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ARMATURE WINDINGS

OF

DIRECT CURRENT DYNAMOS

EXTENSION AND APPLICATION OF A GENERAL WINDING RULE

BY

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PREFACE.

WHILE lecturing upon electrotechnics at the Polytechnic in Riga, I experienced the difficulty of presenting to the students in a brief and simple manner the various methods of winding armatures for direct current machines, so as to enable them to solve independently any assumed problem in winding. In consequence of this, I endeavored to establish rules for the various windings, and found that all so called closed-coil windings with either a series or parallel arrangement of the inductors could be embraced under a general rule which applied equally well to ring, drum, and disk armatures. The common as well as the peculiar properties of the various windings can be accurately observed with the aid of this rule.

The relationship between ring, drum, and disk armature windings, is brought into prominence, and the transition from one winding to another can be accomplished without difficulty. This rule not only embraces all known windings, but accomplishes even more, — *a general solution of the winding problem.* By the aid of this rule, and in conjunction with the various methods of connecting inductors treated in the first section, it is possible to design other windings. In the later sections I have shown several designs for connections, which to my knowledge have never been published before. The results which I have obtained appear to be of sufficient interest to be made public, the more so because even in the best text books on electrotechnics, armature windings, especially those of multipolar machines, have been treated somewhat unsatisfactorily.

(SIGNED) E. ARNOLD.

RIGA, *March* 5, 1891.

TRANSLATOR'S PREFACE.

Professor Arnold's "Ankerwicklungen," in which is given his general formula for the design of direct current armature windings, has been considered of sufficient importance to be translated and published in the present form.

Many of the designs shown by him are of historic interest only, but the principle expressed is fundamental, and of value to the enigneer or designer, and no attempt has been made to go beyond the subject as treated in his book.

The translator's thanks are due to Messrs. A. W. K. Peirce and W. F. Crawford, for valuable assistance in preparing the work.

F. B. De Gress.

New York, *March 5th*, 1902.

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ARMATURE WINDINGS.

METHODS OF CONNECTING INDUCTORS FOR OBTAINING DIRECT CURRENTS.

If an inductor be moved in a magnetic field in such a manner as to cut the lines of force, an electromotive force will be induced in the inductor.

If the inductor belongs to a closed circuit, maintains its position relative to the direction of the lines of force, and be moved with a constant velocity, a constant electromotive force will be induced, and a current of constant strength will be obtained.

The electromotive force is induced as shown in Fig. 1, perpendicularly to the lines of force and perpendicularly to the direction of motion.

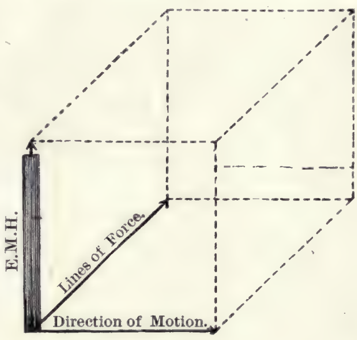


Fig. 1.

Let Fig. 2 represent a magnetic field produced by two poles of opposite sign; let the North pole stand over the paper so that the lines of force pass into the paper from the North to the South pole.

If an inductor be moved in the direction of the double arrow through the given field, an electromotive force will be induced in it in the direction of the single arrow.

To produce a closed circuit, it is assumed that the conductor slides upon two fixed rails, *A—B* and *C—D*, whose ends are joined by the conductors *AmC* and *BnD*. Under these conditions a current will then flow in the direction shown by the arrows.

A continuous current could only be maintained in this manner if the field were infinitely large; for as soon as the

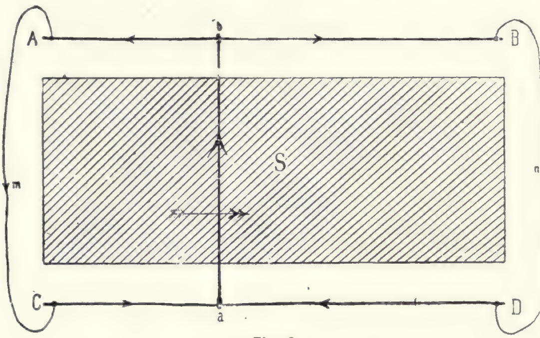


Fig. 2.

inductor leaves the magnetic field the induction ceases, and if the direction of motion be reversed, the direction of the flow of current is also reversed.

A continuous magnetic field, from which a continuous cur-

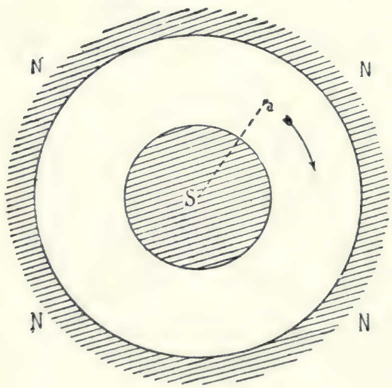


Fig. 3.

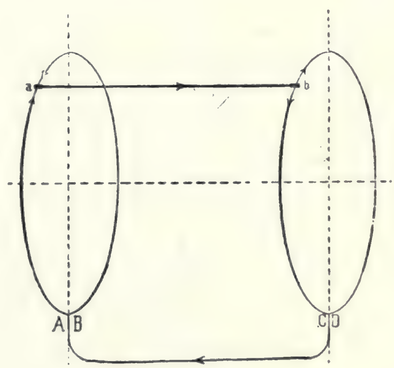


Fig. 4.

rent can be obtained, will be made if the field be transferred to the surface of a cylinder, and the inductor be moved in a circular path as shown by Figs. 3 and 4.

This arrangement involves the principle of a unipolar machine. The magnitude of the electromotive force depends on the intensity of the magnetic field, on the length of the inductor, and on its velocity. The intensity of the field and the velocity of the inductor cannot be increased indefinitely; therefore, beyond a certain point an increase of the electromotive force can only be obtained by increasing the length of the inductor.

But even here certain complications arise. Single straight inductors, as *ab* in Fig. 4, can only be used to obtain small E. M. F.'s; higher E. M. F.'s must be obtained by collecting the impulses induced in several inductors and putting them in series. The unipolar induction, as shown in Figs. 2, 3, and 4, does not permit of series connection; for if several inductors, *a—b*, *c—d*, *e—f*, *g—h*, be connected by the cross connectors, *bc*, *de*, *fg*, as in Fig. 5, the cross connectors by their motion through the magnetic field would also have E. M. F.'s generated in them, which oppose the E. M. F.'s of the inductors; so that after subtracting these opposite E. M. F.'s, there would remain that of one inductor, *gh*; therefore every attempt to construct unipolar machines with inductors in series, even with the most ingenious connections and devices, must fail.

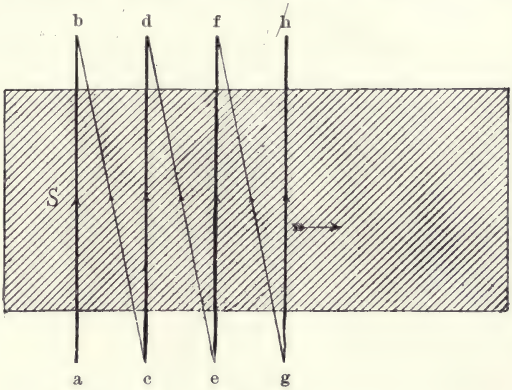


Fig. 5.

For series grouping, successive poles must be of opposite sign.

If an inductor be moved in a straight line or rotated in a magnetic field of alternating polarity, at each change of polarity a change in the direction of the E. M. F. takes place, and a direct current can only be obtained by the use of a commutator.

The arrangement of these inductors and their connection with the commutator must be carried out in such a manner

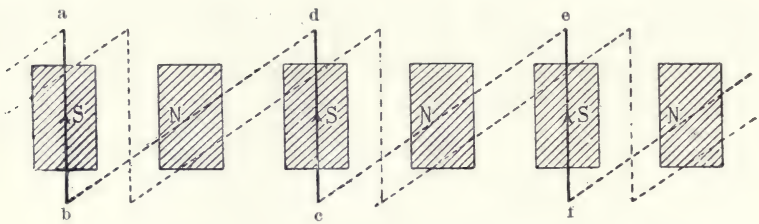


Fig. 6.

that the E. M. F.'s in all the inductors have the same relative direction, and also that the change in the direction of the current takes place at the right time.

In the following figures, the magnetic poles are considered as being arranged in a circle at equal distances apart and of

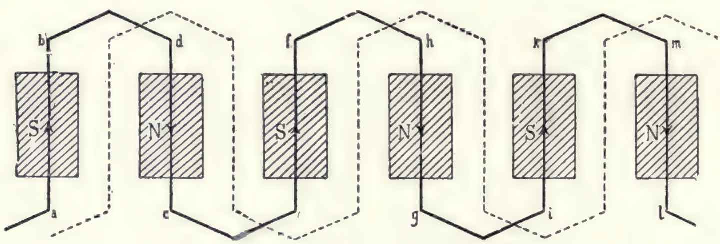


Fig. 7.

alternate polarity. For convenience in representation, the circular path of the inductors is developed into a straight line, and the circular arrangement of the poles is likewise represented. Some simple ways of connecting several inductors in series are thus shown in Figs. 6 and 7.

The inductors *a—b*, *c—d*, *e—f*, *g—h*, are connected in such a manner by the inactive connectors *b—d*, *c—e*, *f—h* that their E. M. F.'s, as shown by the arrows, are additive.

In Fig. 6 the distance between the inductors is equal to twice the distance between the poles, while in Fig. 7 it is the

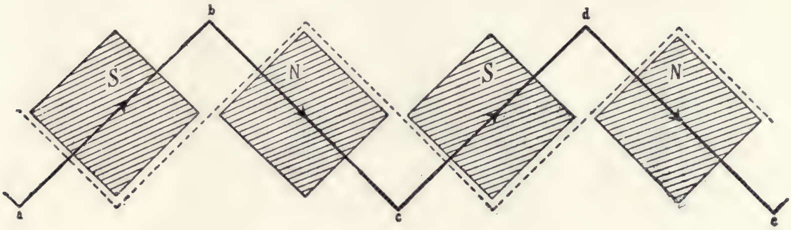


Fig. 8.

same as the distance between the poles. The dotted lines show the position of the inductors at commutation. The use of connectors can be overcome by placing the inductors in an oblique position, as shown in Fig. 8. With this method of connection, it is necessary that the pole pieces be lozenge-shaped, in order

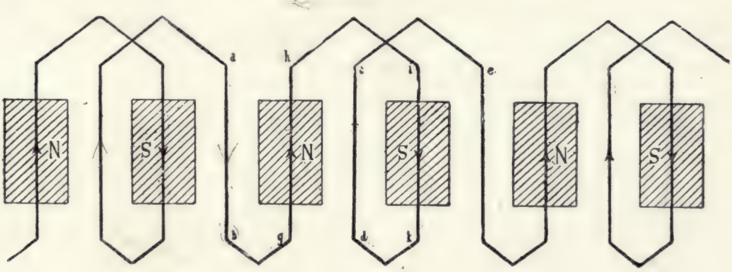


Fig. 9.

that an inductor should not be in two magnetic fields and have opposing E. M. F.'s induced in it. The dotted lines again show the position of the inductors at commutation.

If the inductors *a—b*, and *c—d*, in Fig. 7, be connected, not direct, but as shown in Fig. 9, through *bg hi kd* so that the magnetic field be passed through twice, then the inductors *a—b* and *g—h*, also *c—d* and *i—k*, are alternately under induction.

It follows therefore, that the distance between these inductors must at least equal the width of the pole; for if both inductors should come within the same magnetic field, the E. M. F.'s induced in them would be opposed. Fig. 10 agrees with Fig. 9, except in the circular form which has been given to the induc-

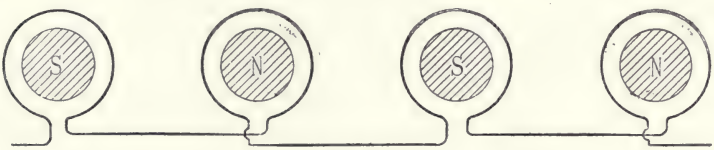


Fig. 10.

tors in place of the rectilinear form heretofore used. The inductors in Fig. 10 are in the position of commutation, while Fig. 9 shows the point of maximum induction. Figs. 9 and 10 represent a form of winding, which will be spoken of as "loop-winding."

This "loop-winding" may also be obtained by joining together inductors that are moving under poles of the same

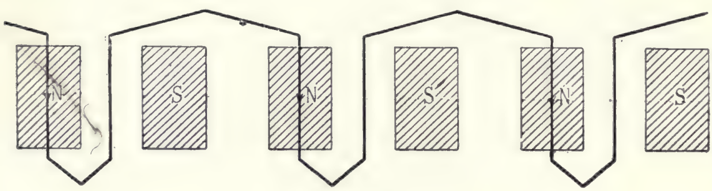


Fig. 11.

sign as in Fig. 6, or by connecting, in Fig. 9, *h* to *e* direct, which gives the arrangement shown in Fig. 11.

It is evident that we cannot obtain a direct current of a constant intensity from the arrangements heretofore shown, because the commutation of all the inductors takes place at the same moment and when they are all inoperative.

In order to obtain a direct current of constant intensity, a large number of inductors must be used, so arranged in different parts of the field, that in a certain number of them the maximum induction takes place, in others a lesser amount, and in some none at all. Then the inductors may be connected with one another as follows:

1. In such a manner that they constitute a closed or endless winding, and so that between the points of commutation no opposing E. M. F.'s will be induced at any time. The connection with the exterior circuit must be made in such a manner that a reversal of the current in the inductors can take place in those only which at the time are not under induction. This form of winding will be spoken of as a closed-coil winding.

2. The inductors may be connected in groups, in which all the members of each group are in a magnetic field of the same intensity, and only that group which is subject to the maximum, or nearly the maximum, induction is connected to the exterior circuit, while all the other groups are entirely cut out. This form of winding will be called an Open-Coil Winding.

Closed-coil windings will be considered first.

In Fig. 12 there are two poles, of opposite sign, and the inductors are placed at equal distances apart. If we assume that the lines of force pass from the North to the adjacent South pole, then the series winding can be so arranged that the opposite ends of adjacent inductors are connected together by inactive

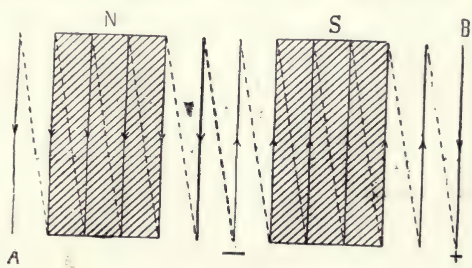


Fig. 12.

conductors, i.e., by conductors so arranged as not to cut lines of force. These are shown in the figure by dotted lines; their position in space must be imagined to be somewhat as shown in elevation by Fig. 13. If the cross connections are drawn in for all the inductors, and the direction of the current flowing is indicated by arrows, supposing the inductors to move to the right, it will be found that they are divided into two groups,

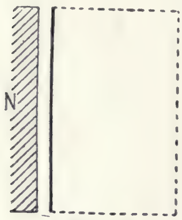


Fig. 13.

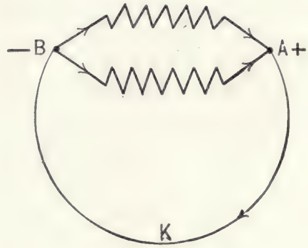


Fig. 14.

in which all the E. M. F.'s of positive sign and all of negative sign are additive.

If the scheme of Fig. 12 be arranged in a circle, and A be joined to B, an endless spiral is obtained with the permanent points of commutation, + and —.

The reversal of the current does not take place in all the inductors at once, but only in those which are at the point of

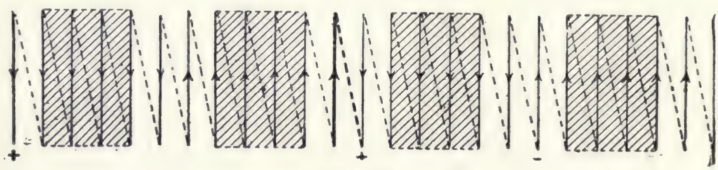


Fig. 15.

commutation, therefore by using a sufficiently large number of inductors the variations in the intensity of the current are not noticeable. The current divides itself at the — point into two branches which reunite at the + point: this branching of the current always takes place in a closed-coil winding, and therefore only half of the total number of inductors can be in series with each other.

Fig. 14 shows this branching of the circuit in which

A—K—B represents the exterior circuit. Fig. 15 represents a 4-pole arrangement, which is obtained by doubling the arrangement shown in Fig. 12. Here a double branching of the circuit takes place as shown in Fig. 16.

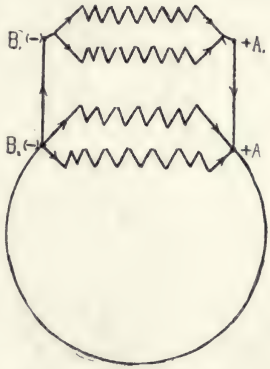


Fig. 16.

The inductors are divided into 4 equal groups, the inductors of each group being in series, while the groups themselves are in parallel. Under similar conditions, the E. M. F. obtained is equal to that of Fig. 12.

The inductors can also be connected in a closed-coil winding, so that only a single branching takes place; that is, half of the inductors are connected in series whereby double the E. M. F. is obtained. This is represented in Fig. 17; the joining of the successive inductors agrees with the arrangements of Fig. 6, and Fig. 17 may be regarded as an extension of Fig. 6. The distance between these inductors is either greater or less than the distance be-

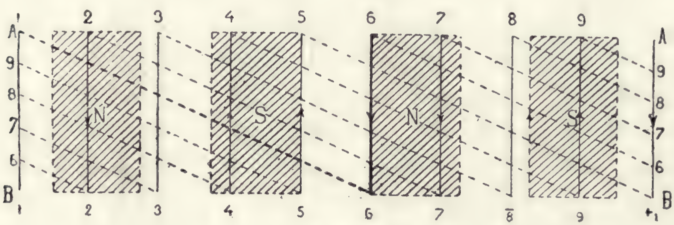


Fig. 17.

tween poles, but the sum of them is no longer optional. The whole winding develops into several angular figures of the form 1—6—6, which figure can be considered as the element of the winding containing only one inductor subject to induction. If this scheme be considered as wound either upon a cylinder or disk, so that the inductor *AB* coincides with *A′B′*, then the number of inductors must be so chosen that the cross connections shall always embrace an equal number of divisions, and in following out the winding through every inductor the last inductor considered will be found connected to the first. The inductors must, of course, be taken in their natural succession; that is, starting with 6, after going through the whole scheme once, we should come to the adjacent inductor 5 on the left, or 7 on the right. The proof that this method of winding is correct, and gives a single branching, according to Fig. 14, can be shown by indicating the direction of the current, and following it out in the drawing. Starting from the point of commutation 8, and going either in the direction 8, 3, 4, etc., or in the direction 8, 3, 3, 7, etc., in either case, by following the direction of the current through half the inductors, the second point of commutation (+) will be reached. At any instant the reversal of current takes place only in the two inductors which are at the points of commutation, at which time they pass from one branch of the circuit to the other.

A new scheme of the utmost importance in the design of multipolar machines may be deduced from Fig. 17, if, instead of connecting together those inductors which pass under poles of the same sign, as in Fig. 6, we connect those inductors which, as in Figs. 7 and 8, pass under all poles successively. The number of inductors and the number of divisions between two inductors which are to be connected together must be so chosen, that an uninterrupted circuit may be traced out, which, after passing through each point of division, returns to the starting-point. Figs. 18 and 19 show Figs. 7 and 8 changed to meet these conditions.

In each element of the winding there are two inductors, which are shown by heavy lines in Figs. 18 and 19. If the direction of the current be again followed out, there will be found only two points where the current apparently runs in opposite directions. These are the points at which the current for the exterior circuit is collected. We can now solve the problem for series winding in general for any number of pairs of poles, by multiplying the number of inductors in Figs. 17, 18, and 19. It will always be found that by this arrangement

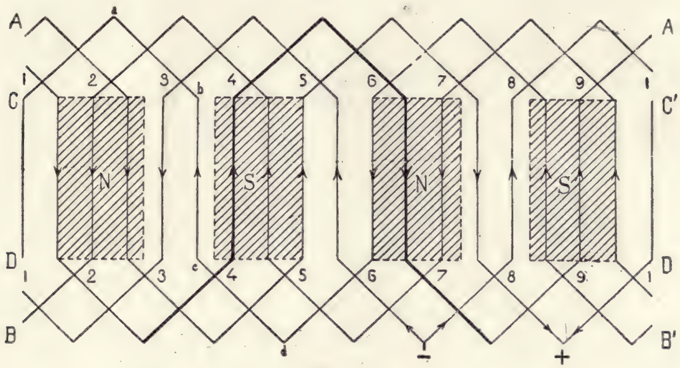


Fig. 18.

one-half of the inductors can be connected in series with each other, therefore only two points of commutation are required. It is evident that the last three schemes can be used in the design of direct current windings if every element which

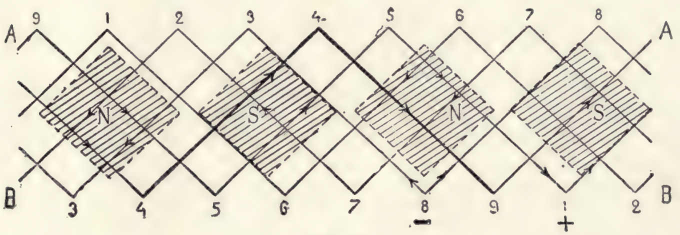


Fig. 19.

passes through a magnetic field of alternate sign has induced in it E. M. F.'s which are additive. To obtain a complete plan of a winding of this character, it is only necessary to join together several elements in a closed circuit, and to observe that no variation from the assumed form of the element shall take place.

Many schemes in addition to those shown in Figs. 9, 10, and 11 can be devised to meet the conditions outlined above.

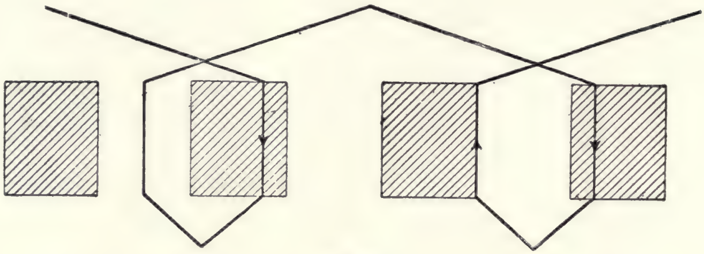


Fig. 20.

Figs. 20 and 21 show the elements of two windings of this character. The element shown in Fig. 20 may be obtained

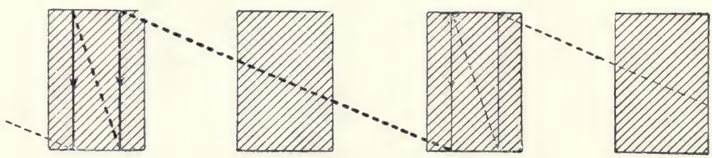


Fig. 21.

from Fig. 9, and that in Fig. 21 by uniting Figs. 6 and 12. Fig. 22 is a scheme elaborated from Fig. 9, and Fig. 23 from Fig. 11. One element of Fig. 22 contains 4 inductors.

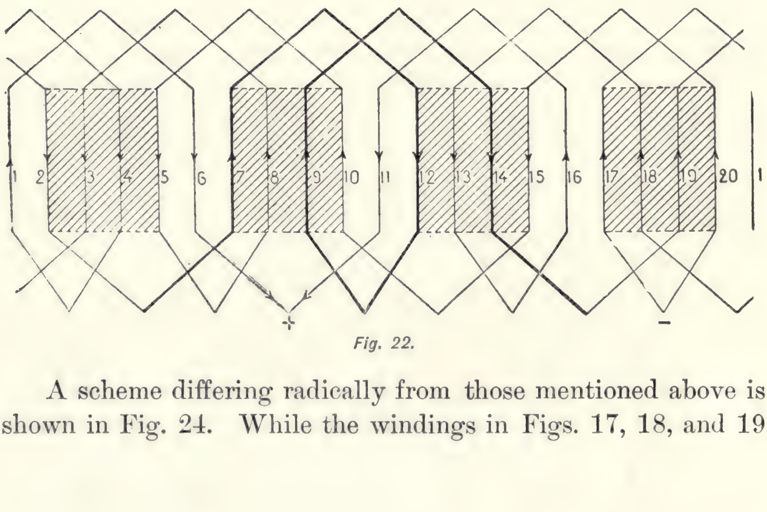


Fig. 22.

A scheme differing radically from those mentioned above is shown in Fig. 24. While the windings in Figs. 17, 18, and 19 always advance through the successive fields in zigzag form; that shown in Fig. 24, alternates back and forth. The inductor is bent along the broken line 1, 2, 3, 4, 5, 6, 7, making a hexagonal or rectangular element, which ends at the adjacent

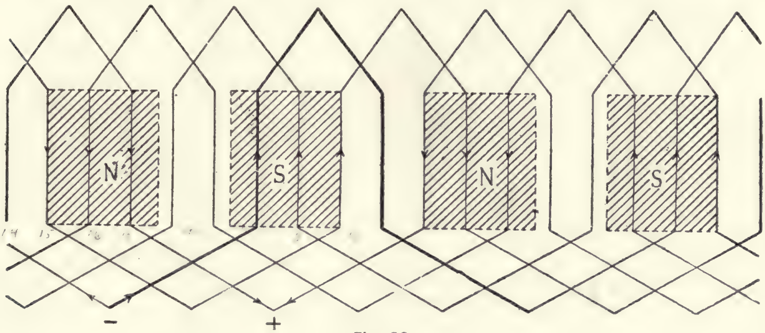


Fig. 23.

points 1 and 7. If new elements of the same shape be added, continuing from number 7 on through all the points of division, the last element must end at point 1, which gives the scheme developed in Fig. 25.

As may be seen from the figures, each element is subject to the action of two poles of opposite sign; by following out the direction of the current the points of collection (+) and (−) may be found. This winding may be spoken of as "loop winding," and that of Figs. 17, 18 and 19 as "wave winding."[1] Fig. 22 is a mixed wave and loop winding, but as it has the peculiarities of a wave winding it will be classed under that head.

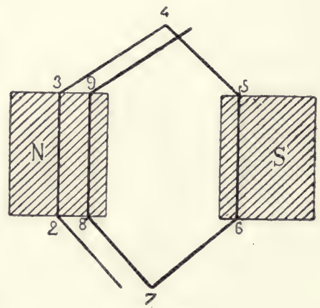


Fig. 24.

The characteristic difference between these windings appears immediately upon comparing schemes like that of Fig. 25 with others similar to Fig. 18. While the wave winding has only

[1] See W. Fritsche. Die Gleichstrom-Dynamomaschinen. Berlin, 1889.

two neutral points independent of the number of magnetic fields, the loop winding has as many neutral points as magnetic fields. The wave winding in Fig. 25 gives for multipolar machines a series winding, while the loop winding gives a mul-

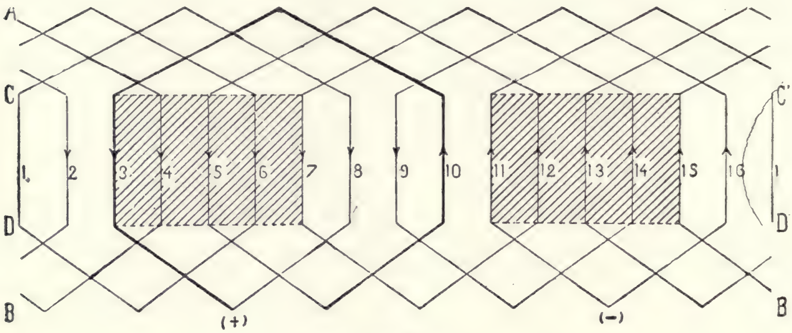


Fig. 25.

tiple winding. Fig. 15 is therefore to be regarded as a loop winding (spiral winding).

Let z be the total number of inductors moved in the field, and n the number of poles. Then with the wave winding the number of inductors connected in series is equal to $\frac{z}{2}$, but with the loop winding it will be equal to $\frac{z}{n}$. Under equal conditions the E. M. F. in the first case will be $\frac{n}{2}$ times that of the second.

In the series winding, the inductors are arranged in two groups, corresponding to the single branching of the circuit, while in the loop winding it is divided into n groups having $\frac{n}{2}$ branches. The inductors of the single groups are in series, but the groups themselves are in parallel. As will be shown later, the wave winding may also be used for parallel winding, but the loop winding cannot be used for series winding.

The system of winding given in Fig. 25 can be further developed. W. Fritsche suggests that the vertical parts of the elements, indicated by the numbers 1, 2, 3, 4, etc., be eliminated, thereby giving the elements a rhombic form as shown in Fig. 26.

To avoid generating opposing E. M. F.'s, the pole pieces also must be given a rhombic shape.

The element of a loop winding may be so formed that it will lie within the influence of two poles of the same sign as shown in Fig 27. The peculiar feature of this scheme is, that it is only good for 4, 8, 12, etc., poles, and in this case

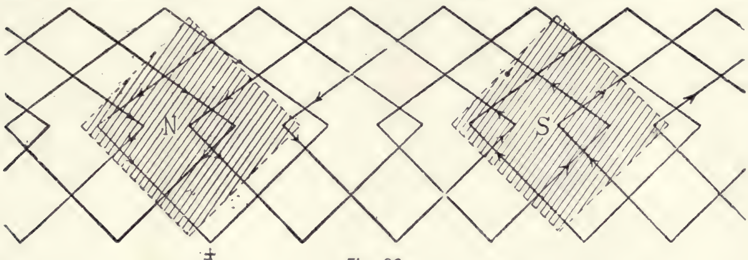


Fig. 26.

$\frac{2z}{n}$ inductors are joined in series and not $\frac{z}{n}$ inductors as in the first loop windings considered. In a four pole scheme ($n=4$), there will be but two neutral points, as in the wave winding. The cross-connectors in this figure can be so arranged that

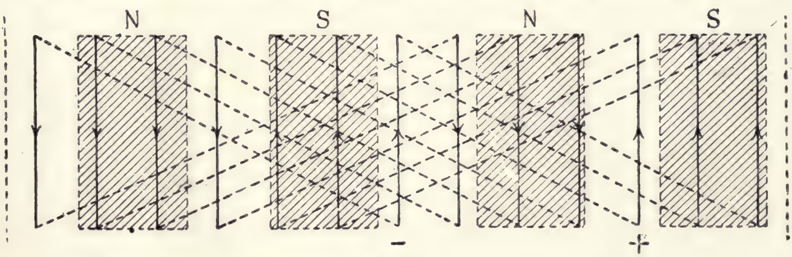


Fig. 27.

they will not cross each other, which gives a wave winding similar to that of Fig. 17.

These general schemes outlined above will now be applied to the windings of armatures for direct current machines. Nothing further will be said here about open-coil armatures, they being treated in a separate chapter.

A. CLOSED-COIL WINDINGS.

GENERAL FORMULA FOR WINDING DIRECT CURRENT ARMATURES.

FROM an examination of the windings of armatures for bipolar and multipolar machines with parallel or series grouping applied to ring, drum, or disk armatures, it appears at the first glance, that owing to the great variety of them, it would be impossible to make a general formula for winding, which would cover all these conditions.

A thorough examination will show that in reality a simple formula will cover all windings; that is, for parallel or series groupings, for bipolar or multipolar machines, for ring, drum, or disk armatures, and one which will show the necessary connections of the armature inductors for obtaining the desired results. From the observations in the first chapter, it is evident that a correct winding will be obtained when those inductors lying at the same distance apart in the magnetic field are joined together in such a manner that an equal number of inductors or divisions are always included between two inductors that are connected together, and after tracing the connections through all the inductors, in which, in the separate branchings of the circuit the impulses are additive, the last inductor is connected to the starting-point.

The distance between the poles determines which inductors are to be connected together. From Figs. 17, 18, and 19, it is clear that in following out the schemes, we move alternately from the division points on a line AA', to those on a line BB'.

If, for example, Fig. 19 be redrawn so that the points on the imaginary lines AA' and BB' become two concentric circles of which BB' is the inner, the development of winding becomes identical with the following geometrical problem:

Let the circumferences of two concentric circles be divided into $\frac{z}{2}$ *equal parts. Between the z points of division a line is to be drawn so that either one continuous line or several lines result, which will be closed on themselves. This will depend on the assumptions made, and each line in passing once around the circle will give a variable number of points of intersection or bending, which will also depend on the assumptions made.*

The problem is solved when y, the number of spaces on either circumference between successive points of intersection on that circumference, satisfies the equation,

$$y = \frac{1}{k}\left(\frac{z}{b} \pm a\right) \text{ where}$$

k and a are whole numbers.

b = the number of inductors lying between two successive points of intersection of the broken line on the circle.

z = sum of the inductors or the sum of the points on both circles.

In Fig. 28, where $z = 20$, $k = 3$, $a = 1$, $b = 2$, we have

$$y = \frac{1}{3}\left(\frac{20}{2} - 1\right) = 3,$$

and a broken line of this character is represented.

Let the division points of the outer circle be numbered successively from 1 to 10; now if y, the number of divisions which should lie between two points, equals 3, then 1 should be joined with $(1 + 3) = 4$, 4 with $(4 + 3) = 7$, etc. On the inner circle we observe the same rule. The 20th inductor, $h1$, returns to the starting-point. Since $b = 2$ there are between two successive points in the same circle, for instance 1 and 4, two inductors, $1a$, and $a4$.

If 1 be joined direct to 4, then b will equal 1, and z will then denote the number of divisions on the outer circle, the inner circle being no longer necessary for the construction.

Starting at 1, by going once around along the broken line, the points $a4$, $d7$, $g10$, are obtained. If z and b are given, the sum of the broken lines closed on themselves (or loops), or the number of points, depends on the assumed values of k and a. Returning to the winding, let $k = \frac{n}{2}$ equal half the number of poles, and therefore n equals the number of poles. Let z = number of inductors on the circumference of the armature; y any whole number chosen with reference to the number of poles and number of inductors; a a constant which when $a = 1$ gives a single branching, when $a = 2$ a double branching, when $a = 3$ a triple branching, etc.; b equal the number of inductors in an element; of the winding, x any element.

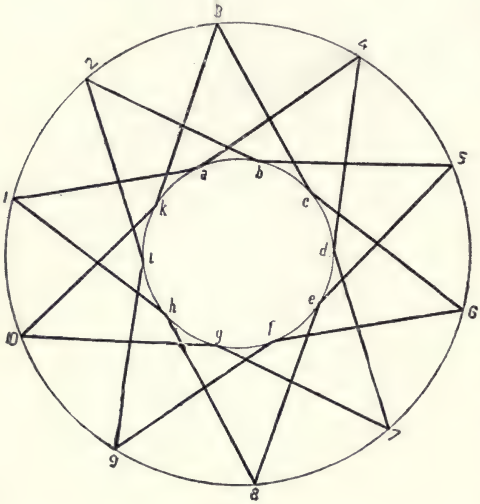


Fig. 28.

We have then generally,

$$z = b\left(\frac{n}{2}y \pm a\right) \text{ and}$$

$$y = \frac{2}{n}\left(\frac{z}{b} \mp a\right).$$

In regard to the value of z and b, it should be noticed that if the inductor consists of several strands lying alongside of or above one another, they are to be considered as a single inductor.

The general rule is:

The end (beginning) of the xth element shall be joined to the beginning (end) of the $(x+y)$ element.

The sum y gives the number of inductors over which it is necessary to advance to reach that inductor whose beginning shall be joined to the end of the inductor started from. y may be called the "spacing" of the winding.

With the aid of the formula,

$$z = b\left(y\frac{n}{2} \pm a\right)$$

the winding of bipolar and multipolar machines can be classified as follows:

1. SERIES WINDING. For this $a = 1$. In the special case when $n = 2$, parallel and series windings are identical, and the winding can be a wave winding as well as a loop winding. This is also the case where $\frac{n}{2} = 2$. (Compare Figs. 44 and 45.) When $\frac{n}{2} > 2$ a wave winding always results.

2. PARALLEL WINDINGS. Windings with $\frac{n}{2}$ branchings can be classified: —

A. Parallel winding with loop or spiral winding. In this case a multipolar armature is considered as being built up from several bipolar armatures and independent of the number of poles; the values $n = 2$, $a = 1$ are always substituted in the formula.

B. Parallel connection in wave winding. Here $a = \frac{n}{2}$. If a single winding, closed on itself, is desired, y and $\frac{z}{b}$ must be numbers prime to each other.

3. MIXED WINDINGS. Here $a > 1$ and $a \lessgtr \frac{n}{2}$. This case results in either several windings closed on themselves with special points of collection on the commutator, or a single winding closed on itself with a branchings.

The number of closed windings or elements can be determined generally, if it is noted that all the elements can be joined in a single winding, only when y and $\frac{z}{b}$ are numbers prime to each other. If they have a common factor, as $\frac{z}{b} = i \times p$, and $y = i \times q$, where p and q are two numbers prime to each other, i closed windings or i independent circuits result.

The total number of branchings still remains equal to a, and the points of collection equal to $2a$.

In the following pages we shall consider ring, drum, and disk armatures, and prove the correctness of the above formulae. We will see at the same time that the formula will always give a correct scheme of winding, and that the laying out of a scheme for winding by means of the formula is very much simplified.

The methods of representation vary ; in most schemes the circular form is retained and the commutator end of the armature is shown. The connectors on the front end are shown as full lines, those on the back as dotted lines, or they are omitted.

This method has the advantage over others, that the practical development of the winding can be shown, and that the transition from ring to drum and disk windings can be best observed. Where it is desirable to show the relationship of various windings, Fritsche's method is used. This gives a developed scheme, as shown in the first chapter.

RING ARMATURE WINDINGS.

1. BIPOLAR RING ARMATURES.

The first winding to be considered will be a simple bipolar scheme of the Pacinotti-Gramme type of armature, and in this case, with twelve coils.

All the coils are so connected that they constitute an endless spiral. At each point where two coils are joined, a connection is made to one of the twelve segments of which the commutator is composed. This commutator rotates, of course, with the armature.

With the given position of the poles and the given direction of rotation of the armature, a current is induced in the inductors whose positive direction is shown by arrows. The stationary

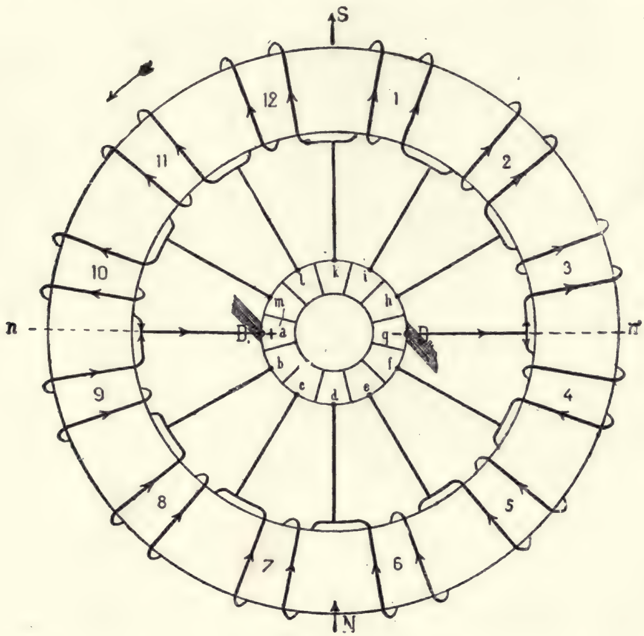


Fig. 29.

brushes which carry the current to the exterior circuit, bear on the commutator at D_1 and D_2, and a direct current is obtained, which, if the number of coils be sufficient, is of a constant intensity.

A shortcircuit of the armature coils in the neutral zone occurs when the brushes are resting upon the two commutator segments to which each coil is connected. This shortcircuit is followed by a reversal of current in these coils. If the brush D_1 should rest upon the segments a and m, and at the same time D_2 should rest upon f and g, coils 10 and 4, respectively, are shortcircuited through the brushes. While thus short-circuited they are inactive; but as they pass beyond the point of commutation the direction of the current in them is reversed.

The Gramme winding agrees with the scheme given in Figs. 12 and 14. In Fig. 30 it is shown again how the current branches into the two parallel halves of the armature, D_1SD_2 and D_1ND_2.

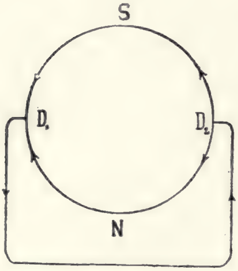


Fig. 30.

This style of armature winding for even, sparkless operation requires that the two branches of the armature circuit be subjected to an equal induction; therefore both halves must have an equal resistance, an equal length of wire, and must induce equal electromotive forces — that is, equal lengths of wire must move with equal mean velocities in a field of equal intensity.

For ring windings, the number of coils which is denoted by s, must always equal the number of inductors, z; and the general formula gives $b = 1$, where $a = 1$, $n = 2$, $z = s = 12$, and $y = s \pm 1 = 13$ or 11.

The beginning of the xth coil is, where $y = 11$, to be joined with the end of the $x + 11$th, and therefore the beginning of 1 with the end of 12. When $y = 13$, it follows that 1 shall be joined to 14 $(12 + 2)$, or with No. 2, which agrees with our rule.

When $a = 2$ and $y = s - 2 = 10$, coil 1 must be joined with $1 + 10 = 11$, and correspondingly, when $y = s + 2 = 14$, with $(1 + 14) = 12 + 3$, or with coil 3. In this manner two independent windings would be obtained, each with one commutator. To the one would belong coils with odd, to the other those with even, numbers.

The bipolar windings, according to Wodicka* and Swinburne,† can be so developed that the number of commutator bars should be equal to half the sum of the coils. Fig. 31

* La Lum. Elec., 1887, Vol. xxv., p. 44. † Ibid., Vol. xxvi., p. 157.

shows Wodicka's scheme worked out for 16 coils. The opposite coils are so joined that their impulses are additive.

An element of this winding consists now of two coils. The beginning of the eight elements or pairs of coils will be denoted

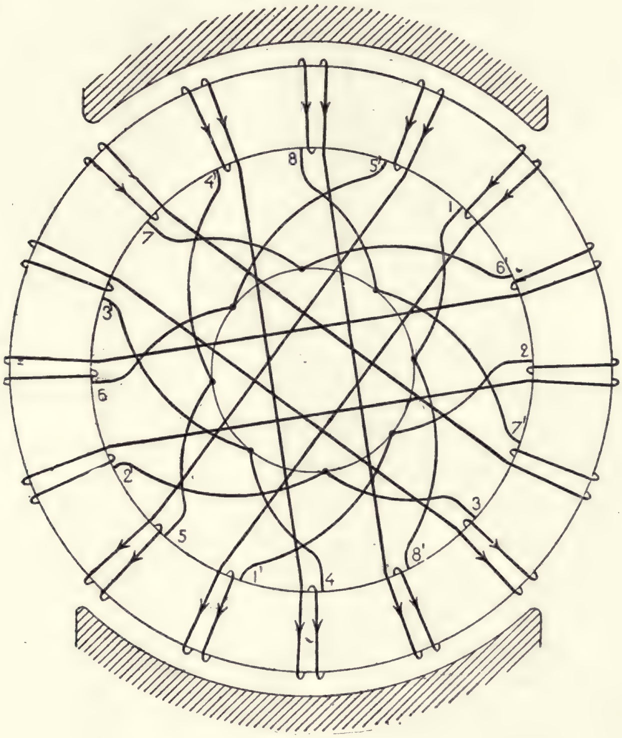


Fig. 31.

by 1—2—3 . . . 8, and the ends, respectively, by 1^1—2^1—3^1 . . . 8^1. The general formula is applicable also in this case:

Here $z = s = 16$, $b = 2$, $n = 2$, $y = \frac{s}{b} - 1 = 7$.

The beginning of pair number 1 is to be connected with the end of the pair $1 + 7 = 8$; that is, with 8^1, etc. The difference between the Gramme winding and that of Wodicka becomes more noticeable if the Wodicka ring with its winding is developed as heretofore. (See Fig. 32.) By comparison with the

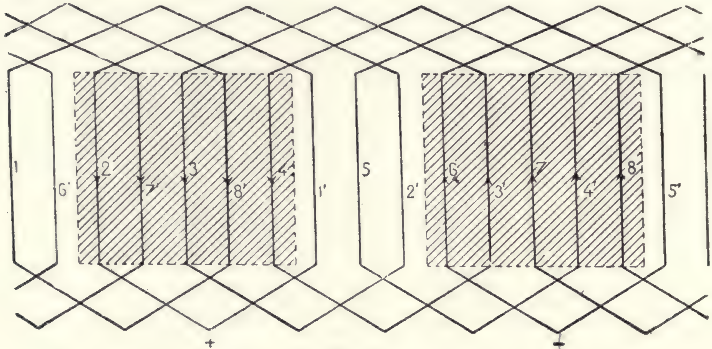


Fig. 32.

scheme of Fig. 71, which shows the Hefner-Alteneck drum winding, it will be seen that they are identical.

2. MULTIPOLAR RING ARMATURES WITH PARALLEL WINDING.

The connections of the single coils for parallel winding can be carried out in the same manner for multipolar as for bipolar armatures. The winding consists then, independent of the number of poles, of a continuous spiral divided up into a number of equal sections, at the junctions of which connections are made to the commutator. The branchings of the circuit correspond to Fig. 16. The coils of each branch follow each other successively in the ring, and lie in the same magnetic field. The number of brushes and the number of circuits is equal to the number of poles. Fig. 33 shows this arrangement for a 4-pole ring armature. Observing that this arrangement agrees with the bipolar arrangement of Fig. 29, and that each coil is to be regarded as a single element, the general formula applies as follows:

$$z = s = b\left(y\,\frac{n}{2} \pm a\right)$$

where $n = 2$, $b = 1$. If $a = 1$ and $s = 16$, then $y = 15$. The formula requires that the beginning and the end of the adjacent coils be joined together. If it be desired to retain $\frac{n}{2}$ branchings of the circuit, by inserting the value $a = \frac{n}{2}$, another scheme results. The coils belonging to the same branching are no longer adjacent, but lie at the same time in two or more magnetic fields.

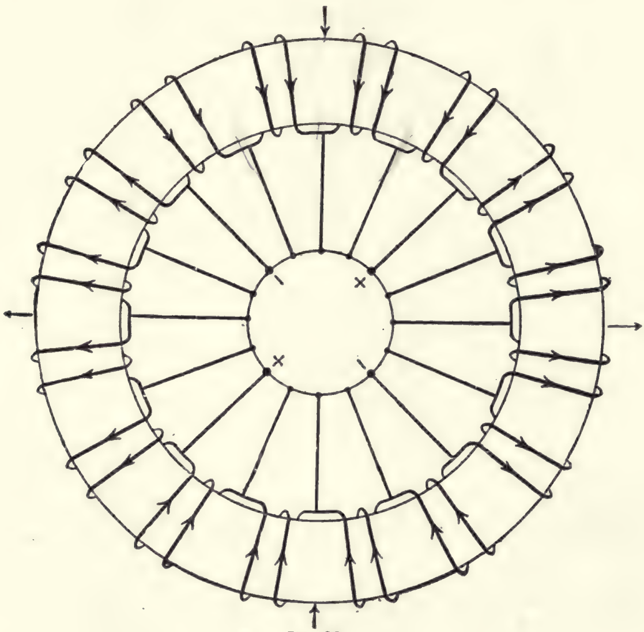


Fig. 33.

When $n = 4$, and $a = \frac{n}{2} = 2$, the number of coils s remaining 16, then $y = 9$. Now the end $1'$ should be joined to the beginning of $1 + 9 = 10$, etc., as represented by Fig. 34 (compare also Figs. 81, 82).

Developing this circular arrangement, Fig. 35 is obtained, in which each coil is represented by a straight line, and may be more easily followed.

To obtain the points of commutation, denote the direction of the current in the inductors by arrows; and in following these

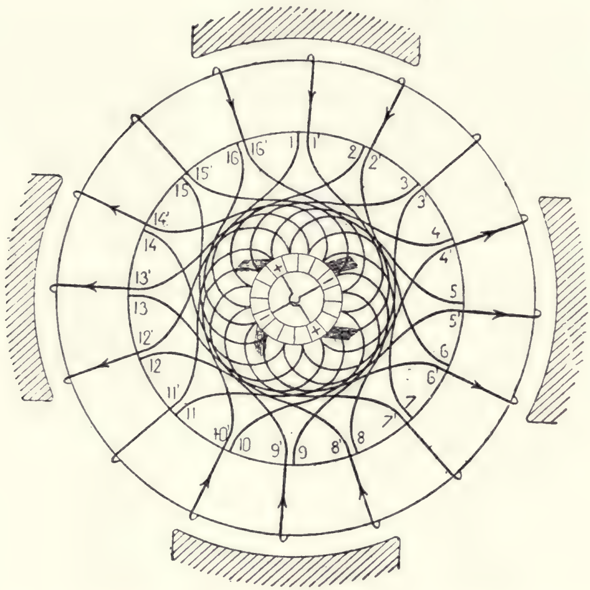


Fig. 34.

out it will be seen that there must be 4 brushes, located at the points marked + and –, in order that there shall be no opposing E. M. F.'s in the branches.

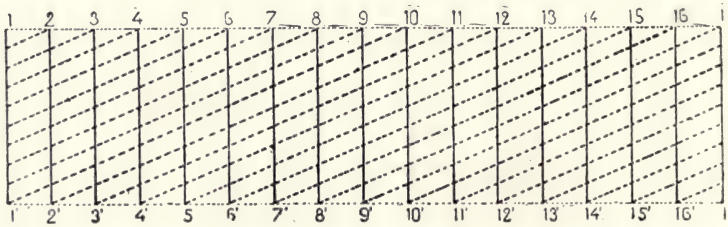


Fig. 35.

To observe the shortcircuiting of the coils the positive and negative brushes respectively must be considered as connected together by connectors within the commutator, which is shown in Fig. 34. At the moment when the coils are in the position shown, 15 and 7 are cut out by the negative brushes, and 11 and 3 by the positive brushes.

The great number of brushes which is required for the multipolar parallel winding can be avoided, if desirable, by the use

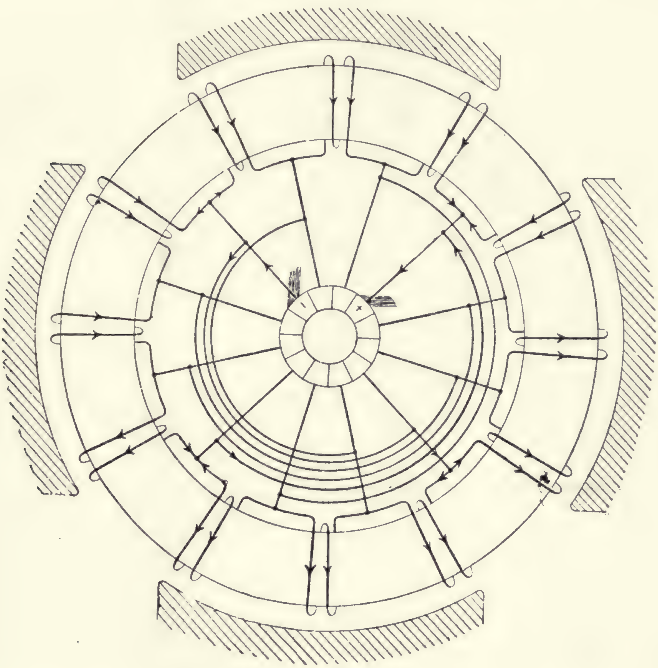


Fig. 36.

of a winding advanced by Mordey for this purpose. The segments of the commutator which are symmetrically disposed relative to the fields, are connected together. Then, independent of the number of poles, only two brushes are required, as shown in Fig. 36.

The Mordey winding can be more easily arranged if the connectors shown in Fig. 36 be joined, as shown in Fig. 37.* The

* W. Fritsche, Die Gleichstrom-Dynamomaschinen, page 4.

number of segments will then be $\frac{2s}{n}$ and to each segment $\frac{n}{2}$ connectors are attached. The winding of Wodicka, shown in Fig. 31, can also be used for multipolar armatures. Let w be

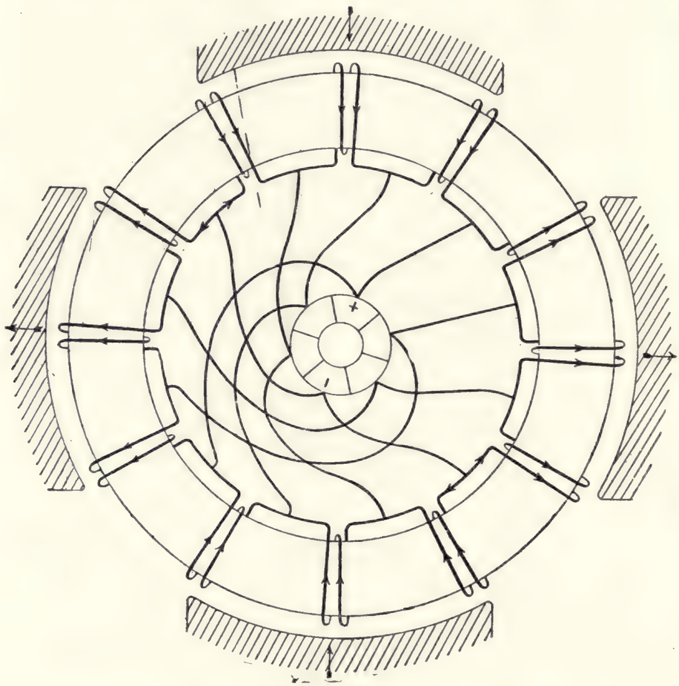


Fig. 37.

the number of winding spaces * on the armature, n the number of poles, then those coils which lie between $\frac{w}{n} \pm 1$ winding spaces should be connected together as one pair. In Fig. 38, $s = w = 16$, $n = 4$, and between each pair of coils, for example, 1 and 1′, there are $\frac{w}{n} + 1 = 5$, winding spaces. The ends of the coils are connected together according to the scheme shown in Fig. 33; that is, 1′ with 2, 2′ with 3, etc. In this case $b = 2$,

* "Wickungsfelder" = winding spaces, divisions for winding.

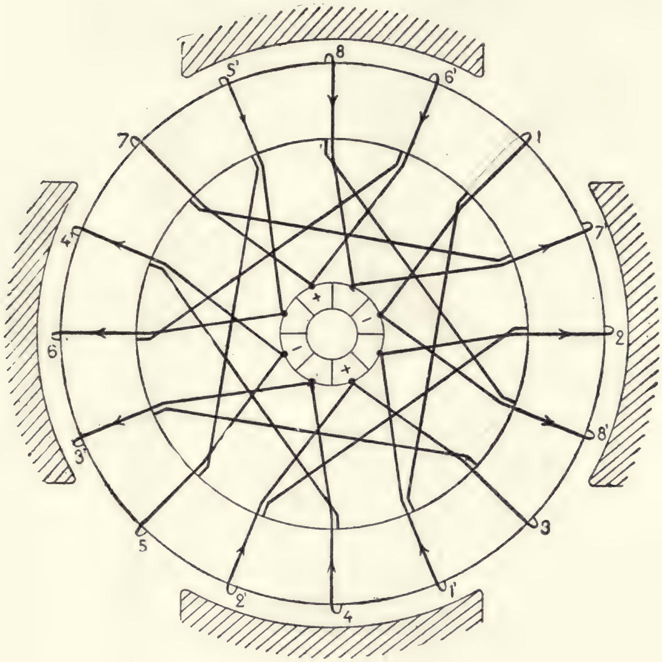


Fig. 38.

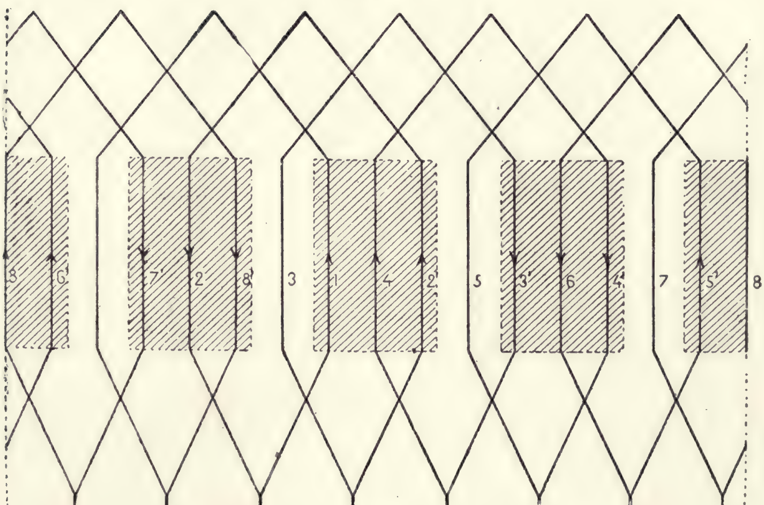


Fig. 39.

$a = \pm 1$, and the value $n = 2$ must always be substituted in the general formula, independent of the number of poles. Fig. 39 shows the development of this scheme. Wodicka's method of procedure can be expanded by uniting in series n coils, if there

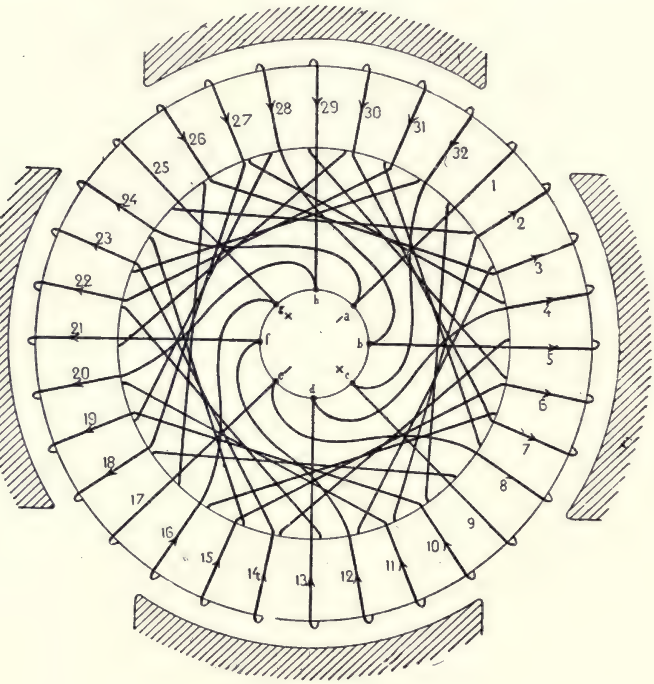


Fig. 40.

be n poles. There must be a segment of the commutator for each of these groups, the total number being $\frac{s}{n}$. The number of winding spaces lying between two coils of a group is again $\frac{w}{n} \pm 1$. Fig. 40 shows such an arrangement, where $s = w = 32$, and $n = 4$. Denoting the coils by successive numbers, and advancing each time, $\frac{w}{n} + 1 = 9$ winding spaces, the armature coils to be joined together will be found to be according to the following table : —

1	10	19	28.
5	14	23	32.
9	18	27	
4	13	22	31.
8	17	26	
3	12	21	30.
7	16	25	
2	11	20	29.
6	15	24	1.

The formula gives this winding by inserting the values

$$b = 2,\ a = \pm \frac{n}{2} \text{ if } n = 4,\ s = 32,\ y = \frac{2}{n}\left(\frac{s}{b} \pm a\right) = \frac{2}{4}\left(\frac{32}{2} + 2\right) = 9.$$

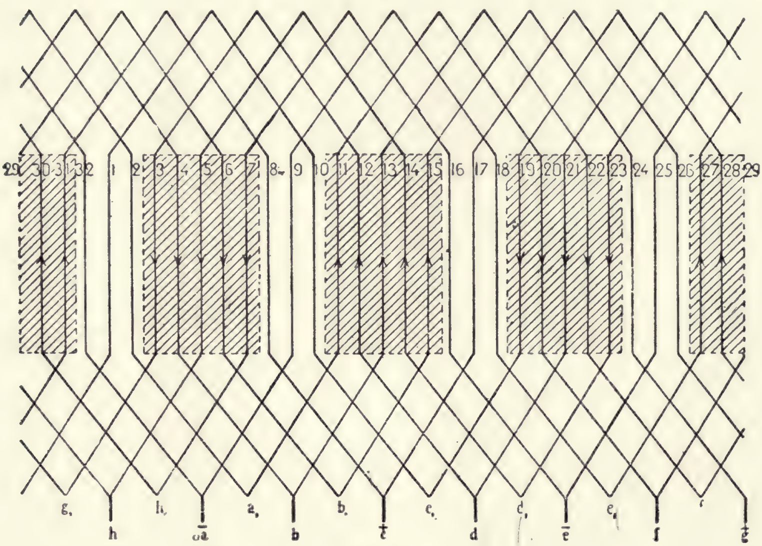


Fig. 41.

Fig. 41, a development of this winding, shows that the scheme of connections is identical with that of a wave winding.

Preserving the same method of winding, it is evident, from

Fig. 41, that the number of commutator segments can be doubled by leading to the commutator the connectors coming together at a_1, b_1, . . h_1.

3. MULTIPOLAR RING ARMATURES WITH SERIES WINDING.

In the parallel winding of multipolar armatures, there are as many branchings in the circuits as poles. In the series windings, there being but two branches, only two brushes are required.

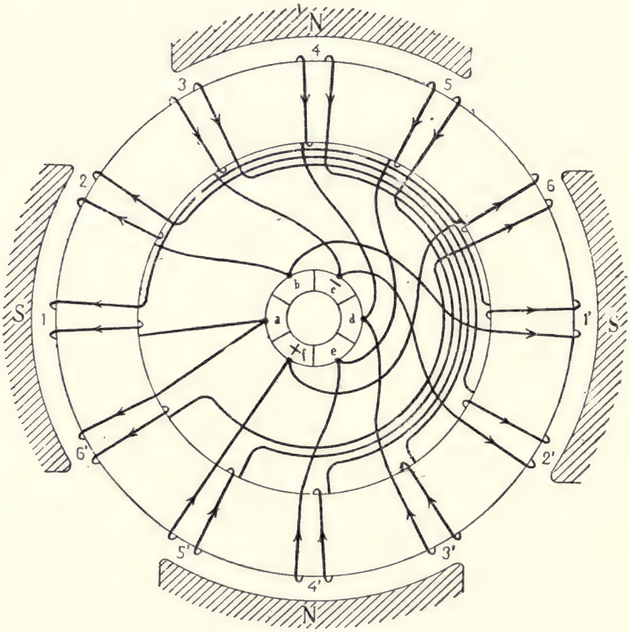


Fig. 42.

The scheme for bipolar armatures given in Fig. 30 is therefore also applicable to multipolar armatures with series winding.

All the coils, starting from the brushes, form two groups in which the direction of the current is opposite. Both groups must have an equal inductive value.

Under similar conditions, with the same number of turns on the armature, the E. M. F. induced by a series winding would be $\frac{n}{2}$ times that of a parallel winding, while the current would be reduced in the same ratio.

Series windings should, therefore, be used for high E. M. F.'s, or where a low peripheral speed of the armature is desired or necessary. As a series winding allows a more simple con-

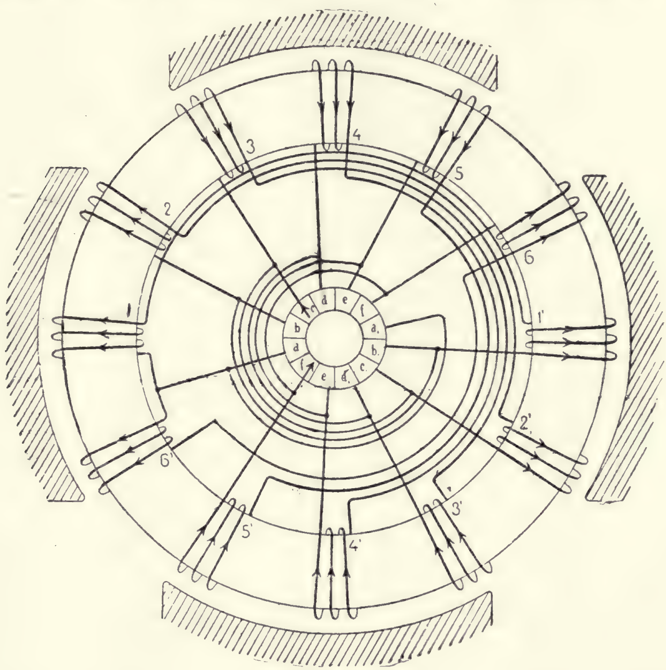


Fig. 43.

struction of the commutator and brush connections, it is also useful in certain cases where a parallel winding might be used.

A scheme for series winding can be deduced from a parallel winding in a very simple manner. In the case of an even number of coils, those lying symmetrically and in the same parts of the field are joined so that they may be regarded as a single coil, and therefore require a single commutator bar.

As the number of equivalent coils is equal to $\frac{n}{2}$, then the number of commutator segments, c, will be $c = 2\frac{s}{n}$.

Fig. 42 shows a scheme where $n = 4$, $s = 12$, $c = 6$.

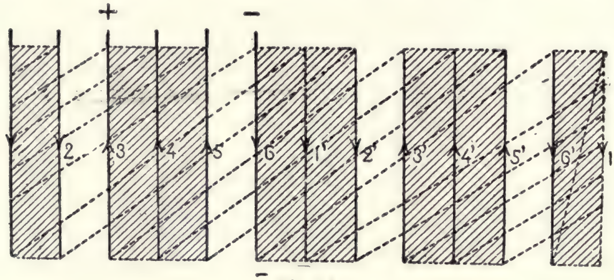


Fig. 44.

Starting from segment a, and regarding the diametrically opposite coils 1 and 1′ as a single coil, the end 1′ is joined to the segment b, adjacent to a, and with the beginning of the coil 2 lying next to 1; 22′ will be the next coil, etc. In this manner the multipolar scheme is practically reduced to a bipolar arrangement and the general formula applies.

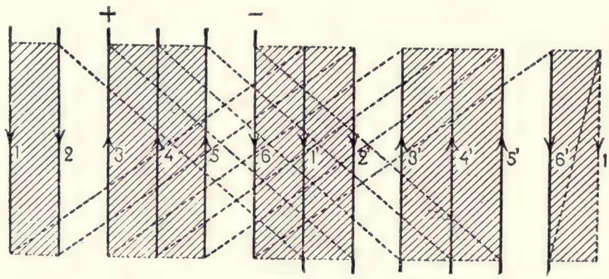


Fig. 45.

In each coil the direction of the current is reversed four times in a revolution, therefore there are $4 \times 12 = 48$, or generally speaking $n \times s$ current reversals per revolution. When the commutator segments $c = 6$, and with two brushes, each brush shortcircuits $\frac{ns}{2c} = \frac{48}{12} = 4$ coils. As seen from the scheme of winding, only two coils are shortcircuited at the same time, therefore the scheme cannot be used in this form. This difficulty can be overcome by doubling the number of commutator bars, as shown in Fig. 43.* To the segments

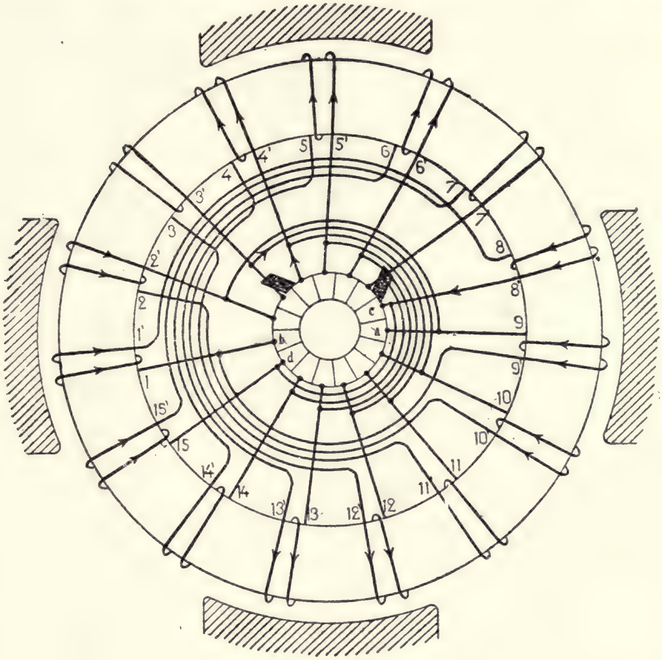


Fig. 46.

a, b, c, d, e, f, in Fig. 42, must be added $a_{\prime}$, $b_{\prime}$, $c_{\prime}$, $d_{\prime}$, $e_{\prime}$, $f_{\prime}$, which lie diametrically opposite (where $n = 4$), and to which they are joined.

Generally if the number of coils s is a multiple of $\frac{n}{2}$, when n represents any even number of poles, the number of commutator bars will equal s, and each $\frac{n}{2}$ segments lying $\frac{2 \times 360}{n}$ degrees apart are connected together. Then through each brush $\frac{n}{2}$ coils

* La Lumière Elec., 1887, page 514; The Electrician, 1889, page 139.

will be shortcircuited at the same time. Figs. 44 and 45 show the developments of 42 and 43. The connectors or dead wires are so drawn in Fig. 44 as to give a wave winding, and in Fig. 45 a loop winding.

In these figures the joining of 6′ with 1 makes the wind-

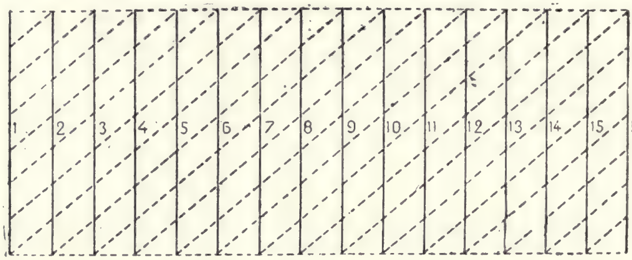


Fig. 47.

ing unsymmetrical, owing to the even number of coils. As $b = 1$ and $z = s$, if the number of coils be selected according to the formula,

$$s = \frac{n}{2} y \pm 1,$$

the cross connectors will be perfectly symmetrical.

If $\frac{n}{2}$ be odd, s can still be an even number. In Fig. 46 $s = \frac{4}{2} \times 7 + 1 = 15$ and $y = 7$. Numbering the coils successively, and considering 1, 2, 3, etc., as the beginning and 1,′ 2,′ 3′, as the ends of the coils, then according to the general formula 1′ is to be joined to $1 + 7 = 8$, and 8′ with $8 + 7 = 15$, etc.

The commutator bars must be joined together according to the rule given; but having an odd number, one segment, b, cannot be so connected. According to the development there are always two coils between two segments, and through each brush two coils are shortcircuited, except between the segments a and b, where there is a single coil. If $\frac{n}{2}$ be odd and s even, this unevenness disappears. The developed scheme is shown in Fig. 47, where a zigzag wave winding with non-inductive connectors is obtained.

From Fig. 46 a new winding can be developed, if, instead of joining 2 $\left(\text{or generally } \frac{n}{2}\right)$ coils together without branching off, the beginning or ending of each coil be connected to a commutator segment. That is, if in Fig. 46 segment *b* be connected

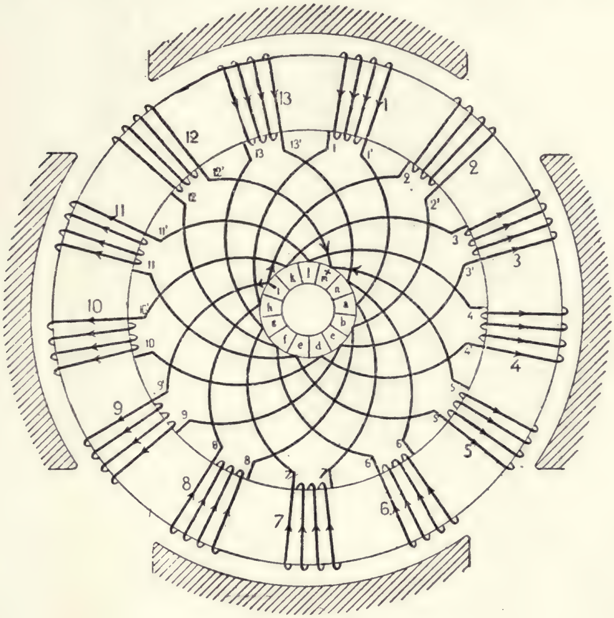


Fig. 48.

to the coil $1-1'$, $1'$ be joined not only with 8 but also with segment *c*, but $8'$ only with segment *d*, and 15, etc. This winding was first used by Andrews.* Perry gave this winding in 1882.† S. P. Thompson ‡ is of the opinion that this winding is only applicable to an odd number of coils. This view is only correct when $\frac{n}{2}$ is even. The number of coils must be generally

* G. Kapp, The Engineer, 60 p. 62, 1885. Kippler, Handbuch, Vol. i., page 533.

† S. P. Thompson : Dynamo Electric Machinery, 3d ed., p. 163.

‡ Ibid.

$s = \frac{n}{2} y \pm 1$. A winding of this character, when the values are $p = 4$, $s = 13$, $y = 6$, $c = 13$, is given in Fig. 48. Numbering as usual, and applying the general formula, it is found that the end of the first coil, 1′, is to be joined with the beginning of the $y + 1$

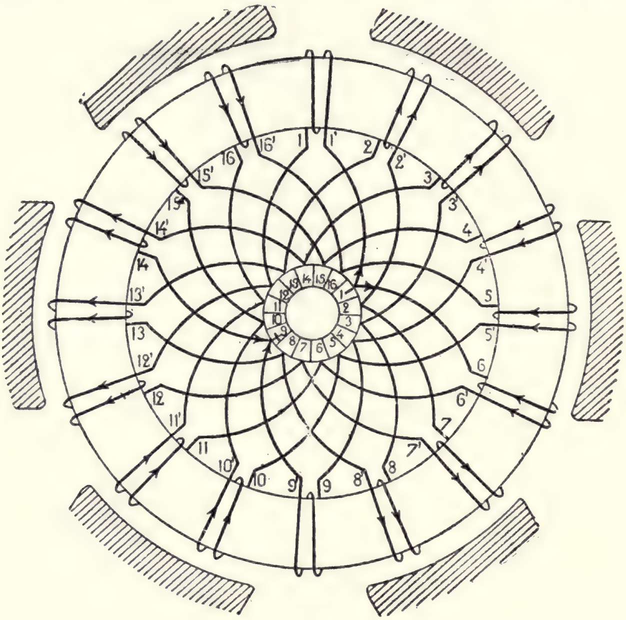


Fig. 49.

coil, or of No. 7, etc. By following the direction of the current the position of the brushes is found to be 45° apart. When $\frac{n}{2}$ is odd this winding can be used for an even number of coils. In Fig. 49, this is shown, using the values, $n = 6$, $y = 5$, $s = \frac{6}{2} \times 5 + 1 = 16$. Here the peculiarity exists that the brushes are 180° apart. If s be odd, which would be the case if $y = 8$, then $s = 3 \times 8 - 1 = 23$, and the position of the brushes would be 60° apart.

In Fig. 48, as well as 49, the connections with the commutator can be made in two planes; that is, in Fig. 48 the connections $a1'$, $b2'$, $c3'$, are in one plane and $a7$, $b8$, and $c9$, in the other, by means of which good insulation is more easily maintained. The number of coils which are short-circuited by one brush in Figs. 48 and 49 equals $\frac{n}{2}$. In the latter figure six coils are cut out of the circuit at the same

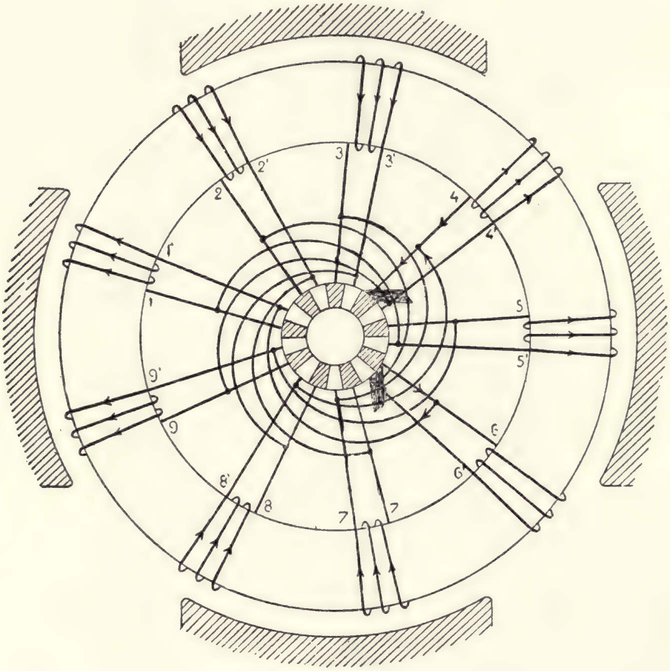


Fig. 50.

time. Under such conditions, to obtain a steady current and to prevent sparking at the commutator, the number of commutator bars should be made as large as possible.

A greater number of commutator bars can be secured, either by increasing the number of coils in the armature, or, while still conforming to the scheme of Fig. 43, by inserting more segments. Using this latter method, and making the number of segments $c = s\frac{n}{2}$, then each brush will shortcircuit $\frac{sn}{2c} = \frac{sn}{sn} = 1$ coil. Desroziers * has applied this winding to a disk armature shown in Fig. 124. The number of commutator segments is generally $s\frac{n}{2}$, and $\frac{n}{2}$ segments which are $\frac{2 \times 360°}{n}$ apart are joined together, and the number of coils is again $s = \frac{n}{2}y \pm 1$.

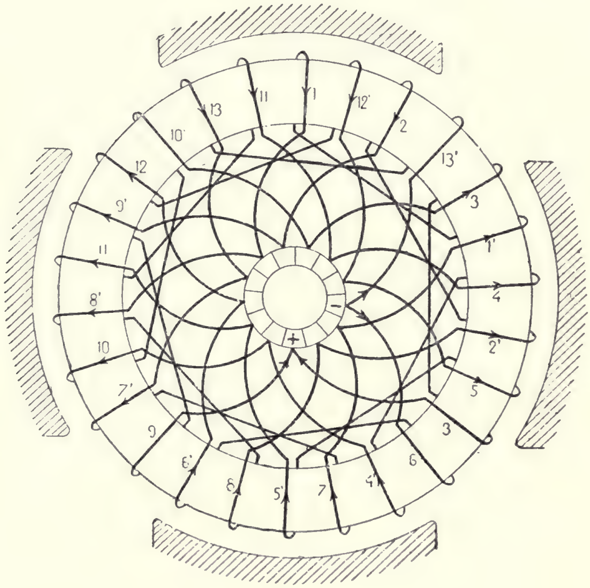


Fig. 51.

Fig. 50 shows a Desroziers winding applied to a ring armature† where $n = 4$, $s = 9$, $y = 5$. Here $1'$ is joined to $1 + 5 = 6$, and $6'$ with $6' + 5 = 9 + 2$, therefore with number 2.

The extra bars necessary are shown in section; omitting these, the winding of Andrews and Perry results. If it be desirable, the number of collector bars can be decreased by applying the scheme of the drum winding to the ring. If the number of

* Electrotech. Zeitschr., Vol. x., p. 200, 1889.

† Rechniewski, La Lum. Elec., Vol. xxiv., p. 516, 1887.

coils be $s = \frac{n}{2}\left(\frac{n}{2}\,y \pm 1\right)$, then the winding can be so arranged that $c = \frac{2s}{n}$. Fig. 51 shows this winding, using the values $n = 4$, $s = 2 \times 13$, $c = 13$, $y = 6$. The pairs of coils belonging together are shown by the same numbers, and the connections are carried out according to the general formula.

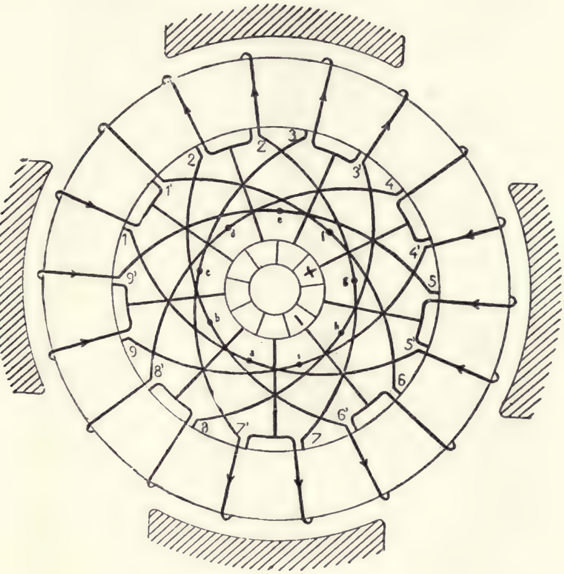


Fig. 52.

Instead of joining in pairs coils lying in magnetic fields of opposite polarity, as shown in Fig. 51, adjacent coils may be so joined. The number of segments would then be generally $\frac{s}{2}$, assuming $b = 2$ and $s = 2\left(\frac{n}{2}\,y \pm 1\right)$. In Fig. 52 the values assumed are $n = 4$, $s = 9$, $y = 5$, and the beginning and ends of pairs of coils are indicated by the same numbers.

To obtain a series winding according to the general formula 1′ is joined with 6, and 6′ with 2, etc., and to each junction a commutator bar is connected. If the points $a, b, c, d, e, f, g, h, i$ on the cross connectors be connected to the commutator, the resultant winding will be the same as that given by Andrews and Perry.

This winding can also be carried out if the number of coils be a multiple of the number of poles; but the winding will no longer be symmetrical, as in Fig. 52, but unsymmetrical, as in Fig. 53.

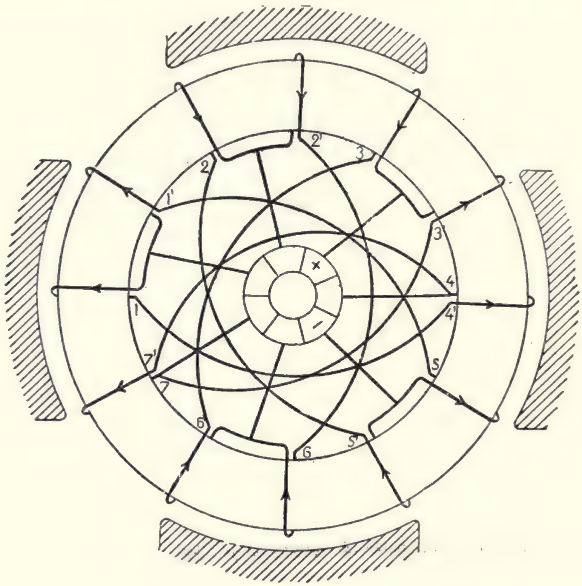


Fig. 53.

The number of segments becomes $c = \frac{n}{2} y \pm 1$. As there are 12 coils altogether, 10 of which are joined to form 5 pairs, the two remaining must be connected independently so that 7 collector bars are necessary; therefore $y = 4$. The number of coils that are shortcircuited in Fig. 52 by one brush, is equal to $\frac{sn}{2c} = \frac{sn}{2\frac{s}{2}} = 4.$

This number can be decreased for any number of poles, n to 2, by using the methods in Figs. 43 and 50, and by making the number of commutator bars c equal to $\frac{sn}{4}$. A scheme result-

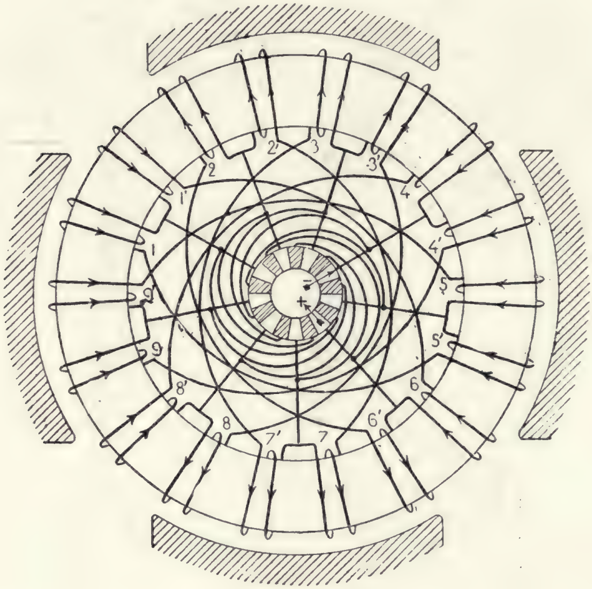


Fig. 54.

ing from this arrangement is shown in Fig. 54.* An element of this winding contains two inductors, so that if $b = 2$, $y = \frac{2}{n}\left(\frac{z}{b} - 1\right)$ or $y = \frac{2}{4}\left(\frac{18}{2} - 1\right) = 4$, and 1 is joined to 5′ or 1′ to 5. Omitting the segments shown in cross-section, the scheme shown in Fig. 52 again results.

Alioth & Co. use this scheme for drum windings, and Jehl and Rupp use it for disk armatures. (Compare Figs. 91 and 131.)

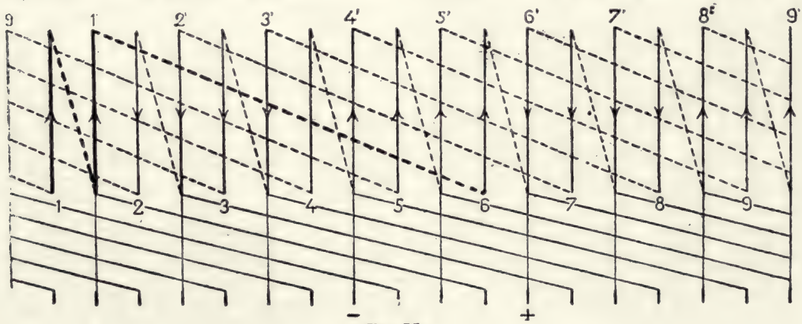


Fig. 55.

* La Lum. Elect., Vol. xxiv., p. 515.

Fig. 55 is the development of Fig. 54, and shows a wave winding, with alternate long and short waves.

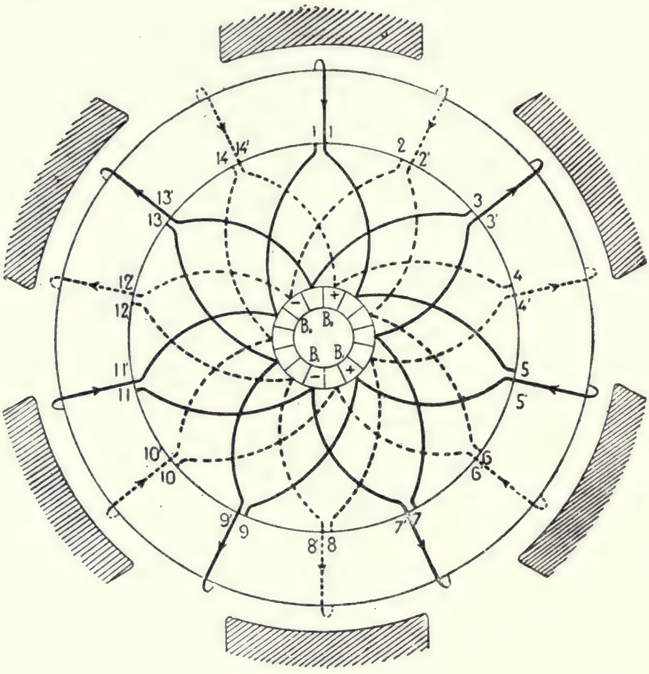


Fig. 56.

4. MULTIPOLAR RING ARMATURES WITH MIXED WINDINGS.

The term "mixed windings" is applied to those which result when a has the value $a > 1$ and $\begin{smallmatrix}<\\>\end{smallmatrix}\frac{n}{2}$ in the general formula $s = b = \left(y\frac{n}{2} \pm a\right)$.

The possible number of these windings, if developed for parallel or multiple windings, would be large. It is not the intention to investigate here their usefulness or significance, but to present a few typical cases. In Fig. 56 the values $n = 6$, $b = 1$, $a = 2$, $y = 4$, are assumed, then $s = 14$, and the scheme gives two independent series windings which require the brush positions B_1, B_1, B_2, B_2. If the number of coils be odd, for instance, $y=5$ and $s=17$, a simple winding closed on itself would result, requiring 4 brushes. Fig. 57 represents this case where $n=8$, $a=2$, $b=1$, $y=5$, $s=22$. All the coils are joined into a closed spiral. If the assumption is made that $n=6$, $a=4$, $b=1$, $y=10$, $s=34$, the interesting winding shown in Fig. 58

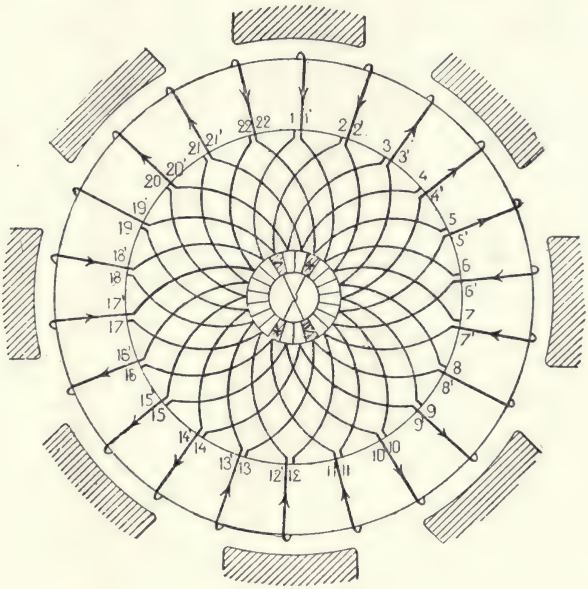


Fig. 57.

results. This arrangement has two independent windings for each set of 17 coils, with the brush positions a, c, e, g and b, d, f, h, which fall together in pairs. So that although the coils are joined in eight parallel groups, only four brushes of double width are required, therefore, for a six-pole machine, an eight-branch-winding with four sets of brushes results. Fig. 59 shows the arrangement for a six-pole machine if the number of coils is odd, which would be the case if $y=9$, $a=4$, $s=31$.

All the coils belong to one winding. Of the eight brush positions in two places two of them fall on adjacent commutator bars, so that six brushes are sufficient.

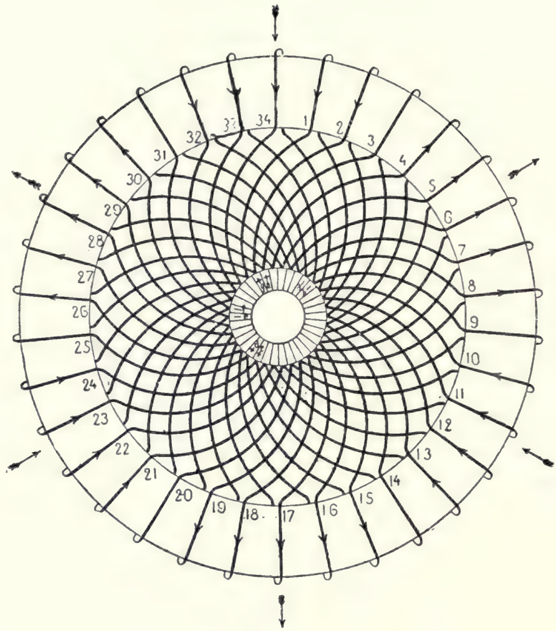


Fig. 58.

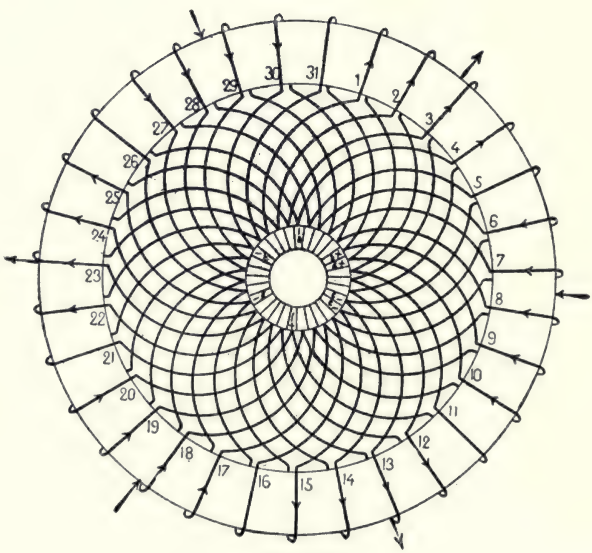


Fig. 59.

DRUM WINDINGS.

1. BIPOLAR DRUM ARMATURES.

From the Siemens double-*T* inductor and two-part commutator, Von Hefner Alteneck, in 1872, developed an armature winding which for direct-current use was fully equal to the ring winding of Paccinotti.

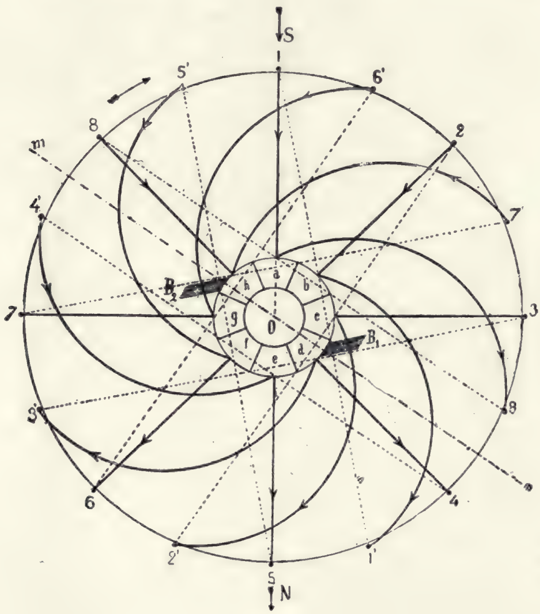


Fig. 60.

Von Hefner Alteneck wound the coils upon a drum parallel to its axis, so that by rotating the drum in a magnetic field the two sides of a coil on the surface of the drum were subject to induction. In this form of winding, it is evident that the number of inductors z is equal to double the number of coils S. There are as many commutator segments as coils, and each segment is connected with two coils in such a manner that the whole forms a closed winding which is divided in two parallel branches between the brushes.

For simplicity in representing this form of winding, a scheme employing eight coils, and therefore eight commutator bars, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, will be selected as in Fig. 60, which represents this armature viewed from the commutator end. The inductors around the circumference of the drum are therefore

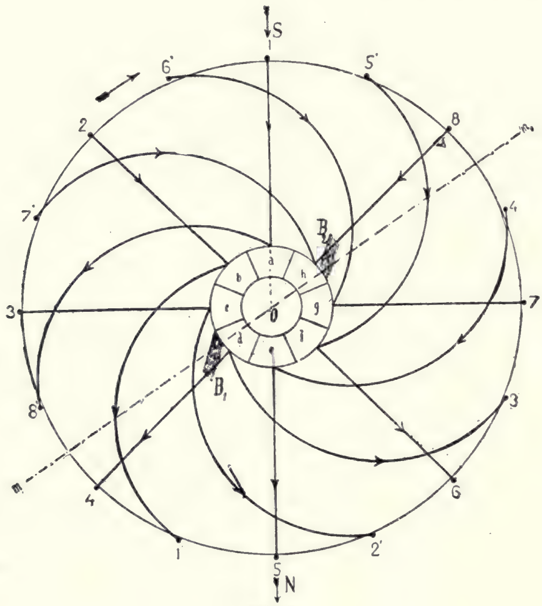


Fig. 61.

represented by points, while the connectors across the back are shown by dotted lines, or entirely omitted. Assuming that the inductors lie at equal distances apart, as each element has two inductors, 16 winding spaces are required. The circumference of the cylinder is therefore divided into 16 equal parts, and alternate divisions are numbered 1 2 . . . 8. Space number 5 is diametrically opposite to space number 1. In order that the second inductor 1′ of the coil 1 1′ shall not fall upon space number 5, it must be carried either to the right or to the left of that space. In Fig. 60, 1′ lies to the right of 5. Starting from 1′ and following out the numbering, clockwise, in the same direction and manner as before, the remaining divisions will be numbered successively 2′ 3′ . . . 8′. The numbers 1 to 8 will represent the beginnings, and 1′ to 8′ the ends of the corresponding coils. For instance, to obtain the coil 1 1′,

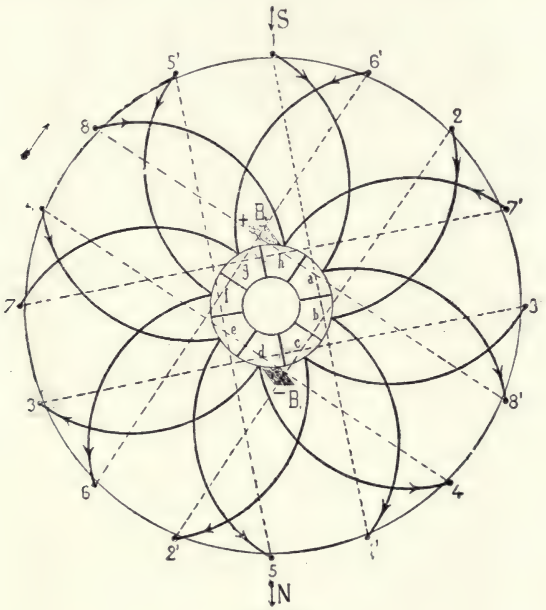


Fig. 62.

starting at 1, the conductor is carried along the surface of the cylinder to the rear end, then at right angles along the dotted line 1′ 1 across the rear end, and brought to the front again, then along 1 1′ to the point of departure. This is repeated until the coil has the desired number of turns. The end of the last turn is not carried back to 1, but is left of sufficient length at 1′ to be connected to its segment of the commutator.

In this manner 16 sections, 1 to 8, 1′ to 8′, are obtained, whose connections to the commutator are absolutely determined by the general formula. Observing the rule that every cross connector must be connected to a commutator segment, it is

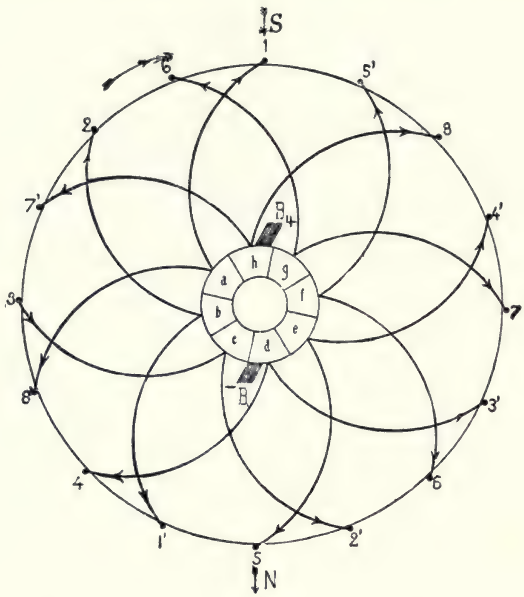


Fig. 63.

evident that the number of commutator segments must be equal to the number of coils or sections.

It is immaterial from which section the start is made, that is, which commutator segment is connected with 1; but it is necessary that the remaining sections be connected in succession, advancing either to the right or to the left. The first is spoken of as a clockwise, the latter is an anti-clockwise direction of winding.* Fig. 60 represents the development of a Von Hefner Alteneck winding with a clockwise, and Fig. 61 with an anti-clockwise advance. In both figures, $b = 2$, $a = 1$, $n = 2$,

* Compare Dr. A. Von Waltenhofen, Zeitschrift für Electrotech., 1887, p. 316.

$z = 2s = 16$, $y = \frac{2}{n}\left(\frac{z}{b} - 1\right) = 7$. Therefore the beginning of any coil x is to be joined to the end of the xth + 7th coil; that is, 1 with 8, etc.

Following out the direction of the current, which is shown by arrows, the position of the brushes can be easily determined.

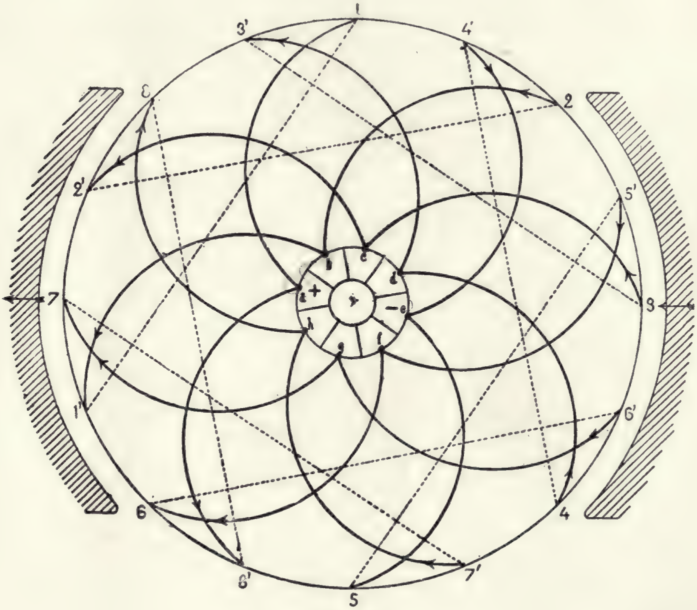


Fig. 64.

It will be observed that on rotating the armature clockwise the negative brush will be to the right of the line joining the north with the south pole if the advance is also clockwise, and to the left if the advance be anti-clockwise. Both brushes are upon the diameter $mm_{,}$, which, if there be a large number of coils, is nearly perpendicular to the line joining the north to the south pole. In Figs. 60 and 61, which have only eight coils, the brushes are noticeably advanced in the direction of the winding, so that the angle mOS departs considerably from 90°.

Starting from the negative brush the current divides into the two branches,

$$B_1 d\ 4\ 4'\ e\ 5\ 5'\ f\ 6\ 6'\ g\ 7\ 7'\ B_2 \text{ and}$$
$$B_1 d\ 3'\ 3\ c\ 2'\ 2\ b\ 1'\ 1\ a\ 8'\ 8\ h B_2.$$

It will be observed that two adjacent coils are shortcircuited as soon as they lie in a plane perpendicular to the pole line *N.S.*, for example, 3 3′ and 7 7′, Figs. 60 and 61.

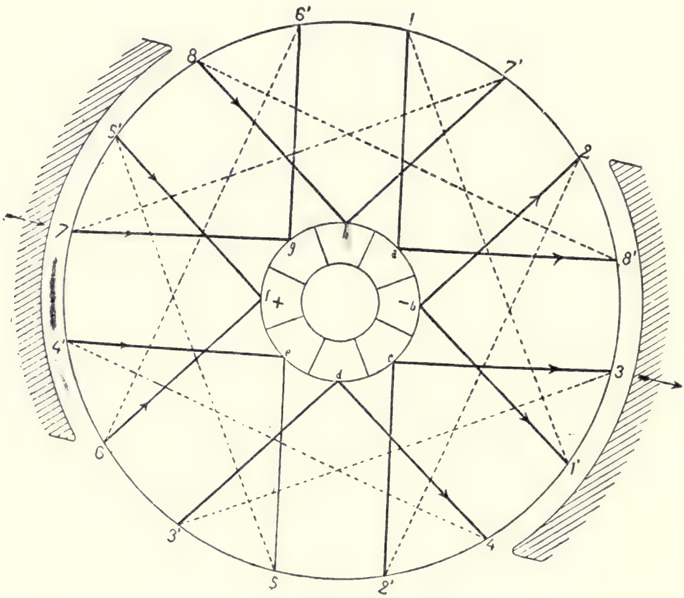


Fig. 65.

The only distinction between the Edison winding and that of Von Hefner Alteneck is, that the connections with the commutator in the former case are so carried out that the position of the brushes coincides with the pole line *N.S.*

Figs. 62 and 63 show two schemes with this change, and with clockwise and anti-clockwise advance. The change consists in turning the commutator and connections through the angle *m′ OS* (Fig. 61), in the direction of the winding. The position of the negative brush becomes independent of the direction of the winding. Its change of position with the positive brush depends only on the change of direction of rotation. As already stated, in the old Edison and Von Hefner Alteneck method of winding, two adjacent coils are shortcircuited at the same time. With high potentials it is difficult to maintain a good insulation between the coils, and Bréguet found it advan-

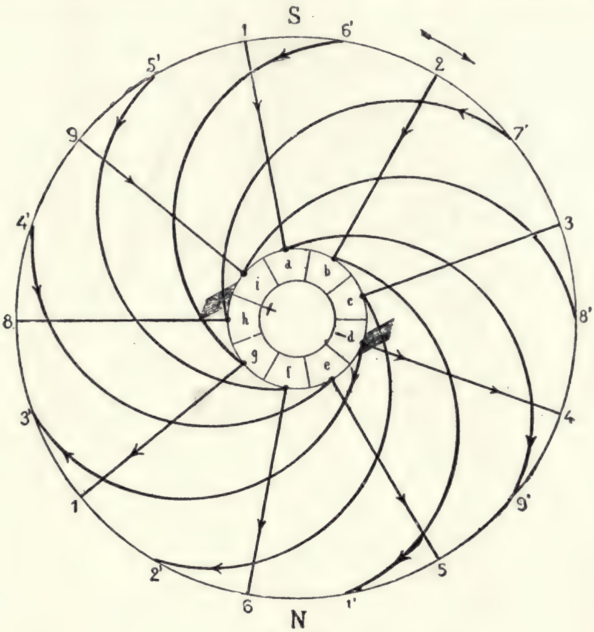


Fig. 66.

tageous to develop the winding in such a manner as to prevent the shortcircuiting of two adjacent coils. Figs. 64 and 65 show this method for the same number of sections. The difference between this and the previous schemes is that inductor 1′ of the section 1 1′, does not lie immediately to the right or to the left of number 5, but, as in Fig. 64, is carried to the left of 6, or as in Fig. 65 to the right of number 4. The two coils which are shortcircuited in this case, would be 1 1′ and 5 5′, or 3 3′ and 7 7′, each pair being separated by two winding spaces.

The drum windings which have been so far considered have had an even number of sections, and further the winding spaces of all the coils have been side by side upon the surface of the drum. To accomplish this, it has been necessary to make the rear connection follow a chord.

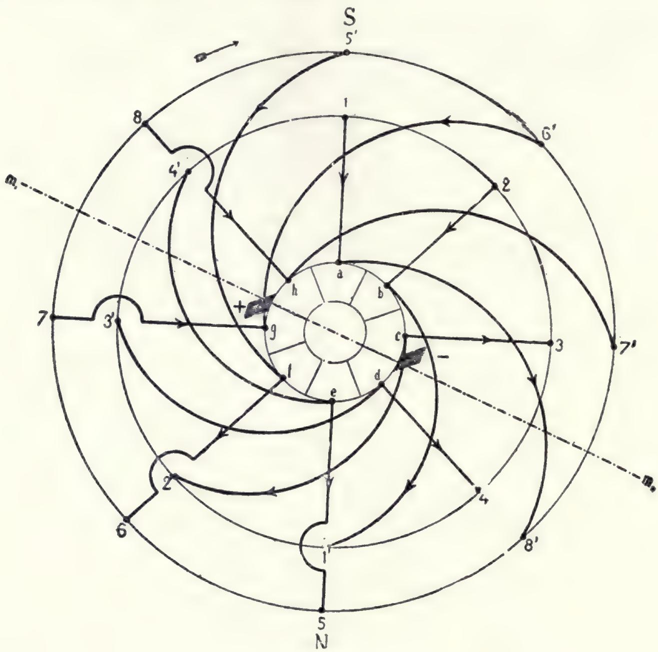


Fig. 67.

They can be wound along a diameter providing:

1. An uneven number of coils be employed, and

2. Superimposed winding spaces be used with an even number of coils.

Fig. 66 represents the winding with an uneven number of sections, in this case $s = 9$. In the position shown, while the negative brush lies upon the segment d, the positive brush is shortcircuiting coil 8 8′, and lies upon two segments h and i.

Two coils are never shortcircuited at the same time, and therefore, as in the Bréguet winding, two adjacent coils are never shortcircuited. The circuit through the armature is through the remaining eight coils in the two directions;

$$d\ 4\ 4'\ e\ 5\ 5'\ f\ 6\ 6'\ g\ 7\ 7'\ h,$$
$$d\ 3\ 3'\ c\ 2'\ 2\ b\ 1'\ 1\ a\ 9'\ 9\ i,$$

each having equal lengths of conductor. As there is not always room enough to place the winding spaces side by side,

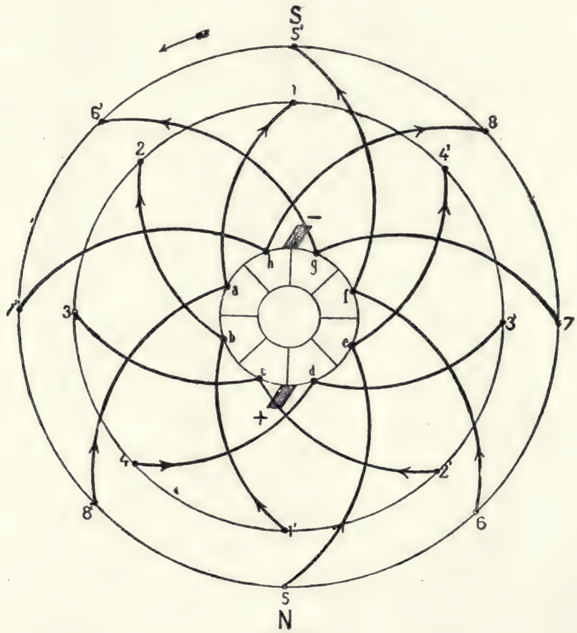


Fig. 68.

it is at times necessary to superimpose the winding spaces of two adjacent coils. Fig. 67 shows this arrangement for a Von Hefner Alteneck winding, advancing clockwise, and Fig. 68 for an Edison winding, advancing anti-clockwise. In both these schemes the number of coils is eight, and the number of winding spaces also eight. If the coils $a\ 1\ 1'$, $b\ 2\ 2'$, $c\ 3\ 3'$, $d\ 4\ 4'e$

be put on first, the eight winding spaces will be occupied and four commutator segments, *a*, *b*, *c*, *d*, used. In order to use the other four commutator segments *e*, *f*, *g*, *h*, the remaining four coils may be wound over those already put on; that is, 5 5′ over 1 1,′ 6 6′ over 2 2′, 7 7′ over 3 3′, 8 8′ over 4 4′, and 8 returns to the starting-point. The two coils 3 3′ and 7 7′ which lie

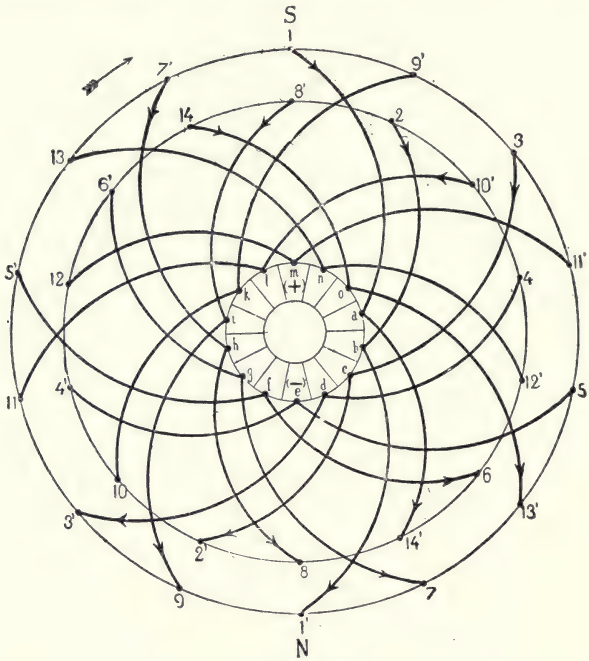


Fig. 69.

upon a diameter perpendicular to the diameter *N. S.*, and therefore in the neutral zone, are the coils which are short-circuited by the brushes, thus determining their position.

The connections of the coils and the position of the brushes follow the rules previously given. Although the schemes described are frequently employed, they have a slight disadvantage in that the two parallel circuits of the armature have not an equal inductive value, which increases the tendency to spark at the commutator. To balance the two circuits of an armature it is necessary that they be of equal resistance, which implies an equal length of conductor in each, and that the inductors of each half have an equal mean velocity. In the schemes where the sections are wound alongside each other these conditions are obtained, neglecting the small mechanical difficulties in

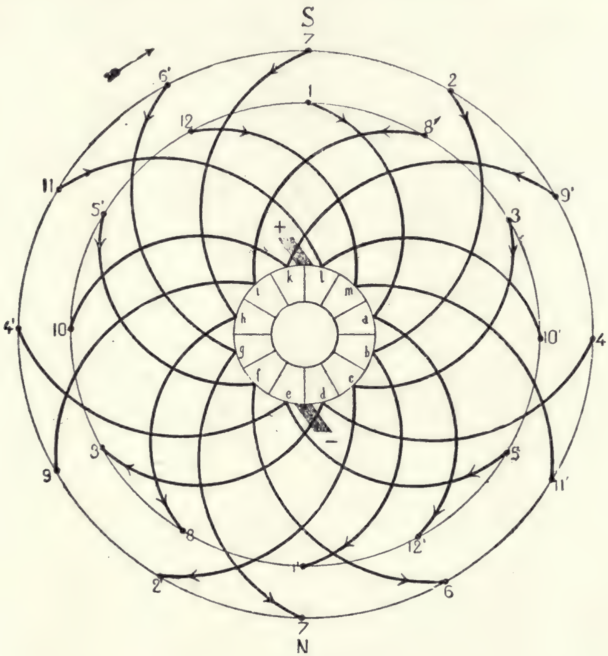


Fig. 70.

crossing at the ends, but not in the schemes with coils superimposed in pairs. If the armature in Figs. 67 and 68 be turned through an angle so that segments *a* and *e* are under the brushes, the two branches of the armature are as follows: *a* 1 1′, *b* 2 2′, *c* 3 3′, *d* 4 4′*e*, *a* 8′ 8, *h* 7′ 7, *g* 6′ 6, *f* 5′ 5 *e*. One consists of all the interior, the other of all the exterior coils. The induction in each half, and also the resistance, is equal only at that time when the brushes lie upon *c* and *g*,

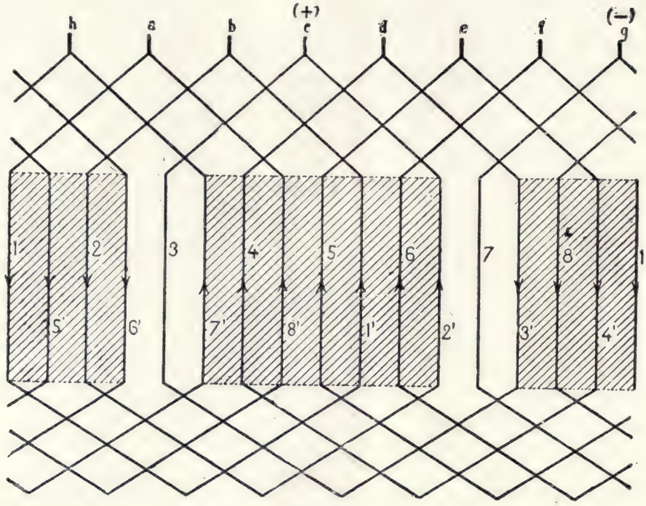


Fig. 71.

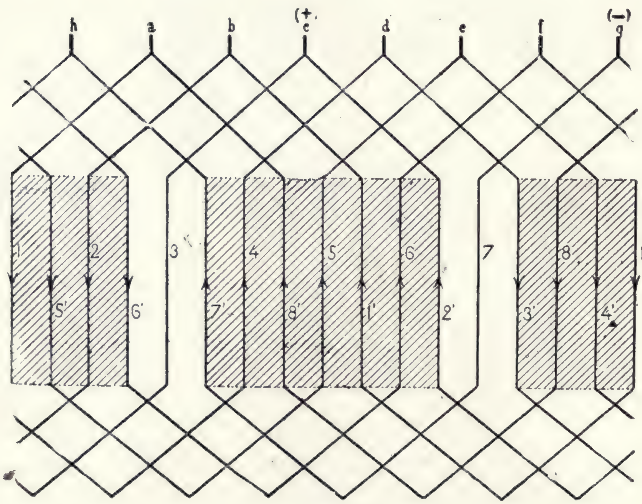


Fig. 72.

as there are then in each half two exterior and two interior coils.

The evils arising from this inequality in the two branches of the armature can be easily overcome by properly connecting the coils. An absolute balance in the induction for every part of the revolution can only be obtained when half the sum of the coils is odd. Fig. 69 shows such an arrangement having 14 coils.

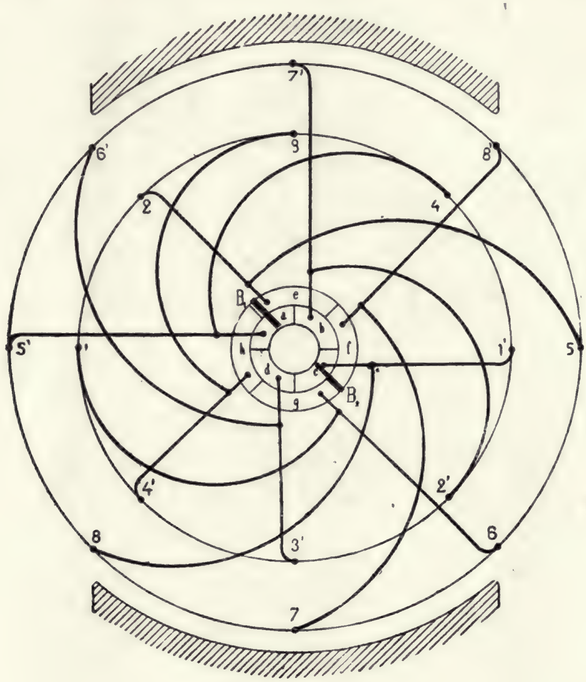


Fig. 73.

In laying out this diagram the winding spaces are numbered 1, 2, 3, etc., alternating between the exterior and interior circle, and the coils are connected according to the general formula. The successive sections will then lie alternately upon the outer and inner cylinder, and the halves will balance.

If half the number of coils be even, as in Fig. 70, the scheme no longer gives a symmetrical winding, and the numbers do not alternate successively from the outer to the inner cylinder, but in one place two winding spaces on the outer and two on the inner cylinder are adjacent. In Fig. 70, *f* 6 6′ *g* 7 7′ *h*, and *b* 1′ 1 *a* 12′ 12 *m*, are the coils referred to. This variation of the Siemens winding, which was proposed by Weston, has the disadvantage that the difference of potential between the superimposed coils is as great as that between the adjacent coils of the Siemens scheme. The use of heavier insu-

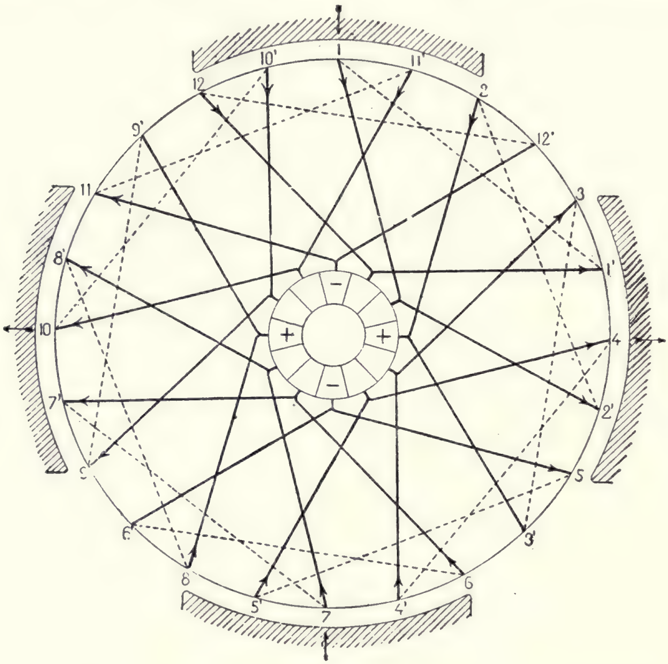


Fig. 74.

lation, which higher differences of potential necessitate, increases in the Weston armature the depth of the winding and consequently the distance of the core from the pole pieces.

Fritschie's method of representation is especially applicable to drum armatures. The development of one of the given schemes with eight sections or 16 inductors is shown in Figs. 71 or 72.

The poles are shown in cross-section, and the connectors are indicated by the broken lines as heretofore. The point of commutation can be obtained by following the direction of the currents as indicated by the arrow points. The cross connections are such that in Fig. 71 a loop winding results, while in Fig. 72 they give a wave winding.

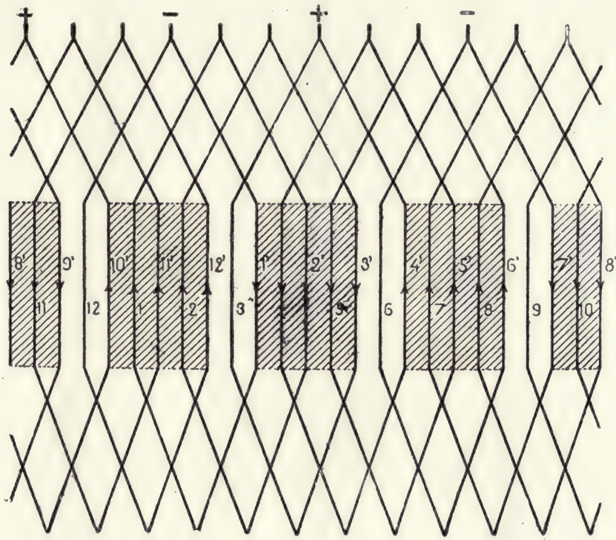


Fig. 75.

This method of representation led Fritschie to another style of drum winding. Consider the scheme of either Fig. 71 or 72 in unchanged form as being wrapped around a cylinder, then the faces of the cylinder remain free from cross-connectors, the whole winding being carried on the surface of the cylinder. A peculiar application of the Von Hefner Alteneck winding is shown in the armature of the Immisch motor, Fig. 73.*

This has two commutators, each with $\frac{s}{2}$ segments. These commutators are so placed that the middle of a segment of one is opposite the space between two segments of the other. Each brush consists of two parts joined together and resting

* La Lum. Electr. 1887, vol. 24, p. 261; Elektrotechn. Zeitschr., 1887, p. 531.

upon both commutators. In Fig. 73 these commutators are represented as concentric circles. The circuit is the same as in a Von Hefner Alteneck drum, and both windings would be identical if the segments of one commutator (in the Immisch armature) were inserted between those of the other, for example, *c* between *a* and *b*. The double commutator gives the same result as the ordinary form, except that the coils remain shortcircuited longer.

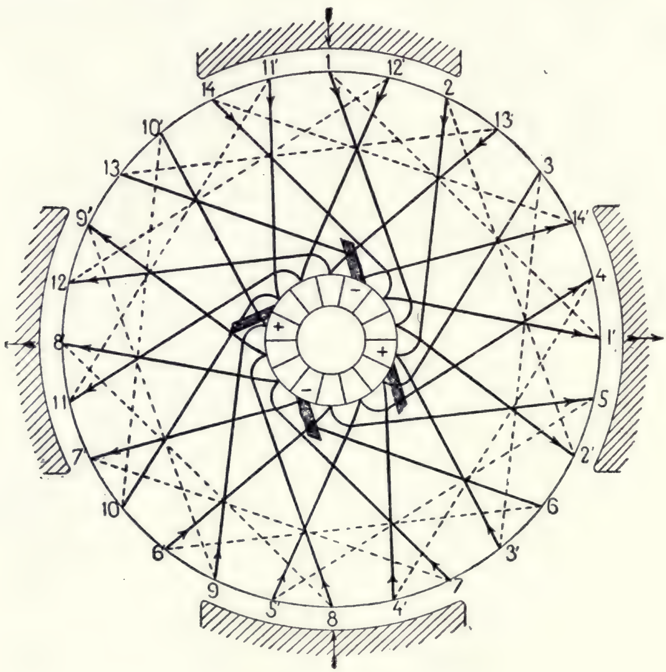


Fig. 76.

2. MULTIPOLAR DRUM ARMATURES WITH PARALLEL WINDING.

In designing an armature winding of this character the method of procedure is the same as before. The core is divided into the desired number of winding spaces, the ends of the coils numbered 1, 2, 3, etc., and 1′, 2′, 3′, etc., and the general formula applied. If the parallel branchings of the armature are to have equal lengths of conductor it is necessary that the number of coils be made a multiple of half the number of poles $\left(\frac{n}{2}\right)$.

If $\frac{n}{2}$ be even, then the number of coils must be even, but if $\frac{n}{2}$ be odd, then the number of coils may be either odd or even. If the number of coils be a multiple of n, then n coils will be shortcircuited at the same moment by the n brushes; but if s be only a multiple of $\frac{n}{2}$, then theoretically, only $\frac{n}{2}$ coils will be shortcircuited, but practically n coils will still be

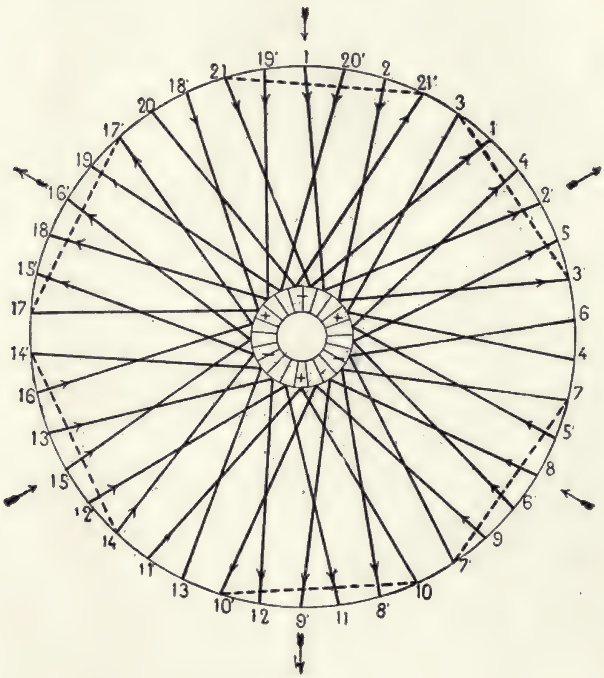


Fig. 77.

shortcircuited at the same time, owing to the width of the brushes.

This may be observed in Fig. 74, where $n = 4$, $z = 2s = 24$. In the general formula, $y = \frac{2}{n}\left(\frac{z}{b} \pm a\right)$, the values $a = 1$, $n = 2$, are substituted to obtain a parallel winding, and $y = \frac{z}{b} - 1 = S - 1 = 11$. Therefore 1′ is to be joined to $1 + 11 = 12$, and to one commutator bar, etc. If this be reversed, and 1 be

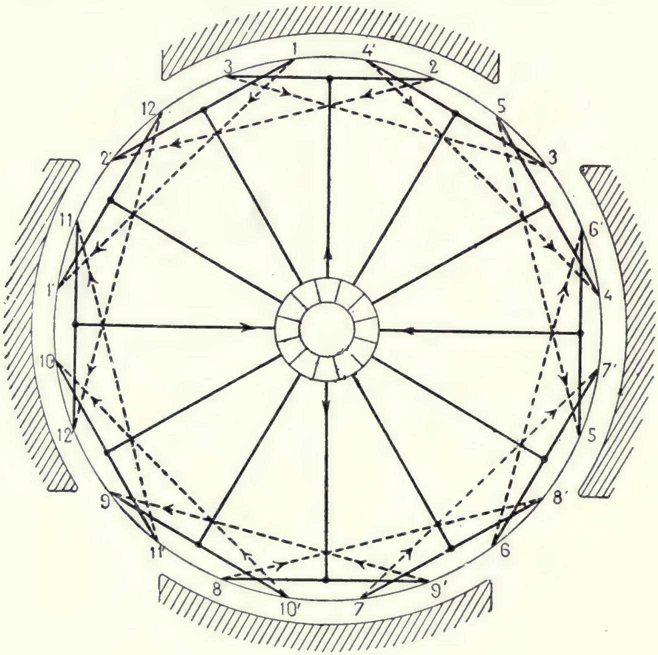


Fig. 78.

joined to 12′, an equally correct scheme will result, the only difference being that the positive and negative brushes change places. In Fig. 74, 4 coils are simultaneously shortcircuited, for example, 3 3′, 6 6′, 9 9′, 12 12′. Fig. 75 represents the developed scheme of a multipolar loop winding.

If the position of one inductor of a coil, e.g., 1, be assumed, then the position occupied by the second inductor 1′ will be the same as that in a bipolar armature. In Fig. 74, 1′ can lie as well to the right as to the left of 4, or following Bréguet two additional winding spaces can be inserted between 4 and 1′, 1′ may also be wound over 3 or 4. The conditions which govern the number of coils in this case are similar to those of a bipolar

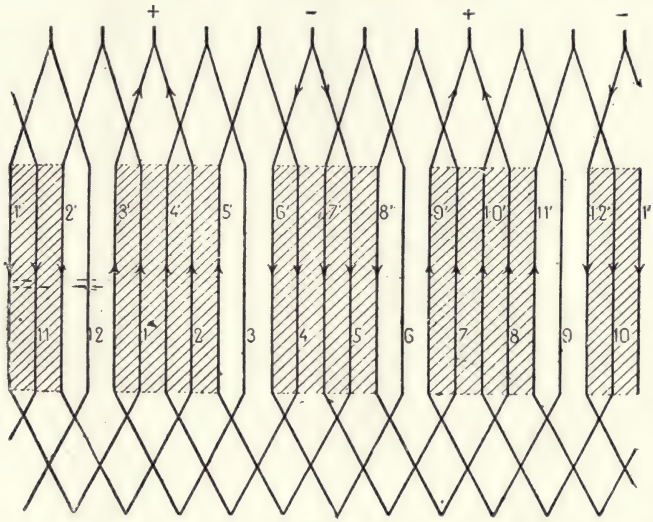


Fig. 79.

armature with an odd number of coils. This number must be a multiple of $\frac{n}{2}$, but not of n, and only $\frac{n}{2}$ coils are simultaneously shortcircuited, as can be seen from Fig. 76.

If the coils are wound side by side, each coil can be so placed that its inductors lie symmetrically in the field; that is, each coil embraces the $\frac{1}{n^{th}}$ part of the circumference of the drum. This angle of embrasure can be greater, or preferably, smaller; for the smaller the angle the fewer the number of crossings of the coils, but at the same time the surface embraced by each coil is so much less.

This can be observed in Fig. 77 with $n = 6$, and an odd number of coils, $s = 21$, $y = s - 1 = 20$. In the position shown in Fig. 76, coils 10 10′, and 3 3′, are shortcircuited, and in Fig. 77 coils 7 7′, 14 14′, 21 21′, are likewise shortcircuited. On rotating the armature to the right, the next coils to be shortcircuited are: in Fig. 76, 13 13′, and 6 6′, and in Fig. 77,

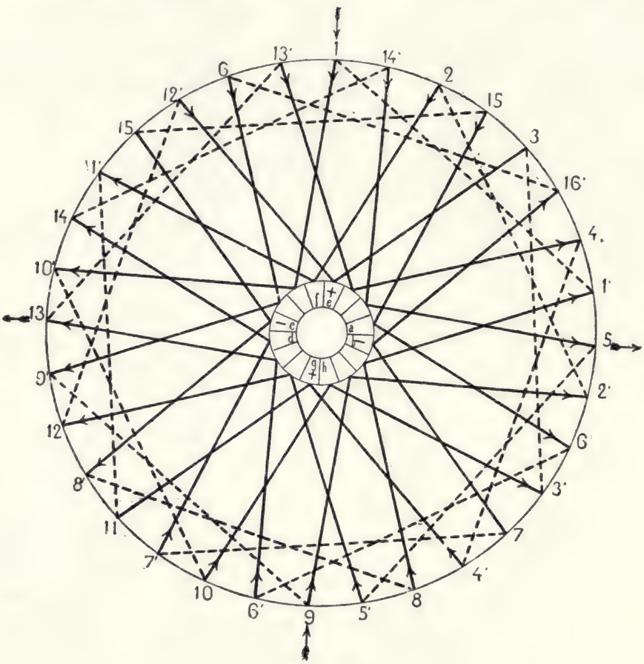


Fig. 80.

3 3′, 10 10′, 17 17′. The number of winding spaces in Figs. 74 and 76, which lie between the inductors of two coils, for example, 1 1′, are counted in the direction of the numbering; for example, 1′ lies to the right of 1. If 1 be considered as lying the same number of winding spaces to the left as it was previously to the right, retaining the same system of numbering, a scheme will be obtained which has been used by Thury for multipolar drum winding. In this scheme of Thury's, which

is shown in Figs. 78 and 79, there are not so many crossings of coils, having a considerable difference of potential between them, as in the drum windings previously given. This can be observed by comparing Fig. 79 with Fig. 75.

If a be given the value $\frac{n}{2}$ in the general formula, $y = \frac{2}{n}\left(\frac{z}{b} \pm a\right)$, another scheme of parallel winding (wave winding) can be

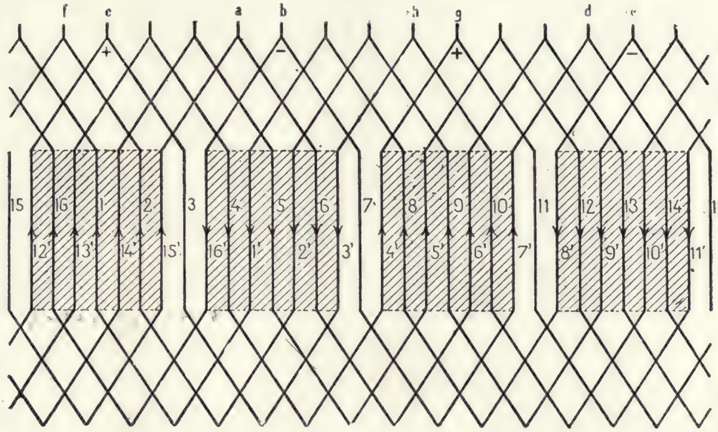


Fig. 81.

obtained. The scheme shown in Fig. 80 is obtained by assuming the values $n = 4$, $z = 2$, $s = 32$, $y = \frac{1}{2}\left(\frac{32}{2} - 2\right) = 7$.

All the coils are joined together in a single closed winding. This winding is peculiar in the fact that the coils are shortcircuited by two brushes, either the two positive or the two negative; for example, if the two brushes lie upon the segments *ab* and *cd*, then 15 15′ and 7 7′ are shortcircuited, and when they lie upon *ef* and *gh*, then 11 11′ and 3 3′ are shortcircuited. It is understood that the brushes of the same sign are connected together, or else that the corresponding segments are joined as in a Mordey winding. Comparison of the scheme of Fig. 81 with that given in Fig. 41, shows that both windings are of the same character.

If y and s have a common factor, then this winding scheme no longer gives a single circuit, but several circuits closed on themselves. If $n = 4$, $s = 14$, $y = 2\,\frac{s-2}{n} = 6$, two interlaced windings would result, each being a series winding with two brushes. In Fig. 82 the full lines represent one of these

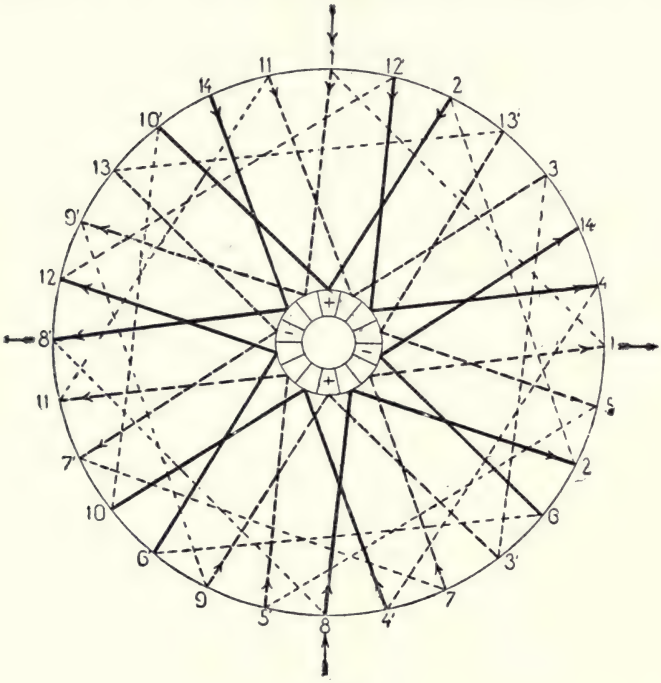


Fig. 82.

windings, the dotted lines the other, and the coils 13 13′, and 6 6′ are shortcircuited. The construction of machines using multipolar windings with parallel branching requires great care, not only with regard to the symmetry of the winding itself, but also with regard to the intensity of the magnetic field. The effect of different intensities in the several fields are overcome in the winding schemes shown in Figs. 81, 82, as the coils lying between two brushes are distributed through all the magnet fields.

If the coils be superimposed as assumed in Fig. 83, a symmetrical arrangement of the same can be attained by connecting alternate inside and outside coils with one another. (Compare with Fig. 69.)

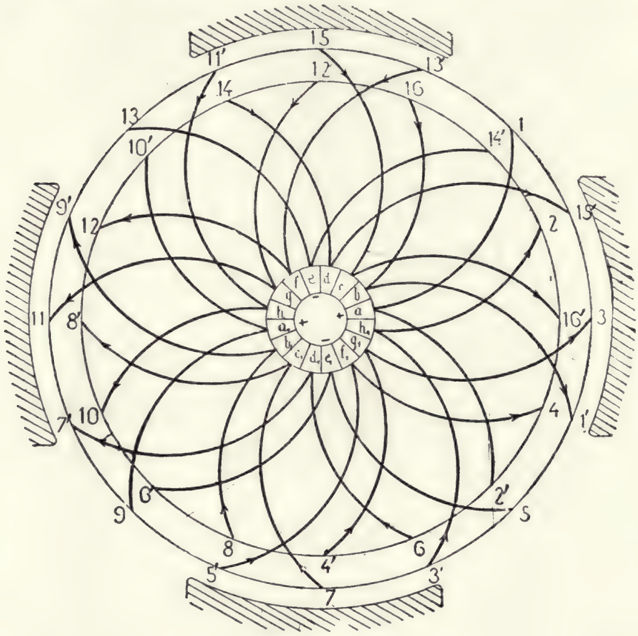


Fig. 83.

In this figure, with the position given, the four branchings of the circuit are :

e, 14′ 14, d, 15′ 15, c, 16′ 16, b, 1′ 1, a,
e, 13 13′, f, 12 12′, g, 11 11′, h, 10 10′, a,
$e_{,}$, 6′ 6, $d_{,}$, 7′ 7, $c_{,}$, 8′ 8, $b_{,}$, 9′ 9, $a_{,}$,
$e_{,}$, 5 5′, $f_{,}$, 4 4′, $g_{,}$, 3 3′, $h_{,}$, 2 2′, a.

To each of these branchings belong two inside and two outside coils. The Mordey winding for ring armatures, as shown in Figs. 36 and 37, can be carried out in the same manner for drum armatures.

A four-pole drum armature of Alioth & Co., in which each commutator bar is connected to the bar directly opposite, is shown in Fig. 84; of the ten coils there given, 10 and 5 are in the neutral zone and are shortcircuited.

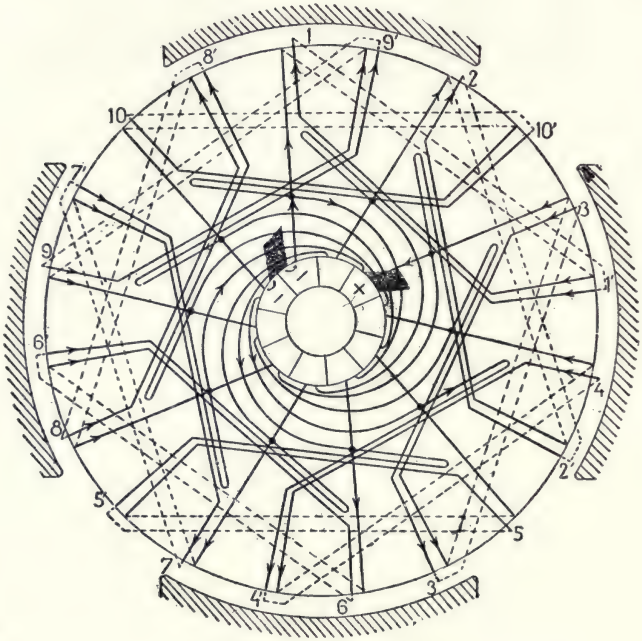
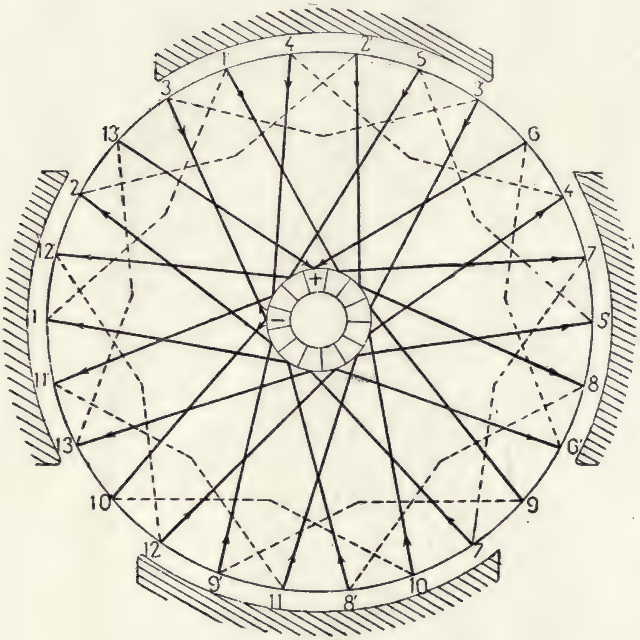
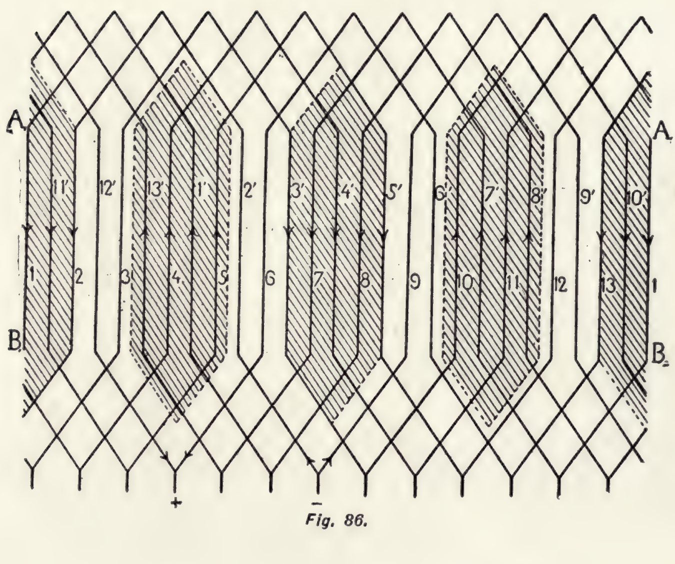


Fig. 84.

3. MULTIPOLAR DRUM ARMATURES WITH SERIES WINDING.

As no radical differences exist between series windings for ring and drum armatures, the same conditions apply to both. (See page 33 *et seq.*) Observing that $b = 2$ and $z = 2s$ the general formula gives $s = y\frac{n}{2} \pm 1$, and the number of coils shortcircuited by each brush simultaneously is $\frac{sn}{2c}$, c being the


1'
4
2'
5
3
3'
13'
6
2
4'
12'
7
+
1
−
5'
11'
8
13
6'
10
9
12
7'
9'
11
8'
10
Fig. 85.


A
A
11'
12'
13'
1'
2'
3'
4'
5'
6'
7'
8'
9'
10'
1
2
3
4
5
6
7
8
9
10
11
12
13
1
B
B
+
−
Fig. 86.

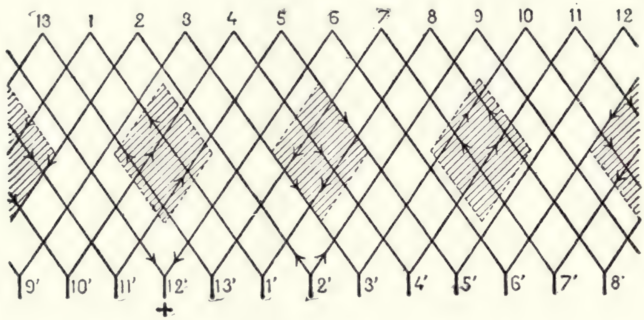

13
1
2
3
4
5
6
7
8
9
10
11
12
9'
10'
11'
12'
13'
1'
2'
3'
4'
5'
6'
7'
8'
+

Fig. 87.

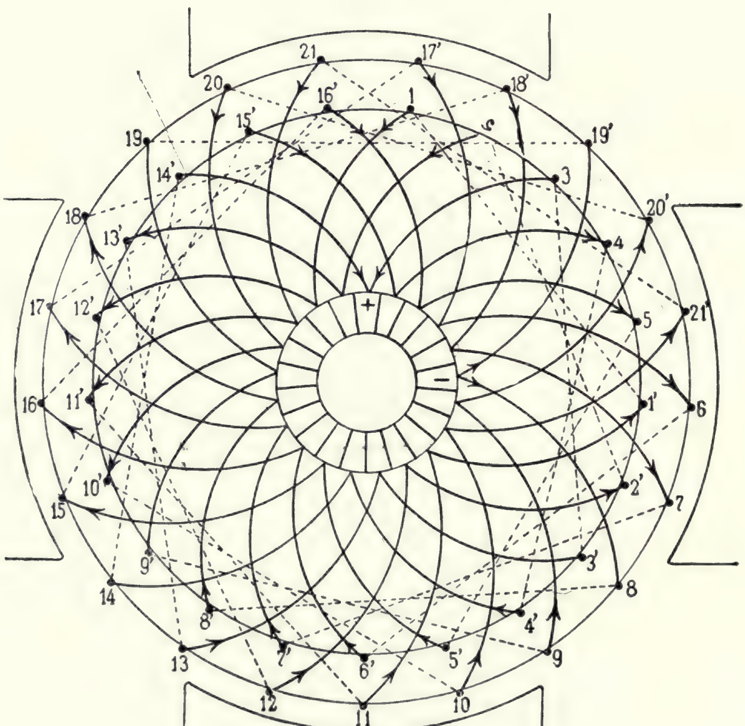

21
17'
20
18'
16'
1
15'
19
19'
14'
3
18
20'
13'
4
17
12'
5
21'
16
11'
1'
6
10'
2'
15
7
9'
3'
14
8
8'
4'
13
7'
6'
5'
9
12
11
10
+
−

Fig. 88.

number of commutator bars. Assuming $n = 4$, $y = 6$, $s = 13$, Figs. 85 and 86 give a scheme complying with these assumptions and agreeing with the Andrews-Perry winding, shown in Fig. 40. This winding can be easily carried out on the surface

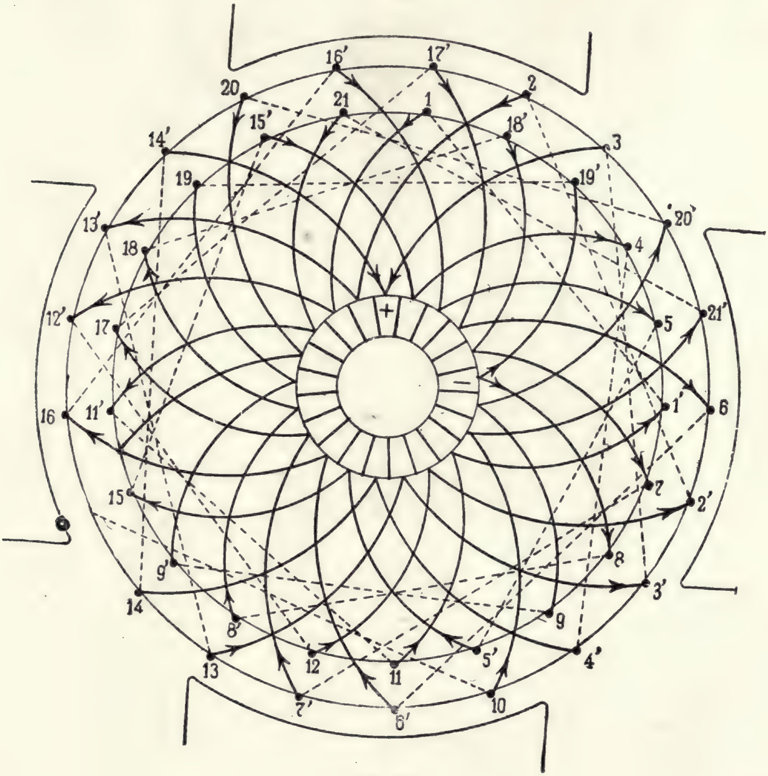


Fig. 89.

of the drum as the development shows. In order to increase the effective length of inductor the poles are given the shape shown in Fig. 86.

If the rectangle $A_1 A_2 B_2 B_1$ be eliminated, and the remaining parts drawn together, the scheme shown in Fig. 87 is obtained, which method is given by W. Fritschie.* The single

* German patent, No. 45808.

inductors are laid on the surface of the drum without double bending.* With a large number of poles the inductors have only a slight bend.

This variation can also be introduced into the parallel winding scheme of Fig. 81. The general formula becomes

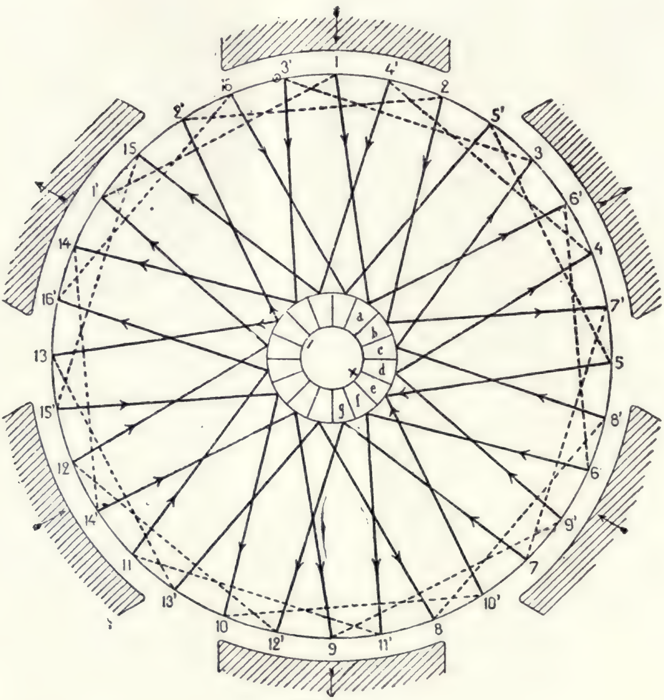


Fig. 90.

especially valuable in the case of superimposed winding spaces.

Let $n = 4$, $s = y\frac{n}{2} + 1 = 10 \times 2 + 1 = 21$, $y = 10$, and that inductors from two coils shall be superimposed on the circumference of the drum. In Fig. 88 the coils are laid out in their natural succession, 1 1′, 2 2′, 3 3′, etc., and connected to-

* Kräpfung.

gether according to the formula, i.e., 1′ with $1 + 10 = 11$, 2′ with $2 + 10 = 12$, etc. The position of the coils and their connections are extremely unsymmetrical, and without a winding rule it would be very difficult to connect the coils properly. The coils 1 1′ to 5 5′ lie only on the inner sur-

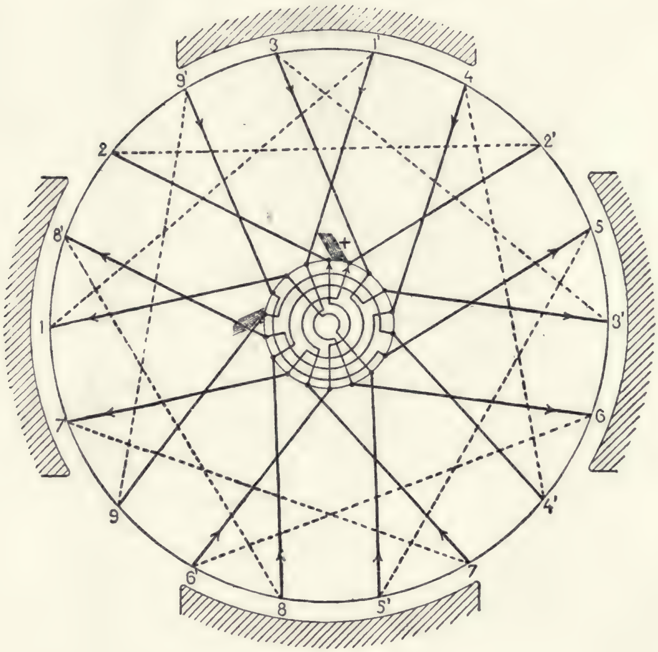


Fig. 91.

face, and coils 6 6′ to 16 16′ on both the inner and outer surface.

The completed winding may be better represented if the coils be indicated in succession, and distributed around the circumference as equally as possible.

In Fig. 89 the following succession is observed: 1 1′, 5 5′, 11 11′, 15 15′, 18 18′, 8 8′, 9 9′, 19 19′, 17 17′, 4 4′, 12 12′, 7 7′, 2 2′, 21 21′, 10 10′, 20 20′, 16 16′, 6 6′, 13 13′, 3 3′.

With an even number of coils the brushes are 180° apart, as in a ring winding. In Fig. 90 a winding of this character is shown, the assumption being $n = 6$, $y = 5$, $s = 5\,\frac{n}{2} + 1 = 16$. This winding is only applicable where $\frac{n}{2}$ is odd. If it be desired that only one coil be shortcircuited by each brush at the same

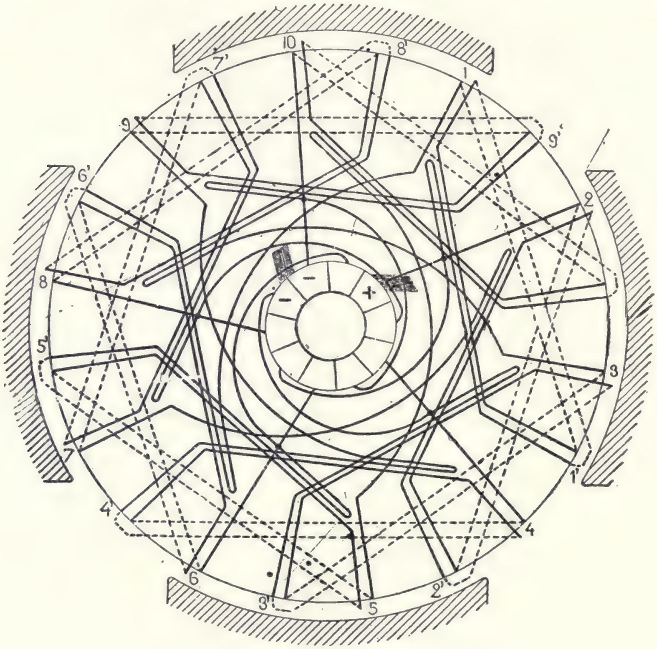


Fig. 92.

time, it is necessary that the number of commutator segments be $\frac{n}{2}s$, and that those at an angle of $\frac{2 \times 360}{n}$ degrees apart be connected together. Fig. 91 gives a scheme employing 9 coils and 18 segments with four poles. The cross-connections are shown within the commutator, similar to the Mordey winding. In the given position 2 2′ is shortcircuited, 9 9′ having just passed that point, and 4 4′ is approaching it.

A drum winding of Alioth & Co. shows that where $\frac{n}{2}$ is even, a series winding can be obtained with an even number of coils, which winding is shown in Figs. 92 and 93, and agrees with the scheme of Fig. 54. The Alioth winding can be better understood from Fig. 93. The heavy lines show the front of

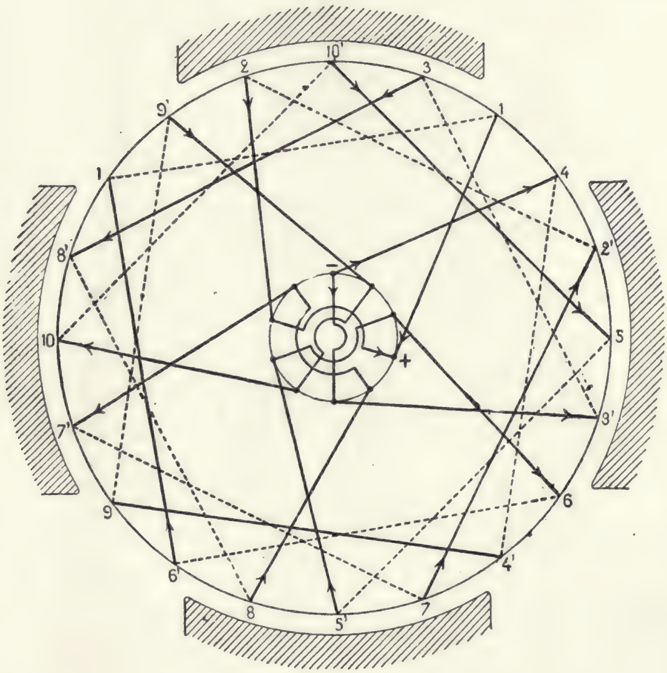


Fig. 93.

the armature and the connectors to the commutator. The developed scheme, Fig. 94, is interesting from the fact that it shows a mixture of loop and wave winding.

Each element has four inductors ($b = 4$) shown in Fig. 94 by heavy lines. There are five elements altogether. The numbers *Ia*, *IIa*, *IIIa*, *IVa*, *Va*, denote the beginnings, and the ends are denoted by *Ie*, *IIe*, *IIIe*, *IVe*, *Ve*.

From the formula, $y = \frac{2}{4}\left(\frac{20}{4} + 1\right) = 3$. Therefore, *Ie* is to be connected to *Ie*, + 3 = *IVa*, and *IVe* with *IVe*, + 3 = 7 = 5 + 2, therefore with *IIa*, etc.

4. MULTIPOLAR ARMATURES WITH MIXED WINDINGS.

The schemes given for ring armatures are easily applied to drums, and no new examples need be given.

REMARKS UPON THE CONSTRUCTION OF DRUM ARMATURES.

The practical construction of a winding, especially with a drum armature, differs considerably from the schemes given. It is therefore important to call attention to a few salient points.

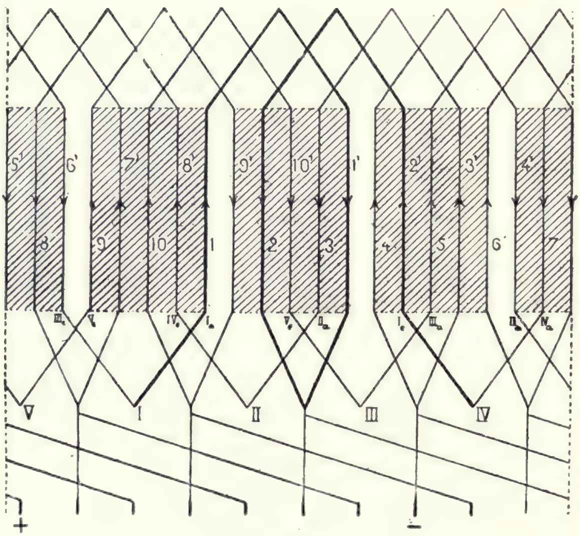


Fig. 94.

The methods used to wind the coils upon the armature may vary. Fig. 95 gives a commutator end view of a bipolar armature. The number of coils is assumed to be 14; the number of winding spaces 28. Corresponding with the schemes in Figs. 60 and 61, the coils must cross the rear end on a chord of the circle.

Beginning with the winding at *a*, the conductor is first taken to the point *b* on the front end, then carried along the surface of the drum to the back end, then carried across along

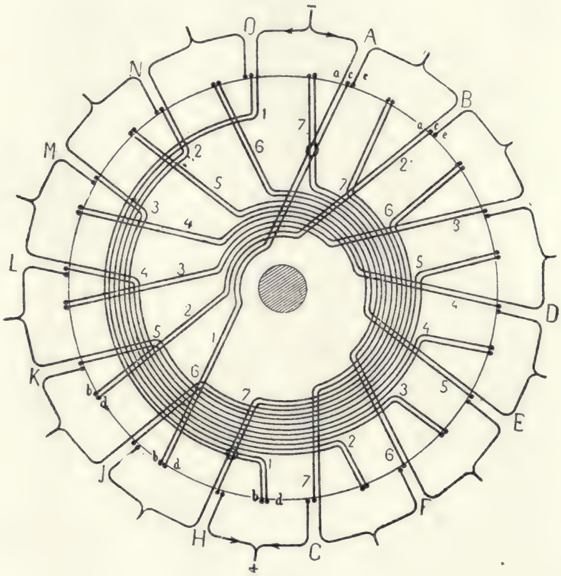


Fig. 95.

a chord, and brought forward again to the point *c*. The operation is repeated until the desired number of turns is obtained. In this figure each coil has only two turns. If 2—3—4—6, or more conductors of smaller sections be substituted for one of the large conductors previously considered, they may all be wound as one conductor or as several.

If coil *A* be obtained in this manner, and taking each time alternate winding spaces, the coils *B*, *C*, *D*—*O* be wound, when the last coil *O* is finished, all the winding spaces will be occupied; and on joining together the free ends as specified, the fourteen points of connection to the commutator segments will be obtained.

If the number of winding spaces be equal to the number of coils, Fig. 67, the coils must be wound in successive spaces. When half the number of coils have been thus wound, all the winding spaces will be occupied, and the remainder of the coils must be wound over the first half, each two adjacent ends being joined to one commutator bar.

If the connections to the commutator are to follow the schemes given in Figs. 62, 63, 68, 69, it is better not to bring out both ends, *a* and *e*, on the same side of the drum, but to start the winding at *b*, then one-half of the projecting ends are bent to the right, and the rest to the left, and joined to the commutator according to the scheme selected.

A better arrangement of the mass of wires on the ends of the drum, and a winding of better appearance, can be obtained if, instead of the connections being invariably carried across to the right of the shaft they be divided between the two sides. This has the disadvantage, however, of taking up more room on the ends. With large conductors this becomes particularly noticeable, but may be obviated by the use of several smaller wires wound as a single conductor.

For example, given a drum whose circumference is divided into 24 winding spaces in which 24 coils are to be wound, each coil to consist of two convolutions of four wires each whose diameter is about 1.5 mm. The connections are to be carried out according to the scheme given in Fig. 68. In Fig. 96, the position of the first four coils is given. These are wound in the succession I, II, III, IV. Beginning with 4 wires at *a*, they are carried to position 1, thence along the surface of the drum to the rear end, then across to the opposite winding space, and along the surface of the drum to 2; across the front end to 3; from here to the rear face again; then across on the other side of the shaft to 4; and along the surface of the drum to the front end, which completes the first coil. After winding twelve coils in this manner twelve more are wound outside of them. One of these outside coils is shown in the figure, 1′ and 4′ being the ends. The method of connecting the 24 coils with each other is obtained from Figs. 68 and 69.

If the conditions given were, to wind twelve coils of two turns each, consisting of 8 wires wound as one conductor, the winding would have been carried out in the same manner. In this case the ends at *a* and 4′ are joined together and to a com-

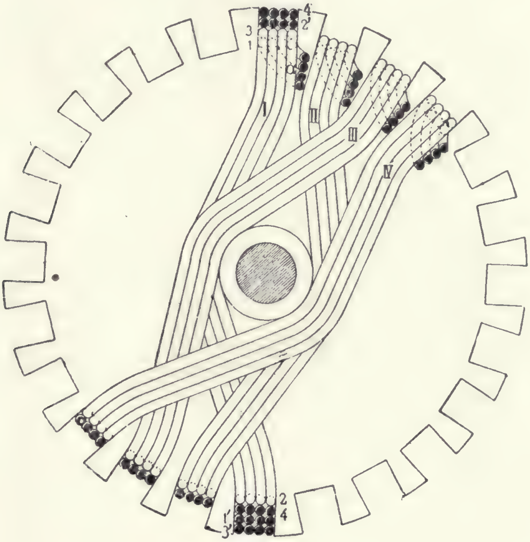


Fig. 96.

mutator segment, also the ends at 4 and 1′. A symmetrical arrangement of the mass of wires and a winding of neat appearance can be obtained by using the method shown in Fig. 97 for a bipolar winding. The coils are wound in pairs, and two successive pairs are at an angle of 90°, or nearly 90°, with each other. It is assumed in this figure that the ends *a* and *e* of a coil are upon the same side of the drum as in Fig. 95. Beginning with the pair 1, observe that the ends *a* and *e* of the first coil lie upon one side of the drum and the ends *a* and *e* of the second coil lie upon the opposite side. The position of all the pairs of coils as indicated in the figure by II, III, . . . VII, are obtained in the same manner. The shaft lies between the two coils of each pair.

If there be 28 winding spaces, and the number of coils remains 28, it would become necessary, after having wound the first seven coils, to wind a second series of coils in the same

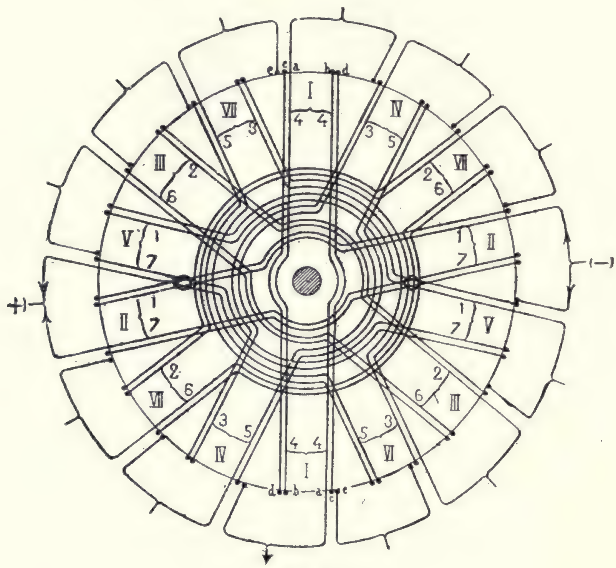


Fig. 97.

succession over the first, in such a manner that the ends of the coil wound over I, should be brought out at *bd*.

If, however, it is the intention to use 14 coils, each occupying two winding spaces, the first pair of the second set is wound over 1 in such a manner that the free ends, *ae*, *ae*, of both pairs coincide in position, for they are in this case connected in parallel.

To properly connect these ends to the commutator, the beginnings and ends of adjacent coils are connected to one bar.

In this winding it is preferable to substitute a conductor of several strands for a solid wire.

To illustrate the difference of potential between successive coils, the coils in Figs. 95 and 97 are numbered from 1 to 7, starting at the negative brush, the numbers indicating approximately the difference of potential between the coils. In the case where two coils cross at some point, the difference of

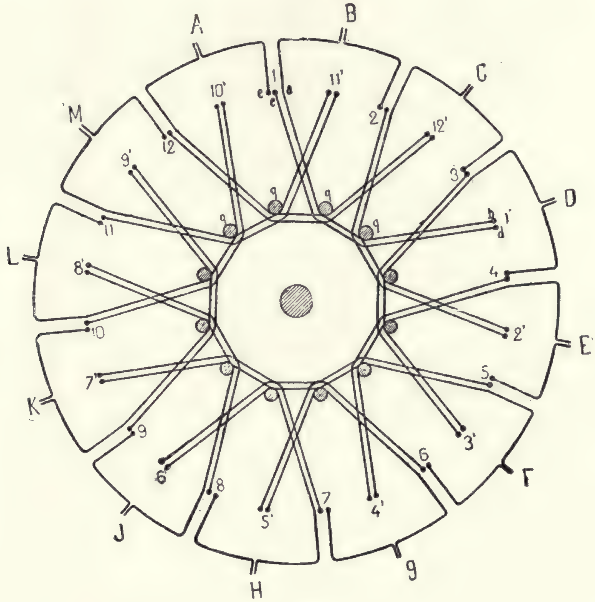


Fig. 98.

potential between the two crossing coils is proportional to the difference between the numbers which represent them. A winding of this description is best arranged when the least difference of potential exists between coils which cross.

In Fig. 95 as well as 97, it is shown that the greatest difference of potential exists between coils which cross; there being a cross between 1 and 7, 7 and 2, and between 6 and 1. These windings are therefore equivalent in this respect.

The exact position of the winding and the number of crossings cannot be previously determined. With careful workmanship both schemes, Figs. 95 and 97, will give good results. The same remarks which have been made upon bipolar armatures can also be applied to multipolar windings. The coils may be wound in either manner with equally good results.

To obtain a better and more permanent position for the wire, a number of pins, made either entirely of insulating material or of metal insulated from the winding, may be let into

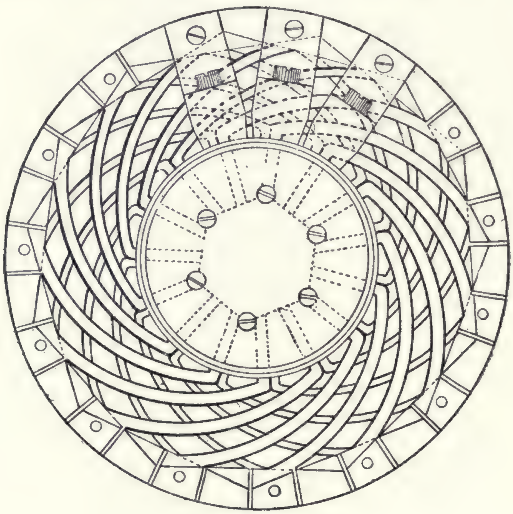


Fig. 99.

ends of the drum to act as points of support for the coil. Fig. 98 represents a 4-pole winding with 12 coils. The succession in which the coils are wound is as follows:

1 1′, 4 4′, 7 7′, 10 10′, 3 3′, 6 6′, 9 9′, 12 12′, 2 2′, 5 5′, 8 8′, 11 11′; if the winding be carried out in this order, the coils will be symmetrical, the mass of wire on the ends of the drum will be well distributed and of neat appearance.

The winding is begun at *a* (see coil **1 1′**); carried across the front end embracing two insulated dividing pins *qq*, to *b*, then along the surface of the drum to the rear end, then again embracing two dividing pins to the second winding space of the coil, then carried along the surface of the drum to *c*. This is repeated until the desired number of turns is obtained. Especial care should be taken in bringing out the ends *a* and *e*. If they be connected as shown in the figure, the points of connection to the commutator segments, *A*, *B*, *C*, are obtained.

After the winding is completed, a disk having holes corresponding in position with the retaining pins may be fastened over the winding, serving to secure the pins in their position.

Alioth & Co. (see Fig. 92) wind their armatures with "formed" coils, which were previously given a trapezoidal shape by being bent over a wooden form. Owing to their method of construction the insulation can be practically perfect.

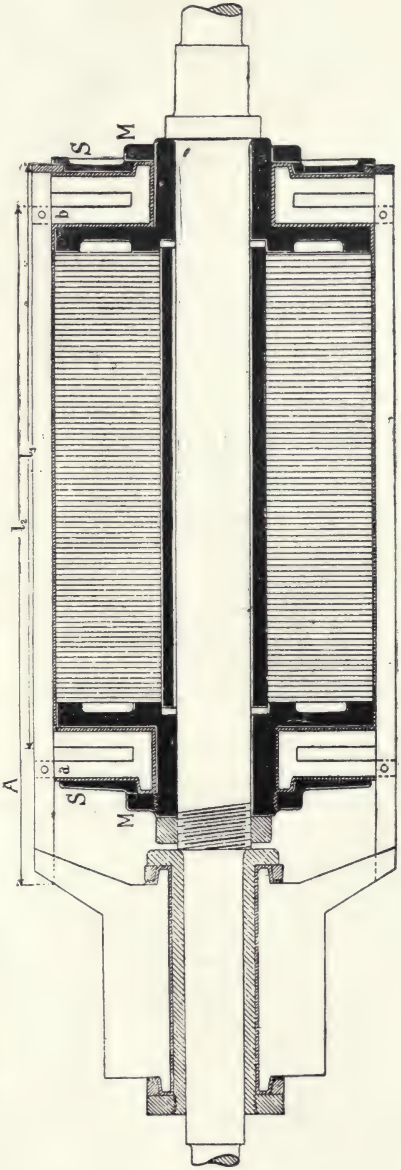


Fig. 100.

Differing radically

from the methods of winding described are those in which the connectors do not touch each other in crossing. The first winding of this description was introduced by the Siemens Company,* and used for armatures of low potentials with heavy currents.

Fig. 99 shows one of these armatures. In this armature, copper rods of large cross-section are used. These are joined to the commutator, according to Fig. 62, by copper strips bent in such a manner as to lie in two parallel planes with air insulation between.

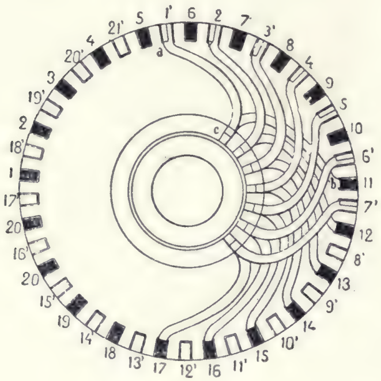


Fig. 101.

Crompton and Swinburne † used this winding for machines of higher electromotive force, using flat copper bars laid edgewise on the drum, with the ends joined by copper strips bent spirally and lying in different planes. The author uses this bar winding for 4-pole and other multipolar lighting generators using notched armatures.

(This method of winding with copper bars and bent cross connectors has been used extensively in this country. — TRANSLATOR.)

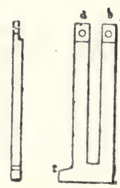


Fig. 102.

Figs. 100, 101, 102, show the winding of a 4-pole armature. To prevent confusion, only 21 coils are shown, consisting of flat copper bars. There are in all 42 copper bars necessary, 21 having the length L_1 and 21 the length L_2. These are laid alternately around the periphery of the drum. Of the bars, those having the length L_2 are connected to the commutator. Around the surface of the drum there are 42 narrow slots into which the insulation and the copper bars are

* Elektrot. Zeitschr., vol. 2, p. 54; S. P. Thompson, Dy. Elect. Mach., p. 266.
† S. P. Thompson, Dy. Elect. Mach., 3d ed., p. 167.

let. The cross connectors are made of sheet copper of the shape shown in Fig. 102, having two arms *a* and *b*, and the lug *c*. These are bent on a form to the right shape, *a c b*, and

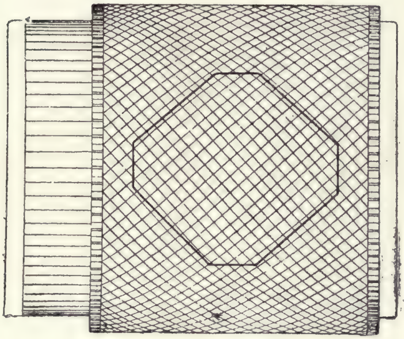


Fig. 103.

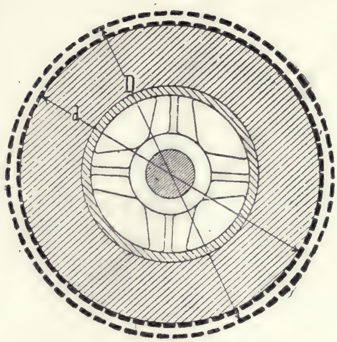


Fig. 104.

the ends *a* and *b* each connected to a bar. The adjacent connectors are separated by a piece of insulating material of the same form (or wrapped with silk tape and shellacked. — Trans.). After all these connectors have been put in place, a ring of insulating materials is slipped over the projecting lugs *c*, and fastened with a nut *m*. If the W. Fritsche winding given in Figs. 81, 86, 88, be represented as on the surface of a drum, and each coil consist of only one turn, the winding can be carried out in the same manner as the Siemens method so that the connectors can cross each other without touching.

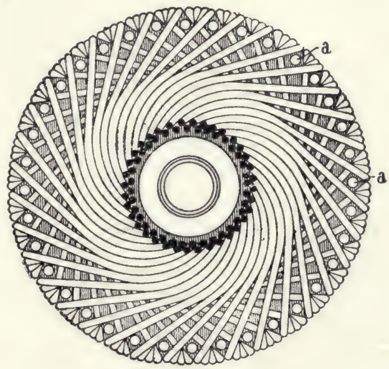


Fig. 105.

Fig. 103 gives a side view, and Fig. 104 the section of a winding according to the scheme given in Fig. 88. The mutually parallel bars 1, 2, 3, ... etc., are placed upon the cylinder whose diameter is d, and the bars, 1′, 2′, 3′, which cross the other bars 1, 2, 3, are situated on the surface of a cylinder of

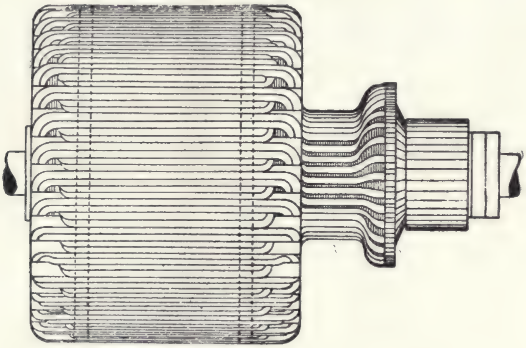


Fig. 106.

larger diameter, D. The points of apparent intersection of the rods lying in the two planes are joined together, but are insulated from the adjacent points of apparent intersection. Between the two cylinders d and D sheets of insulating material are inserted.

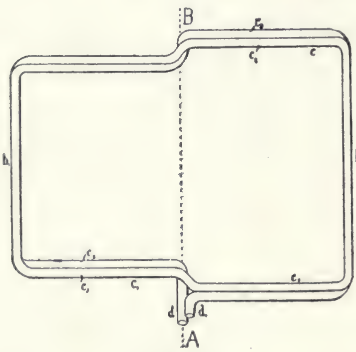


Fig. 107.

The idea of making use of the advantages of the Siemens bar winding for armatures whose coils must consist of several turns, was carried out practically by R. Eikmeyer.* The shaped wire coils, of Eikmeyer, and the bar winding of Siemens, have the same form. Fig. 106 gives a side view of a bipolar drum having 36 coils of the previously mentioned form. Fig. 105 gives an end view of the same with the commutator removed. Fig. 107 gives a plan view of a single coil, A—B being the axis of the drum. The coils are all of the same shape. On one side of the axis

* German Patent, 54413, Feb. 14, 1888.

A—B, the coil is of less outside width than the inside width of the other half. This peculiarity of form is carried out regardless of the number of turns in the coil, and of the changes in the shape of the core.

In Fig. 107, b—b_1 represent the part lying upon the surface of the drum, and c—c_1 the part lying on the face; c_2—c_3 are the windings, and d—d_1 the ends leading to the commutator. The side b of the coil is longer than the side b_1, so that when the coils are in position on the drum, the side b_1 of each coil clears the side b of the other coils. On the circumference of the drum, the long and short sides alternate, and the pins a prevent the coils moving on the drum. The figure shows that the form of the connector across the face of the drum is a spiral, passing from the periphery of the drum toward the center, then along a line nearly parallel to the axis of the drum, and along another similar spiral to the opposite side of the drum.

During this cycle the wires change their position, so that while on the surface of the drum they lie alongside each other, on the ends they are superimposed. This winding of Eikmeyer's, and that of Alioth & Co., have the good feature of equal lengths of wire, therefore equal resistance in the branchings of the circuit, and the additional feature that damaged coils can be readily replaced.

DISK ARMATURE WINDINGS.

The coils of Ring and Drum armatures turn about an axis which is perpendicular to the direction of the lines of force in the magnetic field. From this it follows that the plane of the coil is at one time parallel and at another time perpendicular to the direction of the lines of force.

On account of this arrangement, the lines of force pass for a considerable distance through the armature core. The core is therefore made of iron, and for mechanical reasons, revolves with the inductors. This introduces a number of evils which in multipolar machines are especially noticeable. The repeated magnetization and demagnetization of the core causes losses from eddy currents and hysteresis, which losses amount to several per cent in the best apparatus. Besides this, the heating of the core from these losses limits the allowable heating in the conductors and consequently the total output of the machine; and finally, the inducing coils, which are distributed in various parts of the magnetic flux, cause a cross-magnetization, which weakens and distorts the magnetic field.

In disk armatures, the inductors move in a plane, perpendicular to the direction of the lines of force, about an axis parallel to them. The space which the inductors require in the magnetic field, in the direction of the lines of force, is limited to the thickness of the coils, and the iron core can be omitted, the lines of force passing from pole to pole directly through the armature windings.

These features render it possible to make a disk armature of comparatively little weight, even when a large diameter is employed; it is therefore possible to obtain a high peripheral velocity with a low number of revolutions. Owing to the complete ventilation which may be obtained by this form of construction, it is possible to increase the current density in the armature, and hence increase the output of the machine. As no iron is used in the core, in order to produce an intense magnetic field in the space between the poles in which the armature revolves without excessive magnetizing force, it is necessary that this space be made as short as possible. Therefore the coils, subject to induction, should occupy as small a space as possible in the direction of their axes. This requirement, as well as the connection of the inductors with each other and with the commutator, has prevented the more general adoption of this form of armature, and it is only within the last few years that their difficulties have been satisfactorily overcome.

Disk armatures are generally used for multipolar, but may also be designed for bipolar machines.

Series winding is especially applicable to multipolar disk armatures, as the desired E. M. F. can be obtained with few turns in each coil, and is also free from the difficulty which arises in multipolar armatures with parallel winding; that is, that the various branches are not all subject to exactly equal inductions, hence have unequal E. M. F.'s induced in them.

In the following pages several forms of disk armatures having only historical interest will be mentioned. The first

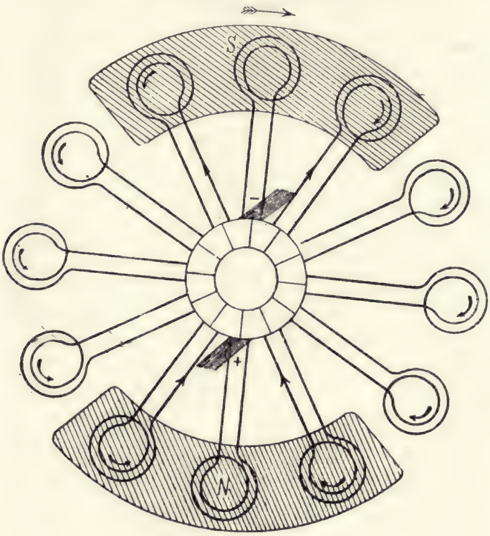


Fig. 108.

considered is the disk armature of Niaudet.* This armature can be regarded as a Gramme ring armature, having the coils turned through an angle of 90°, so that all the coils lie in a plane perpendicular to the axis of rotation. The connections of the coils with each other and with the commutator remain the same, the beginning and the end of two adjacent coils leading to a common commutator bar.

The magnetic field is obtained by the use of two horse-shoe

* Kittler, Handbuch, Vol. ii., p. 23.

magnets, so arranged as to present the north pole of one to the south pole of the other, and *vice versa.*

In Fig. 108, which is a diagrammatic representation of this armature, one of these horse-shoe magnets is considered as above the paper, the other below. If this armature be rotated through the magnetic field as shown, a reversal of current

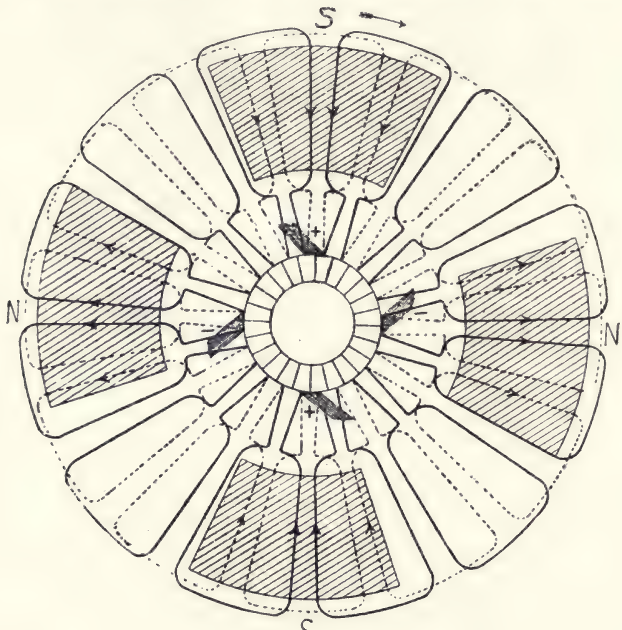


Fig. 109.

takes place in each coil, when it is in such a position that one of its diameters coincides with the pole-line, *NS.*

If the brushes be set so as to shortcircuit the coils that are in this position, the armature will be divided into two branchings, the current flowing in an opposite direction in each, and a direct current will flow in the exterior circuit. The same construction was also adopted by Wallace-Farmer, and Soren Hjorth.

THE HOPKINSON-MUIRHEAD DISK ARMATURE.* (Fig. 109.)

The connection of the coils with each other and to the commutator in this type of armature agrees with that of the Niaudet. A peculiar feature is, that the coils lie in two planes, the coils in one plane being advanced half the width of a coil beyond those in the other.

These coils are fastened to the sides of a core built up of strips of iron, and are held in position by radial bolts. The number of magnetic fields is equal to or less than one-half the number of coils, and they are otherwise arranged in the same manner as Niaudet's.

In the diagram, Fig. 109, the position of the coils in the plane lying to the rear is shown by dotted lines.

SIEMENS & HALSKE DISK ARMATURE.†

VON HEFNER-ALTENECK DESIGN.

A very ingenious method of constructing a multipolar disk armature, with a series winding, was designed by Von Hefner-Alteneck; in this winding, only one coil is shortcircuited at a time by each brush, the same as in bipolar machines. The successive magnetic fields are of alternate polarity. The number of coils in the armature is less than the number of fields, in fact, $s = (n - 2)$.

In Fig. 110, 6 coils are represented, rotating between 8 magnetic fields. Of these 6 coils, but two opposite coils are wholly in a magnetic field, the others being at a greater or less distance from a field. The rotation of the armature, therefore, does not produce a maximum induction in all the coils at the same time, but in successive coils in successive parts of the revolution.

Considering the armature at any part of a revolution, it is

* English patent, 4886, of 1880.

† German patent, 15389. 1881. Kittler, Handbuch, Vol. ii., p. 29.

evident that it may be divided into two halves, by a line passing through its axis, such that the direction of the flow of the currents in the halves is opposite, while the impulses are additive. This division line continually changes its position during the rotation of the armature, but always intersects the points of the circuit formed by the coils which are connected to

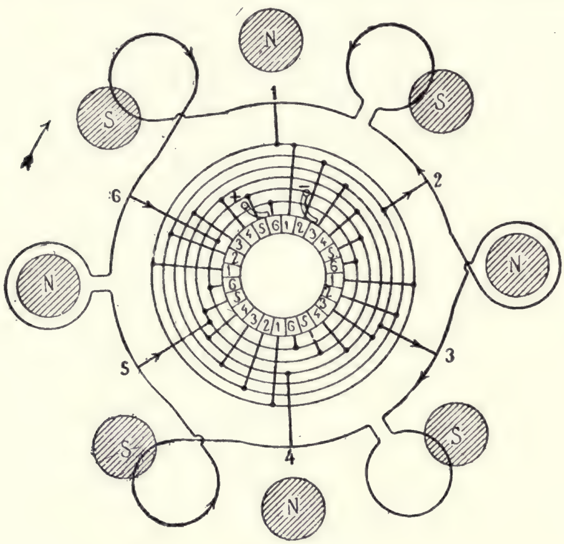


Fig. 110.

the particular commutator segments upon which the brushes rest. The commutator consists of

$$c = \frac{n}{2} \times s \text{ segments,}$$

and every $\frac{n}{2}$ segments which are at an angle of $\frac{2 \times 360}{n}$ degrees apart, are connected together, and are also connected to the connectors of two adjacent coils. In the Fig. the commutator has 24 bars, and $\frac{n}{2} = 4$ segments belong to each group. The connection of the segments in each group (for example, 1,1,1,1, 2, 2, 2, 2,) to each other and to the windings is accomplished by means of insulated rings carried by the shaft. If the successive segments of the 6 groups be numbered from 1 . . . 6, and the corresponding connecting wires between the coils be also numbered 1 . . . 6, then the shortcircuited coils will be those which are included between the points on the connecting wires, whose numbers correspond to the numbers of the commutator seg-

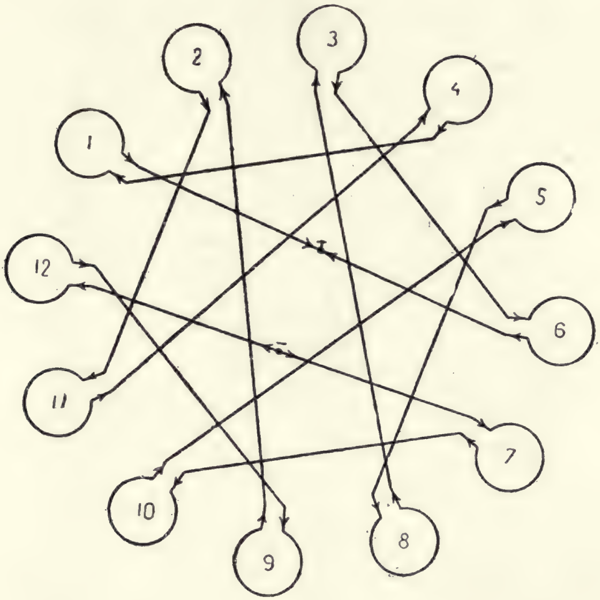


Fig. 111.

ments on which the brushes rest; for example, if one brush rest on segments 5 and 6, and the other upon 2 and 3, the coils lying between the connection wires 5 and 6 are shortcircuited, likewise those between 2 and 3.

Instead of having more magnetic fields than coils the number may be less, and need not be exactly two less. The number of coils may be increased, for example, to double the number. The coils may be located in two planes, as in Fig. 109, for the

Hopkinson-Muirhead disk armatures, not necessarily with the centers of the coils in one plane midway between the centers of the coils in the other. Fig. 111 shows the inter-connections of the coils for a machine with eight fields and twelve coils. The coils which are subject to the induction of the field successively are not connected successively, but at regular intervals, as shown in the diagram, and are correspondingly cut into circuit. The number of commutator sections with this scheme is 48, arranged in 12 groups of 4 segments each.

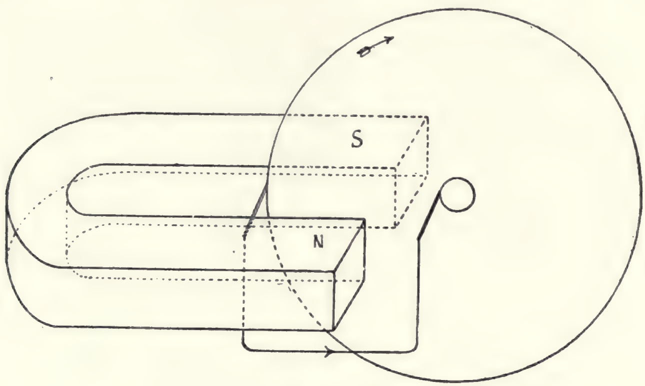


Fig. 112.

The disk armatures which have been described have no practical importance. By application of the schemes developed for ring and drum armatures, practical direct-current disk armatures may be evolved. In conclusion, Faraday's disk may be mentioned. This well-known apparatus is illustrated in Fig. 112, which shows a copper disk rotated in a magnetic field in such a manner that lines of force are continually cut by the disk, and by means of brushes bearing on the axis and periphery of the disk an uninterrupted current is obtained in the exterior circuit.

DISK ARMATURES OF W. THOMSON * AND POLESCHKO.†

If the copper disk (of Faraday) be slit into radial arms fastened to a common axis, but insulated from each other toward the periphery, and if this disk be rotated in magnetic fields of opposite sign as in Fig. 113, Poleschko's arrangement will be obtained. It is assumed that there is above the plane of the figure a north pole opposite to the south pole, and a

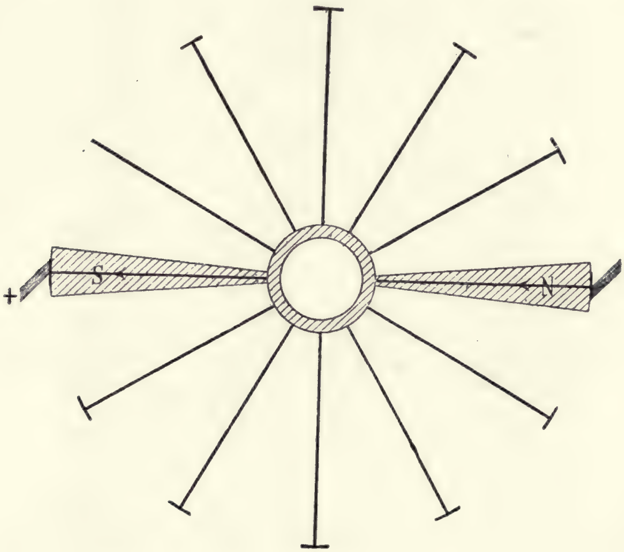


Fig. 113.

south pole opposite the north pole. The brushes bear on the periphery of the disk on a line with the poles (*S. N.*), and as the E. M. F.'s induced in the arms of the disk on which the brushes rest are additive, the E. M. F. obtained will be double that of a Faraday disk. The radial slitting of the disk prevents wasteful eddy currents. W. Thomson joins the outer ends of the radial arms with copper strips, and insulates the

* S. P. Thompson, Dyn. Mach. Third ed., p. 233.
† La Lum. Elec. Vol. xxxv., 1889, p. 610.

inner ends which are joined to the segments of an ordinary commutator with two brushes.

These are open-coil armatures, and are mentioned here as they illustrate the origin of disk armatures.

PACINOTTI'S DISK ARMATURE.*

In 1881 a machine was shown at the Paris Exposition which had been invented by Pacinotti in 1875. His armature also consisted of radial arms rotating between magnetic poles of

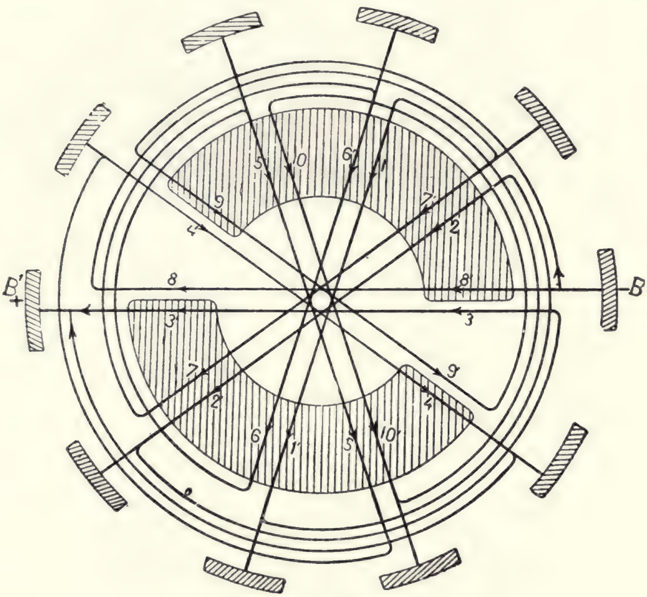


Fig. 114.

opposite sign, but the arms were connected so as to constitute a closed winding. This method of construction is given in Fig. 114. The surface of the poles is very much increased in comparison with those shown in Fig. 113, so that in all the conductors in one-half of the armature the current flows radially

* S. P. Thompson, Dyn. Mach., p. 206.

inward, and in the other half radially outward. The manner of connecting the conductors follows the general rule, here as well as in the Pacinotti Ring armature.

In the scheme given, $s = 10$, $y = s + 1 = 11$, therefore 1 must be connected to $1 + 11 = 12$ or 2. The commutator segments are shown on the periphery for the sake of clearness. The circuit is as follows; from the brush B_1 through the exterior circuit to B_2 into the armature, where it divides itself as follows:

$$B_2, 9, 9', 10, 10', 1, 1', 2, 2', 3, 3', B_1,$$
$$B_2, 8', 8, 7', 7, 6', 6, 5', 5, 4', 4, B_1.$$

EDISON'S DISK ARMATURE.

In 1881 Edison patented a machine in which the armature is nearly the same as that of Pacinotti.

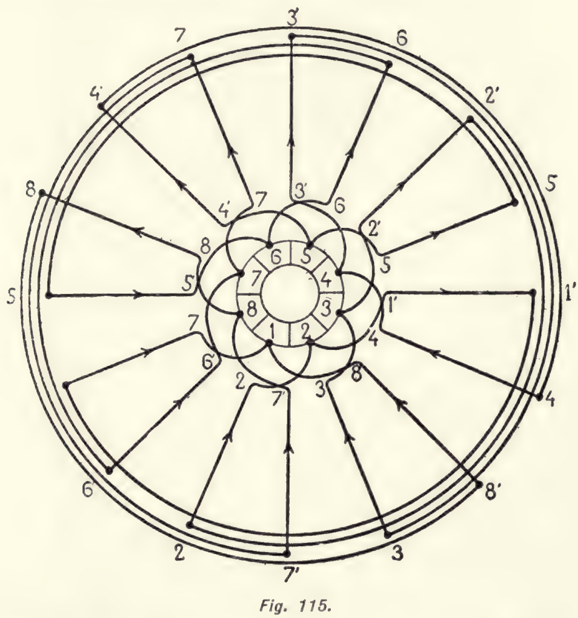


Fig. 115.

By transferring the commutator connections from the connections of the radial arms which lie on the periphery, to

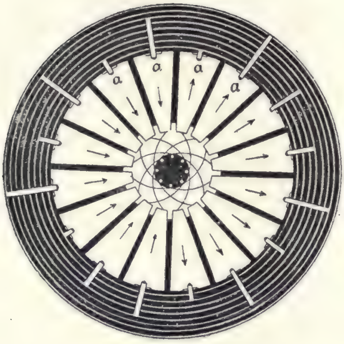


Fig. 116.

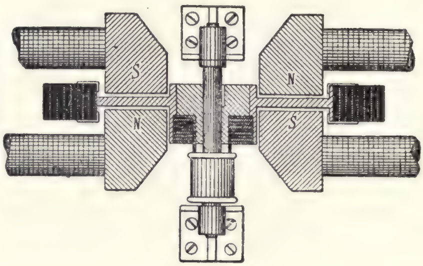


Fig. 117.

those which are in the inner part of the disk, Edison's scheme, shown in Fig. 115, results. The actual construction of this arrangement is shown in plan in Fig. 116 and in section in Fig. 117.

The sixteen radial conductors consist of copper strips (a, a . . .) well insulated from one another. Their connec-

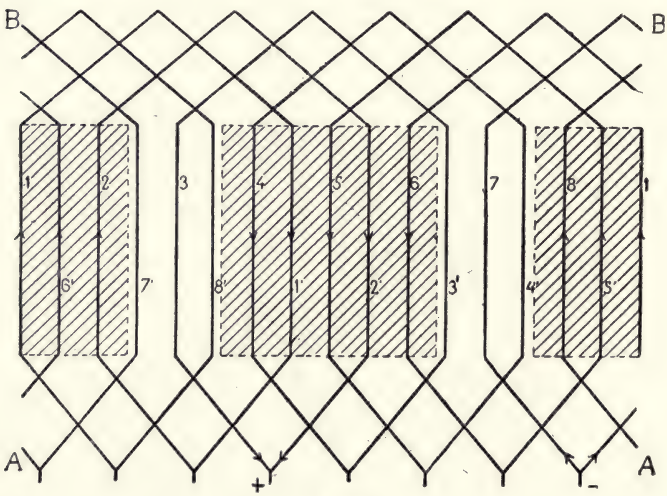


Fig. 118.

tion with each other on the periphery is effected by eight concentric copper bands insulated from each other. The disk is mounted on a wooden hub, and the radial arms are connected to the commutator by means of eight insulated copper rings carried by this hub. The development of both these schemes is shown in Fig. 118.

A comparison of this with Fig. 71 shows the identity of the scheme of connecting with the Von Hefner-Alteneck drum winding. If the development of the scheme given in Fig. 118 be made circular, so that the side *AA* forms the outer circle, Pacinotti's scheme results; if this side be made the inner circle, Edison's scheme is obtained.

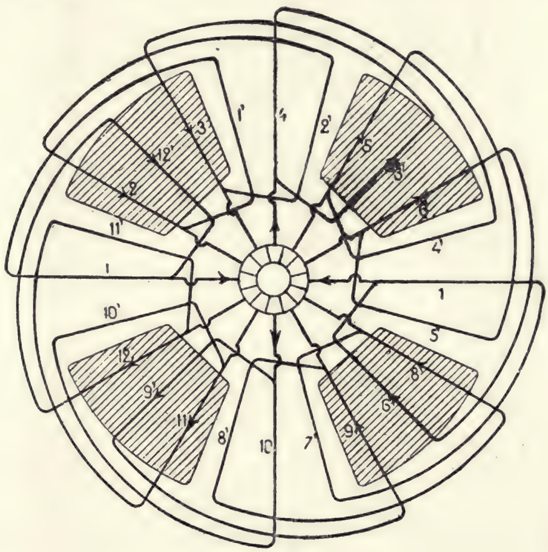


Fig. 119.

EDISON'S* MULTIPOLAR DISK ARMATURE WITH PARALLEL WINDING.

Fig. 119 shows the scheme of connection given in Fig. 115, extended to cover a multipolar field. This is identical with the drum armature winding shown in Fig. 75.

* The Electrician, December, 1889.

APPLICATION OF THE ANDREWS-PERRY WINDING TO DISK ARMATURES.

A new group of disk armature windings may be arranged by applying the Andrews-Perry winding for ring armatures to disk armatures.

The most simple form in which this may be done is to change to a circular form the scheme given in Fig. 86 for drum armatures in such a manner that the parallel conductors

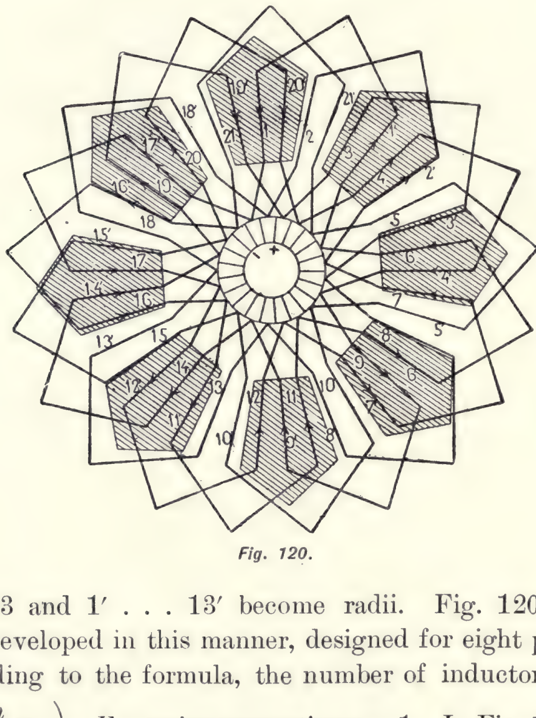


Fig. 120.

1 . . . 13 and 1′ . . . 13′ become radii. Fig. 120 shows a scheme developed in this manner, designed for eight poles.

According to the formula, the number of inductors must be $z = b\left(y\frac{n}{2} \pm a\right)$. For series connection $a = 1$. In Fig. 120, $b = 2$, $y = 5$, therefore $z = 2\,(4 \times 5 + 1) = 42 = 2\,s$. Every two inductors are joined in one pair, forming one coil, indicated by the same numbers. 1′ is to be joined to $1 + 5 = 6$, 2′ with 7, 3′ with 8, etc. The number of commutator segments is 21. There are $\frac{n}{2} = 4$ coils shortcircuited by each brush at the same time, and for the position of the armature shown in the drawing, the coils shortcircuited by the negative brush are [21, 21′] [55′] [10, 10′] [15, 15′], and by the positive brush [18′, 18] [13′, 13][8′, 8] and [3′, 3]. The shape of the pole piece is determined by the shape of the coil. To prevent opposing E. M. F.'s, the poles must be cut off at an angle on the outside, and the edges made radial.

The practical construction of a disk armature according to this scheme presents many difficulties, which have been overcome in various ways.

The first method to be considered is a disk armature with an oblique winding. The over-lapping coils in this armature stand at an angle to the plane of rotation. The angular width

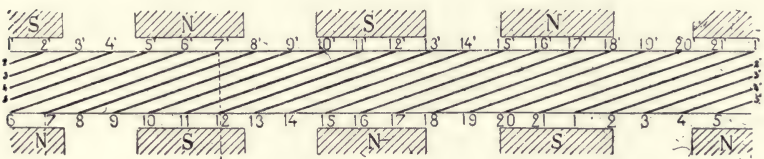


Fig. 121.

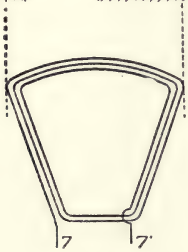


Fig. 122.

is such that when one side of the coil is in one magnetic field, the other side lies in a field of opposite sign. Fig. 121 gives the position of the coils relative to the magnetic field. The development shown gives a view of the circumference of the armature.

The shape of a single coil for 8 poles is shown in Fig. 122. The ends of the coils can be joined, according to Fig. 120, for high E. M. F.'s, or as in Fig. 77, in parallel for low E. M. F.'s.

Windings employing oblique coils have been devised by Ayrton and Perry,* by Elphinstone-Vincent* and by Desroziers.† The method of connection employed is not known to the author. If each coil consist of one turn, and the entire winding be arranged on a thin disk in an oblique position and connected according to the general formula, the scheme given in Fig. 123 will result. This represents a development of

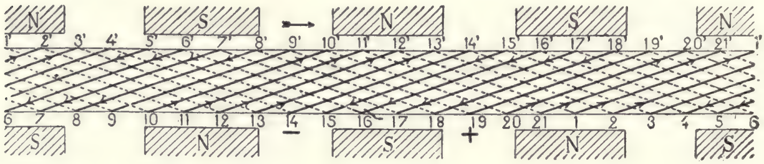


Fig. 123.

the circumference of the armature. The radial inductors are shown as points, the cross connectors on the circumference as full lines, the interior connectors as dotted lines. The winding is carried out as follows: From 1′ along the inner surface to 11, then radially outward, then from 11 obliquely across the exterior surface to 11′, then radially inward, and from 11′ on the inner surface obliquely to 21 and continuing to 21′, 10, 10′, 20, 20′, 9, etc., returning to 1′. No crossing takes place, and the position of the brushes is given in the diagram.

DESROZIERS' DISK ARMATURE.‡

Desroziers' method of winding disk armatures agrees with the scheme given in Fig. 121, which is a wave winding, except that he employs a greater number of commutator bars than is there given. This he did with drum armatures, as shown in Fig. 91, and with ring armatures, as shown in Fig. 50, so that a brush shortcircuits but one coil, that is, one element, at a time. In this armature the number of radial inductors is

* S. P. Thompson, Dyn. Mach., 3d ed., p. 206.

† La Lum. Elec., Vol. xxiv., 1887, p. 293.

‡ Elektrotechnic. Zeitsch., Vol. x., 1889, p. 200. La Lum. Elec., Vol. xxiv., 7 May, 1887, p. 294.

$z = b\left(y\frac{n}{2} \pm 1\right)$. The number of commutator segments, $c = z\frac{n}{4}$, and every $\frac{n}{2}$ segments lying at an angle of $\frac{2 \times 360}{n}$ degrees apart are connected together. Desroziers makes $\frac{n}{2}$ odd in his machines, — actually $n = 6$. The number of inductors, z, is always divisible by 4, and every four inductors with their connectors

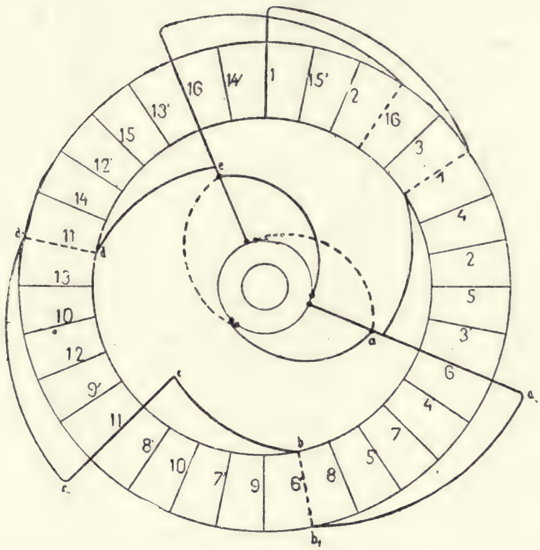


Fig. 124.

constitute an element. In this manner the number of commutator segments is reduced one-half. $c = \frac{z}{4} \times \frac{n}{2} = \frac{zn}{8}$. In Fig. 124 Desroziers' winding is represented assuming $n = 6$, $z = 2(3 \times 5 + 1) = 32$, $y = 5$, and $c = 24$. This winding consists of straight radial conductors which are moved in the magnetic field, and are joined together on the exterior and the interior of the disk by spirally bent wires. Crossings of the connectors are entirely avoided by this method. A coil, as considered in the formula, consists of two radial parts ($b = 2$) and two connecting parts; for example, $a\ a_1\ b_1\ bc$.

An element, according to Desroziers, consists of four radial parts and four connecting pieces, for example, $aa_1\ b_1\ bcc_1\ d_1\ de$. From the junction of two elements, connections are carried to three segments, at an angle of $\frac{2 \times 360}{6} = 120°$.

The complete scheme obtained in this manner is shown in Fig. 125. To prevent crossings (in the diagram) the dotted

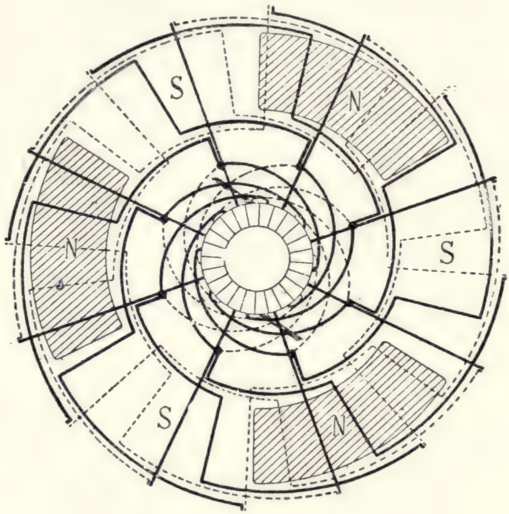


Fig. 125.

parts of the inductors are supposed to lie on the rear face of the disk, and the parts shown by full lines lie on the front face. The necessary rigidity is given to the armature by a wheel-like supporting disk made of German silver 2 *mm.* thick, which is fastened by means of bolts to a hub on the shaft of the machine, and insulated on both sides with sheets of papier-maché fastened to the disk with pins. One-half of the armature winding is fastened outside of each papier-maché disk before it is put in place on the German silver disk, so that two workmen can be employed on a winding, working independently of each other. After the complete halves of the winding have been put in position on the supporting disk, the proper connections are made between the windings and the commutator.

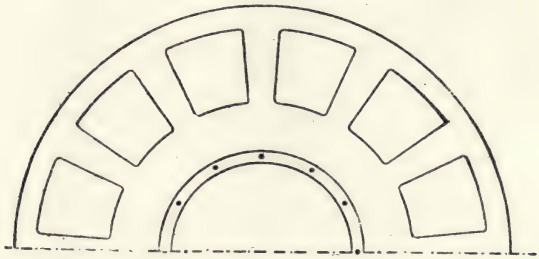


Fig. 126.

FANTA'S DISK ARMATURE.*

Fanta's method of construction requires that the parts of the armature subject to induction be made as thin as possible. Owing to this fact he obtains an intense field with a small magnetizing force.

The armature consists of a metallic supporting disk, *R*, in Fig. 127, having an insulating disk on each side. These insulating disks are each divided into 3 concentric parts, *A*,*B*,*C*, of which the middle one (*B*) can be removed after the armature has been wound. The other two remain permanently fastened in position to the supporting disk *R*.

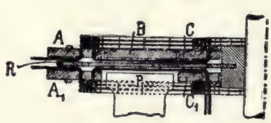


Fig. 127.

Before fastening the insulating disks to the core they are wound with wire. The plan of winding, which is illustrated in Figs. 128 and 129, is similar to that of Desroziers'. The path of the element on the core is as follows: starting from *a*, it passes along the rear side to the hole *b*; passing through this hole, it follows an eccentric curve from *c* to *d*; passes

* German Patent, No. 46240, March 25, 1888.

through the disk A again, and on the other side is carried radially from e to f. At f it passes through the ring C, follows the eccentric curve g, h on the front side of the disk; at h again through a hole to i, and is then brought out radi-

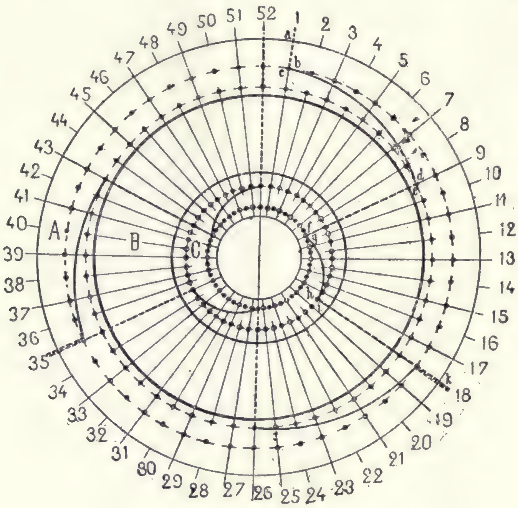


Fig. 128.

ally to k. An element of this winding is shown in Fig. 129. On each of the side plates, $ABC\ A_1B_1C_1$, a certain number of these elements are wound. The parts of the winding which are radial in their direction are all on one side of the disk, lying closely alongside of each other. This side of the wound disks is placed next to the supporting disk, and the rings AA_1 and CC_1 are fastened to it. The central rings, B and B_1, may be taken away, which allows the air gap to be materially reduced. The elements are connected to each other according to the results desired, either in series or in parallel.

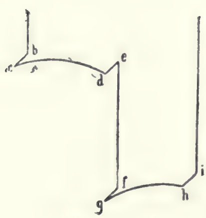


Fig. 129.

JEHL AND RUPP DISK ARMATURES.*

One of the greatest improvements in disk armatures was made by F. Jehl, who in 1887 patented a method of constructing disk armatures.

It is a well-known fact that the cross connections on the rear face of a drum armature, can be so arranged as to avoid crossings. In Desroziers' and Fanta's winding the method by which crossings are obviated, is to build up the windings in two

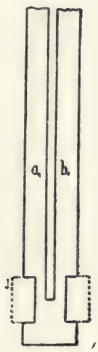


Fig. 130.

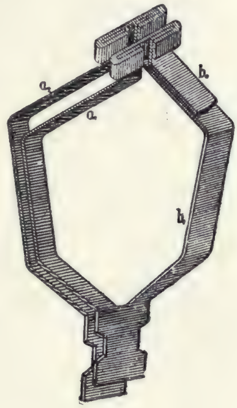


Fig. 131.

separate planes. This is the case in the Jehl and Rupp armature, the halves of the armature being in two parallel planes.

Here the elements do not require any support, being so shaped and proportioned as to give the necessary rigidity. The elements for parallel winding are bent to shape from blanks of the form shown in Fig. 130; and it may be seen from Fig. 131, that the elements a_1 and b_1 lie in different planes. The left end a_1 is connected to the right end b_0 of the preceding element, and the right end, b_1, to the left end, a_2, of the succeeding element.

If all the elements be joined, as shown, a closed circuit winding is obtained, one-half on each side of the armature.

* German Patent, 43298; Kittler, Handb., Vol. ii., p. 39.

The scheme of this winding is shown in Fig. 132, and it will be readily seen that it is a loop winding. For the sake of clearness a winding with a small number of coils has been selected. The parts of the winding a_0b_0, a_1b_1, a_2b_2, etc., belong each to one bent strip. The conductors lying upon the front of the armature are shown by heavy lines.

In order to obtain the greatest number of coils in an armature, the inner parts of the coils can be replaced by a thinner

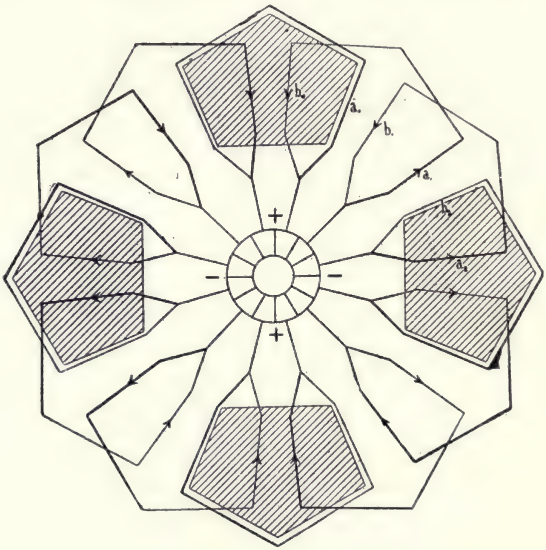


Fig. 132.

metallic band which must be increased in width to retain the original cross-section. With this change the coils may be brought closer together.

The number of commutator segments can be equal to half the number of inductors, or several inductors of a group may be joined together, and the ends brought to the commutator.

If the number of inductors $z = b\,(y\frac{n}{2} \pm 1)$, and they be joined together according to the general rule, a wave winding is obtained. In Fig. 133, $z = 14$, $y = 3$, $n = 4$. If connected, as shown, the number of elements will be 7.

Jehl and Rupp also connect the winding as shown in Fig. 134. Here $b = 4, z = 4\left(y\frac{n}{2} \pm 1\right)$ or $z = 4(3 \times 2 - 1) = 20$, $y = 3$. Each element consists of four radial arms, the beginnings of which are numbered 1, 2, 3, etc., the ends 1′, 2′, 3′, etc. 1′ is joined to $1 + y = 4$, etc.

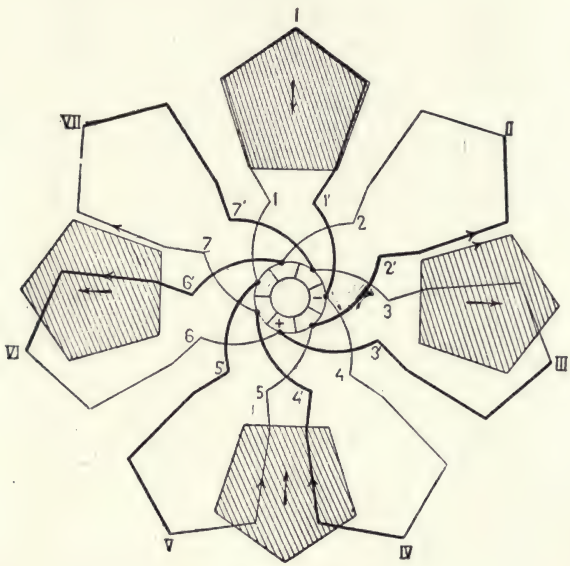


Fig. 133.

In the same manner as in the ring armature shown in Fig. 52, the number of commutator bars may be reduced one-half, but if a commutator bar be inserted diametrically opposite each of the present bars the number will again become $\frac{z}{2}$.

A difference which exists between the disk armatures of Desroziers and Fanta and that of Jehl and Rupp is that in the first the radial inductors belonging to one coil are in different magnetic fields and are both active, while in the latter only one side of a coil is active. The width of the coil is somewhat greater than that of the pole-piece. If the width of the coil were the same as that of the field, the neutral space would

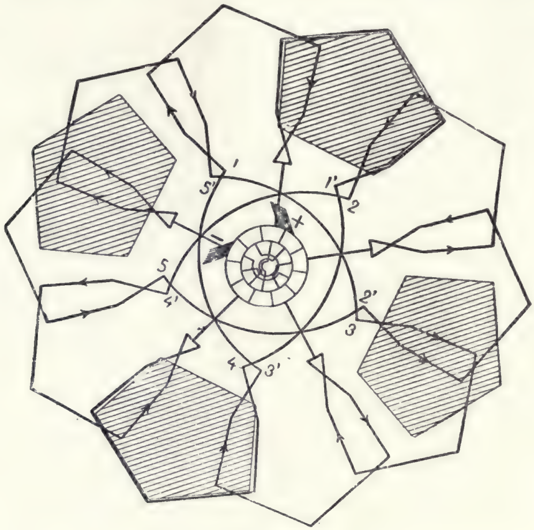


Fig. 134.

disappear; it is therefore imperative that the coils be wider. The construction of armature coils from metallic strips lying in two planes may be advantageously employed in other windings.

W. FRITSCHE'S DISK ARMATURE.*

To W. Fritsche belongs the credit of having united the Jehl and Rupp construction with the Andrews,† Perry and Desroziers windings, and of having evolved a practical method of carrying it out. The fundamental difference between Fritsche's disk armature and those of Desroziers and Jehl is that

* German patent, No. 45808, June 19, 1887.

† Kittler, Handb., Vol. i., Stuttgart, 1886, p. 532.

Fritsche used straight rods bent to lie in two planes. The connection is according to the general rule. Fritsche's winding is given in Fig. 135, where $n = 8$, $z = 42$, $\frac{z}{2} = 21$ (elements) $y = 5$. Inductor 1 is to be connected to $1 + y = 6$. The angle between 1 and 6 is bisected by the line OM. This intercepts the circumference of the interior limit of the winding at a. 1 a and 6 a show the positions of the inductors. The Fritsche winding may be derived from that given in Fig. 120

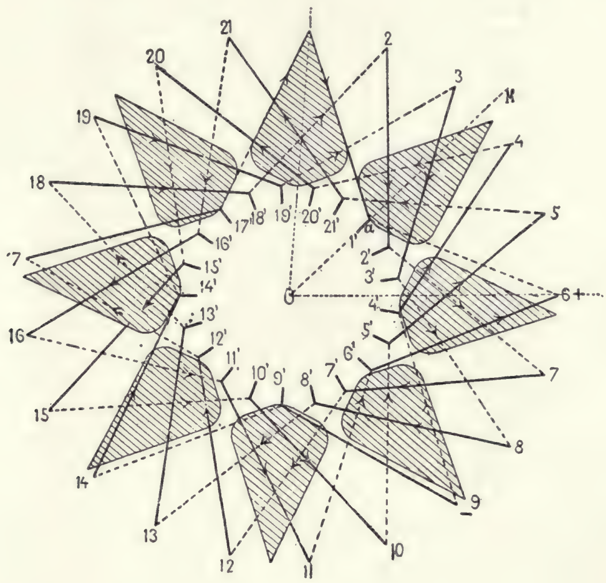


Fig. 135.

by substituting a triangular shape for the polygonal one there given, and by shaping of the pole shoes so as to prevent opposing E. M. F.'s being generated in the inductors. The same winding would be obtained if the scheme given in 87 were developed circularly. A comparison of the Fritsche disk armature with the ring armature of Andrews, Fig. 49, will show that if in the latter figure, 1 and 1′, 2 and 2′, etc., coincide, the cross connectors themselves will give a correct scheme for a Fritsche disk armature, when $n = 6$, $z = 32$, $y = 5$. For a collector, Fritsche uses the connection pieces at the junctions of the elements on the circumference. The position of the brushes on the circumference of the armature is shown in the figure. The inductors themselves are made of bent sheet iron, the inner and outer ends soldered to the connection pieces; the entire system of inductors is fastened to the shaft.

B. OPEN-COIL WINDINGS.

Open-coil windings, whose elements were spoken of on page 7, have become prominent through the Brush and Thomson-Houston machines. Their peculiarities and their methods of operation will not be entered upon here. They have been fully discussed in S. P. Thompson's book, and also in Professor E. Kittler's. The principle of the windings will be shown in the following pages.

1. RING ARMATURE WINDINGS.

BRUSH RING ARMATURE. (Fig. 136.)

There are in all, 8 coils wound in the same direction. The rear ends of two diametrically opposite coils are connected together, that is, 1 to 1, 2 to 2, 3 to 3, 4 to 4; these connections are indicated by dotted lines. The front ends of these pairs of coils are connected to the commutator. The commutator consists of four rings lying alongside of each other on the shaft, each ring consisting of two segments, each segment embracing $\frac{3}{8}$ of the circumference. In the figure these rings are shown as lying in the plane of the paper, and therefore of different diameters. In the two inner rings, having the common brushes P_1 P_2, the corresponding sections are shifted 90°, and are connected to the pairs of coils 1–1, 3–3, which also lie at right angles to each other. The outer rings with the common brushes, Q_1 and Q_2, are connected to the remaining coils, 2–2 and 4–4, and the segments are at an angle of 45° with the first pair.

In the position shown in the drawing, and with the given direction of rotation, the E. M. F. in 1–1 has attained its maximum, that in 4–4 is increasing, that in 2–2 is decreasing, while 3–3 lies in the neutral space. The current enters the armature at P_1, passes through the coils 1–1 to the brush P_2, thence to the brush Q_1, then to the coils 2–2 and 4–4, which are in parallel, to Q_2, and returns to P_1, through the external circuit. The coils 3–3 are cut out entirely. If the coils change position, a corresponding change takes place in the path of the current through

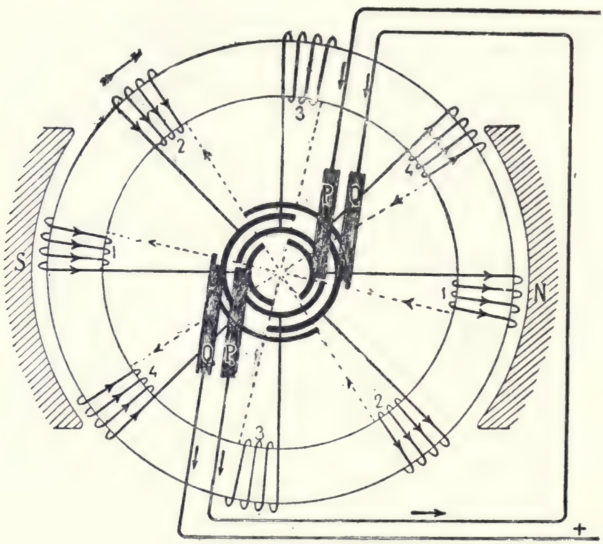


Fig. 136.

them. Each coil is cut out of circuit twice for $\frac{1}{8}$ of a revolution, and at that time when its E. M. F. is approaching or receding from 0. Those coils which are either approaching or receding from the point of maximum induction, are always in parallel.

The number of coils may be increased if desired, still adhering to the Brush winding. Each pair of coils requires a collector ring, and every four coils lying at an angle of 90° require a common pair of brushes. These are connected successively in series. The armature of the largest Brush machine has but 12 coils. Fig. 137 shows its arrangement. While the armature is in the position shown in the figure, the coils 4–4 are in the neutral zone and are cut out of the circuit. The path of the current through the armature is as follows:

$$P_1 - 1 - Q_1 - P_2 < \frac{5}{2} > Q_2 - P_3 < \frac{6}{3} > Q_3$$

through the external circuit back to P_1.

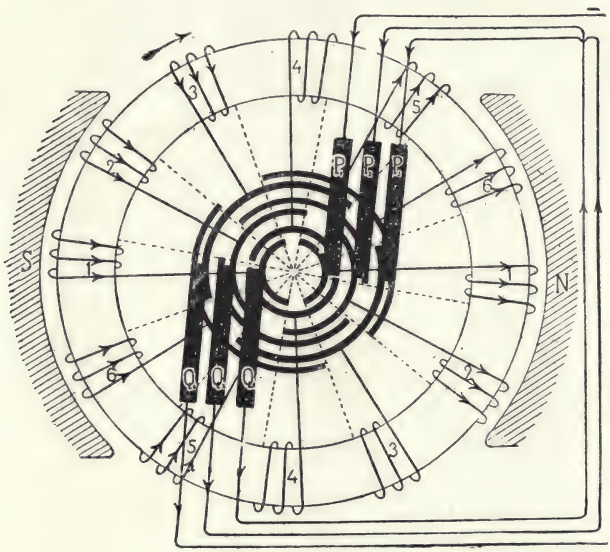


Fig. 137.

2. DRUM ARMATURES, THOMSON–HOUSTON WINDING.

This armature is shown in Figs. 138–141. The core is composed of iron wire wound on two cast-iron supporting spiders, the whole forming an oblate spheroid. Pins are inserted in the edges of the cast-iron spiders for the purpose of properly spacing and guiding the three coils, which are wound on the core at an angle of 120°.

The coils are wound in as follow: first, half of the first coil, then half of the second coil, then all of the third coil, then the other half of the second, and finally the remaining half of the first coil. This method of procedure gives an equal length of wire in each coil, and the mean distance of the coils from the poles is the same. The beginnings of each of the three coils are connected together, and the ends are connected to the three-part commutator. The armature when completely wound is nearly spherical. The developed scheme shown in Fig. 138 represents this winding. The starting ends a_1, b_1, c_1, are con-

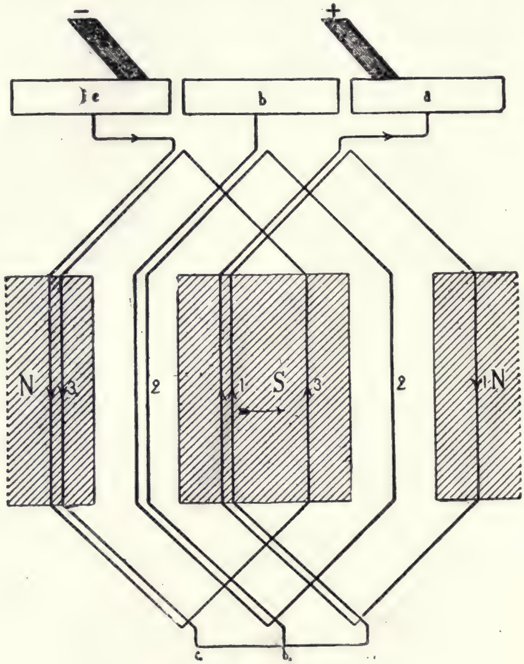


Fig. 138.

nected together, and the ends 1, 2, 3 are connected to the segments a, b, c. Coil number 2 is in the neutral position in the figure, and is cut out of the circuit.

The position of the coils relative to the commutator and to the brushes is shown in Fig. 139. The coils 1, 2, 3, are indicated by radial lines drawn from the segments a, b, c, of the commutator to the center; *N. S.* is the pole line. If the armature be revolved through 30° from the position shown, number 1 will be in the position of maximum induction, number 2

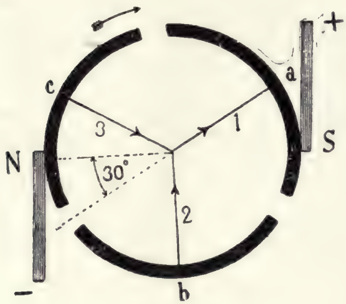


Fig. 139.

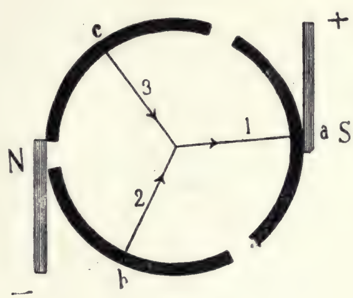


Fig. 140.

approaching this position, and number 3 will be in the neutral position. (See Fig. 140.)

Coils 2 and 3 are connected in parallel, by the brush resting upon both *b* and *c*. On revolving the armature further, number 3 is cut out of circuit, and number 2 takes its place. The time during which two coils are in parallel is therefore very short. To increase this time, and to more advantageously employ the full field flux, the commutator segments might be lengthned so as to overlap, as in the Brush machine. Thomson-Houston attain the same end by using

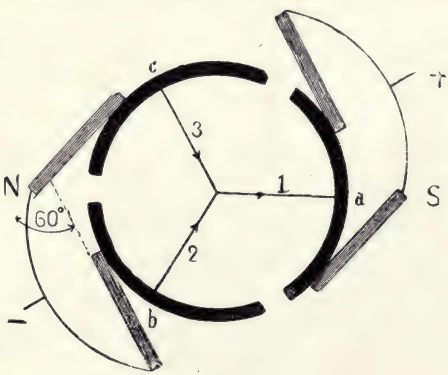


Fig. 141.

a second pair of brushes set at an angle of 60° with the first pair, and connected to them, as shown in Fig. 141.

3. DISK ARMATURE WINDINGS, WILDE'S DISK ARMATURE.

In 1867 H. Wilde patented an alternating dynamo, the armature of which was so connected as to allow a part of the current to be rectified to excite the field magnets; in Fig. 142 an arrangement of this same character is shown.

An armature with eight coils revolves in eight magnetic fields of alternate sign. The coils in the armature are connected so that a reversal of current takes place in all of them simultaneously. The commutator is shown in the figure as two interlocking tooth disks; actually they consist of two toothed cylinders mounted on the shaft. Each cylinder has as many projections as there are fields. One of these cylinders is connected to the beginning of the winding, the other to the end.

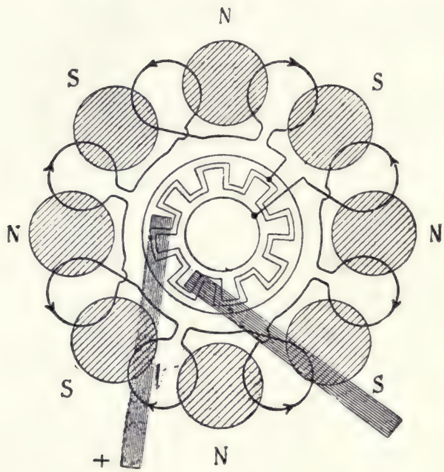


Fig. 142.

A unidirectional pulsating current will be obtained if two brushes be used on adjacent segments of the rectifier.

The coils may also be arranged in parallel, by connecting the beginning and the end of each coil with the rectifier.

FERRANTI–THOMSON DISK ARMATURE.

In this case, as in the previous one, the field magnets are arranged circularly, and of alternate polarity. The armature consists of copper strips bent into a wave-like shape ; the number of layers is optional. In the diagram of this winding, Fig. 143, but two layers are shown. The distance between the radial parts of the coils is the same as the distance between the centers of the fields. The E. M. F.'s induced in the copper

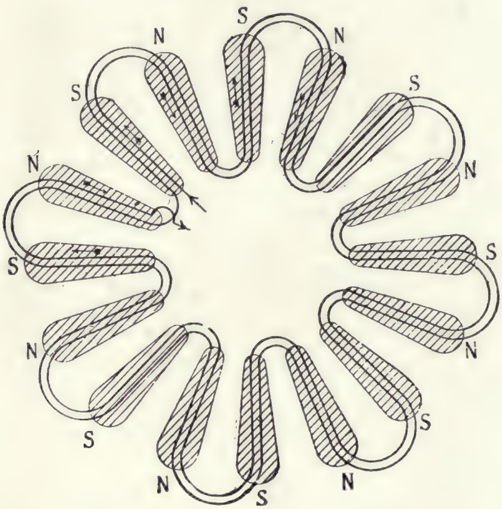


Fig. 143.

strip are additive, and the total E. M. F. can be made available at the ends of a break made between any two adjacent coils of the winding.

When the coils are in the position shown in the drawing, they are in the position of maximum induction. By connecting the armature coils in the same manner as is shown in Fig. 142 a rectified current may be obtained, Instead of brushes, Ferranti uses grooved metal disks.*

* Kittler, Handbuch, Vol. ii., p. 136.

BOLLMAN DISK ARMATURE.*

The Bollman winding resembles that of Ferranti-Thomson, the difference being that in the Bollman armature there are several circuits, and the coils of the various circuits overlap. If a single circuit be taken from the armature it will be found to agree with the Ferranti-Thomson winding. The scheme of

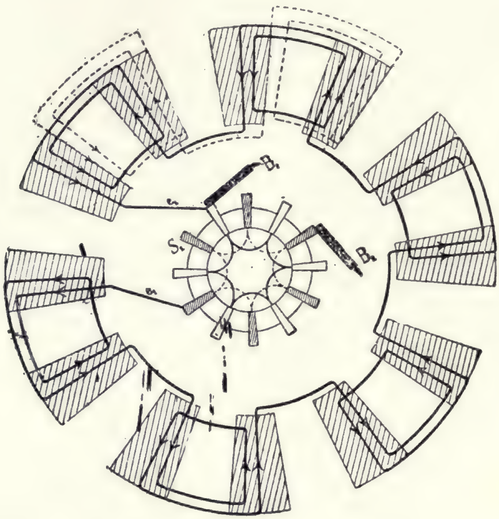


Fig. 144.

Bollman's winding is shown in Fig. 144, in which there are twelve magnetic fields arranged in a circle and of alternate polarity. There are altogether 24 armature coils, divided into four circuits of 6 coils each. The coils are built up of copper strip, and no iron is used in the construction of the armature. Each coil contains several turns, two turns being shown in the diagram, which consist of radial strips, and are connected at the ends by short circular pieces in such a manner that air may circulate through the winding. The coils

* German patent, 35186, Nov. 18, 1884, Kittler, Handbuch, Vol. ii., p. 37.

are all connected in series. The angular distance between coils is equal to that between the poles, therefore each coil is in two fields at the same time.

In the drawing only one circuit is shown, a second being partially indicated by dotted lines. In order that the air-gap may be as small as possible, the radial strips lie in one plane. The connecting strips do not lie in the same plane as the radial strips, but are bent out to one side to prevent crossings, as shown in perspective in Fig. 145. In that figure a, b, i, k, o, n, f, e are the radial inductors, and *bcde*, *fghi*, *klmn* are the connecting strips. The corresponding position of the other circuit is shown by the line *pq*. The connecting strips of two of the

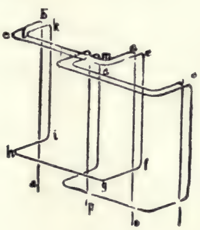


Fig. 145.

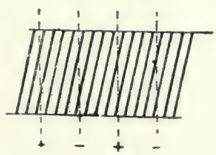


Fig. 146.

circuits are bent to the right, and of the other two to the left. The collector is identical with the rectifier used by Wilde, but with the separate parts multiplied to cover the increased number of armature circuits (in this case 4 times), having in all $2s = 48$ segments. The two ends of each circuit are connected to each $\frac{n}{2} = 6$ segments. The segments for the armature circuits are represented in Fig. 144. The end, e_1, is connected to the shaded segments, and e_2 to the others. The distance between two segments of one circuit $= \frac{1}{n} = \frac{1}{12^{th}}$ of the circumference. In Fig. 146 a developed view of the collector is given, which shows that the segments lie in a position oblique to the axis, so the brushes must rest on at least two, and at times three segments.

Thus, of the armature coils, at least two, and sometimes three, are in circuit. There is always at least one coil that is cut out, and at the time when its E. M. F. is zero, and about to reverse. The + and – signs of Fig. 146 refer to the points between which the direction of the current in the armature circuits reverses, hence the brushes may be either 1—3—5—7—9 or 11 twelfths of the circumference apart.

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