E. J. ANDREWS.

DYNAMO ELECTRIC MACHINE.

APPLICATION FILED JULY 5, 1907.

1,123,161.

Patented Dec. 29, 1914.

4 SHEETS—SHEET 1.

Fig. 6.

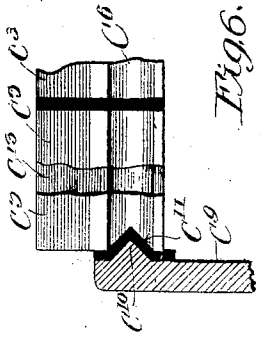


Fig. 5.

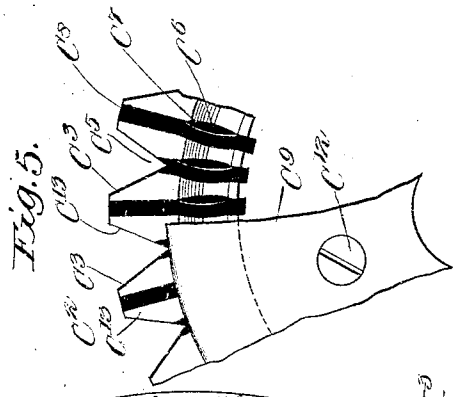
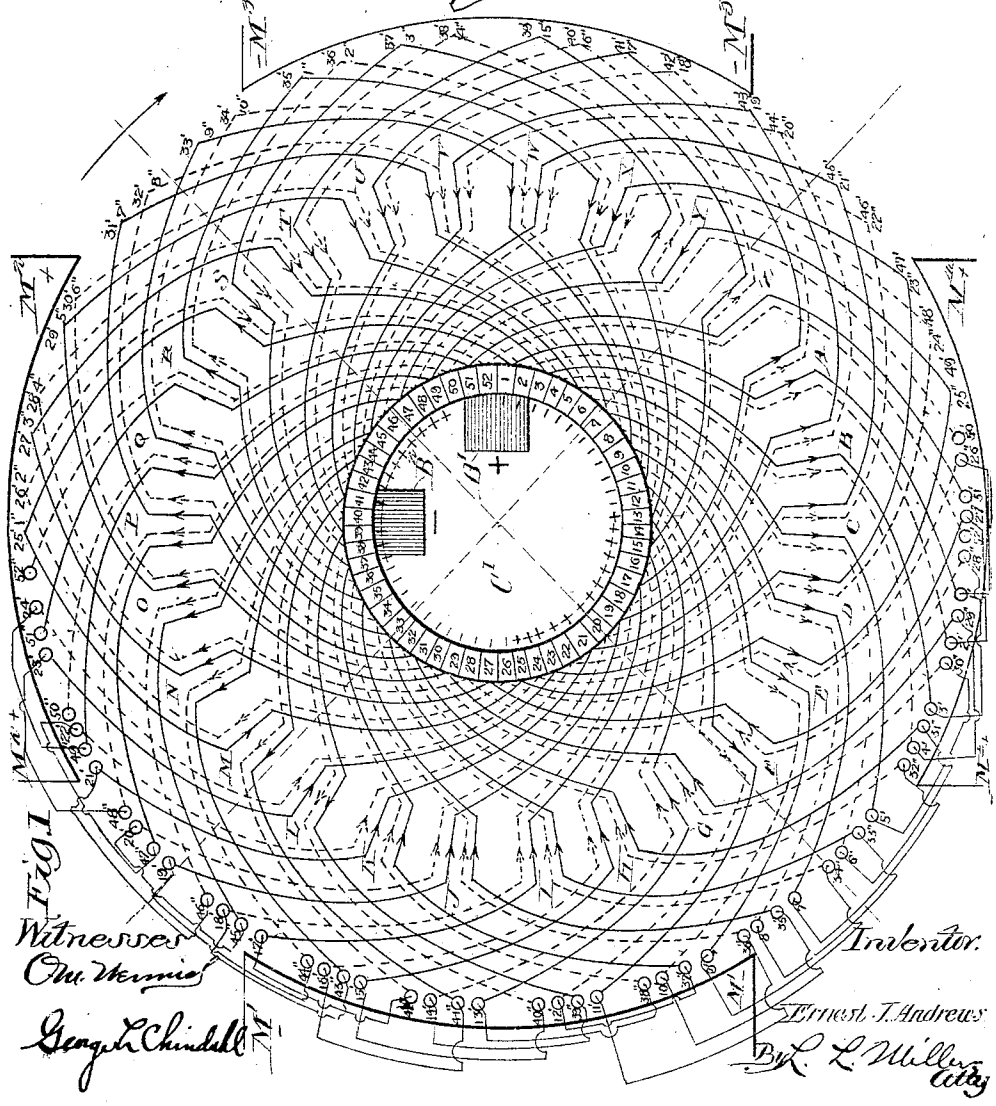


Fig. 1.



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4 SHEETS—SHEET 2.

Fig. 7.

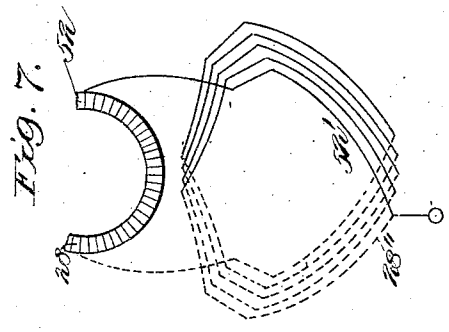


Fig. 3

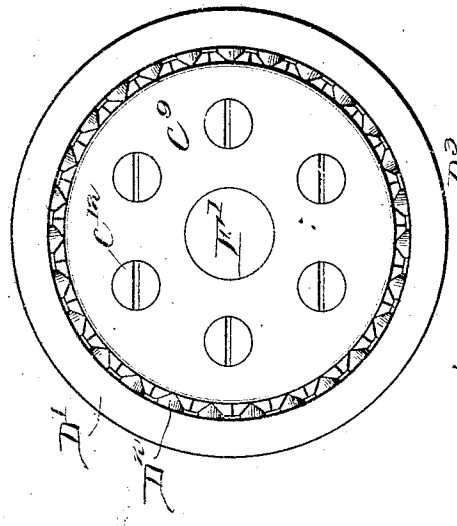


Fig. 4

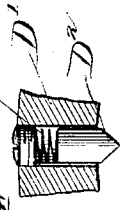
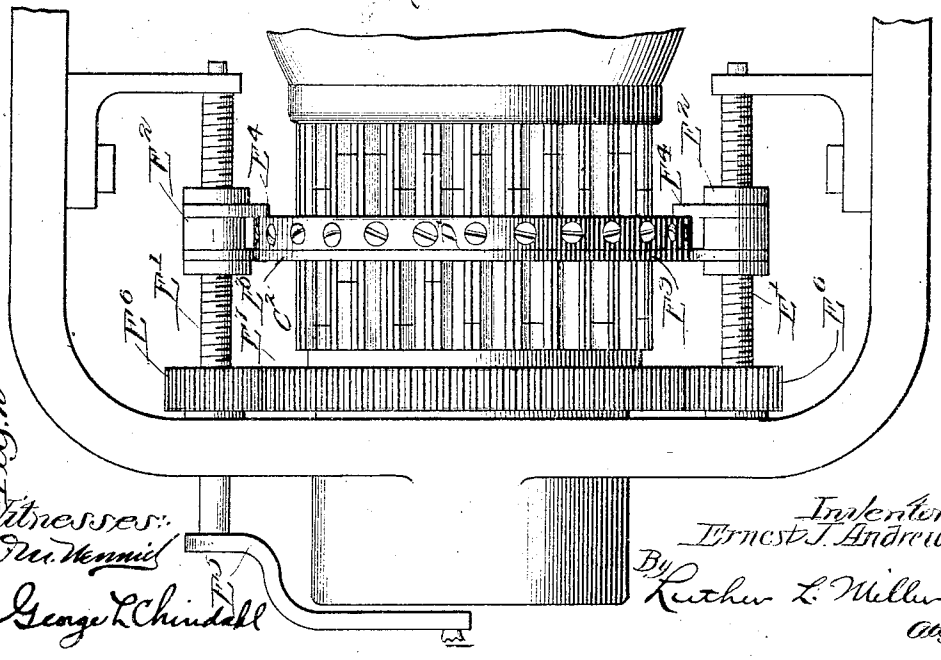


Fig. 2



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4 SHEETS—SHEET 3.

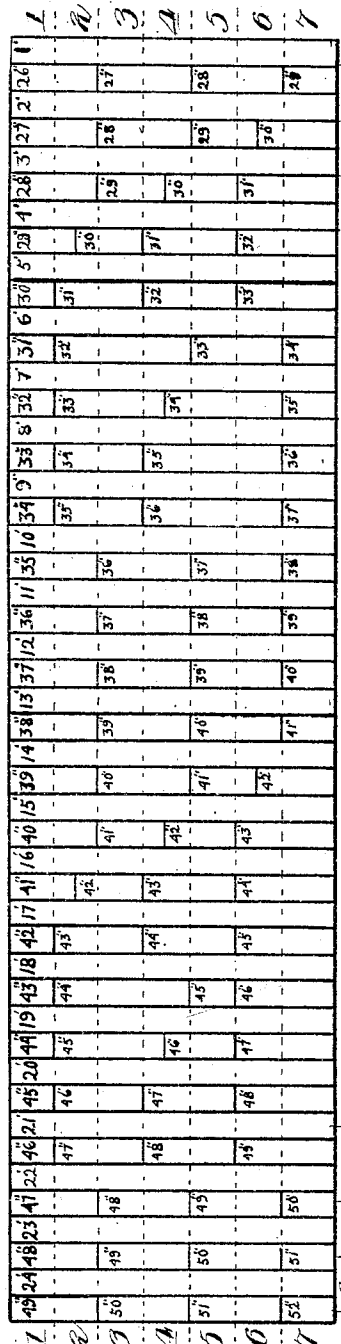


Fig. 8.

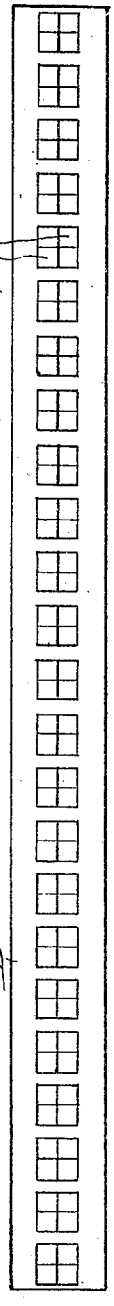


Fig. 10.

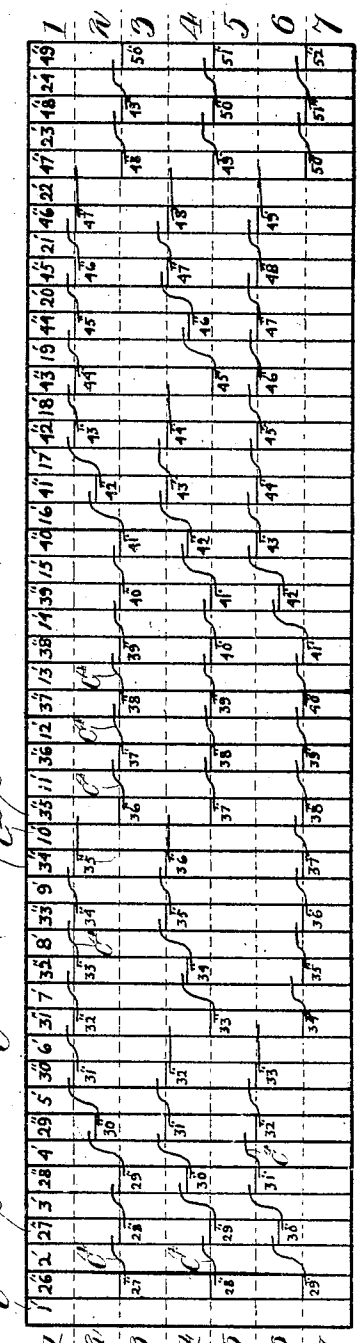


Fig. 9.

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4 SHEETS—SHEET 4.

Fig. 11.

1'-26" 2'-2" 3'-28" 4'-29" 5'-30" 6'-31" 7'-32" 8'-33" 9'-34" 10'-35" 11'-36" 12'-37" 13'-38" 14'-39" 15'-40" 16'-41" 17'-42" 18'-43" 19'-44" 20'-45" 21'-46" 22'-47" 23'-48" 24'-49" 50" 51" 52" 25'-1"

Fig. 12.

1'-26" 2'-27" 3'-28" 4'-29" 5'-31" 7'-33" 9'-35" 11'-36" 12'-37" 13'-38" 14'-39" 15'-40" 16'-41" 17'-42" 18'-43" 19'-45" 21'-47" 23'-48" 24'-49" 50" 51" 52" 25'-1"

Fig. 13.

1'-27" 3'-29" 5'-31" 7'-33" 9'-35" 11'-37" 13'-39" 15'-41" 17'-43" 19'-45" 21'-47" 23'-49" 51" 25'-1"

2'-28" 4'-30" 6'-32" 8'-34" 10'-36" 12'-38" 14'-40" 16'-42" 18'-44" 20'-46" 22'-48" 24'-50" 52" 26'-2"

Fig. 14.

1'-27" 3'-29" 5'-32" 6'-35" 11'-37" 13'-39" 15'-42" 17'-41" 18'-44" 20'-47" 23'-49" 25'-1"

2'-28" 4'-30" 6'-33" 9'-36" 12'-38" 14'-40" 16'-43" 19'-45" 21'-46" 22'-48" 24'-50" 26'-2"

Fig. 15.

1'-26" 4'-31" 7'-34" 10'-37" 13'-40" 16'-43" 19'-46" 22'-49" 25'-1"

2'-29" 5'-32" 8'-35" 11'-38" 14'-41" 17'-44" 20'-47" 23'-50" 26'-2"

3'-30" 6'-33" 9'-36" 12'-39" 15'-42" 18'-45" 21'-48" 24'-51" 27'-3"

Fig. 16.

1'-28" 4'-32" 8'-35" 11'-38" 14'-41" 17'-45" 21'-49" 25'-1"

2'-29" 5'-33" 9'-36" 12'-39" 15'-42" 16'-46" 22'-49"

3'-30" 6'-33" 9'-36" 12'-39" 15'-43" 19'-47" 23'-50" 26'-2"

3'-31" 7'-34" 10'-37" 13'-40" 16'-44" 20'-46" 24'-51" 27'-3"

Fig. 17.

1'-29" 5'-33" 9'-37" 13'-41" 17'-45" 21'-49" 25'-1"

2'-30" 6'-34" 10'-38" 14'-42" 18'-46" 22'-50" 26'-2"

3'-31" 7'-35" 11'-39" 15'-43" 19'-47" 23'-51" 27'-3"

4'-32" 8'-36" 12'-40" 16'-44" 20'-48" 24'-52" 28'-4"

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UNITED STATES PATENT OFFICE.

ERNEST J. ANDREWS, OF CHICAGO, ILLINOIS, ASSIGNOR OF ONE-FOURTH TO GEORGE L. CHINDAHL, OF CHICAGO, ILLINOIS.

DYNAMO-ELECTRIC MACHINE.

1,123,161. Specification of Letters Patent. Patented Dec. 29, 1914.

Application filed July 5, 1907. Serial No. 382,156.

To all whom it may concern:

Be it known that I, ERNEST J. ANDREWS, a citizen of the United States, residing at Chicago, in the county of Cook and State of Illinois, have invented certain new and useful Improvements in Dynamo-Electric Machines, of which the following is a specification.

One of the objects of my invention is the provision of improved means for regulating the power capacity of dynamo-electric machines.

My invention relates to the regulation of the speed of dynamo-electric motors by varying the inductive length of the armature conductor in series, and thereby coincidently varying the counter electromotive force of the motor, and by the same means regulating the electromotive-force of so-called dynamo-electric generators, or current-producers.

The invention also relates to other improvements in dynamo-electric machines hereinafter set forth.

In the accompanying drawings, Figure 1 is a diagrammatic representation of an armature winding embodying some of the features of my invention. Fig. 2 is a side view of a mechanism for changing and varying the current paths or the electric circuits through the armature. Fig. 3 is an end elevation of the part hereinfater termed the regulator cylinder. Fig. 4 is a detail view of one of the movable contact members, partly in section. Fig. 5 is a fragmentary, enlarged detail view, illustrating the construction of the regulator cylinder. Fig. 6 is a fragmentary cross-sectional view of the same. Fig. 7 shows a single armature coil with its various turns. Fig. 8 is a flat development of the periphery of the regulator cylinder. Fig. 9 is a flat development of the inner surface of said cylinder Fig. 10 is a flat development of the inner surface of the movable contact ring. Fig. 11 is a schematic development of connections of the various coils, or sections, of the armature to produce maximum electro-motive-force, or counter-electro-motive-force, as the case may be, which I will call simplex winding. Fig. 12 is a similar though modified scheme, showing certain of the coils in parallel relation. Fig. 13 is a scheme showing a uniform circuit or path through each side of the armature, doubled, or a double parallel relation, which I will call duplex winding. Fig. 14 is a modification of Fig. 13 showing further sub-paralleling of certain of the coils. Fig. 15 is an arrangement of coils by means of which three uniform current paths, or circuits are provided around each side of the armature. This arrangement I have called triplex winding. Fig. 16 is a modification of the arrangement similar to that shown in Fig. 15, but showing sub-paralleling of the coils at certain selected parts of the armature. Fig. 17 is a scheme of connections by which four uniform current paths or circuits are provided around each side of the armature. This arrangement I call quadruplex winding.

In all of the views the same reference characters refer always to the same parts.

It is well known that in dynamo-electric machines in which the extent and density of the magnetic field of force is constant, the electromotive force may be varied by increasing the speed of the armature or by increasing the active length of the inducing conductor, or both. A given turn of wire on an armature will generate a definite electromotive force. If all of the turns or coils be joined in series the electromotive force will equal the sum of that of the several coils. If they be connected in parallel the electromotive force will equal that generated by a single coil.

My invention contemplates obtaining a ready adjustment of the speed of a motor or the electromotive force of a generator, by varying the number of armature turns or coils in series, other factors remaining substantially constant, without impairing the inherent qualities of such a machine to operate at constant speed, under varying conditions of load, or constant electromotive force after each change has been effected.

Figure 1 represents diagrammatically a wave-wound armature of a quadrupolar dynamo, opposite magnet field-poles being of the same polarity. C′ indicates the commutator, which is shown to contain 52 segments or bars numbered from 1 to 52, inclu-

sive. The inductive sides of the coils of the armature winding represented by straight, approximately radial lines, are contained in slots or grooves made in the armature core, of which there are 26, indicated by the twenty-six letters of the alphabet, there being portions of four different coils in each slot, *i. e.*, there are two coils per slot. For the sake of clearness, each coil is shown to consist of but one turn, and the number of coils and commutator sections are less than would usually obtain in practice.

The inner portion of the diagram represents the commutator and its connecting leads. The outer portion represents the rear end of the armature. The small circles located substantially on the left of a median line, on the peripheral boundary of the diagram, represent the terminals of the coils which are connected in various ways by means of the regulator, or which may be in a few cases left open or disconnected. The coil terminals which are in some cases left disconnected are 50′, 51′, 52′, 50″, 51″ and 52″. In Fig. 1 the last mentioned terminals are shown disconnected. The coil terminals represented by small circles are indicated in each case by a numeral corresponding with the reference number of the commutator-section to which it is connected, with a prime (′) exponent, from 1′ to 24′, inclusive, and with a second (″) exponent from 25″ to 52″, inclusive. The prime numbers in Figs. 1 and 11 to 17, inclusive, represent the coil leads which pass away from the commutator in a clockwise direction; the double-prime numbers represent leads passing away in a counter-clockwise direction. In Figs. 8 and 10 the prime numbers indicate segments which are connected to the prime coil leads, and the double-prime numbers those connected to the double-prime leads. It will be noticed that the coils leading to the terminals 50′, 51′ and 52′ have each two such terminals, making 54 terminals for 52 coils. In the connections necessary to produce the varied results hereinafter explained, these three coils, in several instances, or some of them, are not included in the live circuit when such changes do not require the full number of coils contained in the armature. Although these reference numbers 50′, 51′ and 52′ indicate normally open terminals, yet they are nowhere shown in Figs. 11 to 17, inclusive, for the reason that whenever they are connected in any of the circuits they are always connected with the next adjacent terminal. Thus as 48′ is always connected to 24″ and 49′ is always connected to 25″, so is 50′, when connected at all, always connected to 26″, 51′ to 27″, and 52′ to 28″; so that it is not necessary to so indicate in the various figures.

The field magnets of the diagram are indicated by M^1, M^2, M^3 and M^4, the even numbers being of one polarity and the odd numbers of the other polarity.

The collecting brushes B^1 and B^2 are shown, for clearness, inside of the commutator, bearing on the commutator bars or segments. Each brush is sufficiently wide to span a little more than four commutator bars, for a purpose hereinafter more fully described.

The coil terminals are connected together by the wires (diagrammatically representing the controller connections) shown at the extreme periphery of the diagram, on the left. Thus the coils are included in circuits in accordance with the schematic development of Fig. 11, when the coil terminals are connected as indicated in Fig. 1, resulting in that which I term the simplex winding. This result is arrived at when the regulator contact ring indicated by Fig. 10 is placed in the position 1 of the regulator indicated by Figs. 8 and 9. The numbers with the dashes between indicate the coil terminals which are connected. Those numbers which have dashes under them, or are underscored, represent coil terminals which are not included in the active circuit. The coils corresponding therewith, to wit, coils having terminals 50′, 51′ and 52′, are left open in scheme Fig. 11, and remain "dead" or inactive.

It will be observed that beginning at commutator section 1, the current will pass in two parallel paths through the armature, both circuits finally terminating at the negative brush B^2. One path is from commutator segment 1 through slot A, in the direction indicated by the arrow, to terminal 1′, thence through the circuit-changer connection diagrammatically shown, to terminal 26″ through slot E, in the direction shown by the arrow, this slot being near the neutral zone, then to commutator section 26, then through slot M to point 26′ at the opposite side of the armature, through slot S to commutator section 2. This circuit may be thus traced, touching commutator sections in regular sequence, and through the coils in the same order, until it terminates at the brush B^2 by the final wire leading from terminal 37″. The parallel path or circuit through the other half of the armature is from commutator section 1 through slot S, this slot being near the neutral zone, to point 25′ through slot M, this slot being near the neutral zone, to commutator section 25, through slot E to point 25″ 49′ through slot Y back to commutator section 49, which is the next "live" section following section 1 in that direction. From section 49 the circuit is completed, touching in regular sequence commutator section 48 to 42, inclusive.

The first path which I have just outlined

contains coils which connect with commutator sections which I have arbitrarily marked with a minus (—) sign. In the second path or parallel circuit thereto from brush to brush, the coils are connected to commutator sections which I have arbitrarily marked with a plus (+) sign. The commutator sections which are connected to the "dead" or open coils, are not marked with either sign. In the schematic illustration Fig. 11, and in the diagrammatic representation Fig. 1, it will be seen that coil terminals 50′, 51 and 52′ are not included in the circuit.

In the arrangement of connections outlined in the schematic arrangement Fig. 11, and in diagram Fig. 1, it is shown that there are two sets of coils in series, and that these sets are in parallel, or two-circuit relation, from brush to brush,—a connection which produces the highest electromotive force or the lowest speed, as a maximum number of coils are connected in series.

When the disconnected ends or terminals of the coils are connected as indicated in Fig. 13, by means of my controller or circuit-changer to be hereinafter described, there will be four circuits through the armature, in which event the speed of the armature of the motor will be doubled, for then there will be only half of the original number of coils (shown in Fig. 11) connected in series, and it will be necessary for the armature to revolve at double the number of revolutions in order to produce the requisite counter electromotive force. The active inductive armature conductor-length being halved by this arrangement, the velocity must be correspondingly increased; the speed ratio is two. By speed ratio I mean, whenever the term is used, the ratio of the maximum to the minimum speeds. In this instance the maximum speed is two times the minimum speed.

When the connections are made as indicated in Fig. 15, there will be six circuits through the armature; the speed ratio is, in this illustration, three.

When the coils are connected together as indicated in Fig. 17, there are eight circuits through the armature from brush to brush, and the speed ratio is four.

The schematic arrangements to which I have briefly referred show the connections to be made by means of my speed controller, to double, triple or quadruple the speed of the revolving armature.

It is highly important that a definite and suitable number of coils should be contained in the armature in order to reach the highest efficiency and to attain the best operative results under certain given conditions. Therefore a reliable formula by means of which the desired number of coils may be readily determined is of great value.

It is essential, in order that each circuit shall return on itself, after passing entirely around the armature, taking in each commutator segment in the proper and regular sequence or order, or every alternate commutator segment or every third or fourth segment, according to the type of circuit, as shown in Figs. 11, 13, 15 and 17, that the circuit shall contain an odd number of coils. The simplex winding (Fig. 11) should have an odd number of coils actually in use. The duplex winding (Fig. 13) should have in use a number of coils divisible by two, but not by four, or a number which, being divided, provides two halves, each an odd number, so as to give two circuits passing entirely around the armature each an odd number of coils. The triplex winding requires a winding having a number of coils divisible by three, but not by six. The quadruplex winding should be divisible by four, but not by eight.

Let R = the speed ration, and n = a whole number, we should have in use with a machine of any ratio for the particular winding giving that speed ratio, $R+2nR$ coils. This formula, however, gives a different number for each schematic change, therefore a compromise is necessary if the different schematic connections as herein illustrated are to be obtained.

With my method of connecting the various coils for different conditions of operation, or for various changes of speed, there is greater tendency to spark at the commutator when the connections are made for high-speed operation, by paralleling the circuits, because, owing to the parallel relation of the circuits and commutator sections, the total electro-motive-force or difference of potential is broken up by the fewer effective commutator breaks, and the potential drop between adjacent commutator sections which are not in circuits parallel with each other, is correspondingly greater. Conditions, for this reason, should favor the arrangement for producing the highest speed.

Owing to the fact that certain of the controller connections to produce the different graduations of speed, as illustrated in Figs. 11 to 17, inclusive, require a greater or less number of coils in the armature, in certain arrangements there must necessarily be some coils that are not included in the active circuit, as illustrated in Figs. 11, 12, and 13, while in the illustration Fig. 17, for instance, the highest speed arrangement, all of the coils are included in the active circuits.

In order to fulfil all the conditions of the various schematic illustrations, there must

be some dead coils with some of the windings, and if there are dead or inactive coils in a particular schematic connection there must be corresponding dead commutator segments. In the maximum-speed connection (Fig. 17), the effective commutator-segment surface is greater, owing to the paralleling of several adjacent commutator bars in their regular order. In other words, the effective commutator segments under these conditions are wider, consisting of four adjacent bars; and a dead segment, in such a connection, would be an additional surface for the brushes to bridge. Dead coils, therefore, in the maximum-speed connection would increase the necessity for wider brushes, and cause a decrease in operative efficiency of the motor. Dead coils in the connections where the circuits are not paralleled to such an extent would not operate to require wider brushes; hence the connections whereby maximum speed is attained should control the number of coils to be contained in the armature; and coils in excess of the number required for other connections may be left dead or idle in such other connections.

Now applying the formula to the four-ratio connection: $R+2nR$ gives 84, 92, 100 coils, and so on. For the three-ratio connection, we have 81, 87, 93, 99, and so on. If the four-ratio is to control, in no case would the number of dead coils in the three ratio be more than five. In the two ratio there never would be more than two dead coils. But as this formula applied to any ratio will give many values for the number of coils, it is possible to select from these values certain that are best suited to the other connections. If for the four ratio we take 100 coils it would give but one dead coil for the triplex connection (Fig. 15). This should be considered when we want the highest efficiency attainable.

To give the best results for the three-ratio connection, one coil less than the best number for the four ratio should equal the proper number for the three ratio; or $R+2nR-1$ should equal $R-1+2n'(R-1)$. From this, when $R=4$, n should equal $\frac{3}{4}n'$ or three-fourths of some whole number. But as we cannot have any fractions of a coil, n must be multiplied by some whole number which is a multiple of $\frac{3}{4}$. The smallest number is 3. Hence we have the best number of coils for the four ratio: $R+2\times3nR$. But $2\times3R=\overline{R}$, in this case $\overline{R}$ being equal to $1\times2\times3\times4$, so that the number of coils should be $R+n\overline{R}$. This formula applies also to the three and to the two-ratio connections. These formulas, however, apply only to quadrupolar dynamo-electric machines, such as referred to in connection with Fig. 1. With other types of machines the number of coils on the armature will be proportional to the number of field magnet poles. Hence for machines where other considerations than the highest efficiency enter as factors, the number of coils should be

$$\frac{(R+2nR)}{4}P,$$

where P is the number of field poles. And where high efficiency is very material, the number should be

$$\frac{(R+n\overline{R})}{4}P.$$

So far I have considered only the full ratio changes in speed. I will now discuss the fractional changes. The former I will call the major changes and the latter the minor changes. A considerable portion of the value of my invention lies in the ability to make these minor changes of speed without materially decreasing the efficiency of the machine, and whereby close regulation and slight variations as well as a large range are possible.

The schematic connection indicated in Fig. 12 shows the general method of obtaining the minor changes. In this scheme some of the coils of the simplex scheme are shown placed in parallel with other coils in the two parallel circuits extending from brush to brush, so that the total number of coils in series is correspondingly reduced. As the speed of the armature is inversely proportional to the number of coils in series, it may be thus gradually increased by the connections shown, and by further similar enlargements, until the duplex connection is reached. Similarly, circuit connections Fig. 14 show how the speed may be increased by further paralleling the coils of the armature from the duplex to the triplex connections.

The circuit connections, Fig. 16, show a step between the triplex and the quadruplex or four ratio.

By referring to Fig. 1 it may be seen that the coils 29'' and 30'' which begin one of the shunts of circuit 12, lie in the same slot of the armature. If the shunt started with 28'' and 29'' it would start in different slots, the wires would lie in magnetic fields of different densities, and the electro-motive-force generated in the two coils would be different. This would cause a local current to flow in and through the shunt itself, which would cause extra work and heat. Similarly, coils corresponding with terminals 9' and 10' are in the same slot, for the same reason. In order to obtain these results there must be two coils in each slot. But it is not sufficient to start and to end the shunts in the same slots. The two branches must lie in the same slots or be otherwise adjacent throughout.

Referring to circuits Fig. 14, which show

a minor change between the duplex and the triplex connections, if the shunt beginning with 29″ and 30″ were continued on and not closed at 5′ and 6′ we should have 5′ passing into 32′ and 6′ into 33″. But as 32″ and 33″ are not in the same slot a local current would flow. And this would be true even though the shunt were continued on so as to finally end in the same slot. To avoid this I have shown in Fig. 14 a method of making the minor changes between the duplex and the triplex connections. This is a multiple-shunt method, each shunt being closed before passing into different slots, and the complete change being produced by increasing the number of shunts.

In order that the counter-electro-motive-force in the two branches of the same shunt may be balanced, they must be composed of an equal number of coils. And in order that the counter electromotive force shall be the same in the various parallel circuits, the number of coils in series in all must be approximately equal. And the two halves of the different circuits must also have approximately the same number of coils. To obtain the latter the beginnings of the homologous shunts must be approximately one half of the total number of coils in series apart.

With reference to the form of the armature, we need consider next the arrangement of the coils in the slots of the armature. Here again, for similar reasons, the maximum speed connections must be favored. Fig. 17 shows that the four-ratio winding is perfectly symmetrical. All of the others are unsymmetrical, and as these circuits are formed by shifting the connections from the four-ratio always in the same direction the simplex winding, Fig. 11, is the most unsymmetrical. Yet the slow pitch, that is, the number of slots from one side of a coil to the other, is very important, because with brushes sufficiently broad to bridge the segments for the circuits of the maximum speed, the coils of the minimum speed connections will be short-circuited, and if any of them are then in the active magnetic field sparks and local currents will result. Considering first, armatures with several turns per coil, as is indicated in Fig. 7, and assuming that the wire shifted in each case is the last turn of the coil, in Fig. 1 it will be the wire indicated by the primed number. Thus wire 1′, if connected to wire 29″ by the regulator (and wire 29″ passes directly to the segment 29 of the commutator), is shifted backward by the regulator to 28″ for the triplex system, to 27″ for the duplex system, and to 26″ for the simplex system or minimum speed position. In shifting, the pitch of the coil itself is not changed, as this depends only on the original winding of the coil. But the pitch from the last half of the coil which lies in slot G, to the first half of the next which is in slot O, is changed. By shifting 1′ back to 26″ the last half still lies in G, but the first half of the next coil now lies in M. The pitch of the coil itself was six, and remains so, but the pitch between the two coils is changed from 8 to 6. If the pitch between the coils 1′ and 29″ had been seven the pitch after shifting would have been five, and this would have been too small because it would throw some of the coils of the simplex system into the active magnetic field and cause sparking. If the coil pitch between the sides of the same coils were seven the pitch between the different coils would be five or less, which would be fatal. In each of these cases some of the pitches would be too far from the average pitch, that is to say, the total number of slots divided by the number of poles.

The general principle that must be followed is: The pitches between the sides of the same coils must be as near the average as possible, without exceeding it. This applies, however, to coils with several turns. If there were but one or two turns per coil the case would be reversed. The pitch of the coils then should be as small as possible without being less than the average pitch.

We now come to a consideration of the means by which the coils are disconnected and reconnected in order to produce the system of circuits desired for any particular speed.

It is very desirable that the speed of the motor, at least at certain times, may be changed while the armature is rotating; and to accomplish this the regulator or circuit-changer should be placed upon the shaft of the armature so as to rotate with it. As a large number of the leads from the armature coils are necessarily connected to the circuit-changer, in order to reduce the length of these leads and to avoid unnecessary resistance of lead wires and other undesirable complications the circuit-changer should be placed as near the armature coils as possible. For this reason I prefer to place it at the rear end of the armature between the bearing and the armature core. It is also desirable to place the circuit-changer in the rear of the armature so that the bracket sustaining the front bearing of the shaft need not project so far from the main body of the motor. As the lengths of the commutator and of the circuit-changer are usually about the same, the machine with the circuit-changer in the rear is better balanced without impairing its stability and appearance.

The success of the invention depends much upon reducing to a minimum the number of wire connections that are broken and made in making the necessary changes.

The connections of Figs. 1 and 11 constitute a wave winding. In such a connection when the brush spans two commutator segments it "shorts" two coils in series: as for instance, in the simplex connections 26″ and 2″. It is a multiple winding when the brush shorts only one, or several in parallel. If it were a multiple or parallel winding and wire 1′ were shifted back to 28″ from 29″, the only coil that would be affected would be 28″. With the wave winding, shifting wire 1′ carries with it coil 25″. This at once reduces the number of connections that need to be broken and remade, one half. Hence the winding should be a wave winding.

The circuit-changing device or controller herein shown for conveniently and properly making the various connections outlined in Figs. 11 to 17, inclusive, comprises a cylinder C^2 rigidly mounted on and carried by the armature shaft F′, and preferably at the rear end of the armature, between the core thereof and the armature shaft bearing. Said cylinder comprises a plurality of blocks C^3 and bars C^{13}, insulated from each other, but electrically connected by short wires C^4 into groups, shown in Fig. 9, some of said blocks and bars extending the full length of the cylinder and others but a part of said distance. One bar of each of said groups is electrically connected with and forms a terminal for each terminal of those armature coils that are arranged to be opened and closed by the circuit changing device. The terminals indicated by circles in Fig. 1 are each connected to one of a group of bars, which are correspondingly numbered.

The blocks C^3 and bars C^{13} have beveled faces, and are arranged so as to provide V-shaped grooves C^5 between them, said grooves extending longitudinally of the cylinder C^2. In the sides of the blocks C^3 and bars C^{13} are formed shallow grooves C^6. The insulation between the blocks and bars preferably consists of strips C^7 of vulcanized fiber and strips C^8 of mica extending the full length of the bars and entering the grooves C^6, said strips serving to hold the blocks in place. The bars C^{13} are secured together by means of insulated end disks or plates C^9, having annular ribs C^{10} thereon, which extend into grooves C^{11} in the bars. The blocks C^3 (or fractions of bars) are placed end to end, provided with suitable insulation therebetween, so as to insulate one block from the next, and the terminal blocks are secured by the end plates in the same manner as are the bars. The end plates C^9 are secured together by means of the bolts C^{12} passing therethrough, or by any other suitable means.

The bars C^{13} may be electrically connected to approximate blocks C^3 in such a manner as to form the combinations exemplified in Figs. 11 to 17 inclusive, by means of certain contact pieces D^2, Fig. 4, adapted to be slidingly moved through the respective grooves C^5, by means of a longitudinally movable ring D′ which carries said contact pieces. The pieces D^2 are slidably and radially mounted in the ring D′. The contact pieces have wedge-shaped points corresponding in angularity with and adapted to be freely moved through the slots C^5 of the cylinder C^2

Springs D^3 lie in the recesses in which the contact pieces are mounted and serve to elastically press said contact pieces into firm electrical connection with the bars and blocks on either side of the cylinder C^2.

The means herein shown for longitudinally shifting the contact ring D′ of the cylinder C^2, to provide the various combinations of connections disclosed in Figs. 11 and 17 inclusive, to the respective positions 1 to 7 inclusive of Figs. 8 and 9, consists of a pair of feed screws E′, rotatably mounted in the motor framework. Each screw is provided with a nut E^2, which is threaded on said screw, and the two nuts are connected by a semicircular ring E^3 extending half way around the contact ring D′ and at one side of the latter. Said nuts also have fingers E^4 thereon, adapted to lie at the opposite side of said contact ring. A crank E^5 upon the outer end of one of the feed screws E′ provides means for rotating the latter. Motion is transmitted to the other screw by means of gear pinions E^6 E^6 and the idler gear wheel E^7. With the terminal bars and blocks of Figs. 8 and 9 connected to the coil terminals of Fig. 1 in the manner indicated by the similarity of the reference characters, seven different speeds may be secured by moving the contact ring D′ into the seven different positions indicated in Figs. 8 and 9; and the movement of the ring D′ from one position to another, to effect a change of speed of the motor armature may be accomplished while the said armature is in motion, as will be readily apparent.

When the contact ring D′ is in position 1 (Figs. 8 and 9) the terminals of the armature coils (Fig. 1) will be connected by means of the contact pieces D^2 making proper electrical connection between the respective bars C^{13} and blocks C^3, as indicated in Fig. 11. This arrangement leaves three unused, or dead coils, having terminals 50″, 51″ and 52″ out of the circuit, and forms two series sets of 24 active coils, in each circuit, the coils of each set being in series with one another, and the two sets of coils being in parallel with one another, or the two circuit simplex winding.

By shifting the contact ring D′ to position 2, the terminals will be connected together as shown in Fig. 12, providing two circuits through the armature, each circuit comprising practically eighteen coils in se-

ries, with a shunt of six coils in parallel with six other coils in each circuit.

By shifting the contact ring D′ to position 3 it connects the terminals together, as indicated in Fig. 13, and provides four circuits through the armature, each circuit comprising practically twelve coils in series. The number of coils in series having thus been reduced from 24 to 12, the speed is approximately doubled.

When the contact ring is shifted to position 4, four circuits, corresponding with Fig. 14, are formed, there being practically ten coils in series in each circuit.

When the contact ring D′ is shifted to position 5, corresponding with Fig. 15, six circuits are provided through the armature, and the number of coils in series in each circuit is reduced to practically eight. In this case the speed will be increased to three times the velocity obtained with the circuit arrangement indicated in Figs. 1 and 11.

With the ring in position 6, six circuits are formed, as shown in Fig. 16, each circuit having practically seven coils in series.

When the contact ring is placed in position 7 (Fig. 8) the terminals will be connected together as shown in Fig. 17 to form eight circuits through the armature, there being practically six coils in series in each circuit, and the speed will be practically four times as great as that obtained with the connections of Fig. 11, or the first described simplex connection.

The words "normally-open" are used in the claims in a sense to express the conditions of the armature coils without reference to the circuit-changer; as when the winding of the armature is just completed, and before the application of the circuit changer, some of the coils are left open, to the terminals of which the various parts of the circuit-changer are to be electrically connected.

It will be noted that the circuit-changer is located, in an electrical sense, between the brushes, and that the brushes are not more in number than the poles.

It is evident that many modifications and variations may be made from the exemplification herein disclosed without departure from the spirit and scope of my invention. For instance, a greater or less number, of the total number, of the coils of the armature may be actively included in the various schematic connections, than shown, and in some instances all of the coils in the armature may be included in the active circuit. I do not desire, therefore, to be limited to the precise structure and arrangement herein set forth except as indicated in the appended claims.

I claim as my invention:

1. A dynamo-electric machine provided with an armature having a plurality of inductive coils, a commutator having as many sections as coils to which said coils are connected in consecutive series order, a circuit changer adapted and arranged to vary the series and parallel relation of said coils in circuit, and a pair of brushes fixed with relation to each other and bearing on said commutator.

2. A dynamo electric machine having an armature provided with a plurality of inductive coils normally open, a circuit changer carried by the armature shaft, comprising in part a series of bars and blocks parallel with said shaft to which the terminals of said armature coils are electrically connected, and a member of said circuit changer carrying contacts and provided with a means for laterally moving it to different positions with reference to the first mentioned element to effect different connections of the coils to join a greater or less number of said coils in parallel and series relation.

3. A dynamo electric machine having an armature provided with a plurality of inductive coils, in combination with an element of a circuit changer consisting of a number of longitudinally arranged, insulated parallel bars connected to the terminals of certain of said coils, and insulated blocks arranged for convenient electrical connection with certain of said bars respectively, also connected to certain of said coils, and an element of said circuit changer carrying contact devices arranged and adapted to electrically connect certain of said bars and blocks together to effect different parallel and series relations of said coils, when moved to definite positions relative to the first mentioned element.

4. A dynamo electric machine having an armature provided with a plurality of inductive coils, normally open, in combination with a circuit changer comprising a cylinder composed of a series of bars and a series of shorter blocks placed end to end, and alternating with said bars, said bars and blocks connected respectively to the terminals of certain of said coils, said cylinder secured to the shaft of said armature, and a device carrying a series of contacts for electrically connecting certain of said bars and said blocks together, to electrically join the coils in different relations when said device is moved to certain selected positions to effect the given changes.

5. A dynamo-electric machine having an armature provided with a plurality of normally open inductive coils, a commutator to which said coils are permanently connected, and a circuit changer on the armature shaft for changing the series and parallel relation of said armature coils.

6. A dynamo-electric machine having an armature provided with a plurality of nor-

mally open inductive coils, a commutator at one end of the armature to which said coils are permanently connected, a circuit changer located at the opposite end of the armature and comprising parts connected respectively to said open coils, and having a laterally shiftable contact structure to effect various electrical series and parallel connections between said coils, and having a laterally shiftable contact structure to effect various electrical series and parallel connections between said coils, and a means for laterally moving said shiftable contact structure to various selected positions while the armature is in motion.

7. A dynamo-electric machine of variable active capacity having a drum armature provided with a plurality of normally-open inductive coils, the core of the armature having coil slots therein, the slot pitch of the two sides of each armature coil being as great as possible without exceeding that determined by the total number of slots in the armature core divided by the number of field poles, and means for adjustably grouping entire coils in circuits.

8. A dynamo-electric machine having an armature provided with a plurality of normally open inductive coils, and means for changing the electrical relation of said coils, the number of coils in said armature being equal to

$$\frac{(R+2nR)P}{4},$$

where R is the speed ratio, P the number of field poles and n some whole number.

9. A dynamo-electric machine having an armature provided with a plurality of normally open inductive coils, and means for changing the electrical relation of said coils, the number of coils in said armature being equal to

$$\frac{R+n|R|P}{4},$$

where R is the speed ratio, P the number of field poles and n some whole number.

10. A dynamo-electric machine comprising an armature, said armature being provided with windings of normally open coils, an armature shaft, a circuit-changer mounted on said shaft, the terminals of some of the portions of the armature winding being connected to said circuit-changer, and said circuit-changer having shifting contact means, certain portions of the armature winding being connected in series, and other portions of the winding being connected in series and as shunts in parallel with certain portions of the first mentioned series, said shunts being of greater inductive length when said contact means are in one position than when said means are in another position.

11. A dynamo-electric machine provided with an armature having a plurality of coils, a commutator having as many sections as there are coils in said armature, said coils being connected in consecutive series order to said commutator, a circuit-changer, approximately one-half of said coils being connected to said circuit-changer, said circuit-changer comprising a movable contact piece, said armature being connected as a two-circuit armature when said piece is in one position, and said armature having more than two circuits when said piece is in another position.

12. A dynamo-electric machine having a wave-wound armature provided with a plurality of normally open coils, a circuit-changer mounted on the armature shaft, one terminal only of substantially one-half of the coils of said armature being connected to said changer, and wires connecting each of said terminals with one of the commutator segments of said armature, said circuit-changer comprising means for varying the electrical connections among said terminals and said segments.

13. A dynamo-electric machine comprising armature coils, and an armature shaft, coil-grouping means mounted on said shaft, said means normally maintaining the armature coils in closed condition; said means comprising a movable member; said coils being grouped into a plurality of circuits, with a plurality of coils in series in each circuit when said member is in one position, and when said member is moved to another position said coils being grouped into a plurality of circuits with fewer coils in series in each circuit than when said member was in said first position.

14. A dynamo-electric machine comprising an armature, a plurality of coils on said armature, an armature shaft, coil-grouping means mounted on said shaft, said means comprising a movable member, said coils being grouped into a plurality of circuits with more coils in series in each circuit but with fewer circuits when said movable member is in one position than when said member is in another position.

15. A dynamo-electric machine having an armature provided with a plurality of coils, a commutator on one end of the armature to which the terminals of said coils are at all times connected when in operation, and a circuit-changer located on the opposite end of the armature and having a movable member adapted to vary the series and parallel relations of said coils.

16. A dynamo-electric machine having an armature provided with a plurality of inductive coils, a commutator to which said coils are permanently connected, and a circuit-changer on the armature shaft, said circuit-changer comprising a movable piece,

said armature coils having certain parallel and series connections when said piece is in one position, and when said piece is in another position said coils having different parallel and series connections.

17. A dynamo-electric machine having an armature provided with a plurality of coils; a circuit-changer carried by the armature shaft, said changer comprising a series of bars and blocks running parallel with said shaft, the terminals of some of said coils being electrically connected to said bars and blocks; said changer also comprising a longitudinally slidable member carrying contacts, and means for sliding said member to various positions with reference to said bars and blocks to effect various series and parallel connections of said coils.

18. A dynamo-electric machine having a wave wound armature provided with a plurality of coils, a circuit-changer carried by the armature shaft, said changer comprising a series of bars and blocks to which one terminal only of substantially one-half of the coils of said armature are electrically connected, and means connecting each of said terminals with one of the segments of the commutator of said armature.

19. A dynamo-electric machine provided with an armature having a plurality of coils, a commutator having as many segments as there are coils in said armature and to which said coils are connected, a circuit-changer adapted to vary the number of coils in series on said armature, and a pair of brushes fixed relative to each other and bearing on said commutator.

ERNEST J. ANDREWS.

Witnesses:
V. L. SHEARMAN,
GEORGE L. CHINDAHL.

Corrections in Letters Patent No. 1,123,161.

It is hereby certified that in Letters Patent No. 1,123,161, granted December 29, 1914, upon the application of Ernest J. Andrews, of Chicago, Illinois, for an improvement in "Dynamo-Electric Machines," errors appear in the printed specification requiring correction as follows: Page 3, line 106, strike out the article 'the"; same page, line 125, after the word "all" insert the word *of;* page 5, line 43, for the word "slow" read *slot;* page 8, lines 9–12, claim 6, strike out the words "and having a laterally shiftable contact structure to effect various electrical series and parallel connections between said coils"; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 21st day of March, A. D., 1916.

[SEAL.]

J. T. NEWTON,
Acting Commissioner of Patents.

Cl. 171—230.