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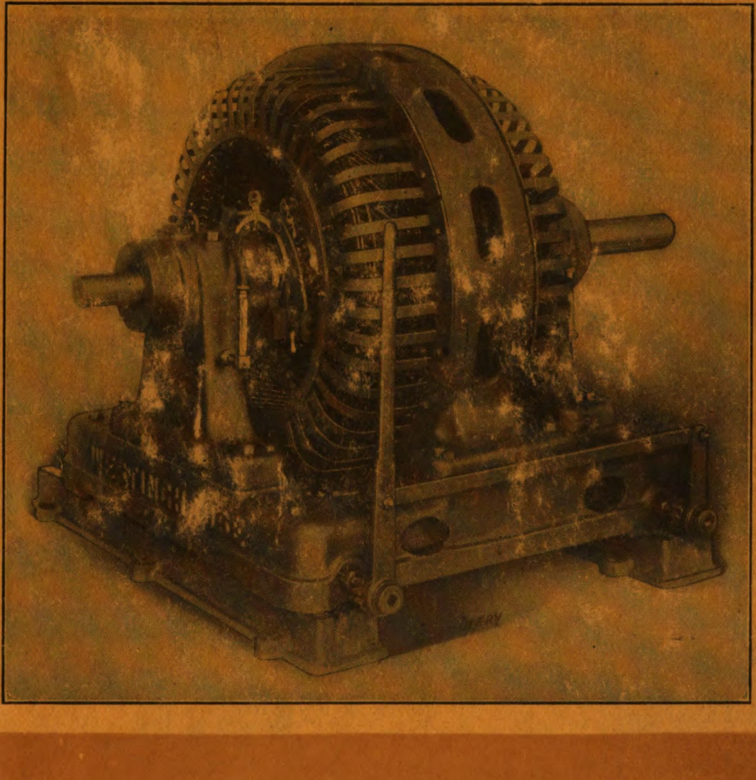
PRINCIPLES AND APPLICATIONS OF
ELECTRICITY

PART III—DYMAMOS—MOTORS—ELECTRIC RAILWAYS

SECOND EDITION



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NUMBER 75

PRINCIPLES AND APPLICATIONS
OF
ELECTRICITY

PART III

DYNAMOS—MOTORS—ELECTRIC RAILWAYS

SECOND EDITION

CONTENTS

CHAPTER I

DYNAMOS

A dynamo is essentially a machine which generates electromotive force. The process of generating electromotive force, or E. M. F., as it is abbreviated, is by means of conductors moving in a magnetic field. When mechanical energy is applied to conductors which are passed through magnetic lines of force in a certain direction, an electromotive force is developed in them, which will be proportional to the speed with which they are moved, the number of conductors moved, and the strength of the magnetic field. The current produced in these turns or coils of wire will be proportional to the electromotive force generated and inversely proportional to the resistance. A dynamo, briefly, is a machine in which mechanical energy is transformed into electrical energy. A motor, in contradistinction, is a machine in which electrical energy is transformed into mechanical energy. Both the motor and dynamo are mutually convertible into each other by the mere fact of applying the power in a mechanical or an electrical form. This identity of these two machines or types of machines has been of the greatest importance in the fields of practical work, particularly in those of electric power transmissicn, transformation and distribution.

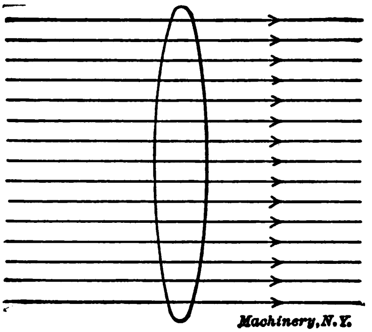
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Fig. 1. Conductor Forming a Closed Circuit Moving in a Magnetic Field

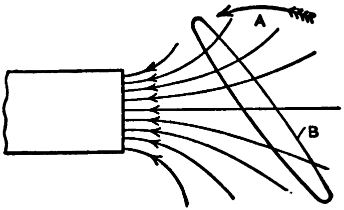

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Fig. 2. Conductor Forming a Closed Circuit Moved so as to Cut the Lines of Force

The subjects of electromagnetism and magnetic fields have been treated in MACHINERY'S Reference Series No. 74, "Principles and Applications of Electricity, Part II," and the expression "lines of force" has also been defined in that book. If a wire or conductor forming a closed loop or circuit, as shown in Fig. 1, moves parallel to the direction of the lines of force in a magnetic field, so that no lines of force are cut by the loop, no current will flow in the conductor. If the loop *B* rotates as indicated by arrow *A* in Fig. 2, however, so that the lines of force are cut by the conductor, and so that the number of lines passing through the loop is constantly changing, either decreasing or increasing, then a current will be induced in the conductor. If the conductor merely cuts the lines of force, but in such a manner that the number of lines passing through the loop of the conductor remains constant, then an electromotive force will be produced, but no current will flow. Each half of the loop becomes impressed with an electromotive force of the same strength and polarity as the other half, and as the two oppose each other, no current will flow. The principles outlined may be summarized as follows:

The physical law upon which the generation of electromotive force is based requires the absence of uniformity in the motion of the conductor through a uniform field of magnetism. The conductor must move in such a manner that the number of lines of force it cuts are constantly changing in number. It other words, it may be stated that the generation of electromotive force depends upon a variation in the number of lines of force intercepting the conductor.

The direction of motion plays a great part in the direction of the current in a conductor exposed to the influence of lines of force. The conductor develops positive and negative electricity at ends which reverse their polarity when the direction of the motion is reversed. For instance, if a conductor is moved downward in front of the north pole of a magnet as shown to the left in Fig. 3, the current will tend to flow outward from the plane of the paper. The exact nature of the action which takes place and owing to which a closed electric circuit, when moved in a magnetic field, is able to absorb mechanical energy and give out its equivalent in electricity, even if known, would have no influence upon the practical application of this principle in electromagnetic machinery. Such knowledge would merely add another link to the chain which is being slowly forged in the physical laboratories of the world, connecting fact with fact and associating principle with principle for the purpose of showing the truth of great generalizations already made.

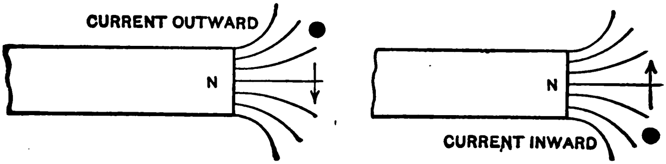

Fig. 3. Illustration showing Relation between Direction of Current and Direction of Motion of Conductor

When a conductor is moved upward in front of the north pole of a magnet, electromotive force is also generated, but in this case the positive and negative poles of the conductor will be at such ends of the wire that the current with reference to the plane of the paper will tend to flow inward. Thus it is evident that an up and down motion of the conductor in front of the north pole would produce a series of electromotive forces which would be proportional to the number of movements per second, the strength of the magnetic field, and the length of the conductor in operation.

Direction of Field Around Inductive Wires

A wire producing electromotive force is acting as an inductor, because an electromotive force is being induced in it. The "blow" of a downward moving wire, upon the lines of force of a north pole produces a magnetic whirl around the wire, coincident with the generation of its electromotive force, and its polarity, or positive and negative ends. A reversal of the motion produces a reversal of the magnetic whirl around the wire, and of its electrical polarity and electromotive force.

If this experiment could be regarded as that of a stout metal rod striking a number of projecting flexible steel wires, it is easy to understand that a downward and upward blow would make them coil around the rod in opposite directions. There is this difference, however, that in the case of the metal rod, energy is consumed with each motion, while in the case of a moving conductor energy is consumed only in proportion to the current which flows. Consequently, if the conductor does not form part of a closed circuit, only electromotive force, but no current results, and no energy is consumed. This fact is of importance because it shows that a dynamo on open circuit, although producing electromotive force, only takes from the engine enough power to overcome the requirements of friction at the bearings, commutator, etc.

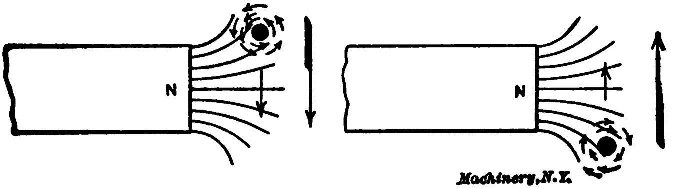

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Fig. 4. Illustration showing Direction of Magnetic Whirl

The direction of the magnetic whirl around wires moving in a magnetic field, as shown in Fig. 4, is an indication of the direction of the current in them. The presence of this magnetic whirl, however, acts as a deterrent to the motion of the wire. It is this which constitutes in a mechanical sense the reaction. In fact, it is impossible to produce a current in a wire by its movement through a magnetic field without experiencing this drag on the conductor.

Elements of a Dynamo

If a north and south pole are now placed opposite to each other, as in Fig. 5, the magnetic lines have a free path across to the south pole. The number of the lines of force from the north pole have not changed because of the presence of the south pole; they simply continue on their way unchanged into the south pole. A conductor moving downward in front of the north pole produces a magnetic whirl which is in the opposite direction to the whirl produced around the conductor moving upward in front of the south pole. This means that the current issuing from the first wire will flow in an opposite direction to that issuing from the second wire. If they were connected at their ends as in Fig. 6, and then rotated around an axis instead of being individually moved up and down in the magnetic field, practically the same movement would be accomplished by circular motion. In a dynamo this idea is followed out, and the result is that the conductors constantly produce a reversing or alternating current. Certain practical details require attention in this respect in order to outline the conditions resulting from such an arrangement in actual practice.

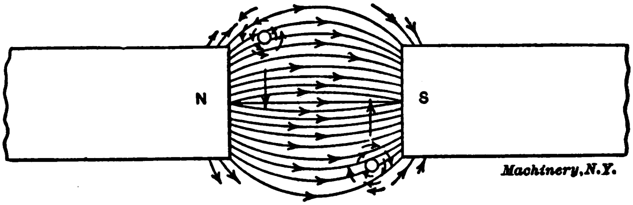

Fig. 5. Conductors Moving between the Poles of a Magnet

Alternating and Direct Currents

There are two kinds of dynamos or generators in use for generating current for electric lighting and electric power. They are called alternating and continuous (or direct) current machines. The difference between one class of machines and the other is entirely due to the fact that in the first class, that for producing alternating current, the electrical energy is permitted to issue in the same manner as it is produced or generated. In the other class, the direct current generators, the alternations or reversals of current are rectified by means of a device called a commutator. This device is the means of causing all the impulses of current to be divided up into those which leave at the positive and those which enter at the negative pole. In other words, it sends out all positive currents from one pole of a dynamo and receives all negative at the other. The difference, therefore, between so-called alternating and direct current machines is not due to the fact that they generate different currents, because both develop alternating currents, but is due to the fact that the direct current machines have a commutator or rectifier and the alternating current machines have not.

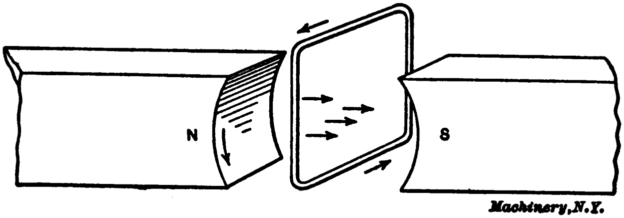

Fig. 6. The Elementary Principle of the Dynamo

The Calculation of Electromotive Force

The meaning of the word current with respect to electricity has no significance unless associated with a conception of the electromotive force. As already stated, there are three elements necessary for the development of electromotive force, these being lines of force, conductors, and motion. Cases arise in connection with alternating and direct currents where motion is not apparent. Yet it is there; if not visible, it must be the motion of the magnetic field. If a conductor is held stationary, and a magnet moved so that its lines of force cut the conductor, a parallel case is presented; but even in this instance the magnet is moved, whereas under particular conditions only the magnetic field itself moves.

Electromotive force is measured in volts. One volt is equal to the cutting of one hundred million lines of force by one conductor in one second. The conclusions to be drawn from this statement are obvious. If one hundred million lines of force must be cut by one conductor to generate one volt, then one-half as many cut by two conductors in one second or one-quarter as many cut by four conductors in one second will generate one volt, etc. From this statement is drawn the conclusion necessary for deducing a very simple formula, by means of which the electromotive force of a dynamo is calculated before construction takes place as follows:

E.M.F. in volts = (number of lines of force × number of conductors × revolutions of the wire per second) ÷ one hundred millions. Transscribing this formula into symbols for convenience:

$$\text{E.M.F.} = \frac{F \times S \times r}{100{,}000{,}000}$$

where $F =$ number of lines of force,
$S =$ number of conductors,
$r =$ revolutions per second.

To illustrate the application of this formula let $F = 5{,}000{,}000$; $S = 100$; and $r = 20$, which represents 1200 revolutions per minute. The volts would equal 5,000,000 × 100 × 20 divided by 100,000,000, which equals 100 volts.

The Magnets of a Dynamo

Before going further, it will be necessary to define the meaning of the expressions "armature" and "field magnets". The armature of a dynamo, in general, is that portion of the machine which is revolved between the poles of the magnets of the dynamo. These magnets are usually called field magnets. The armature consists of coils of insulated wire and an iron armature core, on or around which the coils are wound. The magnets are electromagnets, energized through coils of wire wound around their core, an electric current, called the field current, being sent through the coils of the magnets for this purpose.

The three important parts of a continuous current dynamo are the armature, commutator and field magnets. The commutator is not required for an alternator, or machine generating alternating current.

The conductors wound and firmly secured around the armature core have terminals ending in the commutator. Both commutator and armature are mounted on one shaft, by means of which the conductors are rotated in the magnetic field provided by the magnets. In some dynamos the coils of the magnets act almost directly on the armature, the magnetism passing through the end of the core which is curved to conform to the cylindrical shape of the armature and at the same time permitting it to rotate freely. In other dynamos the core is attached to a pole piece which may be of the same metal as the magnet core. If this is not the case, the core is generally of wrought iron and the pole pieces of cast iron. The ultimate purpose of the magnet winding is to force a certain amount of magnetism across from one pole piece to another. In order to get across, the magnetism must pass through the air-gap existing between one pole piece and the armature core and then again from the armature core through the air-gap back to the other pole. It is of the greatest importance in a continuous current dynamo for incandescent lighting, that the magnetism, speed and armature turns co-operate so advantageously that the electromotive force produced by the machine for outside use remains unchanged.

Construction of the Armature

The armature core is not composed of a solid cylinder of iron; on the contrary, it consists of a great number of thin sheets of wrought-iron bolted together to give mechanical rigidity. If the armature was not composed of laminæ in this manner, it would act as a solid conductor moving in a powerful magnetic field and in consequence would generate a strong current. The effect of this current would be the generation of an intense heat and a great waste of energy. Foucault was the first to suggest and to try the effect of subdividing the armature core at right angles to the lines of force in which it rotated. This practice is now followed out universally and is termed "lamination." The sheets of iron are stamped, and in some cases thin paper is placed between the laminæ, although experience has shown that a coating of varnish or the oxide of the iron itself is all that is necessary to prevent electrical contact between plate and plate. Originally the conductors of direct current dynamos were wound on the outside of the core and held in place by bands of wire, but the armature cores are now slotted and the wires are wound in these slots and held either by means of bands of brass wire surrounding the armature or by fiber strips slipping into and held by these slots, over the wire they contain.

Armature cores may be either simple cylinders, which have the wire wound completely around them, or they may be hollow inside and represent what are called ring and disk armatures. Both of these last named armature cores have the wire threaded through them instead of around from one side to the other across the ends. The cylindrical core is called "drum" armature and the ring "gramme" armature. The disk armature is sometimes called "the flat ring," to distinguish it from the ring, which is longer axially. Ring armatures are mounted on the shaft by means of spiders to secure them against slippage and vibration. The question of speed must be carefully considered in the construction of armatures and their mountings. The most solid type of armature and one largely in vogue at present is the drum. In the ring armature the conductors are wound around the ring; the consequence of this is that the inside wires are not generating electromotive force. In the drum armature the end wires crossing both bases of the cylinder are inactive and do not generate electromotive force.

Types of Direct-current Dynamo Windings

The manner in which a dynamo begins to generate electromotive force is best understood by referring to the method of winding the fields and connecting them to the armature. There are three general types of dynamos, bearing the names of series, shunt and compound, according to their windings and connections. In the series wound dynamo, a diagram of which is shown at *A* in Fig. 7, the current generated in the armature flows out into the outside circuit, generally of lights, and returns to the dynamo through the winding of the fields. The circuit is therefore completed by the armature, lights and field being *in series* with each other. The shunt dynamo, as shown at *B*, operates differently, the current from the armature passing through the outside circuit and returning to the armature, the field taking its current independently from the armature terminals or *in shunt*. The

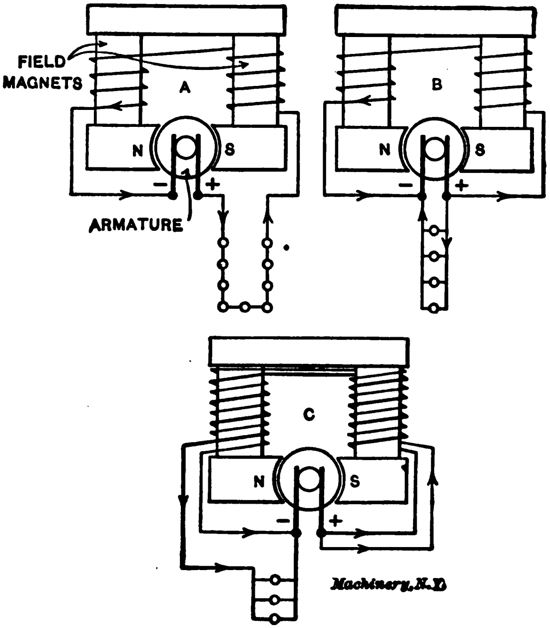

Fig. 7. Types of Dynamo Windings

compound wound dynamo, as shown at *C* in Fig. 7, represents a combination of these two windings. It has a shunt field which takes its current from the armature terminals and an auxiliary series winding through which all the current of the machine passes in series with the entire outside circuit.

Generating Electromotive Force

When a series, shunt or compound wound dynamo is set into operation, the action by which electromotive force is developed and a current thrown into circulation does not take place instantaneously. The process is a self-regenerative one and depends in the first stage of its growth upon the presence of *residual magnetism* in the iron core and pole pieces of the machine. The least trace of magnetism in the pole pieces will enable the armature to generate a little electromotive force. This electromotive force will send a minute current through the magnet windings, whether it be a shunt or series wound machine. The effect of this current is to produce a little more magnetism in the magnets and thus supply more lines of force to the armature to cut for the generation of more electromotive force. With more electromotive force, a stronger current circulates through the magnet windings, continually augmented in strength by the reinforcements of electromotive force from the armature, until a climax of development is reached when the dynamo is delivering its normal pressure. The process cannot go on indefinitely because the magnets will not produce more than their proper quota of lines of force, and neither the speed nor conductors can change in numerical value. Therefore, when the iron becomes saturated and the speed and conductors remain unchanged, the electromotive force will not vary. It must be understood, however, that if any one of these three items undergo a change, a corresponding change will be experienced in the development of electromotive force. A dynamo which can increase or decrease its magnetic field will proportionately affect the voltage produced. If by any means, the speed remaining the same, the number of the conductors can be controlled in a dynamo, in like manner the electromotive force will increase or diminish.

The Alternator

The alternating current dynamo generates a current which cannot be used for exciting a magnetic field in the same manner as a current produced by a direct current machine. The electrical energy of an alternator consists of a rapidly reversing electromotive force and current. The positive and negative poles of the dynamo are constantly reversing, and the number of alternations per second depend upon the speed of the armature and the number of magnetic poles the conductors move past per second. The magnetic field is obtained from the current of a small continuous current dynamo called the "exciter." This machine may be permanently attached to the alternator, or it may be merely belted to the shaft supplying both with power. Its entire function is to supply current to the field magnets of the alternator, which current, it must be distinctly understood, is not always obtained in this manner. It is sometimes obtained from an auxiliary or independent winding on the alternator armature which is connected to a commutator and thus makes the alternator self-exciting. The general plan, however, is to keep the exciter separate in the manner described. An alternator generally consists of four or more poles or magnets. A few figures are given in the following table showing how the reversals of current are due to the number of poles and the speed:

Revolutions per Second	Pairs of Poles	Complete Reversals of Current per Second
10	1	10
15	1	15
20	1	20
25	1	25
30	1	30
10	2	20
15	2	30
20	2	40
25	2	50
30	2	60
10	4	40
15	4	60
20	4	80
25	4	100
30	4	120

The idea represented here is as follows: A conductor moving past a north pole develops a current opposite in direction to that developed when moving past a south pole. A complete cycle only occurs when the wire sweeps past a north and south pole in succession. In this case the wire generates an electromotive force which rises from zero to its full value, and drops again to nothing just the instant before it passes under the opposite pole. When passing under the opposite pole the process is repeated in a reversed direction and when completed the wire is about to enter upon the same cycle again. This is therefore called a complete reversal of current and is due to a conductor passing *one pair of poles.* If it passes a pair of poles 10, 15, 20, 25 or 30 times a second, just so many times will a complete reversal of current take place. Multiplying the revolutions per second by the number of pairs of poles will give the reversals, or as it is generally called, the frequency of the current.

Waves of Electromotive Force

The function of the commutator and its relation to the impulses of electromotive force generated in the armature can be best understood by reference to what is called "a wave of electromotive force." In any dynamo, whether it be a bipolar or multipolar, every conductor passing the poles has an electromotive force generated in it which is in strict proportion to the lines of force it cuts. If the electromotive force of a conductor passing in front of a north pole is estimated in a series of positions, the product of the number of lines of force by the speed of the conductor will give the amount of electromotive force developed. Suppose the electromotive force is measured while the conductor is rapidly passing through these positions, then, at each point, the electromotive force will differ, provided the rate of motion is uniform, because the lines of force are so distributed that in their case no uniformity exists. If use is made of such data as can be obtained in this manner to graphically represent the entire process, as shown in Fig. 8, then, by letting the length of vertical lines be a measure of the electromotive force developed at each instant, and a base line be proportioned to the time during which these various electromotive forces are produced, a curve can be drawn through the extremities of the vertical lines which will adequately picture the rise, full growth, and fall of the electromotive force. As the wire moves on to pass beneath a south pole, the generating process is repeated and the result in consequence is a wave of electromotive force in one direction under a north pole and a wave of electromotive force in the opposite direction under a south pole. The more abruptly these waves are produced, and the greater the electromotive force they represent the more difficult it is to obtain what is commonly called a continuous current. If heavy impulses, due to a great many turns acting cooperatively, are rectified by means of a commutator, which would, under the circumstances, consist of comparatively few segments, then such a current would represent a series of direct pulsations. The current is direct, but not, in the strict sense of the word, continuous. It is like the stream which issues from a powerful force pump without a pressure chamber—the stream is all directed one way, but occurs in increasing and diminishing spurts. If, on the other hand, the armature conductors are so arranged that only a few are connected to each commutator segment, then there would be many commutator segments required. The result of this would be to bring the current down to a gentle ripple, approximating uniformity. It would still pulsate, but with small pulsations, which is the object sought by designers when laying out continuous current machines for incandescent lighting. A graphical illustration of the statements just made is shown in Fig. 9.

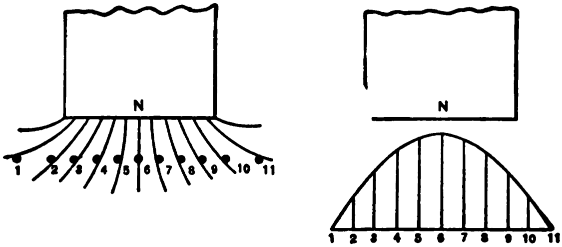

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Fig 8. Graphical Illustration of the Rise and Fall of Electromotive Force in a Conductor

It is needless to state that if an armature core was wound with 1000 turns of wire, by means of which, when revolving at 1000 revolutions per minute in a magnetic field, 100 volts were generated, a commutator consisting of only two segments would cause destructive sparking. If, however, the commutator segments were increased to 4, 6, 12, or in fact to something like 50, and the 1000 conductors were divided up between them, then the sparking would be very much reduced. In other words, the commutator segments, and the volts produced by the armature conductors, must be proportioned with regard to two things: First, the uniformity of the current; second, the sparking at the dynamo brushes.

Heavy pulsating currents are employed for high tension arc lighting. Direct currents of a uniform character are employed for low tension incandescent lighting. In Fig. 9 the change of the curve from a heavy impulse to a ripple-like flow is due to the use of a greater number of commutator segments. Carrying out this idea to its practical limitations would give a current so uniform in character that it would compare with the discharge from a storage battery through a fixed resistance.

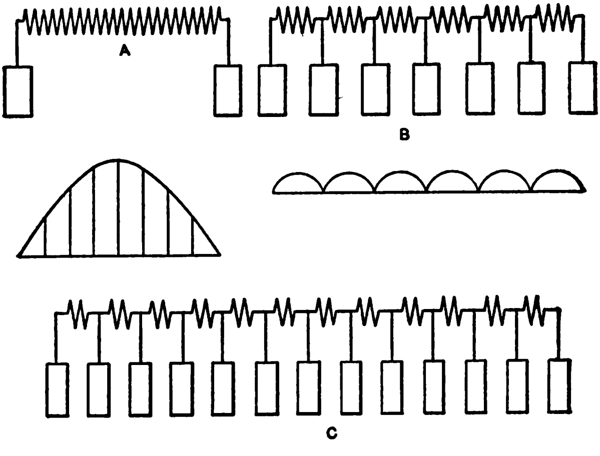

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Fig. 9. Graphical Illustration of the Influence of the Commutator Construction on the Current Pulsations

Alternating Current Dynamos

There are several varieties of alternating current dynamos, distinguished from each other by an interesting peculiarity called "phase." To enumerate, there is the single phase, two phase, and three phase dynamo. The meaning of phase may be readily understood with reference to the character of the currents they individually produce; but it is necessary to represent these differences partly by a diagram.

A wire on the armature of an alternator rotates past a series of poles of different polarities. It passes a north pole, then a south pole, then a north pole, and so on, as it continues its rotations. (See Fig. 10.) Every north pole it passes produces an impulse in the same direction; that is, all one way, and every south pole it passes produces an impulse in the opposite direction. Thus, the impulses of current due to the north poles are all in one direction and the impulses of current due to the south poles are all in the opposite direction. This idea is represented by a series of curves placed over or under a baseline, as shown at *B* in Fig. 11. All the curves or waves over the line can be regarded as impulses due to north poles, and those under the line as impulses due to south poles. Therefore a diagram of this character adequately represents the increase and decrease of the electromotive force as the conductor sweeps past a north pole, the particular instant at which no electromotive force is generated just as the conductor has emerged from the lines of force of the north pole and is about to enter those of the south pole, and the rise and fall of the electromotive force due to the south pole with a return to practically the same conditions as the cycle is about to be repeated. Each pole is capable of producing one wave of electromotive force in a conductor, and in consequence it is customary to depict this process of electromotive force development by a curve as described. The name given to a curve of this character by mathematicians, and so called by electricians, is "the sine wave."

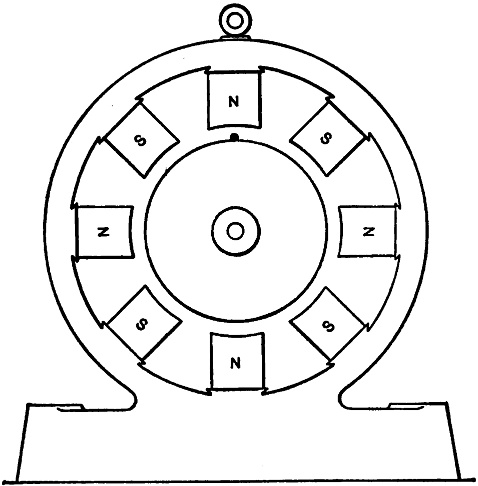

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Fig. 10. Elements of a Dynamo

A great many impulses occur in the winding on the armature of an alternator every time the conductors pass each pole. It has been necessary to devise a winding which would throw all similarly moving currents in one direction and thus avoid opposition between them. This is readily done by laying flat coils on the armature, each around a projecting core, and connecting their ends together, the outside terminals of adjacent coils and the inside terminals of those next adjacent, and so on, as shown in Fig. 12, until the two final ends are connected respectively to collector rings (see Fig. 12 and upper view *A* in Fig. 11), from which by means of brushes an impulse is collected as the coils on the armature pass a pole piece.

Two and Three Phases

If another current follows after the first impulse of an alternating current, but not so slowly that it differs in any respect from the first except in being an instant behind it, there are what are called two phases acting in the circuit. If three distinct currents follow each other in this manner, each an instant behind the other, yet not so far behind that the three currents are not at some stage of growth or diminution at the same moment, there are three phases of current in the circuit or it represents a three-phase current.

Phases of this kind are produced in a very simple manner. The armature conductors are connected in such a way that in the case of a two or three-phase dynamo practically two or three distinct windings are in operation at once. In one winding the armature conductors, for instance, are one-third of the distance across a pole piece before the second winding is in operation. By this means the beginning of an impulse is one phase, which follows all the laws of an ordinary alternating current. The phase beginning when the first conductors have already been developing electromotive force along one-third of the arc of the pole piece also rises to its full value and acts like the first phase. A third can follow in the same manner if the conductors are properly arranged and connected to individual collector rings. Thus, instead of only one—two, three or more phases or currents can be developed by this method, each distinct from the other, an instant behind it, and serviceable for electric lighting and power transmission. Rotary converters found in power houses and sub-stations, and nearly all self-

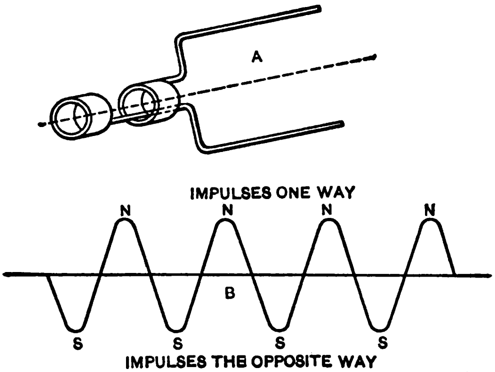

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Fig. 11. Collector Rings and Graphical Illustration of Characteristics of Alternating Currents

starting alternating current motors, are actuated by multiphase currents of either of two or three phases.

Hence it will be seen that by adding further windings, in intermediate positions relative to the first or original winding, any number of alternating currents may be generated, each differing from the other in phase, that is, being a very small fraction of a second behind it. For each phase two conductors are necessary. Hence, it is necessary to limit the number of phases, so that undue multiplication of conductors is avoided.

For two-phase currents, for example, four conductors are necessary, except in cases when a single return conductor is used, when three conductors are sufficient. For three-phase currents six conductors would be required, except for the condition that the current flowing in one phase is always equal and opposite to the sum of the currents in the other two phases. Hence the return wire for each phase may be omitted, and three conductors only need be used.

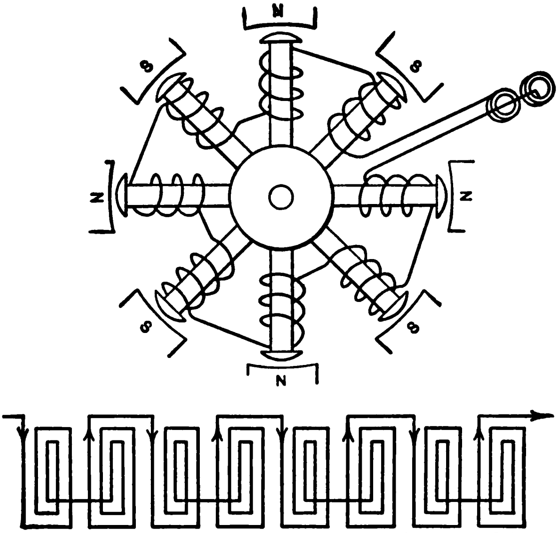

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Fig. 12. Principle of Winding an Alternating Current Dynamo

Hysteresis

The iron core of the armature is magnetized first one way and then another, whether it belongs to an alternator or a direct current dynamo. The effect of this is to consume power which manifests itself as heat. This phenomenon always appears when iron is magnetized and demagnetized. The reason why power is consumed is as follows: When a bar of iron is magnetized by means of a coil carrying a current, and the ampere turns or magneto-motive force is great enough to saturate it, the molecules of iron assume a certain polarized position. If an equal and opposite magneto-motive force is applied by means of the coil, the iron *will not* of itself return to its normal condition; it will require extra magnetizing force to accomplish this, and if the process is continued until the iron is magnetized as highly in the opposite direction (with reverse poles) as before, and then brought back to where it started from, it will be found that a considerable amount of power has been absorbed. A process of this kind is called a cycle of magnetization, and is graphically illustrated in Fig. 13. Although the process merely consists of the magnetization and reverse magnetization of iron with a final return to the starting point, yet each instance presents an opportunity for power to be absorbed, which increases as the degree of magnetism to which the iron is subjected increases, and also with the rapidity and frequency of the cycles. If a cubic foot of soft iron is put through such a process, it will, according to a noted authority, when magnetized up to 60,000 lines of force per square inch, absorb 10 foot-pounds of energy. If the process is carried on at the rate of 100 times a second, 1000 foot-pounds of energy are absorbed. It is easy to estimate that each minute would represent a power consumption of 60,000 foot-pounds or nearly 2 horsepower, at this rate of change. All armature cores, therefore, must be calculated with respect to such a dissipation of energy, and it is necessary to obtain figures which will enable such calculations to be carried out. A formula has been deduced by Steinmetz, upon which all calculations of hysteresis (the name given to this property of iron) are based.

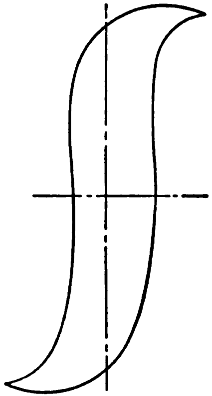

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Fig. 13. Hysteresis Curve

The Steinmetz Formula for Hysteresis

The Steinmetz formula requires an understanding of quantities with fractional exponents, and the use of logarithms.* In the formula a constant is multiplied by the lines of force per square centimeter, the latter value being raised to the 1.6th power; this gives the power consumed in *ergs* (see definition in the following) in one magnetic cycle for one cubic centimeter of iron, or:

Power consumed = 0.002 × (lines of force per square centimeter)$^{1.6}$, in which 0.002 is called the hysteretic constant, and is an average of the actual constant for different classes of iron. The actual constant is for:

Wrought-iron—hysteretic constant	0.0017
Steel—hysteretic constant	0.0025

The above formula, reduced to symbols, would appear as follows for one cubic centimeter of iron:

$$W = 0.002\,B^{1.6},$$

where W = power consumed in ergs in one magnetic cycle,

B = lines of force per square centimeter.

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* See MACHINERY'S Reference Series No. 53, "The Use of Logarithms."

The value of an erg is best understood by reference to a foot-pound. A foot-pound equals 13,350,000 ergs. In the following table, in which the lines of force per square centimeter and per square inch are given, the calculations by the Steinmetz formula are carried out for iron subjected to a series of increasing magnetizations:

FLEMING'S TABLE

Lines of Force per sq. cm.	Lines of Force per sq. inch	Ergs per cubic cm.
1,000	6,250	126
2,000	12,500	383
3,000	18,750	732
4,000	25,000	1,160
5,000	31,250	1,658
6,000	37,500	2,222
7,000	43,750	2,840
8,000	50,000	3,516
9,000	56,250	4,244
10,000	62,500	5,022

When using this table, the number of complete reversals of magnetism per second must be multiplied by the waste of power per cycle. For instance, if the frequency of an alternating current is 120 per second, a well known commercial rate for lighting circuits, the power wasted at 5000 lines of force per square centimeter, or 31,250 per square inch, would be 3.22 foot-pounds for a cubic foot of iron per complete reversal. For 120 complete reversals the power wasted would be 120 × 3.22 = 386 foot-pounds.

In reference to the equivalent of an erg in foot-pounds, it may be stated that one pound equals 445,000 dynes. A dyne is the force required to impart to a gram a velocity of 1 centimeter per second. An erg is *the work* done in moving a body a distance of 1 centimeter against a force of 1 dyne. If a gram is moved against gravity a distance of 1 centimeter in 1 second, 981 ergs of work are done. A pound is equal to 453.59 grams, and the force of gravity equals 981 dynes per gram; hence, 453.59 × 981 = 445,000 dynes or 1 pound. If 1 pound

POWER WASTED PER CUBIC FOOT OF IRON AT 120 REVERSALS PER SECOND

Lines of Force per Square Inch	Lines of Force per Sq. cm.	Ergs per Cubic cm.	Foot-pounds per Cubic Foot
6,250	1,000	120 x 126	29.32
12,500	2,000	“ “ 383	89.13
18,750	3,000	“ “ 732	178.00
25,000	4,000	“ “ 1160	270.00
31,250	5,000	“ “ 1658	386.00
37,500	6,000	“ “ 2222	517.06
43,750	7,000	“ “ 2840	661.00
50,000	8,000	“ “ 3516	818.17
56,250	9,000	“ “ 4244	987.60
62,500	10,000	“ “ 5022	1168.60

is lifted 1 foot, it means a force of 445,000 dynes operating over a distance of 30 centimeters, the basis of estimate being 0.4 inch per centimeter and therefore 30 centimeters per foot. This calculation gives $445{,}000 \times 30 = 13{,}350{,}000$ ergs = 1 foot-pound. If the last column of figures in the Fleming table, which gives the energy wasted in ergs, is given in the English system for 1 cubic foot of iron magnetized and demagnetized at the rate of 120 times a second, the result will be as given in the lower table on page 18.

For armature cores this last table is very useful, as well as in those cases where the use of magnets on alternating current circuits are proposed. In alternating current work in general, whether single, two or three phase, dynamos, motors and transformers are of necessity in almost constant use; and these machines call for a careful application of the principles outlined so far as hysteresis is concerned, otherwise the internal development of heat within the iron would not only waste power, but rapidly put a stop to the operation of such machines altogether.

CHAPTER II

THE ELECTRIC MOTOR

An electric motor is a machine in which electrical energy is transformed into mechanical energy. This is the reverse of the dynamo, which is a machine in which mechanical energy is transformed into electrical energy. To transform electrical energy into mechanical energy the medium of the electro-magnet comes into play.

The construction of the motor is practically the same as that of the dynamo, and a dynamo is capable of running as a motor if supplied with current through its armature and magnets. The principle upon which the action of the electric motor is based is that a conductor carrying an electric current tends to move if it is placed in a magnetic field. The tendency is for the conductor to move into a position where the lines of force passing through its loops become parallel to, or coincide with the lines of force in the field of the magnets. Hence, a motor, like a dynamo, consists of a magnetic field, produced by field magnets, and conductors wound on an armature core, and so arranged that they can move when acted upon by the field. This is the simple theory of action and construction of an electric motor, and while the theory may be elaborated upon, as in the following, it should be borne in mind that the fundamental principles are simple and easy to comprehend.

The development of a magnetic field within a loop of wire, when affected by a current of electricity by which it acquires all the qualifications of a magnet, was first discovered and enunciated by Oersted. Thus is became subsequently possible to express magnetism qualitatively and quantitively in terms of electricity. In other words, it was found that magnetism produced by electricity could be calculated with exactitude, and the polarity as well, anticipated. Each turn of wire carrying a certain current can be regarded as a lamellar magnet possessing a certain magneto-motive force. A succession of such small magnetic pumps, as they might be called, force the magnetism through the medium whether it be iron or air. As the number of them is augmented, and the current in them increased, their power or magneto-motive force increases in proportion. Thus, when such coils are so situated that their influence upon each other is productive of motion, it becomes evident that the power produced mechanically is in proportion to the magnetic pull resulting from the arrangement of coils and poles, and the rotative speed.

Relation of Lines of Force and Current

The lines of force, when meeting those of another field, tend to set themselves parallel, or as it would seem, tangent to those of the other field. When a bar of iron is inserted within a series of electromagnetic helices its polarity becomes most pronounced and manifests itself, if movement is possible, by motion towards an opposite pole or away from a similar pole. When the magnetic field of a motor is considered, its lines of force pass between the two poles via the armature core of laminated iron placed within it. A coil of wire wound around this core can occupy a series of positions with respect to the horizontal or vertical plane. Let three positions be considered—one in the horizontal plane, one in the vertical plane, and one in a plane situated at an angle of 45 degrees, as shown in Fig. ~~14.~~ This coil, we assume, has as yet exercised no influence upon the magnetic field which streams across from the north pole to the south pole of the motor. It is then to be considered as occupying the first of the positions referred to, namely, one in the horizontal plane, as shown at *A*.

On sending a current through the coil when in a position in the horizontal plane, it acts in every respect as any other electro-magnet irrespective of the fact that it is already in a magnetic field. The turns of wire which compose it act upon the armature core of laminated iron which they embrace, and magnetize it. If a coil were in a horizontal position in space, and did not contain any iron, it would produce a comparatively weak field, but whose lines of force would lie in a vertical direction. Situated as it is with a core of wrought-iron between the poles of a powerful field, the same phenomenon takes place. The coil produces a vertical field, a field in fact whose lines of force are at right angles to those of the original field. It would tend to move the now vertically suspended electro-magnet so that its poles would seek the opposite poles of the surrounding field. The motion would be one of rotation either to the right or to the left, depending upon the relative position of the poles produced by the ampere-turns of the horizontal coil and those of the field in which the armature core rests. The lines of force of the coil will, if permitted, set themselves parallel to those of the field, and in so doing motion would be produced.

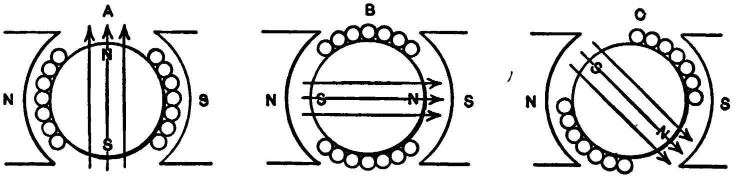

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Fig. 14. Graphical Illustration of Action of an Electric Motor

A coil situated in the vertical plane, as shown at *B* ~~in~~ Fig. 14, produces a magnetic field at right angles to itself or in a horizontal plane. Its lines of force would therefore merge with those of the surrounding field, or, if the poles were opposed to each other, reduce it to an extent dependent upon its magneto-motive force. In either case, whether the field is augmented or reduced, no motion will tend to result from such a relative position, as the lines of force are now in a position of parallelism with respect to each other.

It is evident from the positions of the coil in a horizontal and vertical plane that these are not the ones best suited to the production of either great pull or torque or motion. A coil at an angle of 45 degrees, however, producing a magnetic field at right angles to itself as shown at *C*, ~~Fig. 14~~, also presents poles in a position with reference to those of the field surrounding it, so that motion must result. Not only will a tendency to swing around be perceived, but a strong pull will accompany it. The lines of force of the coil can set themselves parallel to those of the field only by moving the core. This will actually take place not only when coils occupy a position at 45 degrees to either the horizontal or vertical plane but when they are slightly inclined to either. Thus it becomes evident that the constant effort taking place between the lines of force due to the coils on the armature and those of the field, which are supposed to remain comparatively unchanged, can only take place when they occupy certain positions with respect to the field. Under these conditions it might be said that the circumstances present the case of one fixed magnet whose field generally retains its position and a series of movable electro-magnets whose fields are constantly tending to assume positions in which their lines of force lie parallel to and in the same direction as those of the field. Increasing the current under these general conditions would mean an increase in pull between the stationary magnet of the field and the movable electro-magnet caused by the various positions of the coils on the armature. The torque of the armature, therefore, is entirely a question of magnetic field and current in the armature, which is merely another way of saying that it is simply a question of the amount of pull resulting from a stationary and a movable magnetic field, the latter being capable of increasing by an increase of current.

Magnetism and Mechanical Pull

The relation existing between magnetism and mechanical pull, in the case of an electro-magnet, to the poles of which a piece of iron or armature is to be attracted, is very simple. The formula for this relation gives the pull in dynes as follows:

$$P = \frac{B^2 \times A}{8\pi}$$

in which

$P =$ pull in dynes,
$B =$ lines of force per square centimeter,
$A =$ area in square centimeters,
$\pi = 3.1416$.

To illustrate the application, take the case of a magnet having 100 square centimeters of pole surface, and the lines of force equal to 10,000 per square centimeter. The calculation will show the following result:

$$P = \frac{10{,}000 \times 10{,}000 \times 100}{8 \times 3.1416} = 398{,}000{,}000 \text{ dynes} = 895 \text{ pounds.}$$

The Counter Electromotive Force of a Motor

The adjustment which takes place between the load of a motor and the power it consumes is brought about by means of the counter electromotive force. This electromotive force is developed within the armature for the same reason that any other electromotive force is generated in conductors cutting a magnetic field. The armature of the motor, although caused to rotate by the reaction between the field of the magnets and the field of the conductors, nevertheless presents the case of free conductors rotating in such a manner that the lines of force they meet are cut and necessarily produce electromotive force. It is a simple matter to calculate this counter electromotive force by multiplying the revolutions per second by the number of conductors by the lines of force of the field, and dividing by 100,000,000.

The conditions which exist within the armature of a motor when in action are as follows: Current is allowed to enter the motor, energizing the field magnets, and passing through the armature in a limited manner. The rotation which then ensues is the means of generating an electromotive force within the armature conductors. There are, therefore, two electromotive forces in action within the armature, one of which tends to send a current through it, and the other, which opposes or counteracts the effect of the entering electromotive force. The electromotive force *generated* within the armature conductors is called the counter electro-motive force, and the electromotive force applied to the motor is called the line or impressed electromotive force.

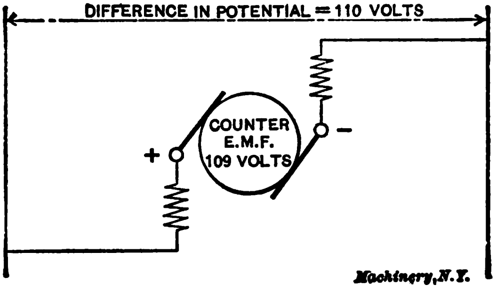


Fig. 15. Graphical Illustration of the Principle of the Counter Electromotive Force

A study of electromotive force with respect to its generation by means of motion, lines of force and conductors, shows how variations in the amount of electromotive force developed may be brought about. Any increase in the number of conductors on the armature of a motor will give rise to a higher counter electromotive force. Any change in the speed of a motor will give rise proportionately to an equivalent change in the counter electromotive force of a motor. Finally, any increase or decrease in the strength of the magnetic field will be the means of causing a change in the counter electromotive force. These influences are referred to because the regulation and operation of motors is dependent upon these principles not only in theory but in actual practice.

When an impressed electromotive force acts upon the field and armature windings of a motor, current is sent through the first, producing a field of given strength, and through the second producing rotation and, hence, power. The remarkable fact about the work a motor is doing and its counter electromotive force is this: When the motor is running free, or "idle" as it is called, the motor is developing the highest counter electromotive force, and in consequence the impressed electromotive force is only able to send a small current through the armature. The effective electromotive force in this case is the *difference* between the impressed electromotive force and the counter electromotive force. This effective electromotive force will send a current through the armature which is governed by the resistance of the same. For instance, assume that the armature has a resistance of 0.01 of an ohm, that the impressed electromotive force equals 110 volts, and that the counter electromotive force equals 109.5 or 109.75 volts. The difference between 110 and 109.5 volts is 0.5 volt, which gives a current of $0.5 \div 0.01 = 50$ amperes. The difference between 110 and 109.75 volts is 0.25 volt and this would send a current through the armature of $0.25 \div 0.01 = 25$ amperes. Therefore a very low resistance armature needs but a very small effective pressure to send a heavy current through.

The frequent changes of load to which a motor is exposed will, when taking place, vary the speed slightly. If the load is reduced the speed will increase, and if the load is increased the speed will diminish. It is thus evident that the counter electromotive force will vary accordingly, and that less or more current will pass through the armature. The counter electromotive force, therefore, acts as a natural automatic valve which opens wider when the load on the motor is increased, and therefore more current is required, and which, so to speak, closes down when the load on the motor is diminished and less current is required.

Kinds of Motors

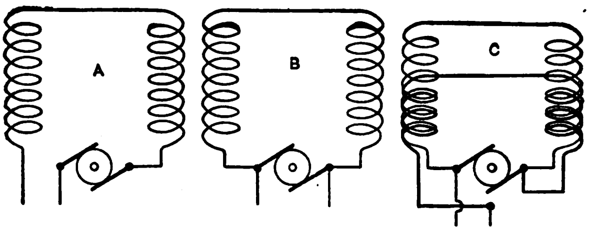
Motors are divided up into classes according to the winding and the character of the current employed for the operation. The direct current is used for motors wound as follows:

Constant current series-wound motors. (See *A*, Fig. 16.)
Constant potential shunt-wound motors. (See *B*, Fig. 16.)
Constant potential differentially-wound motors. (See *C*, Fig. 16.)

Each of these types is distinct, as far as its winding is concerned, although the last is a combination of the first two, that is, shunt and series winding. Series-wound motors are employed on direct current circuits which supply constant current and constant potential. High tension arc light constant current systems make use of them, as well as 550-volt constant potential street railway systems. The shunt-wound motor is used for stationary work, such as the running of machine shops, printing presses, etc.

Speed of Motors

The question of speed is a very important one in connection with motor design and construction. The two possibilities open in this direction are *constant* speed and *variable* speed. The speed can be controlled and varied by placing a resistance in series with the motor, thus controlling the volts and amperes it receives; but automatic control is, perhaps, more easily obtained, in such cases when a constant speed is desired, by differential winding. The ordinary type of shunt-wound motor possesses a fairly constant speed when the load is increased or diminished, whereas the series-wound motor will increase in speed as the load is reduced and decrease in speed as the load is increased. A differentially-wound motor is one constructed with a differential field, that is to say, a field whose magnetic strength is increased or diminished, not with the increase of the load, but reversely. In a motor of this type of winding its field is weakest when its load is greatest and its field is strongest when its load is least. The manner in which this affects the speed will be explained shortly under the head "Differentially-wound Motor."



SERIES WOUND MOTOR
CONSTANT CURRENT

SHUNT WOUND
CONSTANT POTENTIAL

DIFFERENTIAL WINDING
CONSTANT POTENTIAL

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Fig. 16. Types of Motor Windings

The Series-wound Motor in Service

To understand the service for which a series-wound motor is best suited, it is necessary to understand the influence upon it of more or less voltage, more or less current, and a heavier or a lighter load. To begin with, the very nature of a series winding calls for the same current in both armature and field. This fact is emphasized in order to show how responsive the motor is to such changes as may occur in the counter electromotive force of its armature. The current which passes through a motor may be determined by the formula:

$$\text{Current} = \frac{\text{volts of line} - \text{counter E.M.F.}}{\text{resistance in ohms}}$$

Supposing a series motor has a resistance through armature and field of 2 ohms, and its armature develops a counter electromotive force of 400 volts; then, if the impressed or line pressure is 500 volts, the current will be:

$$\text{Amperes} = \frac{500 - 400}{2} = 50.$$

Examination of this formula will show that if the resistance is increased the current will diminish, and also that an increase in the counter electromotive force will reduce the current. It will show in addition that if the voltage supplied to the motor is increased, more current will flow; there will therefore be more torque or pull to the armature and in consequence a higher speed. Manipulation of the field strength is the means employed for affecting the counter electromotive force; in this case, if the field is cut down either by shunting the field winding or by short-circuiting part of the lines of force, less lines of force are cut by the armature conductors and a lower counter electromotive force is produced. More current cannot pass in if the machine is series wound and fully loaded on a constant current circuit. Therefore, under such conditions, with a weakened field its pull would be reduced and its speed slackened. As already stated, a series motor increases in speed as its load is reduced and diminishes in speed as the load is increased. A reduction of the load causes the then present pull of the motor to increase its speed; this also increases its counter electromotive force and consequently reduces the current in both armature and field. Although there is now a weaker field due to fewer ampere-turns on the field magnets, there is a higher speed. A still further reduction of the load will increase the speed still further until, if the motor is entirely without load, it will run fast enough to destroy itself.

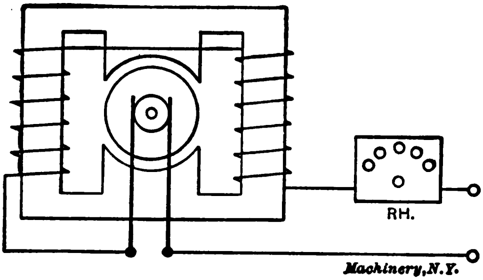


Fig. 17. Series Motor with Resistance

In street railway service the series motor is used exclusively, and its regulation in regard to speed and power is carried on by a controller which throws the motor circuits from being in series with each other, eventually into multiple, it being understood that more than one motor per car is in operation at a time. A series motor with a resistance box in series with it, as shown in Fig. 17, represents in many respects the method of controlling a street car motor, only, instead of a resistance of this character, its place is taken by another series motor, as shown in Fig. 18; two series motors in series, and if necessary, with a resistance in series as well, being the present basis for street car control. Either a resistance, or another motor in series, is a means of reducing the pressure and current supplied, which is theoretically and, fortunately, practically a successful method of governing the speed.

The motorman is merely manipulating the circuits of the series motors, so that more or less current and pressure is allowed to affect each motor individually, for the purpose of giving the car a greater or less speed. It has been stated that a series motor running idle, that is, without a load, will tear itself to pieces. In street car service, even though the car is empty, the motor has still the work of carrying the car trucks and car body, and, therefore, cannot develop an abnormally high speed. But it will be readily noticed how much faster an empty car travels, than one filled with passengers. The motors in this case are taking all they possibly can in the way of current at the pressure of the line. Higher voltage would mean an increased speed, or a more powerful field, but the limited pressure of the trolley system, 550 volts, forbids this, and the only means for moving more heavily loaded cars is more powerful motors.

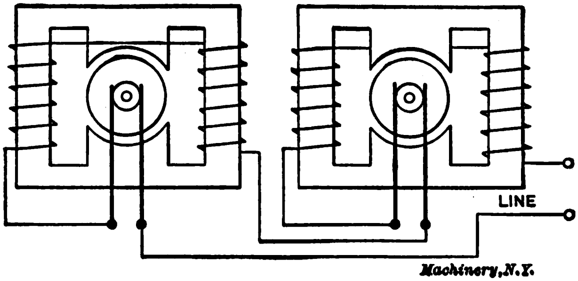


Fig. 18. Two Series Motors in Series

Fan motors are series wound as a rule, unless they are to serve a different purpose from that of only running fans. A series-wound motor must always be doing work when in operation, and the presence of a fan, therefore, represents a load which enables it to comply with the requirements of practice. Different speeds are obtained by means of a switch which governs resistance in series with the motor. At two or three points the switch allows a current of great strength and pressure to enter, which, with the fan load permanent, permits of a higher speed. A series-wound motor for the driving of sewing machines could not be used unless there was a certainty of the load never being removed; otherwise the armature of the motor would fly apart. Intermittent service calls for a motor which can meet conditions of full load or no load without such an abnormal development of speed.

The Shunt-wound Motor

The shunt-wound motor is one in which the speed is fairly well preserved under all changes of load. The field winding receives its current in multiple from the line, and therefore is not affected by the changes in speed or load. The counter electromotive force of the armature is the regulator of the amount of current the motor takes, and this in its place is determined by the amount of work the motor is doing and its effect upon the speed. As the load is increased or diminished on a shunt-wound motor, the speed is affected accordingly; but the counter electromotive force will rise or fall, which will be the means of allowing a current to flow through the armature proportional to the effective electromotive force. The automatic action of the counter electromotive force in this respect has made the shunt motor peculiarly noteworthy. Under these circumstances, it is easy to increase the speed of the motor by means of the field.

If the field of a shunt motor is weakened, the counter electromotive force of the armature would either drop, or (on account of the increased current which would thereby result, and necessarily the greater torque in the armature), the speed would increase. This is found to be the case in practice. That is to say, if a resistance is put in series with the field winding of a shunt motor, the speed of the motor will either increase or decrease as the current in the field winding is decreased or increased. A very interesting experiment, which carries out this idea in practice, is that of running a shunt motor idle and suddenly cutting out the field winding. The effect of this, which should be tried with a small motor, is to raise the speed to a very high point. The motor is not entirely without a field in this case, but depends upon the residual magnetism and armature reaction for that which exists. The counter electromotive force thus suddenly cut down, causes a powerful current to flow through the armature. The effect of this is a greatly increased torque and a higher speed, until, if the motor can stand the strain, it reaches a speed at which there is some approximation between the counter and impressed electromotive force to that existing under normal conditions. Advantage of this fact is taken in the regulation of shunt motors by the so called differential method. By this method the field is weakened when the speed slackens.

Differentially-wound Motor

The differential field is obtained by means of two field windings—one a shunt winding and the other a series winding, as shown in Fig. 19. The shunt winding receives its current and pressure as usual from the main line, but the series winding takes the entire current of the motor. This winding is so arranged, that as the current required by the motor increases, its *demagnetizing* effect upon the field also increases. It is really a compound-wound dynamo turned into a motor. Thus, increasing load means a tendency to increasing speed, which compensates for the number of turns per minute lost through the increased load. When the motor runs idle, the current in these series turns has little or no effect on the speed. In fact, the motor is now a simple shunt-wound machine. A uniform speed is secured by this means, within certain limits, for all changes of load.

Conditions of Service

The two broad groups in which motors may be divided, as far as service is concerned, are the class including motors for stationary, and the class including motors for vehicle purposes. Stationary service may be still further divided as below:

Factory drive, all kinds.
Ventilation, including fan motors.
Hoisting and elevator service.
Mining, such as drilling, etc.

The conditions of service for stationary motors may be extended so as to include applications of less importance, such as dental apparatus, medical appliances, stage devices, etc. The other list of conditions of service, in which the motor is employed for transportation from point to point is as follows:

Electric railway work.
Automobile work.
Launch work.
Agricultural work.
Mining work.

Depending upon the nature of the application of the motor to any specific purpose, the character of the motor itself is determined. This is the influence which gives rise to the employment of series, shunt or differentially wound machines, taking a direct current, or the installation of motors taking an alternating current.

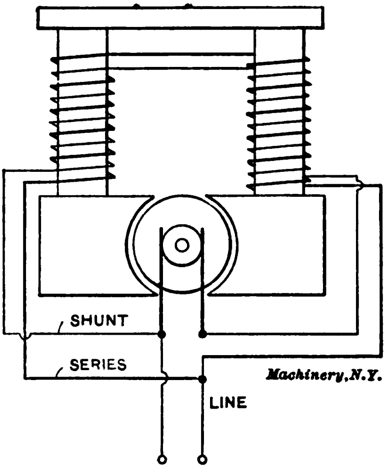


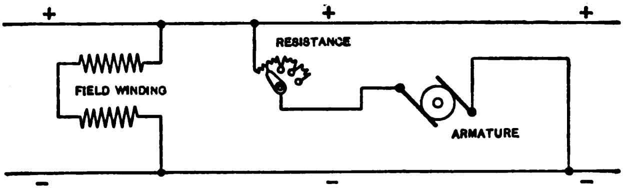
Fig. 19. Differentially-wound Motor

Starting a Motor

To start a motor from a condition of rest requires the employment of a device which will not permit more than the proper quota of current to pass through. In a series motor a resistance interposed between the line and the motor will prove sufficient. In a shunt motor it is necessary to take certain precautions in this direction, so as to limit the flow of current through the armature. Enough time must elapse from the moment the current is turned on until the resistance is cut out, to permit the armature to develop sufficient back electromotive force to act as a restraining influence upon the current. The correct function, therefore, of the resistance is to act as a substitute for the counter electromotive force. It must be remembered that the field windings of a shunt motor are connected across the line and take their energy directly from the circuit. The armature will be connected in the same way *after* the motor is running; but until the motor is developing enough counter electromotive force, a resistance is kept in series with the armature, as shown in Fig. 20. First when the speed is high, is it deemed safe to gradually cut it out. It is thus evident that both field and armature are in multiple with the line receiving the full pressure, but the armature is protected from excessive current when starting, by a resistance in series.

As an example, suppose that the armature itself has a resistance of 0.02 ohm. If no starting resistance were employed, and a 110 volt current were sent through the armature, the strength of the current would be $110 \div 0.02 = 5500$ amperes, which would be destructive to the windings of the machine, causing short circuit. A starting resistance or rheostat, frequently also called starting box, is therefore employed to prevent the strength of the current to rise beyond a reasonable value.

If a resistance box of from 10 to 20 ohms is selected, to put in circuit with the armature, then, even though the armature does not revolve very fast, only 5 or 10 amperes can get through in the beginning, and the danger of a short circuit is removed. After the armature speeds up, however, the resistance is cut out, the counter electromotive force bringing about the proper adjustment between the load and the current consumption. If in the case under consideration, the counter electromotive force is equal to 109 volts, then a voltage of 1 volt, with an armature resistance of 0.02 ohms, will send a current of 50 amperes through the armature winding at full load.



Machinery,N.Y.

Fig. 20. Resistance in Series with Armature when Starting Motor

It is evident that the resistance used must bear a definite relation to the capacity or horsepower of the motor. Hence, rheostats are termed, for example, 110—2 H. P. resistance boxes, or whatever the voltage and horsepower may be in each case.

It should be understood that the current a motor takes is largely a question of its efficiency. For instance, a 10 horsepower motor will take a theoretical current of 74.6 amperes at 100 volts pressure. The total watts are $10 \times 746 = 7460$; but if the efficiency of the motor is not high, it will take more watts in proportion, which with given pressure would mean more current. The amount of current required by a series of motors of 10 horsepower apiece at varying efficiencies could easily be tabulated. Such a table would be exceedingly instructive in showing the relationship between efficiency and the consumption of power. It is not difficult to estimate that a motor of low efficiency will waste in a certain period of time, an amount of power, the cost of which will compare readily with its own cost. In other words, if a motor is cheap because its construction makes it inefficient, it is for that very reason dear, because its power consumption makes it expensive. A high efficiency motor is therefore cheapest, though its first cost may be greater. Another point of great interest is that of speed. Small power users are peculiarly addicted to the habit of overloading motors. Jacobi many years ago enunciated the principle that a motor is doing its maximum work when its speed is one-half its normal speed, through being loaded down. At this rate of speed and load, it has only 50 per cent efficiency. It is therefore consuming twice as much power as it should, and the cost of operation is doubled. While it is true that a motor can do more work if overloaded, it does that extra work on a very wasteful basis. It is not wise, therefore, to place a strain beyond the normal rating upon any motor, unless it be for the purpose of bridging over an emergency for a short period of time.

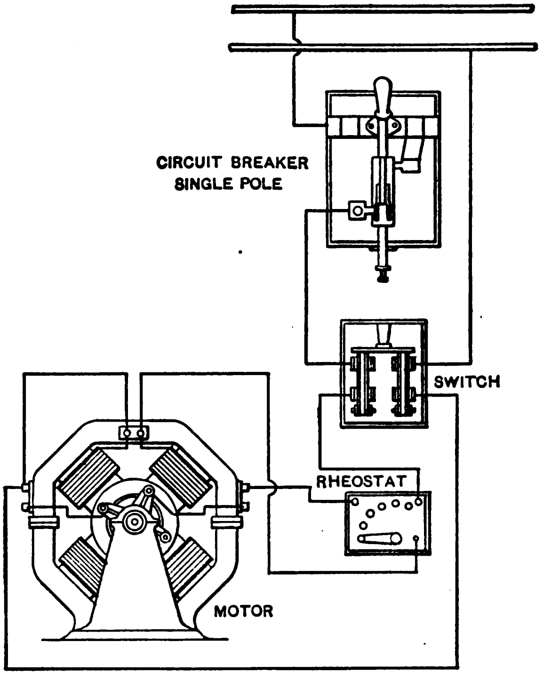


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Fig. 21. Motor with Single-pole Circuit Breaker

Circuit Breakers in Motor Service

The possibility of sudden overload with the resulting inrush of current has been the reason for introducing the circuit breaker, or electro-magnetic switch, for the protection of motor as well as dynamo lines. The electro-magnet and switch, of which it is composed, are simple enough in general construction, but the electro-magnet must be sensitive to a certain value of current, so that if this point is passed, the switch will fly open and disconnect the motor from the line. The switch is so constructed that when it flies open, its action is sudden and arc-less. The circuit breaker is a substitute for the old time fuse, whose dangerous volatilization was an ever present risk of fire during a temporary short-circuit. Motor and dynamo circuits protected with circuit breakers are like boilers supplied with safety valves weighted down with a certain number of pounds. In one case steam pressure will set the valve into sudden operation, in the other case an overflow of current.

A line connecting to either a motor or generator may be protected by the installation of a single pole (see Fig. 21) or a double pole (see Fig. 22) circuit breaker; by this is meant a circuit breaker which is inserted in only one leg of the line involving a single pole, or one engaging both wires or poles.

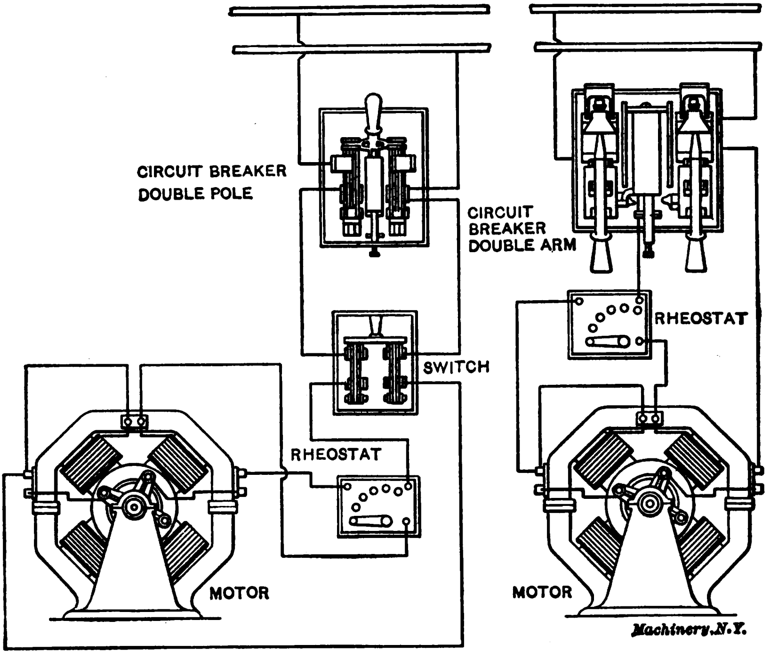


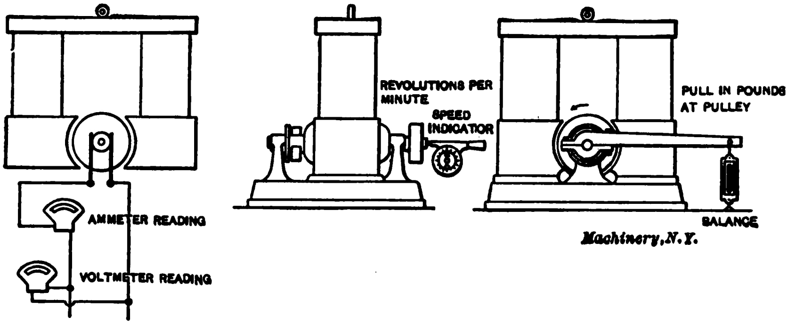
Fig. 22. Motors with Double-pole Circuit Breakers

Commercial Efficiency

The rating of motors for commercial efficiency is based upon the tests to which they are subjected. The tests are simple in character and may be defined as a method of establishing the ratio between the power taken out in a mechanical form to the power sent in, in an electrical form:

$$\text{Commercial efficiency} = \frac{\text{mechanical energy obtained}}{\text{electrical energy supplied}}.$$

The motor is supplied with an ammeter and voltmeter to measure the electrical energy sent in, as indicated in Fig. 23. A tachometer or speed meter is utilized for getting the number of revolutions of the armature per minute. A dynamometer or brake is used for measuring the pull on the pulley or shaft of the motor. If the pull on the dynamometer or brake is taken at a certain rate of speed, it will be accompanied by a certain current consumption, the voltage remaining the same. This data is used for determining the efficiency as follows:



Machinery, N.Y.

Fig. 23. Method of Testing Motors

$$\text{Mechanical H.P.} = \frac{\text{Pull in pounds} \times \text{length of brake arm in feet} \times \text{rev. per min.} \times 2 \times 3.1416}{33{,}000}$$

$$\text{Electrical H.P.} = \frac{\text{Amperes} \times \text{volts}}{746}$$

$$\text{Efficiency} = \frac{\text{Mechanical H.P.}}{\text{Electrical H.P.}}$$

The efficiency is obtained in this manner for all such loads as running idle, quarter load, half load, three-quarter load and full load. The speed, amperes, and pull, will vary in each case, the amperes and pull naturally very much more than the speed.

CHAPTER III

ELECTRIC RAILWAYS

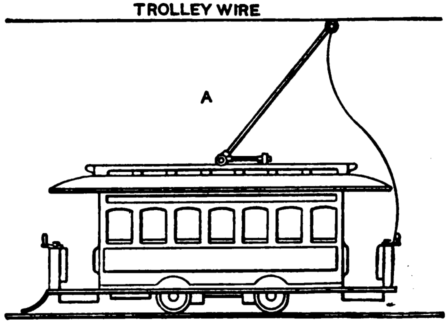
The inventors of electric railway appliances may be counted in multitudes, and their work in the aggregate has been the means of developing the possibilities of electric roads to their present high state. It must not be believed, however, that perfection has been reached as yet; far from it. Yet judging from present conditions, the most definite lines of the problem have been laid down, and further work will be mainly in the line of secondary improvements. The first recorded American inventor in this field was Davenport, who built a small model of an electric car running on tracks, very crude, yet operative, and thoroughly crystallizing the fundamental principles of electric railroading. Among the first applications of the electric motor naturally would be that of applying it to some purposes of traction. Jacobi applied an electric motor run by batteries to the running of a small boat on the river Neva, and the same idea was followed by Trouve in France on the Seine. It was found possible to operate tricycles and small four-wheeled vehicles by electricity, and then a small electric car. The experiments carried on in the initial stages of electric traction were destined to expand, because of the rapid increase of population in large cities, which called for some efficient and safe as well as rapid means of locomotion. The laboratory experiments and scientific tests soon became matters of public interest, and the question of whether the application of an electric motor to a railway truck would prove a success was soon answered in the affirmative.

Systems of Electric Roads

A number of systems of electric roads have been designed whose ultimate object was the solution of the street car problem. Some of them have been tried with every sign of success at the start and have failed, others have been failures in the beginning, but are now established successes. The four principal systems to which general reference is made are:

1.—The overhead trolley system.
2.—The third-rail system.
3.—The open conduit or slot system.
4.—The storage battery car system.

The overhead trolley system is of American origin. It consists of one, or sometimes two wires, suspended over the track and carrying the current. The overhead wire is placed at a sufficient height so that it will not affect street traffic in any way. Poles for supporting the wire are placed either along each side of the street, or in the center of the street between the two tracks in double-track systems. When only one overhead wire is used the return is through the rails. When two wires are used the return is through one of the wires. The overhead trolley system is the cheapest to install and maintain, and with proper care in erection and maintenance it is safe and durable. The main advantage of this system is, of course, the small first cost, and the comparative ease with which it can be kept in repair. The chief objection to the overhead trolley system has been on grounds of its appearance. But this objection can be largely overcome by making the poles supporting the wire of ornamental appearance, and using them for arc and incandescent lighting purposes as well.



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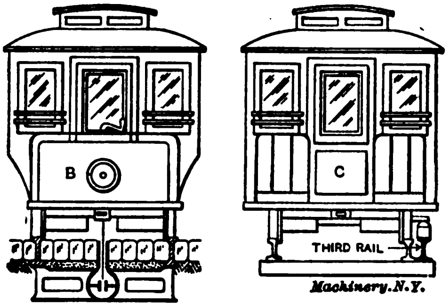
The Overhead Trolley System



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The Conduit System The Third-rail System

Fig. 24. Principal Electric Railway Systems

The third rail system differs from the overhead trolley system in that the current is transmitted through a rail laid on one side of, or between, the tracks. In the open conduit or slot system, a continuous bare conductor is placed underground in an open slotted conduit between the rails, the current being taken off from the conductor by some sliding or rolling contact carried on the cars. The storage battery car system, as the name indicates, depends for its motive power on storage batteries charged with current from a central station. In this case it is evident that the car becomes independent of line conductors.

It is not difficult for the reader to realize that a selection of the correct system, from among those mentioned, suited to the special needs of cities and to suburban use, was a matter calling for the greatest discrimination. It has been pretty well settled in New York that the open conduit is best suited to the peculiar requirements of a large city, where it is imperative to place all wire underground, thus excluding the overhead trolley entirely. The storage battery system was in operation for a few years under the title of the Julian system, but it did not succeed on account of the wear and tear of batteries, the difficulty of handling the same, and the possibility of breakdowns in the midst of busy thoroughfares. The weight of the storage battery added to the problem, with the result that a continuation of the experiment led to great financial sacrifices. Of late, however, the experiments have been successfully resumed with the Edison storage battery.

The open conduit system was a failure for many years because of the imagined difficulty of keeping the conduit clean, and because of the impracticability of many new devices introduced to make it a success. Insulation, drainage and a system of manholes for inspection were the elementary considerations. Along with them came the correct development of a solid and effective method of construction. Sewage connections were made adequate to drain the conduit, and a substantial form of insulator was introduced to support the two rails acting as conductors within the conduit. Ducts with feeders were laid along the tracks, and thus the various, and at one time, apparently insurmountable obstacles, were overcome. The peculiarities of street car service are such that a car must start rapidly, yet without too sudden acceleration. To accomplish this successfully, powerful motors with properly designed controllers, are installed in the cars.

Having now reviewed in a general way the conditions of electric railway systems we will examine the most important systems in detail.

The Overhead Trolley

The cars in the overhead trolley system are fed with current from the trolley wire and tracks. The trolley or pole ends in a trolley wheel which presses against the trolley wire and completes the circuit. The trolley wire, of No. 0 size Brown & Sharpe gage, is supported above the track by means of wires and poles which hold it over the middle of the track. The rails are electrically connected by copper bonds which join adjacent ends. Both trolley wire and tracks are reinforced at intervals by means of additional supply wires called feeders. The current enters at the trolley wheel, passes down the trolley and enters the motors via the controller. The name controller is obviously the best that could be chosen, because by means of this device the current supply is controlled and the speed and power of the motors properly regulated. The pressure employed for trolley car service is generally 550 volts. This is not supposed to be of sufficient strength to destroy human life, although many instances have been recorded of such unfortunate circumstances.

The trolley wire is made of hard drawn copper and the wires stretched across the track from pole to pole are called ***span*** wires. The trolley wire is also supported from brackets attached to or forming part of the posts, which are partly or wholly of metal. The construction in this respect must be such that the trolley wire, though firmly held, is still elastic. At various points along the trolley line, where the traffic is heaviest, the wire is connected to feeders. It is also connected to feeders at those portions of the system furthest removed from the power house. These more or less distant points do not suffer so much from heavy traffic as from the effects of heavy drop. As each car takes from 50 to 150 amperes, depending upon its load and speed, and as the resistance of a few miles of wire, however large in size, is quite an item, it becomes evident that the degree of drop in voltage will be quite a percentage of the total pressure. This would cause the cars to run slow for two reasons—first, because the voltage is low, and second, because the current is less because the voltage is low. The series motor is controlled, as regards its pull and speed, by just such conditions as those described, which can be incorporated into the general statement that where series motors are concerned, as already mentioned in the previous chapter, the following rules apply:

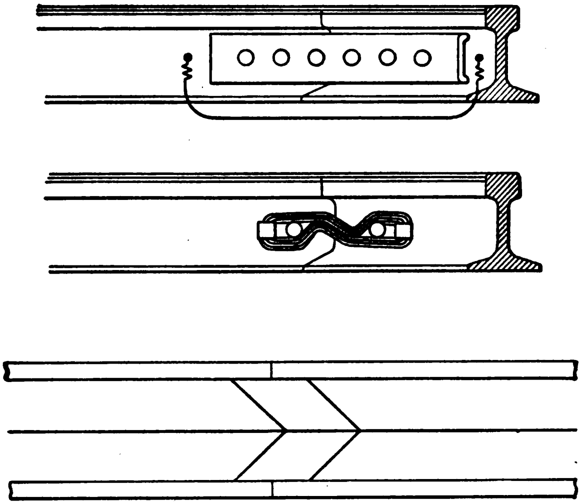
1. In a series motor the pull increases if the current increases and the pull decreases if the current decreases.
2. In a series motor the speed increases if the voltage at its armature terminals increases, and its speed decreases if the voltage at its armature terminals decreases.

Suppose six miles of wire are considered of an average resistance of ½ ohm to the mile; this would give a total resistance of 3 ohms. If one or two cars are consuming about 150 amperes at this point, the drop in the line equals $3 \times 150 = 450$ volts. It is easy to realize how completely a trolley system would fail under these conditions. In fact, a dozen cars would be the means of causing so complete a drop that practically no available energy would reach this distant point. It is no exaggeration to state that in a large city a trolley system is an impossibility unless hundreds of tons of copper, in the form of feeders, are employed to carry current all along its circuit. The trolley wire, therefore, is not actually carrying the whole electrical energy, but the feeders. The problem is one of reducing the drop to a certain practical minimum, which involves one of the heaviest investments in electric railway engineering.

Bonding

All that is required in ordinary railroad practice is to firmly secure the rails together mechanically by means of fish plates. This method of joining steam-road rails is mechanically good, but for electric railway service it is unsatisfactory. Rust soon prevents a good contact, and the result is a high resistance joint. A series of such defects would rapidly use up the voltage when a heavy current is required; hence, an electrical contact is secured by means of ***bonding***. To bond the rails means to establish connection between them by means of a heavy flexible copper wire or cable. The ends of this wire or stranded cable are riveted into the rail, the rivet and joint being proportioned with respect to the current which passes. The rails when bonded represent two long lines of electrical conductors upon which the wheels turn and also complete the circuit through the motors from the overhead trolley wire.

Another method of bonding is to run a wire or cable along the middle of the track and attach wires to it from the rails. In other instances the wire laid between the tracks zigzags from rail length to rail length and establishes connection. The most ideal method, however, is to weld the rails into one continuous track. Track or rail welding is the most satisfactory in the end for all the reasons which appeal to the electrical expert. The other methods though good are subject to conditions which eventually destroy their integrity. If the resistance at any one bonding averages up 1/100 of an ohm, then 1000 bonds give a resistance of 10 ohms. As this is duplicated on the other track as well, and as this track is in multiple, the net resistance would be 5 ohms. Reducing the average resistance of any one bond will still give for the aggregate resistance a very high figure. The most important difficulty lies in the fact that bonding steadily depreciates in quality. Iron and copper form a voltaic couple, which helps to increase the bad effects of general corrosion due to ordinary causes. A current of 1000 amperes given up by the line at any particular spot, due to a block of cars and the almost simultaneous starting of a group of them, would cause a very heavy line drop unless the resistance is exceed-



Machinery,N.Y.

Fig. 25. Methods of Bonding

ingly low. It is readily seen that a resistance of 1/10 of an ohm means a drop of 1/10 × 1000 = 100 volts. On a 550 volt circuit this means a loss of nearly 20 per cent of the total voltage. Examples of different methods of bonding are shown in Fig. 25.

Electrolysis and Bad Bonding

The energy which is not conducted through the tracks will pass through all the available gas and water pipes in the neighborhood. The statement found in Ohm's law, that the current is directly proportional to the electromotive force and inversely proportional to the resistance, explains why the current will leak away from the tracks whenever the bonding is bad and take into its circuit water and gas mains. In passing from one to the other of these, the moist earth acts as the electrolyte and the pipes as the electrodes of an electrolytic cell. The metal is carried from point to point from the outer walls of the pipes as shown by the deep pitting which results. Thus the effects of poor bonding are manifested in two ways, through loss of power and through electrolysis.

In very wet weather these results are exaggerated, and the general leakage throughout the systems rises to very high figures. The two most readily controlled difficulties, however, are those found in a poorly fed trolley wire and a badly bonded track.

Double Overhead Trolley Systems

The double wire trolley system has been adopted only in a comparatively few cases in order to avoid all electrical disturbances in the returns. The system consists of two overhead wires, one positive and one negative, and two trolley wheels and poles. The current arrives at the motors *via* one wire and trolley, and returns to the power house *via* the other trolley and wire. The installation is more expensive than that of the single overhead conductor system, and difficulties are met with at junctions and crossings.

The Switch and the Controller

The current from the line after having passed through the trolley wheel and pole first passes a switch placed over the motorman's platform in ordinary street cars. At the other end of the car there is another switch, both switches being in series with each other. The current after having passed through the switches is led to a mechanical circuit breaker, so that the current can be automatically cut off in case of extreme overload, without causing injury to the motors.

The speed of rotation of the motors driving the car, and hence the speed of the car itself, is regulated through a controller operated by the motorman. By means of this controller and its rheostat the current can be so regulated and distributed to the motors that their power and speed can be regulated at will by the motorman. It may be explained that a rheostat is an adjustable resistance which enables the current to be brought to a standard or fixed value by adjusting the resistance. The term is generally applied to a quickly variable resistance, the varying values of which are known.

The controller has been simplified in the last ten years until it has reached a point which approximates perfection. The car motors are designed with reference to the speed of the car, its weight and acceleration; the controller is designed with reference to the starting and stopping of the car, the current consumption, and the control of the circuits. If two series motors are considered, it is readily realized that the sudden throwing on of the power would result in probable accidents to those on board the car. The suddenness with which the car will start is largely dependent upon the current passing through the motors. If they are at rest, and the current is fully turned on, aside from the action of automatic circuit breakers, it is evident that with no counter electromotive force, an enormous current would tend to flow.

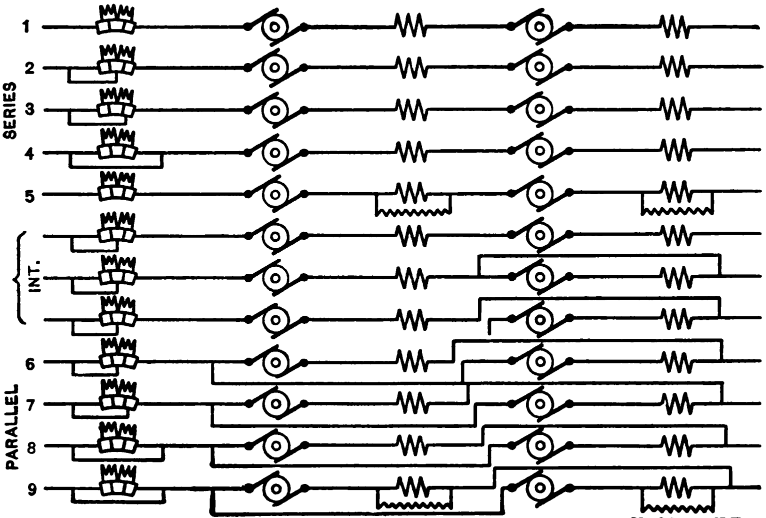


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Fig. 26. Diagram showing Combinations Effected by Controller in Starting a Car

This would start the car with a jerk. The current governs the pull of the motor, therefore to avoid too rapid a development of torque the current must be introduced to the motors through the medium of resistance. A variety of connections must be made and unmade, so as to gradually bring the motors from a condition of rest to one of rapid motion. In the first step considerable resistance is interposed, and in the last both motors are in multiple across the circuit. Between these two extremes exists a series of steps or combinations as follows:

MOTORS IN SERIES

1.—Motors in series with a resistance and with each other.
2.—Motors in series with less resistance and with each other.
3.—Motors in series with still less resistance and with each other.
4.—Motors in series with each other (no resistance in).
5.—Motors in series with each other and fields shunted.

MOTORS IN PARALLEL

6.—Motors in parallel with each other and resistance in.

7.—Motors in parallel with each other and less resistance in.

8.—Motors in parallel with each other and still less resistance in.

9.—Motors in parallel with each other and no resistance in and fields shunted.

These combinations are the ones effected by the General Electric K2 street car controller. As can be seen from the description given in conjunction with the combinations, it is of the series parallel type. There are really a series of combinations produced between 5 and 6 which are called intermediate connections. These are the connections which throw the motors from series into parallel. The equivalent of these combinations are given in diagrammatic form in Figs. 26 and 28, and represent the foundation on which is built the controller largely employed in New York, for street car, elevated and subway service. The combinations 1, 2, 3, 6 and 7 call for the use of the rheostat, while combinations 4, 5, 8 and 9 do not; therefore, the former must never be used for any great length of time to run the car, while the latter are allowable. It is obviously wasteful to run a car with resistance in series, and this rule applies also to the intermediate positions lying between 5 and 6, which are cases where the rheostat is in circuit. Fig. 27 shows the controller contacts. In Fig. 28 the arrangement of the reversing switch is also shown, the movement of which to the right or left reverses the direction of rotation of the motors.

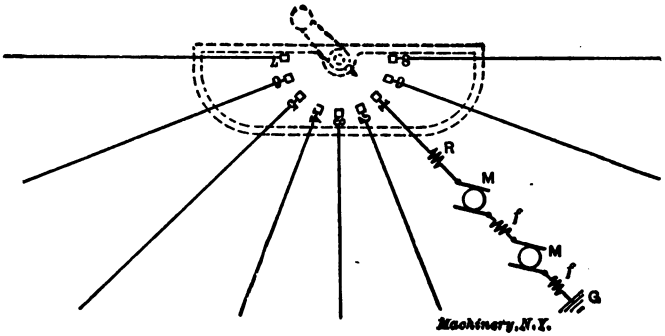


Fig. 27. Contacts of Street Car Controller

To sum up, the requirements for electric railway service, in general, are:

1.—The voltage along the system both in the tracks and trolley wire is sustained by means of feeders.

2.—The current, in starting, is introduced into the motor by an ever-increasing value by means of the controller.

With a uniform voltage along the line the speed will not drop, and with a uniform type of motor and with a scientifically constructed controller the ultimate motor torque will always be at a high figure.

Long Distance Electric Roads

The adaptability of the overhead trolley system to long distance roads is evident from even a superficial examination of practical conditions. The greater the distance between the power house and the end of the road, the greater the cost of the system. This is true particularly with the old established method of using a direct current of 550 volts and an elaborate feeding system to reinforce the voltage and current. The capital invested per mile of track, including the cost of the power house, is the factor which in many respects limits the length of a line. Electric roads can be built to reach as far out into and across the country as steam roads, but the expense attached is high. Thus it becomes evident that engineering projects can only become established as definite propositions if their cheapness as well as practicability can be demonstrated. Long-distance roads must present the feature of high speed. In this respect the adaptability of the motor is unquestioned.

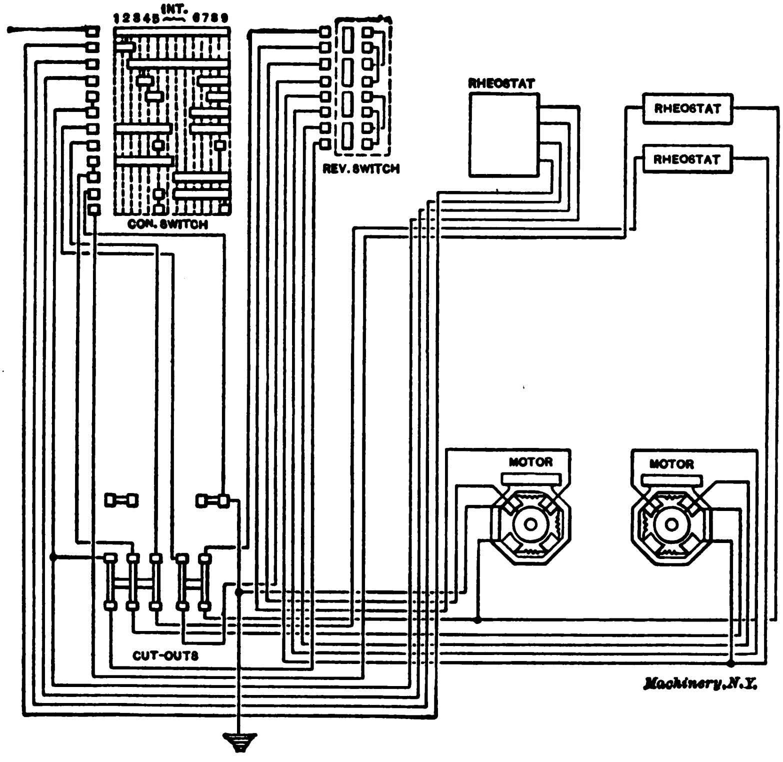


Fig. 28. Wiring Diagram of Street Car Motors and Controller

Within city limits the system in vogue is based upon the idea of substations. The power originally generated is converted into a high voltage alternating current which is distributed to a series of substations or transforming houses. From these, feeding lines radiate to different points of the electric road, sustaining the voltage, and leading, if necessary, to the end of the road. The longer the line, the more numerous become these subsidiary stations. This method of sub-stations is the one which has exerted an extraordinary influence upon the development of electric roads for street railway purposes within large cities. It has paved the way for a normal development of the electric street railway system; the flexibility of the alternating three-phase system aided by the application of rotary converters has placed electric railroading upon a broad and efficient basis.

The requirements of a long-distance road can be tabulated as a series of conditions imposed by the financial and scientific aspects of the problem; they are:

1.—High voltage for transmission.
2.—High insulation for the trolley line.
3.—Low cost per mile of road.
4.—Simple devices to control the car.
5.—Construction of a most durable character.

Though but part of the long list that a close inspection of the proposition would indicate, these items are the most important. To meet the first requirement in a practical and economical manner, experiments have been directed along the lines laid down by alternating current practice. It can be stated almost as a certainty that any great advancement made in electric railroad work will be by means of the direct application of the single-phase alternating current.

Third-rail and Overhead Trolley Compared

Comparison is frequently a better means of presenting ideas than mere description. The only difference between a third-rail and an overhead trolley system might be best expressed by the statement that one is an overhead trolley and the other is a ground trolley. In fact, no actual difference exists except in this respect, either in the character of the machinery employed or the transmission and distribution of the power. The advantage of solidly supporting a live conductor, namely, the third-rail, where it cannot fall, is counterbalanced by the difficulty of insulating it and its direct danger to the public. The third-rail is best suited to elevated structures, to stretches of protected track, to tunnels, etc. Tabulating the statements made, the case is presented as follows:

I. ADVANTAGES OF THE THIRD-RAIL

Solidity of construction.
Cheapness of construction.
Better conductivity.
Greater durability.
Accessibility.

II. DISADVANTAGES OF THE THIRD-RAIL

Difficulty of getting good insulation.
Danger to life.
Exposed to snow and rain.
Requires frequent bonding.

III. APPLICATIONS OF THE THIRD-RAIL

- Elevated structures.
- Protected stretches of track.
- Tunnels.

In contradistinction to these factors are the advantages of the overhead trolley system, with the elimination of the necessity for bonding and the important question of the safety of the overhead trolley as far as life and limb are concerned. The question of insulation is obviously an open one, with greater advantages on the side of the overhead conductor. Climatic conditions, such as the effect of long continued rains, snows, and sleet storms, are obviously bad in both cases. At best, the overhead system is comparatively delicate, and unquestionably doubtful where long stretches of road are to be equipped. Constant inspection would be one of the only remedies for this, backed up, of course, by the use of the strongest and most reliable construction and material.

The Sprague Multiple Unit System

Whether trolley or third-rail is employed, the system of coupling and uncoupling carried out in a steam road, must be duplicated in any electric system which hopes to successfully compete in the open field. The Sprague multiple unit system presents an important feature—the possibility of connecting an electric car to another, or a third or fourth, and having but one motorman exercising control over the entire train. This remarkable feature of electric control, the ability to couple up electric cars, each equipped with their own motor, and all under the management and subject to the will of one man, has greatly furthered the development of electric train service. Both the elevated and underground systems employed in New York, are of the multiple unit system.

Electrical Systems for Regular Railway Service

Three important electrical systems are in use for regular railway operation. These systems are:

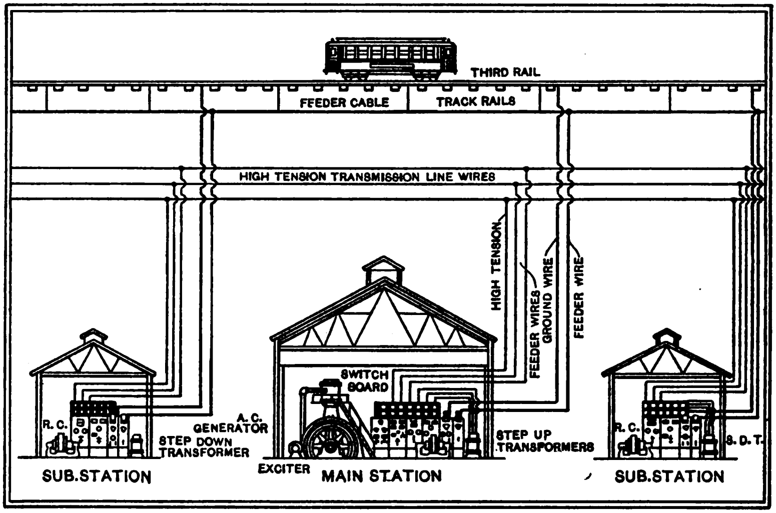
1.—The continuous- or direct-current, usually spoken of as the "third-rail" system, which employs alternating current for transmitting power when the distance is considerable.

2.—The three-phase alternating current system with two overhead trolley wires.

3.—The single-phase alternating current high-tension system with a single overhead wire.

A notable case of the latter system is the installation on the New York, New Haven and Hartford Railroad, where the motors and controlling apparatus are arranged to utilize single-phase current from an overhead trolley wire at 11,000 volts, and also to be operated by current from the 650-volt third-rail system of the New York Central and Hudson River Railroad. This installation demonstrates the wonderful flexibility of alternating current apparatus. The locomotive used on the New Haven road is provided with four motors each of 250 horsepower nominal capacity. The motors are of the gearless type, that is, the armature of the motors is placed directly on the driving shafts.

The reasons given for the use of the single-phase alternating current system and its advantages for heavy traction service are stated as follows: Alternating current is used on account of its facilities for transformation. One trolley only is required, and with alternating current and one trolley wire, any desirable voltage can be used on the line. The type of motor employed can have its speed varied by varying the voltage supplied to it, and uses power practically in proportion to the load. The motor is of the variable speed type, and automatically adjusts its speed to that of the other motors driving the same load.



Machinery,N.Y.

Fig. 29. Elements of an Electric Railway Undertaking

The locomotives of the New York Central and Hudson River Railroads also have their four driving motors applied directly to the wheel axles so that no gearing is required. The motors are 550 horsepower apiece, giving an output of 2200 horsepower, available at the wheels. A speed of 70 miles an hour is readily acquired by these locomotives, and a speed of 90 miles an hour may be obtained under favorable condition. The total weight of this locomotive is 97 tons, of which 70 tons is on the driving wheels. While the rated power is 2200 horsepower, the output can be increased during acceleration of the train to 3000 horsepower.

The Pennsylvania Railroad has installed unusually powerful locomotives for their tunnel service in and around New York City. The starting requirements of these locomotives are unusually severe in that they will be called upon to start a train of 550 tons load on the tunnel grades under the Hudson River, which grades are approximately two per cent. The total weight of these locomotives is 166 tons, of which 104 tons is carried on the drivers. At maximum capacity this locomotive develops 4000 horsepower, and the normal speed with load on level track is 60 miles an hour. The motive power of the locomotive is delivered through two motors operating on direct current at 600 volts.

High Speed Electric Systems

Systems of high speed electric service have appeared from time to time on paper, but few have ever reached a degree of crystallization entitling them to serious attention. The question of lubrication is always a serious one at high speeds; and the relationship existing between the weight of the car and the width and weight of the rails, is of supreme importance. The character of the road-bed must also be considered, and in conjunction with these things, the grades and declivities.

In earlier days the motor was not sufficiently well constructed to stand the wear and tear of much travel. It was geared to the driving wheels of each car, and in consequence a great waste of energy was caused. The latest types of electric locomotives have their driving motors so constructed that the extremities of the armature shaft are supplied with wheels, the power being thus directly applied. A high speed is more readily acquired in this case.

The speeds attainable in practice have reached their highest figures in Germany where an experimental stretch of road was repeatedly covered by an electric car at a rate exceeding 125 miles an hour. The experimental phase of the problem has been successfully reached and passed, and the next stage to undertake is that of reducing the proposition to a more practical form. All of the mechanical objections are present which govern, and perhaps limit, high speed in a steam locomotive. These are air resistance, slippage, lubrication, etc. The ability to increase the grip of the car upon the rails in electric cars by placing the motor, the main weight, where its power is most readily utilized, is a great feature in its favor in high-speed railroading. At high speeds, such as 100 miles an hour or over, the air resistance is very great and seriously impedes the motion of the car or train.

A large amount of power is required to insure the success of such a system, and of necessity the motors must be unusually powerful. Where a steam locomotive develops 1500 H.P. or a little over, an electric locomotive of equal size and weight would produce 2000, and under a severe test 4000 H.P. This power translated into speed represents, in this respect, what may be reached in the future.

OUTLINE OF A COURSE IN SHOP AND DRAFTING-ROOM MATHEMATICS, MECHANICS, MACHINE DESIGN AND SHOP PRACTICE

Any intelligent man engaged in mechanical work can acquire a well-rounded mechanical education by using as a guide in his studies the outline of the course in mechanical subjects given below. The course is laid out so as to make it possible for a man of little or no education to go ahead, beginning wherever he finds that his needs begin. The course is made up of units so that it may be followed either from beginning to end; or the reader may choose any specific subject which may be of especial importance to him.

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Jig Sheets 1A to 5A:—Whole Numbers: Addition, Subtraction, Multiplication, Division, and Factoring.

Jig Sheets 6A to 15A:—Common Fractions and Decimal Fractions.

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Reference Series No. 18. Shop Arithmetic for the Machinist.

Reference Series No. 52. Advanced Shop Arithmetic for the Machinist.

Reference Series No. 53. Use of Logarithmic Tables.

Reference Series Nos. 54 and 55. Solution of Triangles.

Data Sheet Series No. 16. Mathematical Tables. A book for general reference.

Drafting-room Practice

Reference Series No. 2. Drafting-room Practice.

Reference Series No. 8. Working Drawings and Drafting-room Kinks.

Reference Series No. 33. Systems and Practice of the Drafting-room.

General Shop Practice

Reference Series No. 10. Examples of Machine Shop Practice.

Reference Series No. 7. Lathe and Planer Tools.

Reference Series No. 25. Deep Hole Drilling.

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Data Sheet Series No. 2. Screws, Bolts and Nuts. Tables of standards.

Data Sheet Series Nos. 10 and 11. Machine Tool Operation. Tables relating to the operation of lathes, screw machines, milling machines, etc.

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Reference Series No. 57. Metal Spinning.

Jigs and Fixtures

Reference Series Nos. 41, 42 and 43. Jigs and Fixtures.

Reference Series No. 3. Drill Jigs.

Reference Series No. 4. Milling Fixtures.

Punch and Die Work

Reference Series No. 6. Punch and Die Work.

Reference Series No. 13. Blanking Dies.

Reference Series No. 26. Modern Punch and Die Construction.

Tool Making

Reference Series No 64. Gage Making and Lapping.

Reference Series No. 21. Measuring Tools.

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Data Sheet Series No. 4. Reamers, Sockets, Drills, and Milling Cutters.

Hardening and Tempering

Reference Series No. 46. Hardening and Tempering.

Reference Series No. 63. Heat Treatment of Steel.

Blacksmith Shop Practice and Drop Forging

Reference Series No. 44. Machine Blacksmithing.

Reference Series No. 61. Blacksmith Shop Practice.

Reference Series No. 45. Drop Forging.

Automobile Construction

Reference Series No. 59. Machines, Tools and Methods of Automobile Manufacture.

Reference Series No. 60. Construction and Manufacture of Automobiles.

Theoretical Mechanics

Reference Series No. 5. First Principles of Theoretical Mechanics.

Reference Series No. 19. Use of Formulas in Mechanics.

Gearing

Reference Series No. 15. Spur Gearing.

Reference Series No. 37. Bevel Gearing.

Reference Series No. 1. Worm Gearing.

Reference Series No. 20. Spiral Gearing.

Data Sheet Series No. 5. Spur Gearing. General reference book containing tables and formulas.

Data Sheet Series No. 6. Bevel, Spiral and Worm Gearing. General reference book containing tables and formulas.

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Reference Series No. 9. Designing and Cutting Cams.

Reference Series No. 11. Bearings.

Reference Series No. 56. Ball Bearings.

Reference Series No. 58. Helical and Elliptic Springs.

Reference Series No. 17. Strength of Cylinders.

Reference Series No. 22. Calculations of Elements of Machine Design.

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