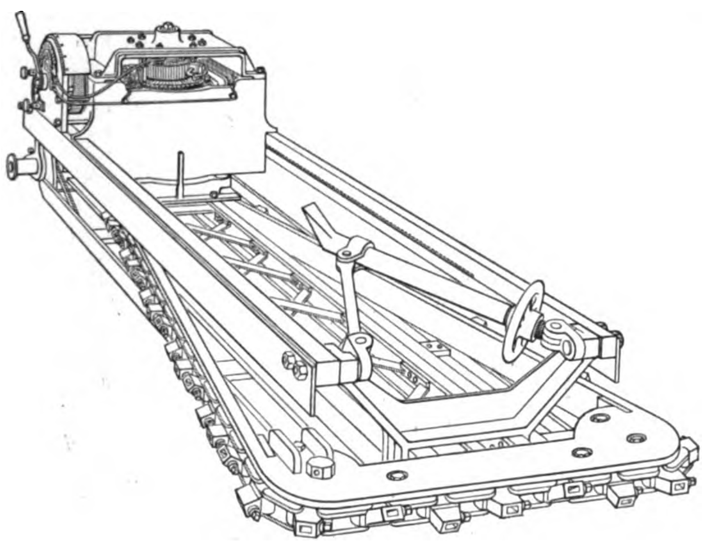


FIG. 2.

below the surface of the armature. This, as in the former machine, protects the coils from danger by rough usage and in case of accident. The field coils are wound on spools that slip over the pole-pieces and can be easily removed.

The gears are made from steel, the teeth being cut out of the solid, thus making the gear solid with the shaft on which it works. The armature being mounted in a vertical position, the pinion on its shaft meshes with a large spur-gear which carries the main drive sprocket. The speed of the chain on this machine is about 273 feet per minute when the armature is running at 750 revolutions per minute at

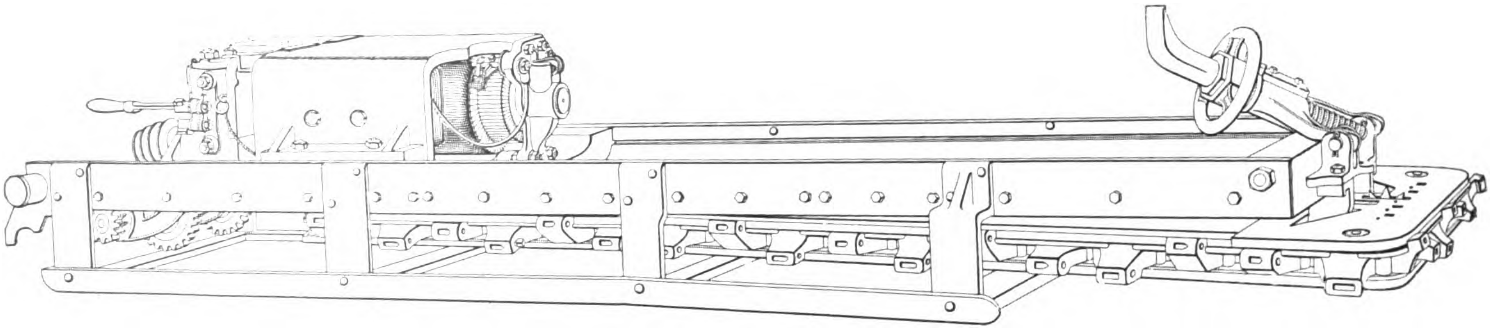


FIG. 3.

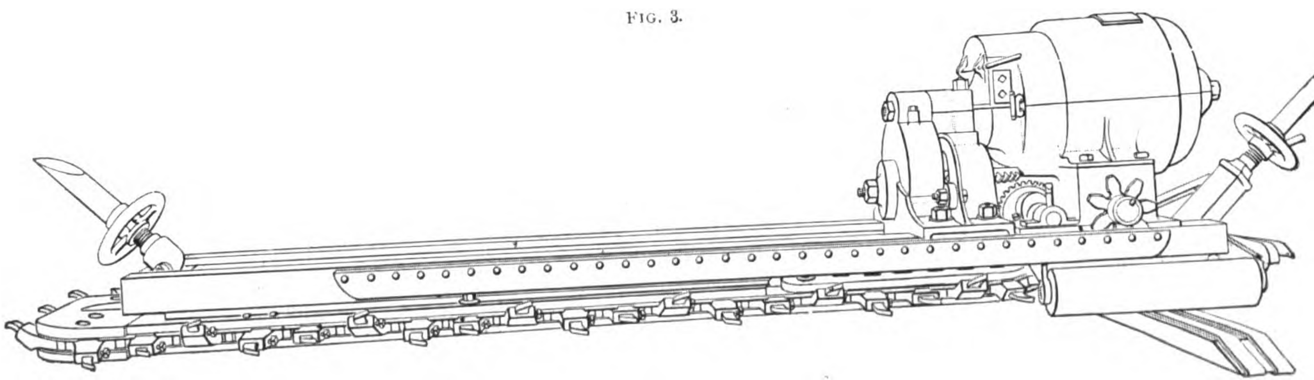


FIG. 4.

220 volts. The general construction of this machine will be understood from the description of the previous one.

The chain used on these machines is of the three-position style, having up, down, and center position bits. All the bits are straight and of the same length, which greatly facilitates the redressing and replacing of them.

7. Much attention has been given lately to the construction of electric machines to be used in mines where the seam of coal is low, and such machines have been designed, and their installation at many mines has proved the practicability of working machines in seams as low as 28 inches. Fig. 3 shows one of these machines. It is essentially the same as the one shown in Fig. 1, but it is much more compact, measuring only 18½ inches over all in height.

8. Another type of the chain-cutting machine is shown in Fig. 4. One of the points of difference between this machine and those previously described is that all the stationary parts of the machine are above the moving and cutting parts. The stationary frame is supported by a shoe at its forward end (not visible in the illustration). This shoe is on a level with the lower row of cutting bits, sc that the cut is made even with the floor of the room and no coal is left to be removed by hand. Another feature of this machine is the rollers attached to the rear end to facilitate moving it along the face of the coal. While the machine is at work the rollers are securely locked in place. The style of motor is also different from those previously shown. The motor, which is of the multipolar type, is enclosed in a barrel-shaped, dust and water proof iron casing. The armature shaft is longitudinal with the machine. At its front end is keyed a cut spur pinion 3½ inches in diameter and having a 3-inch face. This meshes into an intermediate gear of steel 14½ inches in diameter and a 3-inch face. A forged-steel bevel pinion is keyed rigidly to this intermediate gear and meshes into a cast-steel bevel-gear with cut teeth. This bevel-gear is attached to a sleeve [illegible] the [illegible] sprocket [illegible] the lower [illegible]

The [illegible] mechanism will [illegible] are [illegible] machines, the two first being practi- [illegible]

There are other machines which have been built and experimented with [illegible] types. Among these is the [illegible] alternating-current machine, which has for [illegible] A careful study of [illegible] will give an insight into the general construction of machines for undercutting coal, and a closer study of each machine will be necessary to become familiar with the minor details wherein the differences in construction exist.

9. Fig. 5 shows a side view (a) and a front view (b) of a portion of a cutter chain. It also shows a bit or cutter (c), which is made of good tool steel. The chain carrying the cutters is subjected to great stresses and wear and tear, and

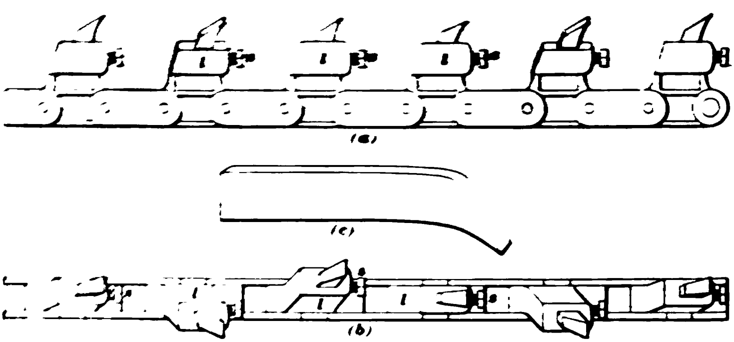


FIG. 5.

consequently must be made strong and of as few parts as possible. Since it is necessary to sharpen the cutters frequently, some easy means of detaching them must be provided. This is done by having a socket in each solid link, or every alternate link *l*, in the chain, into which the bit will fit. After the bit is placed in this socket, it is held in place by means of a set-screw *s*, which is adjusted from the side of the link.

METHODS OF OPERATING AND HANDLING CHAIN-CUTTER MACHINES.

10. By referring to Fig. 6 a very good idea can be obtained of the manner of operating these machines. For transporting the machine from point to point about the mine, a truck such as is shown in Fig. 7 is used. The machine is loaded on this truck and drawn into the room by a mule or its own motor. It is then unloaded and placed directly in front of the working-face at the point where it is desired to begin undercutting, and leveled up to conform to the bottom of the seam of coal. Under the rear end of the machine is placed an oak skid board, upon which is riveted two pieces of half-round iron, upon which the machine can be slid along easily after each cut is completed, the machine resting at the front end on an oak shoe covered with boiler-plate, thus forming a smooth surface upon which to slide when being moved. By means of a rear jack *a*, which is braced firmly against the roof, and the front jack *b*, which is braced firmly against the face of the coal, the machine is held rigidly in place and is prevented from moving in any direction. Two men are required for each machine, an operator, shown in the figure, and a helper. As the chain drags the cuttings out, it is the helper's duty to shovel them back and help the operator move the machine from time to time along the face of the room as each cut is finished. When the room is entirely undercut, the machine is again loaded on the truck and taken to the next room, where the same operation is performed.

11. The cut made by the chain machine is of the same height from front to rear. The average cut of a chain machine is 6 feet deep, 44 inches wide, and 4½ or 5 inches

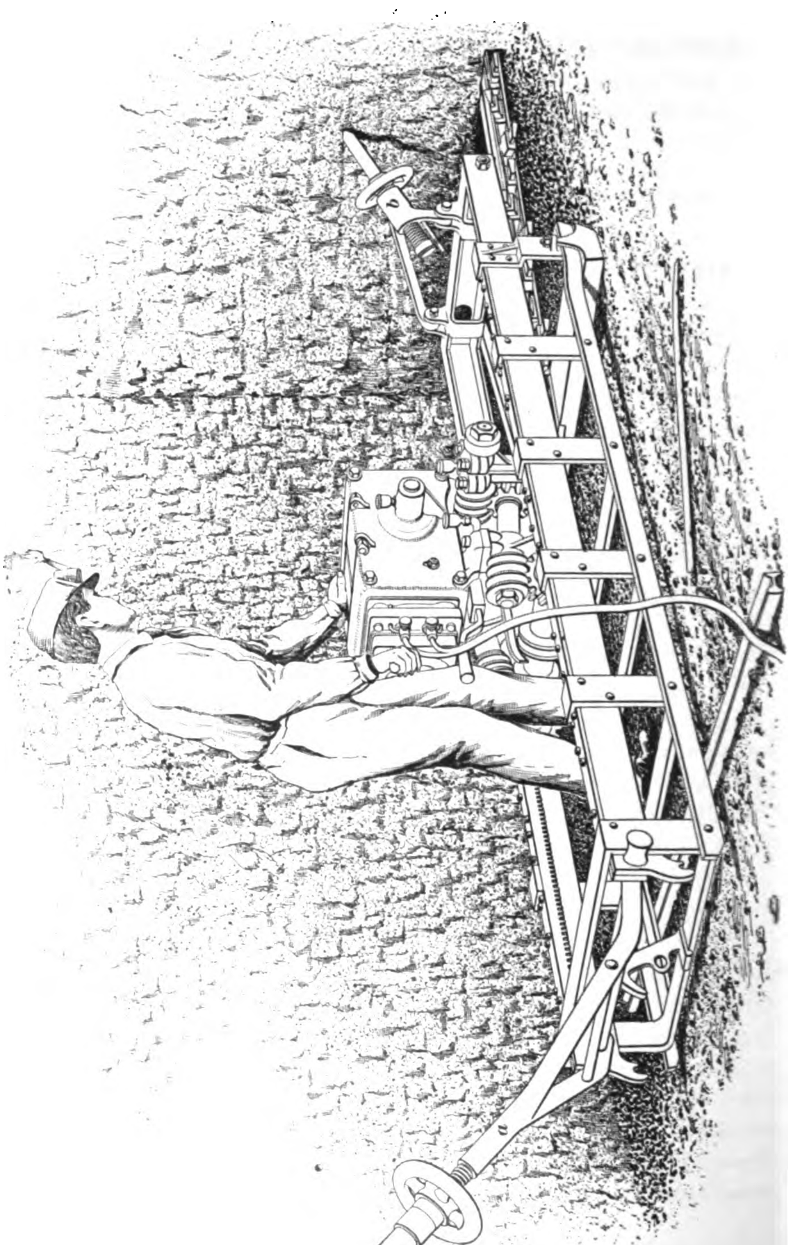


FIG. 6.

high. For such a depth the height of the cut is very low, and the amount of small coal made is but 60 per cent. of that made with pick machines. This is not always an advantage. With some coals this small cut is not enough to allow the coal to fall down and out after the blast. It frequently is necessary for the miners to break down a portion of the coal above and near the front of the cut or lift some of the coal left on the bottom in order to permit the coal to fall well for loading.

On account of the nature of the work, the machines are built to stand a good deal of rough usage, but it is well to impress upon the runner the necessity of taking proper care of his machine. The motor in each of the machines described is protected by a dust and water proof casing, and care must be taken to keep it so, and such bearings as are necessarily exposed to the dust of the mine should be frequently cleaned and kept well oiled. The bits should not be allowed to get very dull. One of the duties of the pit boss should be to see that the runner keeps his machine in good working order, and that the supply wire from the entry to the machine is properly insulated at all times.

12. The height of the seam influences the facility with which the machine can be operated. In a 3½-foot seam three men are usually required to handle a machine to advantage. About 35 cuts per shift of 10 hours can be made under such circumstances, provided other conditions are favorable, while in high seams two men handling the same kind of a machine can make about 60 cuts per shift, and under exceptionally favorable conditions, records of from 80 to 120 cuts per shift have been made. The most suitable height of seam for machine mining is about 5 feet.

13. When a ball of sulphur is encountered and the machine is stopped by the obstruction or by the operator as soon as he notices that it is being damaged and not likely to remove the hard material, it is often found effective to reverse the machine, in order to clean out the cut, and remove some of the cutters which come directly in contact with the sulphur ball, and finally start the machine forwards again. In this way the cutters that are left cut over or under the sulphur ball and those which are in line with it will suddenly take a deep hold, and on account of the increased speed of the machine, possibly remove the sulphur entirely and in one piece. The dull and broken cutters are in low seams usually replaced with sharp ones when the machine is on the heading between the rooms, as the men have here plenty of room to work. This does not interfere with the gathering drivers, as the undercutting is generally done at night, because the miners who are paid by the ton for shooting down the coal and loading it into the mine cars object to the machines being brought into the rooms while they are at work.

14. The truck shown in Fig. 7 is the one most commonly used with the cutting machines. In loading the machine,

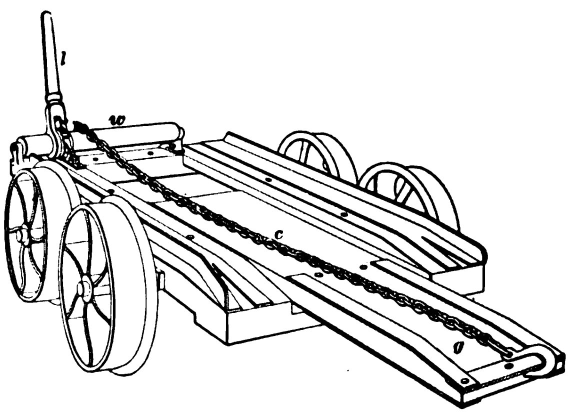


FIG. 7.

the guide *g* of the truck is lowered, so that the rear of the machine will readily slide on to it, and a hook attached to the chain *c* is placed in the ring provided for it in the brace *v*, Fig. 1, at the rear of the machine, which is finally drawn on to the truck by means of the windlass *w* that is operated by the ratchet-lever *l*, and when in position is ready to be moved.

15. Fig. 8 shows a power truck which is operated by the motor of the machine. This truck consists of a well-built frame mounted upon axles and fitted with wheels. A spool with ratchet-wheel, pawl, lever, and chain is mounted on one end in the same manner as on the standard truck.

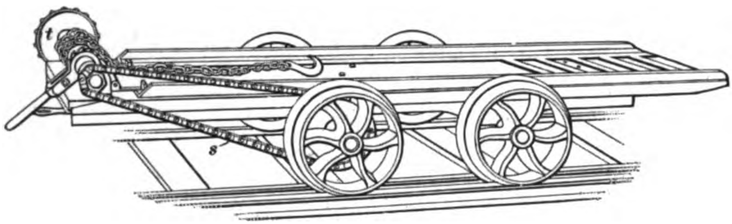
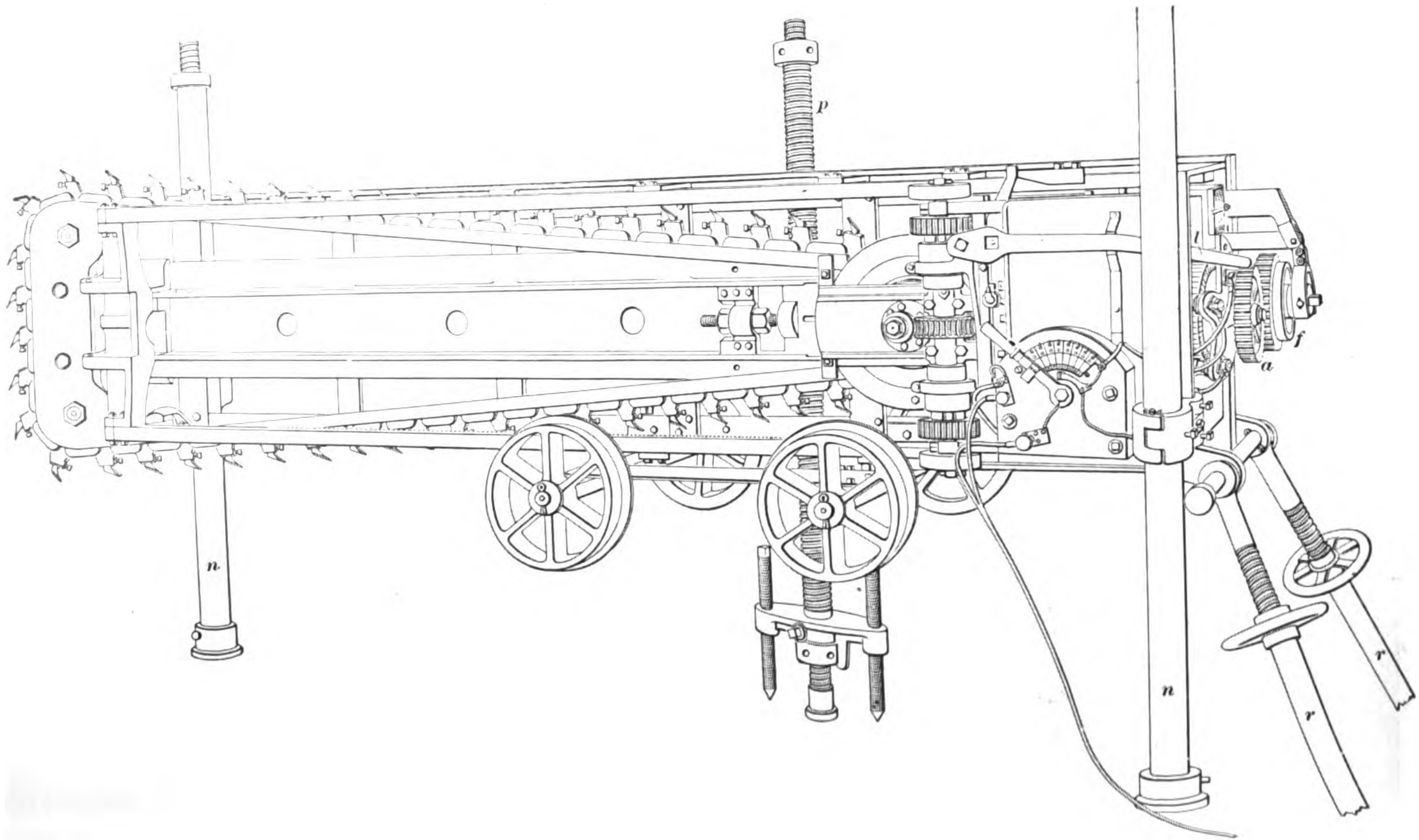


FIG. 8.

Power is transmitted by a chain to the sprocket-wheel *t*, and thence to the truck wheels by means of the chain *s*. The machine is equipped with a clutch, which can be thrown in and out of gear when necessary. When it is desired to utilize the power of the motor to propel the truck, the motor is thrown out of gear with the cutting part of the machine, so that when moving from point to point about the mine, no part of the machine is in motion except that which is necessary to operate the truck. The motor is equipped with a reversing-switch, which allows the truck to travel in either direction as desired. This attachment is being rapidly adopted, as it facilitates moving the machine about the mine, and being entirely independent of a horse or mule, it is especially valuable in thin veins and on heavy grades.

CHAIN-SHEARING MACHINES.

16. Fig. 9 shows an electric chain-cutter shearing machine, which is used principally for entry driving or turning off rooms from the butt entries; it is also used for shearing in rooms when it is difficult to make lump coal by blasting the **tight,** as the miners term the first shot in blasting down the coal over the undercut. Without the use of shearing


p
l
f
a
n
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machines, most of the coal mined in narrow work is quite fine, because so much powder is required to bring it down. This is especially true of the coal made by the tight shot in narrow work.

This machine is essentially the same as that shown in Fig. 2, except that it is mounted on its edge on a truck and provided with gear mechanism for raising it when necessary. This mechanism is driven by the motor, and consists of the spur-gears *a* at the rear of the machine and a rod that runs from these gears back to the column *p*, which is provided with coarse threads. On the end of this rod there is a worm that engages a worm-wheel screwed on the column *p*. When it is desired to raise or lower the machine, this set of gears is made to turn the rod and worm-wheel by throwing in the friction-clutch *f* by means of the lever *l*. As the worm-wheel is turned in the proper direction to raise the machine, it presses against a shoulder or cup so pivoted that the machine may slightly turn on a longitudinal axis without detriment to any part of the hoisting device. The machine is further steadied by the columns *n* on opposite sides and the rear jacks *r*. It will be noticed that the truck is rigidly attached to the machine. Before making a shearing in an entry, for instance, the road can be temporarily shoved to one side, whereby the machine can be run directly to the proper place to commence work. The action and method of operating this machine are precisely the same as that described for other chain-cutter machines. Each cut made by this shearer is 7 feet deep and 3 feet high if desired.

17. Another type of shearing machines is shown in Fig. 10. This machine is supported on four columns or jacks and is provided with mechanism for raising and lowering it. The construction is quite similar to the chain-cutter mining machine. There is a bed-frame, sliding chain-cutter frame, and a motor carriage. The bed-frame consists of two rectangular steel channel-bars and two steel angle-bars firmly fastened together by means of heavy cast-steel braces. A heavy steel casting joins the channel-bars at the

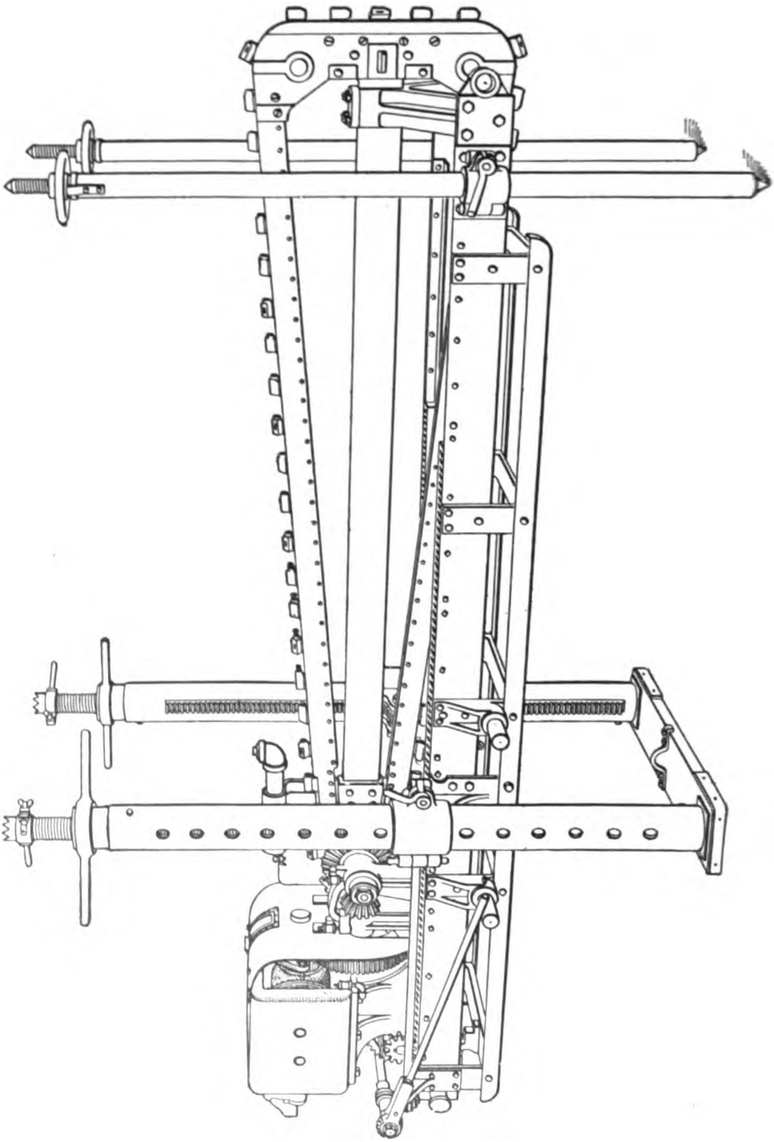

FIG. 10.

front end of the bed-frame and forms the jib or guide for the cutter frame. At the front extremity of the channel-bars two lugs are riveted for supporting the split clamp for the front jack. The supports for the main jacks are located between the center and the rear of the bed-frame, and the bearings for the truck wheels are placed on each side of these supports. The cutter frame consists of a steel center rail, a cutter head, and two steel guides in which the cutter chain runs.

The motor is of the four-pole type with Gramme ring armature and two field coils. The frame consists of one casting, which protects the armature and coils from water and falls of roof.

To operate this machine, it is first placed in position on the floor, the jacks properly set and adjusted, and the machine raised to the top of the vein where the first cut is made. Each cut is 7 feet deep, 3 feet high, and 4 inches wide, and can be made in from 6 to 7 minutes.

CONDITIONS FAVORABLE AND UNFAVORABLE TO CHAIN-CUTTING MACHINES.

18. The careful study of conditions and the rapid development of the undercutting chain machine has made it possible to mine coal with this type of machine under almost all conditions, as machines are built for both thick and thin seams, to cut in hard material by varying the speed of the moving parts, and, in fact, to be used, we might say, in any district where bituminous coal is being produced. It is true, however, that certain local conditions preclude without question the use of a machine of the chain type. Such objections are found to be large quantities of iron pyrites, occurring in the form of a ball or slab at the bottom of the vein where the cutting is done, sharp rolls in the floor causing the cutting to be done in the very hard material of which these rolls are composed, and where the roof is bad enough to require the props to be set very close to the face of the coal, thus not allowing enough room in which to work the machine. Also, when the inclination of the vein exceeds 12 or 15 degrees, the use of chain machines is impossible. Even at a dip of 12 degrees, working with a chain machine is frequently difficult and unsatisfactory. To obtain the best results, the floor should be level or nearly so.

In some cases pick machines have been used in mines having a dip of 23 degrees, but the work was slow and difficult, and only the high price of labor made them profitable. Manufacturers do not care to run the risk of failure in installing machines in mines having an inclination of 15 degrees. The first two conditions mentioned militate against the use of the chain machine, in that the cutters are not capable of disintegrating the material, and either break or are ground off; after the cutters are incapable of cutting, the machine is fed into the material with such force that great strains and stresses are thrown on the various parts of the machine, and unless care is exercised by the runner, damage will be done. While the above conditions may exist to some extent in any mine, it does not necessarily follow that the simple fact of their occurrence decides the question of mining by machines, and before deciding whether or not machine mining is practical, a careful investigation should be made by one who is familiar with the use of machines.

Where most of the mining is done on pillars, as in old workings, the chain cutter is seldom used. The great weight on the coal presses it down upon the machine, and after having made a cut it may not be possible to withdraw, in which case it is necessary to dig the sliding frame of the machine out with a pick. There is also danger of damaging the machine when using it for this kind of work. Under these conditions, it is more economical to use the pick machine or mine by hand. A similar objection works against the chain-breast machines for longwall mining, as too much space is required for them between the gob and the face of the coal. With a wide space between the gob and the face, the pressure of the roof is apt to squeeze the coal and wedge the machine.

WORKING CAPACITY OF CHAIN CUTTERS.

19. As the conditions under which a machine is operating determines the amount of work which it can do, it is possible to give but an approximate idea of the capacity of one of these machines. It is safe to say that where the chain machine can be used it will make from 30 to 40 cuts per day, each cut being 44 inches wide and 5, 6, or 7 feet deep. Allowing for lap in cuts, this would amount to from 100 to 150 lineal feet along the face, or from 500 to 1,000 square feet undercut. The record for cutting with a machine of the chain type is 104 cuts 6 feet deep in 9 hours and 40 minutes, the distance cut along the face being 333 lineal feet. In doing this work, the machine was moved six times and cut both rooms and narrow places.

LONGWALL MINING MACHINE.

20. Mining by machinery having been adopted so extensively has been the cause of developing machines adapted to each system. The longwall system of mining by hand has proved itself to be the most economical where the conditions are such that this system can be followed. Being the most economical to work by hand, the longwall system would naturally offer advantages to machinery which was particularly adapted for it, and a study of this system has developed a machine of the longwall type. The time required to shift a machine of the chain-breast type is so great that one of this kind could not be used, and a machine so constructed that it could cut continually along the face was designed.

21. Fig. 11 shows one of these machines. As will be observed, it is very compact, and is so constructed that maximum strength is contained in minimum space. The machine consists essentially of three parts: the motor, driving mechanism, and feeding gear. These are mounted upon two cast-steel angles, which run the entire length of the machine. The motor is bolted to the angles in the middle,

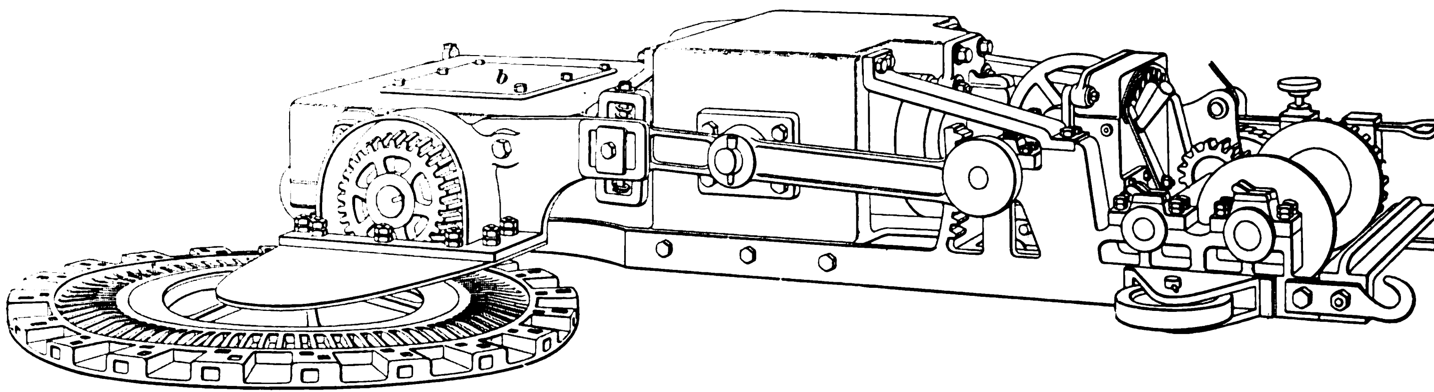

FIG. 11.

the driving mechanism is at one end, and the feeding gear at the other; these are further held together by braces, so that the machine is thoroughly strengthened throughout. At the front left-hand corner of the machine is located the cutter wheel. This is made of malleable iron, cast so that the teeth in which the driving pinion meshes form a part of its periphery; outside of these teeth are the heavy lugs in which the cutters are inserted. The wheel is supported by a heavy steel plate projecting from and bolted to the main portion of the machine.

The motor is of the multipolar type, having an iron-clad armature and two field coils. The armature lies in a position parallel to the length of the machine. A bevel pinion on the end of the armature shaft meshes with a large bevel-gear, which is mounted on a shaft at right angles to the armature shaft and which carries a bevel pinion meshing in the teeth of the large cutter wheel. On the same shaft at the opposite end is a pinion which meshes with a spur gear, driving a shaft to which is attached an eccentric. To this eccentric is attached a rod which passes along the side of the machine to a cross-head, to which is attached a connecting-rod driving a ratchet, which in turn drives a ratchet-wheel geared by a single reduction to a drum, upon which is wound a rope by which the machine is drawn or fed forwards.

The cutter wheels are built of different sizes to cut from 3 to 5 feet deep, the depth of cut depending entirely upon the conditions. The width over all of the machine when the cutter wheel is embedded in the coal is 3 feet 8 inches; its total length is 7 feet 9 inches; its total height is about 18¾ inches.

The feeding mechanism, which has already been described, is variable, allowing the rate of winding the cable on the drum to be changed at will to 8, 16, or 25 inches per minute. The wire cable is run along the face of the coal as far as is desired, then passed around a sheave attached to a jack rigidly set between the roof and the floor, and then back to the machine, where it is hooked on the frame at the hook shown near the drum.

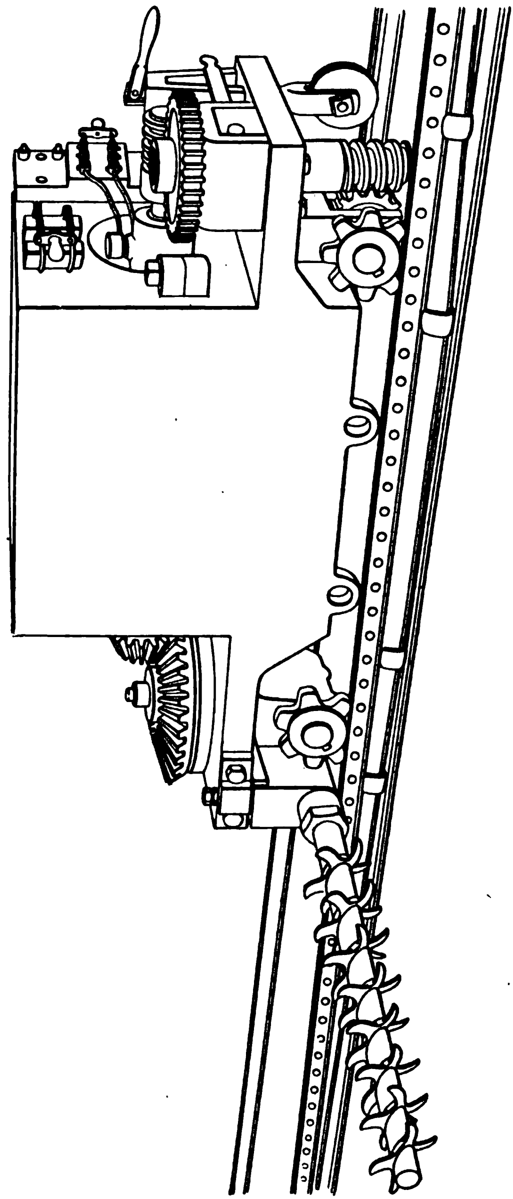

FIG. 12.

The cast-steel box *b* completely encases the gearing and is made oil-tight, so that the gears can be run in oil and any possibility of cutting avoided.

This machine, when in operation, is mounted on a single track or rail, and is known as the single-track type. The rail upon which it travels is held in place by suitably arranged jacks braced against the roof, and consists of two flat bars of iron, one 2 in. × ½ in. riveted upon the other, which is 4 in. × ½ in., the machine resting upon these by two flanged idlers, one at each end of the machine.

The operator, whose duty it is to see that the machine is working properly and to regulate the speed of feeding, can, by means of a hand-wheel, adjust the angle of the cutter wheel with respect to the horizontal, thus making it possible to cut close to the bottom and avoid any impurities which may be encountered, at the same time being able to follow the formation of the bottom or floor.

In addition to the operator, at least two men are required to lay track and remove obstructions.

This machine has been adopted to a limited extent in the United States and very generally abroad.

22. Another type of longwall machine which has recently been successfully introduced into some of the thin-vein mines of the Western fields is shown in Fig. 12. This machine has for its cutting mechanism an extension arm, around which is wound a spiral band of steel with 42 projecting teeth. In addition to cutting the coal, this spiral device acts as a screw conveyer in cleaning out the under cut. The arm can be turned on a pivot, so as to extend from the rear of the wheel for renewal of the spiral band and for starting the cut without recourse to hand picking. The motor is operated on a two-rail track, the rail next the coal being composed of two pieces of angle-bars held 1¼ inches apart by shouldered rivets set at intervals of 1¼ inches. This gives the effect of a rack bar, which meshes with the toothed wheels on that side of the motor. The outside rail and wheels are plain. By means of the handle shown above the right-hand upper wheel, the cutting bar may be made to operate up or down from a horizontal plane, cutting over or under obstructions in the coal, and avoiding irregularities in the floor. Each outer wheel can be raised or lowered separately.

Two sets of rail are used, one being taken up and reset.

THE CUTTER-BAR MACHINES.

23. The first electric chain-breast machine was put on the market in 1894, and almost simultaneously by three manufacturing concerns. Five years before, electricity had been successfully applied to a different type of coal-cutting machine, which had previously been operated solely by compressed air. This machine was what was known as the cutter bar. With the introduction of the chain-cutting machine, the cutter bar became obsolete and its manufacture abruptly ceased; but as some of these machines are still in operation in a few mines in the Western States, and as they mark an important step in the evolution of the successful machine, the student should have some knowledge of their construction.

The stationary frame of the cutter-bar machine was not materially different from that of the present chain machine, and the perfected type possessed a rack-and-pinion feed mechanism similar to that in use on the chain machines. The difference lay in the cutting mechanism itself and the direction of its movement. The cutting tool consisted of a rotating bar of steel extending across the forward end of the machine. The cutting teeth were inserted in its circumference, the second being slightly behind and a little to the side of the first, and so on, so that the line followed by the teeth was that of the thread of a screw. The bar was rotated by an endless chain driven by sprockets attached to the main driving shaft of the machine.

It will be observed that in this machine the coal was attacked in a direction at right angles to that of the chain machine. The power required to operate it was considerably more than that necessary for the chain machine, its rapidity of cutting was less than the chain machine, and more difficulty was experienced in keeping the cut free of dirt. The first of these machines was made in 1876, the last one in 1894

PICK MACHINES.

24. In applying mechanical means for the production of coal, the natural form of machine was one built to attack the coal in a manner similar to that of the miner with his pick, and this idea eventually produced the machine which is commonly known as the "pick" or "puncher" machine, and which is the one that was first adopted for mining coal. The difficulty of transforming a rotary to a reciprocating motion has caused many of the efforts to build a practical electric pick machine to be unsuccessful; but such a machine has been built, and the following is a description of its working and construction. There is a wide field for electric machines of this type.

DESCRIPTION OF A PICK MACHINE.

25. Fig. 13 shows an electric pick machine which has a reciprocating piston actuated by a spring and cam, the spring striking the blow and the cam drawing the piston back. The cam is driven by a motor *m* of the toothed

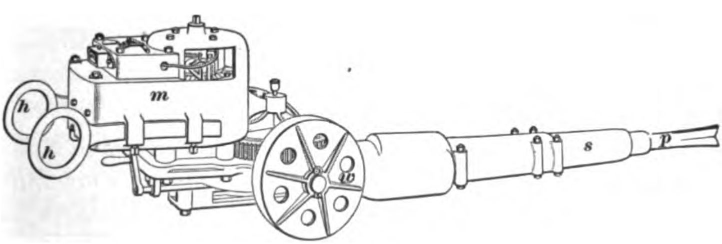

FIG. 13.

Gramme ring type. The important feature is the manner of connection of commutator to coils, there being no wire connections at this point, which makes the armature as nearly indestructible as possible. The pick *p* is attached to the outer end of the piston, which is supported by the sleeve *s*.

The machine weighs 750 pounds and is mounted on wheels *w*. It is controlled, while working, by the handles *h*. Its length is 7 feet and its width over the wheels 21 inches. The piston makes from 175 to 225 8-inch strokes per minute.

METHOD OF OPERATING PICK MACHINES.

26. Fig. 14 shows a pick machine at work where props are set up close to the working-face. It will be noticed

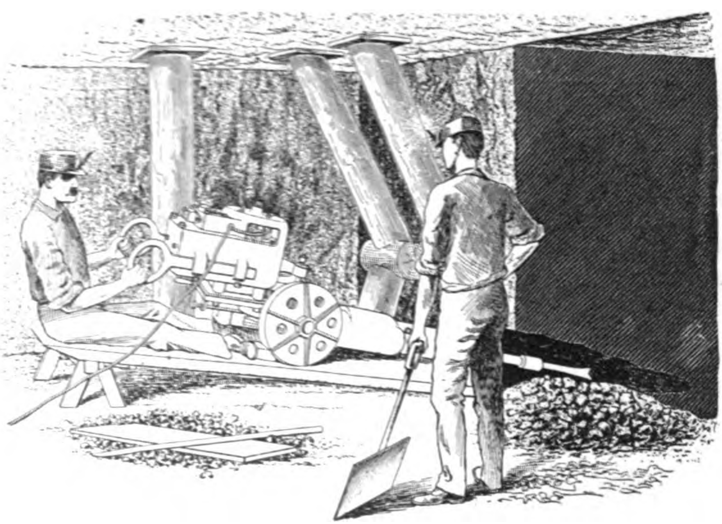

FIG. 14.

that the machine is placed upon a platform which is inclined towards the face, so as to neutralize the recoil of the machine by gravity and at the same time enable the operator to advance the machine easily as the cut deepens. The pick strikes from 175 to 225 blows per minute as desired, and while in operation the runner directs each blow by taking hold of both handles and sitting upon the platform just back of the machine. When necessary he prevents the machine from running back by pushing a block of wood, or simply by placing the heel of his shoe, under one wheel with his foot. (He usually uses a wooden "chock" fastened to the bottom of his shoe.) Only two men are required to operate the machine, one skilled as runner and an ordinary laborer as helper, who shovels away the slack or cuttings from the machine and assists in placing the platforms. In order that the machine can be kept continuously at work, two platforms are used. While the one is in use the helper places the other one alongside of it, so that the operator can run the machine off the one on to the other whenever a cut is completed.

27. In making an undercut, the runner directs the machine so as to make a groove at the bottom of the coal about 1 foot deep and 3 or 4 feet along the face, according to the width of the platform and size of the machine. This groove is then enlarged by blocking down some of the coal, after which the same operation is repeated until the required depth is reached. When finished the front of the cut is about 12 inches high and the back about 2 inches high. This gives the cut a V shape, and causes the coal when blasted down with as light a charge of powder as possible to roll over in such a manner that the loaders can readily attack it.

28. Pick machines being mounted on wheels can easily be shifted or run from one room to another through the cross-cuts or break-throughs by the workmen, and in this respect they are more convenient than other types, which require mechanical means at all times to shift or transport them. Frequently, however, pick machines are run on to a truck for transportation.

29. Fig. 15 shows a pick machine mounted on large wheels for shearing or making vertical cuts in the coal. This machine is in all respects similar to the one already described, except that the wheels *w* are 40 inches in diameter. It will shear 4½ feet deep and 4½ feet high, or higher, if the platform is placed on slack.

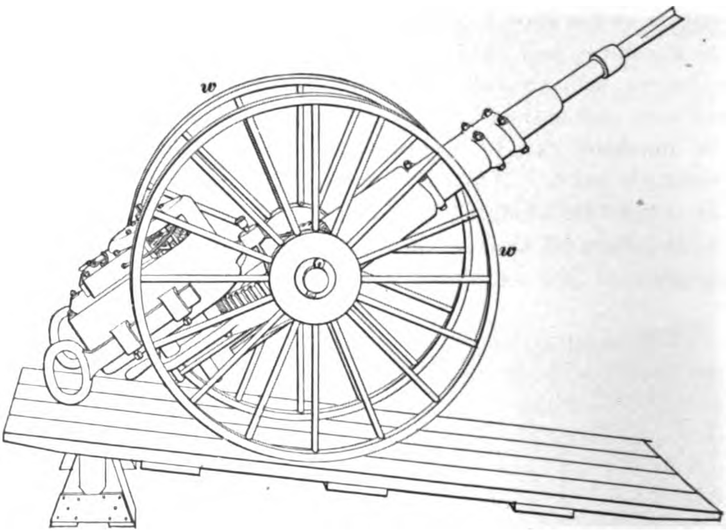

FIG. 15.

30. Fig. 16 shows a machine in position for making a shearing on one side of an entry. It will be noticed that the lower portion of the shearing is made wide enough for the wheels to enter. The operation of the machine for shearing is the same as for undercutting. The shearing is made after the undercut is finished by simply replacing the small wheels with the large ones and operating the machine to form a vertical cut, usually along the side, instead of a horizontal one along the bottom, as is done in regular undercutting. The truck *t* is used to carry the machine from place to place. It is more expensive to shear coal than to blast it, but more lump coal is produced with the shearer, and the air at the working-face is rendered impure by the gases formed by blasting.

CONDITIONS FAVORABLE AND UNFAVORABLE TO PICK MACHINES.

31. The pick machine can be used under all conditions favorable to mechanical methods of mining coal, and the only conditions which preclude its use where undercutting

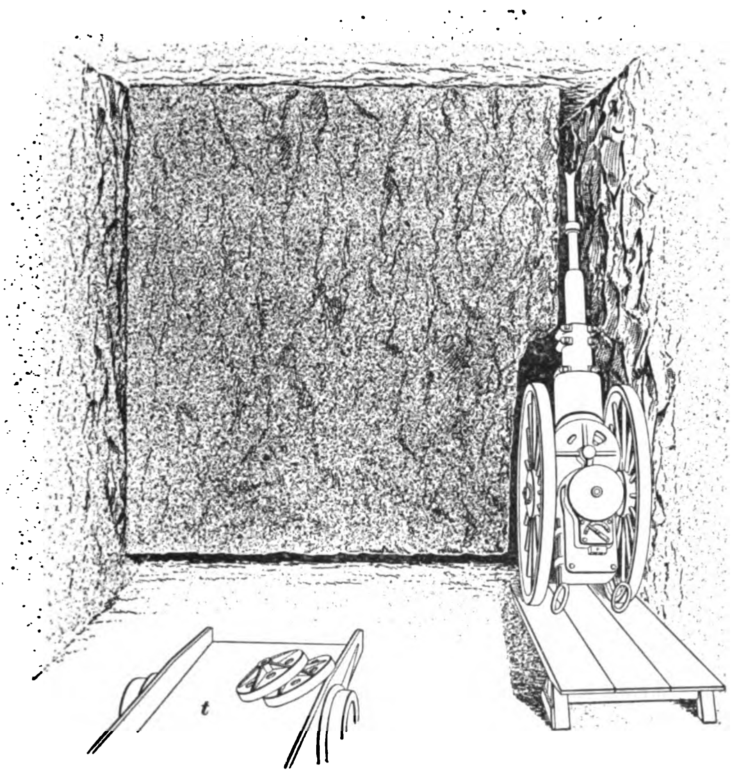

FIG. 16.

is necessary are too great a pitch, too low a seam, and bad roof where props must be set up close to the face and in great numbers. This latter condition affects the pick machine less than other types of coal-cutting machinery, as may be seen by referring to Fig. 14, where a machine is shown at work among props and cockermegs used to support the undercut portion of the coal.

32. It can be seen from the construction and method of operating pick machines that they can cut the coal surrounding any hard foreign matter which may be embedded in the coal, and therefore remove such material without injury to the machine. For this reason pick machines are suitable for working seams of coal containing balls of iron pyrites, which will blunt or destroy any steel-cutting tool with which they come in contact. It is also evident that pick machines are suited to undercut coal on which there is a squeeze.

WORKING CAPACITY OF PICK MACHINES.

33. The amount of undercutting that can be done with any pick machine depends upon the lay and nature of the coal mined and the tact of the runner. A good electric pick machine will undercut about 450 square feet in 10 hours if handled properly, when a miner doing nothing else could undercut only about 120 square feet. In other words, pick machines will each cut from 50 to 100 tons of coal per day of 10 hours in seams varying in thickness from 4½ to 6 feet. The cost of cutting coal with pick machines in seams 4½ feet is approximately 10 cents per ton.

The figures given must not be confounded with phenomenal records which have been made, and which are the exception and not the rule. In Western Pennsylvania a compressed-air pick machine has undercut as much as 1,400 square feet in 9 hours, and in an 8-foot seam has mined as high as 240 tons per shift of 10 hours.

34. The student should carefully notice that the force with which the pick strikes depends upon the distance it penetrates the coal. For example, if the pick struck soft "mother coal" it would penetrate it for perhaps 1 foot, while if it struck hard rock it would only penetrate it for perhaps ¼ of an inch. In either case the energy stored up at impact would be given up in a distance equal to the depth of the cut, and therefore since it requires a greater resistance to stop the pick in ¼ of an inch than in 1 foot, it is clear that the blow is much greater on the rock than on the mother coal, although the work done on each is the same.

GENERAL REMARKS.

35. Whatever the methods of undercutting, a greater proportion of lump coal will be obtained in the high seams, and for this reason the output of screened coal per machine will be much greater in thick than in thin veins. But the increased cost of mining thin veins by hand makes the advantages of machine mining in thin veins much greater than in thick ones. It will be seen by referring to Fig. 17 that the amounts of coal made fine by undercutting in two seams *A* and *B* are equal, because the undercuts are the same size, which is generally so in practice. It is best to undercut a seam of coal at least to a depth equal to its height, in order to get the best results from blasting. When this is done and the undercuts are V shaped, as shown, the ratio of the small coal to the lump is approximately the same for all seams.

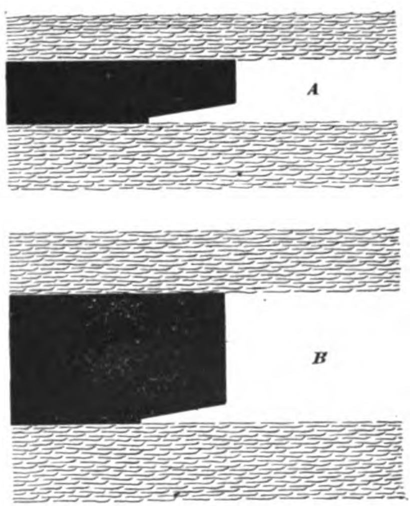

FIG. 17.

36. From the foregoing it will be plainly seen that each mine must adopt the machinery which is especially suited to its conditions and that there is hardly a mine to which some form of machine can not be applied. Where it is possible to have a long working-face, it is more economical to take advantage of this feature, as the machine can be kept constantly at work and less time consumed in moving. But where this can not be done, it simply remains to select the best form of machine for the conditions. There is no doubt that future methods of working coal will be modified to suit mechanical mining, for even with the present methods, mechanical mining has proved to be economical, and with the perfection which has been reached in the construction of machinery for this purpose, it is safe to predict that great reductions in the cost of production will be made in the future by the adoption of new methods of mining and the construction of new machinery.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS

TREATED OF IN THIS VOLUME.

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number as the Question Paper in which the questions or examples occur has been carefully studied.

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What

DYNAMOS AND MOTORS.

(PART 1.)

(1) Fig. 1 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?

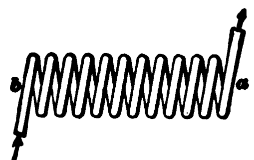

FIG. 1.

(2) (*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? Give reasons.

(3) 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.

(4) The separate resistances 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. { 2.9643 amperes in branch *A*
3.4057 amperes in branch *B*.

(5) Express the equivalent of 2.33 horsepower in watts.

Ans. 1,738.18 watts.

(6) 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? (*b*) What

is the power in watts dissipated between these two points? (*c*) Give its equivalent in horsepower.

Ans. { (*a*) 25.3913 amperes. (*b*) 1482.8521 watts. (*c*) 1.9877 horsepower.

(7) In a voltaic couple of zinc and platinum, which metal will be the negative element? Why?

(8) 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?

(9) Fig. 2 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 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*.

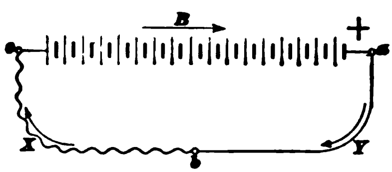

FIG. 2.

Ans. { Total E. M. F. developed by battery = 27.525 volts. Difference of potential between *a* and *b* = 8.475 volts. Difference of potential between *b* and *c* = 6.15 volts. Difference of potential between *c* and *a* = 14.625 volts

(10) 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.

(11) 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.

(12) 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.

(13) Given, electromotive force = 112.5 volts and strength of current = 12.2 amperes; find the power in watts.
Ans. 1,372.5 watts.

(14) 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.

(15) The resistance of a copper wire is 43.2 ohms at 60° F.; find its resistance at 85° F. Ans. 45.5274 ohms.

(16) 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.

(17) 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.

(18) 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.

(19) (*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. { (*a*) The total resistance of the circuit = 5.423 ohms.
(*b*) The internal resistance = .677875 ohm, and the external resistance = 4.745125 ohms.

(20) 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.

(21) 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.

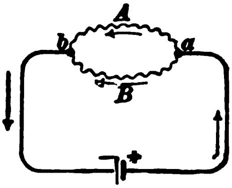

FIG. 3.

(22) In Fig. 3, 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. { The separate resistance of branch $A = 1.7313$ ohms.
The separate resistance of branch $B = 2.3673$ ohms.

(23) 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.

(24) What must have been the strength of current in amperes in a closed circuit through which 368,422 coulombs of electricity passed in 4½ hours? Ans. 22.7421 amperes.

(25) 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.

(26) Given, the electromotive force = 525 volts and strength of current = 12.5 amperes, express the number of horsepower. Ans. 8.7969 horsepower.

(27) (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. { (a) 50,820 watts.
(b) 68.1233 horsepower.

(28) The diagram in Fig. 4 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.

(29) 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.

(30) Find the equivalent of 54,200 watts in horsepower.

Ans. 72.6541 horsepower.

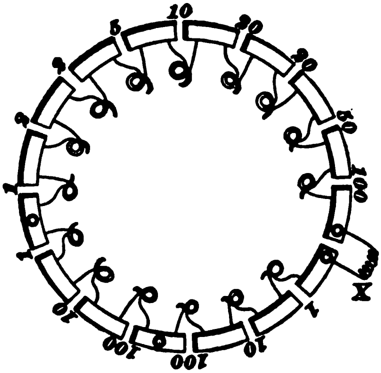

FIG. 4.

(31) 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.

(32) 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.

(33) A voltmeter *V. M.*, Fig. 5, is connected to the poles *a* and *b* of a battery *B* whose circuit is open and indicates

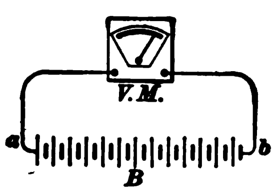

FIG. 5.

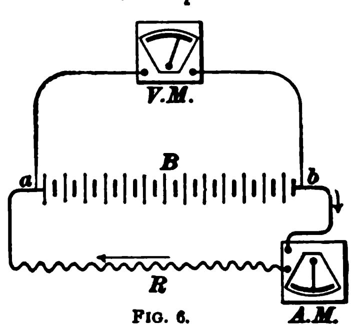

FIG. 6.

an E. M. F. of 24.4 volts. The battery is then connected in circuit with an ammeter *A. M.*, Fig. 6, 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. { Internal resistance = 8 ohms.
External resistance = 22.5 ohms.

(34) 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.

(35) A battery of twenty-four cells is arranged in multiple-series as shown in Fig. 7. There are four groups of six cells each, connected in series, and the four groups are connected in multiple, or parallel, to two main conductors *c* and *c'*. If the E. M. F. developed by each cell is 1.5 volts, what would be the E. M. F. indicated by the voltmeter *V. M.* when its binding-posts are connected to the main conductors *c* and *c'*, as shown in the figure?

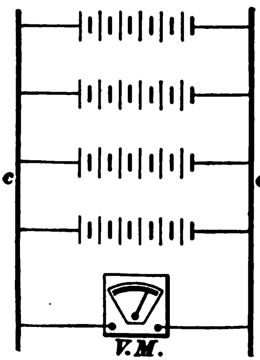

FIG. 7.

(36) 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.

(37) 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?

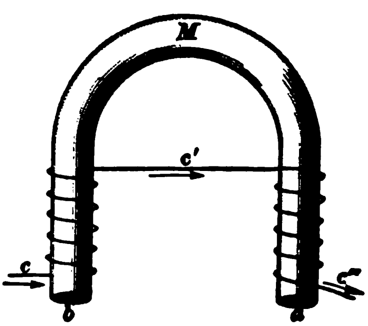

FIG. 8.

(38) Fig. 8 represents a horseshoe electromagnet *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 ?

(39) 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 ?

(40) 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 ?

(41) Give the names of all the known magnetic substances.

(42) A compass *C* is placed between the north and south poles of two magnets, as shown in Fig. 9. Towards which pole will the north pole of the compass needle tend to point, and why ?

FIG. 9.

(43) A compass *C* is placed alongside of a bar magnet opposite the neutral line, as shown in Fig. 10. Towards which pole of the magnet will the south pole of the compass needle tend to point, and why ?

FIG. 10.

(44) 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.

(45) In an electromagnet, Fig. 11, the coil of wire is wound around an iron core in a right-handed spiral.

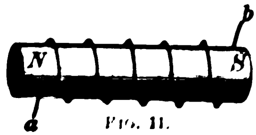

FIG. 11.

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?

(46) The resistance of a platinum wire 112 ft. 6 in. long is 100.8 ohms; calculate the resistance of 11.7 inches of the same wire, other conditions remaining unchanged.

Ans. .8736 ohm.

(47) 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.

(48) 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.

(49) 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.

(50) 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. .686 ohm.

(51) The diagram, Fig. 12, represents a particular pattern of resistance-box for a 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 is the resistance of *X*?

Ans. 7.23 ohms.

(52) 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.

(53) 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.

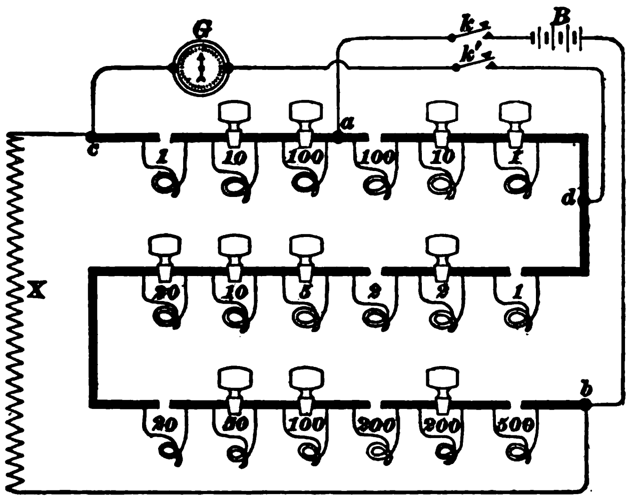

FIG. 12.

(54) 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.

(55) 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.

(56) 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. { (*a*) .3125 ohm.
{ (*b*) .00026 ohm per foot.

(57) 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.

(58) 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. { The current in branch *A* is 29.1176 amperes.
The current in branch *B* is 15.8824 amperes.

(59) 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.

(60) 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 in multiple. Ans. 223.2534 ohms

DYNAMOS AND MOTORS.

(PART 2.)

(1) 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.

(2) 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.

(3) What is the distinction between an alternating current and a continuous current?

(4) Fig. 1 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

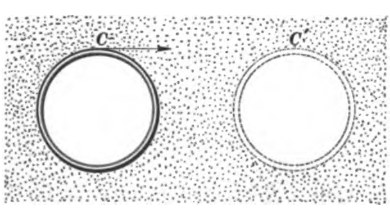

FIG. 1.

suddenly moved from its original position to another position in the field, as to C', as shown by the dotted coil, without changing the relative position of its plane with the direction of the lines of force, state whether or not a momentary current will circulate around the coil when the movement is made, and give the reason.

(5) The efficiency of a dynamo at full load is 88%, and at this load it requires an input of 18 horsepower to drive its armature. Determine the output in watts under these conditions. Ans. 11,816.64 watts.

(6) The output from a certain dynamo is 17,500 watts, and its efficiency at this output is 87.5%. If 2.6% of the input is used to excite the field-magnets, state the field loss in watts. Ans. 520 watts.

(7) The resistance of the shunt-field coils of a constant-potential dynamo is 55 ohms, and the difference of potential between the brushes when the armature is revolving at normal speed is 110 volts. How many watts are required to excite the field magnets? Ans. 220 watts.

(8) What is a commutator and for what is it used?

(9) A field rheostat is connected in series with the field circuit of a constant-potential shunt dynamo. When the external circuit of the dynamo is open, all the resistance of the rheostat is in circuit with the field coils and a current of 1.5 amperes is flowing through the field circuit. After the external circuit is closed and the current from the armature increases, it is necessary to cut out or short-circuit the resistance of the rheostat in order to keep the difference of potential between the brushes at 360 volts from no load to full load. At full load, the current in the field is 1.8 amperes; find the amount of resistance which was cut out or short-circuited in the rheostat. Ans. 40 ohms.

(10) The output of a dynamo is 65,000 watts, and its efficiency at this output is 90.5%; determine the input to the armature, and express the same in horsepower.

Ans. 96.2777 horsepower.

(11) Fig. 2 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 arrow-heads, 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?

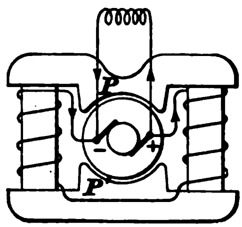

FIG. 2.

(12) Define a ring winding and a drum winding, and point out the difference between the two.

(13) The input to a dynamo is 10 horsepower and its output is 6,341 watts. What is its efficiency at this load?

Ans. 85%.

(14) Fig. 3 represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the

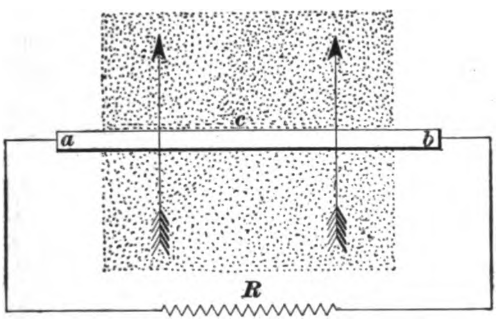

FIG. 3.

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 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?

(15) 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.

(16) (*a*) What is meant by the *counter torque* of a dynamo? (*b*) What causes it?

(17) 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.

(18) In example 17, 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%.

(19) (*a*) What is meant by the *sparking limit* of the load of a dynamo? (*b*) What causes the sparking?

(20) 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 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.

(21) Fig. 4 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?

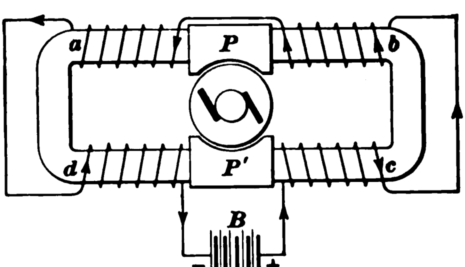

FIG. 4.

(22) What causes the neutral points in a dynamo to shift when a current is flowing in armature conductors?

(23) 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%.

(24) (*a*) In example 23, 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. { (*a*) 2.1881% loss.
(*b*) 1.094% loss.
(*c*) 1.6165% loss.
(*d*) 2.5999% loss.
(*e*) 7.8058% total loss.

(25) 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 remaining unchanged? Ans. 513⅓ volts.

(26) What limits the output of a constant-potential dynamo? Why?

(27) In Fig. 5, *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*. A key *k* is inserted into the primary circuit

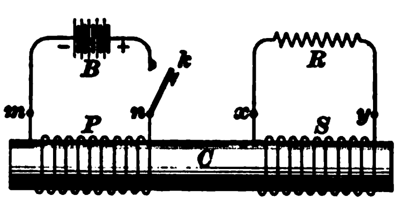

FIG. 5.

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* flow ?

(28) In example 27, 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* flow ?

(29) Give two reasons why carbon brushes will spark less than copper brushes, under the same conditions.

(30) Fig. 6 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.

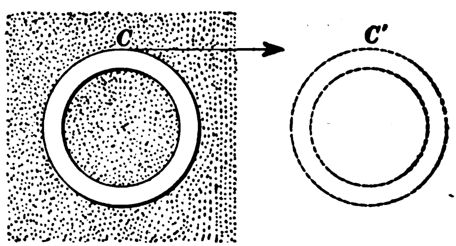

FIG. 6.

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 ?

(31) What is a compound-wound dynamo, and why are dynamos compound-wound ?

(32) If a conductor cuts 8,000,000 lines of force in one-quarter of a second, what is the *rate of cutting* per second ?

(33) State why a solid piece of iron will not answer for a revolving armature core.

(34) 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.

(35) 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. 333⅓ volts.

(36) To what are the following losses in a dynamo due: (*a*) core loss? (*b*) armature loss? (*c*) field loss?

(37) In Fig. 7, 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 arrow-heads, towards which side, *a* or *b*, of the pole face will the conductor tend to move?

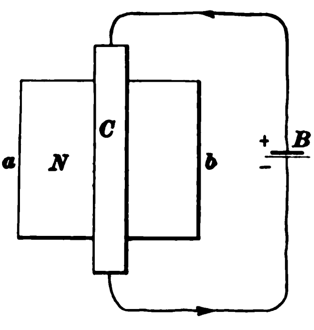

FIG. 7.

(38) 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.

(39) 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%.

(40) Define an open-coil winding and a closed-coil winding, and point out the difference between the two.

(41) 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.

(42) 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.

(43) 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.

(44) What becomes of the heat generated in a dynamo armature?

(45) 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.

(46) 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.

(47) State the differences of separately-excited, shunt, and series-wound dynamos.

(48) 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%.

(49) Why must the brushes of the dynamo be shifted ahead of the neutral point when operating under load?

(50) What is the difference between a consequent pole and a salient pole?

DYNAMOS AND MOTORS.

(PART 3.)

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(1) (*a*) What is a transformer? (*b*) For what purpose is a transformer used?

(2) 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?

(3) How can a short-circuited coil in an armature winding be detected?

(4) Which form (ring or drum) of armature winding is most generally used for alternators?

(5) Why will an ordinary series-wound dynamo, without regulating devices, not give a constant current through a circuit of varying resistance?

(6) What causes the current in an alternating-current circuit to lag behind the E. M. F.?

(7) What is meant when two alternating currents are said to differ in phase?

(8) 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?

(9) What causes an ordinary series-wound motor to race or run away (*a*) when connected in a constant-current circuit? (*b*) when connected to a constant-potential circuit and all the load removed?

(10) (*a*) What is meant by a *cycle* in speaking of an alternating current? (*b*) What is meant by the *frequency* of an alternating current?

(11) How is the Thomson-Houston constant-current dynamo regulated to give a constant current?

(12) What is the *effective* strength of an alternating current?

(13) 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. { (*a*) 13.88 H. P.
(*b*) 86.3%.

(14) Why will an alternator armature not start to turn if supplied with an alternating current from some external source, the fields being excited?

(15) 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?

(16) Draw a diagram showing the connections of a shunt-wound motor with main switch, reversing-switch, starting resistance, and fuse boxes.

(17) How may the speed of a direct-current motor be varied?

(18) Why is the resistance of a circuit having self-induction apparently greater with alternating currents than with continuous?

(19) 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?

(20) 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. 48, Art. **115,** and starting with it in its present condition?

(21) 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?

(22) (*a*) What three general methods of regulation are used with closed-coil constant-current dynamos? (*b*) Which of the three is most generally used?

(23) 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?

(24) 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?

(25) 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 min.

(26) What would be the frequency of the alternating current furnished by a 14-pole alternator running at 1,080 revolutions per minute? Ans. 126.

(27) (*a*) For what purpose is a lightning-arrester used? (*b*) How does it work?

(28) Why is the starting resistance of a shunt motor not included in the field circuit?

(29) How is it that the magnetic field of a rotary-field motor rotates?

(30) How may a grounded field coil in a shunt-wound generator be located, the current from another similar dynamo being available?

(31) (*a*) What is a multiphase alternator? (*b*) How does the current it furnishes differ from that of a single-phase machine?

(32) How is an alternator compounded?

(33) How may a path be provided over which the static electricity which may accumulate on a dynamo frame escapes?

(34) In general, what is the object of a switchboard?

(35) 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?

(36) What is the general principle upon which all electric motors operate?

(37) What are bus-bars, and for what are they used?

(38) Why will an armature of too low resistance give little starting torque in a rotary-field motor?

(39) What is the character of the current in the external circuit of open-coil constant-current dynamos?

(40) For what purpose is the equalizing connection used in connecting compound-wound dynamos in parallel?

(41) 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?

(42) 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?

(43) What is meant by a burned-out armature coil?

(44) How may an armature be balanced?

(45) Why does the neutral line of a motor shift in the opposite direction to that of a dynamo?

(46) 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?

(47) What limits the output of constant-current dynamos?

(48) What losses occur in a static transformer?

(49) What are some of the advantages of magnetic-circuit breakers as compared with fuses for use on switchboards?

(50) 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?

(51) How does armature reaction affect the output (*a*) of synchronous alternating-current motors? (*b*) of rotary-field motors?

(52) 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. { (*a*) 11.76 H. P.
(*b*) 91.17%.

(53) What is the effect of too much oil or grease on the commutator of a direct-current constant-potential machine?

(54) (*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?

(55) How is the E. M. F. of the Excelsior constant-current dynamo regulated to give a constant current?

(56) 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. ?

(57) (*a*) By what two general systems is the current for incandescent lighting distributed ? (*b*) Describe the essential features of each method.

(58) 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 min.

(59) 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 ?

(60) (*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 ?

(61) 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 ?

(62) Why should both parts of the magnetic circuit (field-magnet and armature core) of a rotary-field motor be laminated ?

(63) Why is it necessary to use multipolar field-magnets for alternators ?

(64) In what general respects do switchboards for incandescent-lighting circuits using alternating currents differ from those using direct currents ?

(65) To reverse the direction of rotation of a direct-current motor, what changes in the connections are necessary ?

(66) 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. ?

(67) To what classes of work are (*a*) shunt-wound direct-current motors applicable? (*b*) series-wound motors? (*c*) Why?

(68) Describe the method of shifting the brushes used in the Thomson-Houston constant-current dynamos.

(69) What is a water rheostat, and for what is it often used?

(70) How is it that the armature winding of a rotary-field motor has no connection with the external circuit?

(71) On what conditions does the torque of a direct-current motor depend?

(72) Why does closing the secondary circuit of a transformer increase the current in the primary?

(73) What is meant by the "slip" of a rotary-field motor?

(74) Make a sketch showing your idea of the proper arrangement of the apparatus and the principal connections on a switchboard for a plant employing three compound-wound direct-current dynamos which are to be run in parallel and are to supply seven lighting circuits.

(75) Describe the general features of the Prony brake.

(76) 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?

(77) 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 min.

(78) (*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?

(79) 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?

(80) How may the applied E. M. F. of a direct-current motor be varied?

(81) From the nature of the sparking, how can you tell whether the brushes of a direct-current constant-potential dynamo are too far forwards or too far back?

(82) How are the devices for shifting the brushes of constant-current dynamos with closed-coil armatures usually thrown into or out of action?

(83) A three-phase rotary transformer is to deliver current at 200 volts. What must be the voltage of the alternating current supplied to it? Ans. 122.4 volts.

(84) An alternating current whose curve is of the form shown in Fig. 17 or 18, 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*) 8.48 amperes.

(85) Why will the speed of a direct-current motor increase if the field is weakened?

(86) What is phase splitting?

(87) State two of the methods used in starting polyphase synchronous motors.

(88) How may the direction of rotation of a polyphase induction motor be changed?

(89) How may a two-phase induction motor be used on a single-phase circuit?

(90) What will be the alternating E. M. F. supplied by a two-phase rotary transformer fed with direct current at 220 volts? Ans. E. M. F. of each phase, 155.5 volts.

(91) How may the E. M. F. of the direct current supplied by a rotary transformer be varied?

(92) Referring to Fig. 16, Art. **34**, what will be the E. M. F. between *1* and *4* if the voltage on each phase is 440 volts?

ELECTRIC HOISTING AND HAULAGE.

(1) Compare electricity with steam and compressed air as to their relative advantages in the transmission of power at a mine, both when the major portion of the power is to be used for hoisting and haulage and when drills or pumps are to be operated.

(2) What are the steepest grades on which electric locomotives can be employed ?

(3) What is the advantage of transmitting electrical energy at a high voltage ?

(4) If, for the convenient handling of material, it is necessary to install the power plant at some distance from the mine, what advantage has electricity over steam or compressed air ?

(5) What is the difference between continuous insulation and interval insulation, and what would you consider the advantages of each ?

(6) Where should the trolley-wire, or other electric wires used underground, be placed in relation to the track ?

(7) Describe one method of supporting the trolley-wire for underground traction.

(8) Why is it that wires encased in conduits or moldings can not be depended upon to transmit as much electrical energy as those which are exposed throughout their entire length ?

(9) What precaution should be taken to prevent persons from receiving a shock from the frame or other portions of electric mining pumps, hoists, etc.?

(10) What special advantage has the electric motor for use in connection with hoisting?

(11) Into what two divisions may underground haulage in mines be divided?

(12) What special advantages does the electric locomotive possess for underground work?

(13) When an electric locomotive is controlled by a series-parallel controller, what takes place during each stage of the starting, i. e., upon each movement of the lever?

(14) What is the average speed of mine locomotives?

(15) Is it economy to use light rails where electric locomotives are employed?

(16) How are the motors mounted with the electric mining locomotives manufactured by the General Electric Company, in which two pairs of wheels are employed?

(17) If three pairs of wheels are employed, what provision has to be made to enable the locomotive to go around sharp curves?

(18) Do changes in temperature affect the electric system of transmission as much as the transmission of power by steam or compressed air?

(19) If it is desired to transmit a greater amount of power over a given sized wire, how may this be accomplished?

(20) Why is it not advisable to allow great losses of energy or falls of voltage in the transmission line?

ELECTRIC PUMPING, SIGNALING, AND LIGHTING.

(1) Give a sketch showing how to connect up an electric-bell signal for a shaft so that only one wire in the shaft will be necessary, the ground being used as a return.

(2) Give a sketch showing how to connect up a bell signal for a shaft, using three wires, so that a signal may be given from any intermediate point.

(3) (*a*) Explain the action of an ordinary vibrating electric bell. (*b*) How may a vibrating bell be made into a single-stroke bell?

(4) What style of battery is well adapted for circuits where there is considerable leakage on account of poor insulation?

(5) Give a sketch showing the necessary connections for a shaft flash-light signal system.

(6) (*a*) About how many watts per candle-power does an ordinary incandescent lamp require? (*b*) About how many candle-power can be obtained per horsepower expended? (*c*) About what current does a 16-candle-power, 110-volt lamp take?

(7) (*a*) Give a sketch showing how you would connect 125-volt lamps on a 250-volt circuit. (*b*) Give a sketch showing how you would connect 110-volt lamps on a 550-volt circuit.

(8) (*a*) What do you understand by a *short circuit?* (*b*) Why are short circuits on constant-potential systems liable to cause damage?

(9) (*a*) What is the difference between an enclosed-arc lamp and an open-arc lamp? (*b*) How does the consumption of carbon in the enclosed lamp compare with that in the open lamp?

(10) Give a comparison between the steam consumption per horsepower expended in pumping water by means of steam-pumps and electric pumps.

(11) What advantage have electric pumps over those driven by steam or compressed air in cases where the pump works on air part of the time?

(12) Which is generally the more economical, to pump water by stages or to use a high-pressure pump and force it to the surface at one lift?

(13) (*a*) About how many watts does an ordinary open-arc lamp, rated at 2,000 nominal candle-power, take? (*b*) How many watts are required for a lamp of 1,200 nominal candle-power?

(14) (*a*) What is the approximate efficiency of an electrically driven pump operated by double-reduction gearing? (*b*) What is the efficiency of a pump operated by single-reduction gearing?

(15) Give some of the advantages and disadvantages of centrifugal pumps.

(16) (*a*) What do you understand by the *drop* in an electric light or power circuit? (*b*) On what does the amount of the drop depend?

(17) (*a*) What is the objection to running a number of vibrating bells in series? (*b*) How may this objection be overcome?

(18) Why are bells operated in parallel usually preferred to those operated in series for mining work?

(19) A direct-current dynamo supplies 150 110-volt 16-candle-power lamps situated in a portion of a mine 1,500 feet from the dynamo. The allowable drop in the line is to be 10 per cent. of the pressure at the lamps. Calculate the

size of line-wire required in circular mils, and give the nearest size B. & S.

(20) If the diameter of a wire is .125 inch, what is its area of cross-section in circular mils?

(21) Give a diagram of a simple-haulage signal using a single wire with a ground return and arranged for ringing from either end.

(22) Give a diagram of a simple-haulage signal using three wires with a single battery and two bells arranged so that they may be rung from either end.

(23) (*a*) Explain the method of operating lights by means of the high-pressure alternating current, using transformers for lowering the pressure. (*b*) Why is this system particularly adapted for long-distance work?

(24) (*a*) What are fuses used for in lighting work? (*b*) What would be liable to happen if they were not used?

(25) An alternating-current dynamo operates 1,200 16-candle-power lights from 2,000-volt mains. The distance from the dynamo to the lamps is 2 miles and the allowable loss in pressure is 10 per cent. Calculate the required cross-section of the line-wire and give the nearest size B. & S.

(26) Give a sketch showing how two lamps may be connected up so that they may be controlled from either of two points.

(27) State some of the advantages of electrically driven pumps.

(28) If ordinary arc lamps are to be operated on a 110-volt, constant-potential circuit, how should they be connected up?

(29) If 200 16-candlepower lamps are wired up in sets of five in series across 500-volt mains, what will be the total current in the mains?

ELECTRIC COAL-CUTTING MACHINERY.

(1) What advantages has electricity over compressed air for driving coal-cutting machines?

(2) Why is it that alternating-current machines are not suitable for use in mines?

(3) In the case of thick seams of coal, why does the coal mined with a pick machine fall in better condition for loading than that mined with a machine cutter?

(4) Why can more lump coal be obtained when the coal is both undercut and sheared than when it is simply undercut?

(5) Can pick machines be employed in the case of steeply pitching seams; and if not, what are the limits?

(6) Why is it that chain-cutting machines can not be employed for mining old pillars or coal upon which there is a squeeze?

(7) Describe the two methods of feeding longwall mining machines along the face of the coal.

(8) How do the cutter-bar machines differ from the chain-cutting machines?

(9) How is the rotative motion of the motor transformed into a longitudinal motion of the pick in an electric pick machine?

(10) What kind of an operating platform is used with the pick machines when cutting coal?

(11) What advantage has a pick machine over chain machines when it is necessary to use props and cockermegs near the face of the coal?

(12) What advantage have pick machines over chain machines when they have to be moved from one room to another?

(13) How is the chain coal-cutting machine held in position during cutting so that the reaction of the cutters against the coal will not force the machine out of position?

(14) What advantage has the machine shown in Fig. 4 over those shown in previous figures, especially for work in thin seams of coal?

(15) When a ball of sulphur is encountered which seems to affect some of the cutters only, how may it sometimes be removed with a chain-cutting machine?

(16) How are the chain-shearing machines supported while at work?

(17) Why are the cutting teeth in the longwall machine employing a cutting arm placed in a spiral about the arm?

(18) How many men are commonly required to operate a pick machine, and what is the duty of each?

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