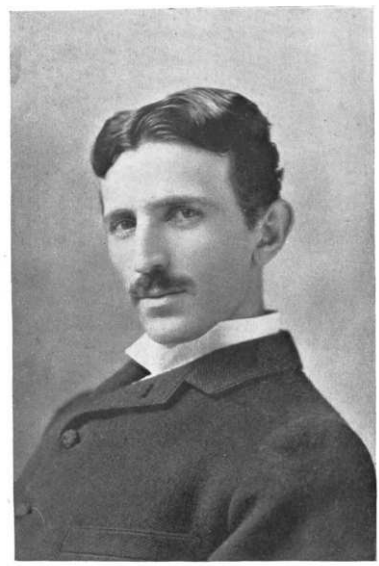
The Inventions Researches and Writings of NIKOLA TESLA



Nikola Tesla

Thomas Commerford Martin

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THE INVENTIONS
RESEARCHES AND WRITINGS
OF
NIKOLA TESLA

TO HIS COUNTRYMEN

IN EASTERN EUROPE THIS RECORD OF
THE WORK ALREADY ACCOMPLISHED BY

NIKOLA TESLA

IS RESPECTFULLY DEDICATED

BY

THOMAS COMMERFORD MARTIN

Editor The Electrical Engineer; Past-President American Institute Electrical Engineers

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PREFACE.

The electrical problems of the present day lie largely in the economical transmission of power and in the radical improvement of the means and methods of illumination. To many workers and thinkers in the domain of electrical invention, the apparatus and devices that are familiar, appear cumbrous and wasteful, and subject to severe limitations. They believe that the principles of current generation must be changed, the area of current supply be enlarged, and the appliances used by the consumer be at once cheapened and simplified. The brilliant successes of the past justify them in every expectancy of still more generous fruition.

The present volume is a simple record of the pioneer work done in such departments up to date, by Mr. Nikola Tesla, in whom the world has already recognized one of the foremost of modern electrical investigators and inventors. No attempt whatever has been made here to emphasize the importance of his researches and discoveries. Great ideas and real inventions win their own way, determining their own place by intrinsic merit. But with the conviction that Mr. Tesla is blazing a path that electrical development must follow for many years to come, the compiler has endeavored to bring together all that bears the impress of Mr. Tesla's genius, and is worthy of preservation. Aside from its value as showing the scope of his inventions, this volume may be of service as indicating the range of his thought. There is intellectual profit in studying the push and play of a vigorous and original mind.

Although the lively interest of the public in Mr. Tesla's work is perhaps of recent growth, this volume covers the results of full ten years. It includes his lectures, miscellaneous articles and discussions, and makes note of all his inventions thus far known, particularly those bearing on polyphase motors and the effects obtained with currents of high potential and high frequency. It will be seen that Mr. Tesla has ever pressed forward, barely pausing for an instant to work out in detail the utilizations that have at once been obvious to him of the new principles he has elucidated. Wherever possible his own language has been employed.

It may be added that this volume is issued with Mr. Tesla's sanction and approval, and that permission has been obtained for the republication in it of such papers as have been read before various technical societies of this country and Europe. Mr. Tesla has kindly favored the author by looking over the proof sheets of the sections embodying his latest researches. The work has also enjoyed the careful revision of the author's friend and editorial associate, Mr. Joseph Wetzler, through whose hands all the proofs have passed.

December, 1893.

T. C. M.

PART I. POLYPHASE CURRENTS.

CHAPTER I.

Biographical and Introductory.

As an introduction to the record contained in this volume of Mr. Tesla's investigations and discoveries, a few words of a biographical nature will, it is deemed, not be out of place, nor other than welcome.

Nikola Tesla was born in 1857 at Smiljan, Lika, a borderland region of Austro-Hungary, of the Serbian race, which has maintained against Turkey and all comers so unceasing a struggle for freedom. His family is an old and representative one among these Switzers of Eastern Europe, and his father was an eloquent clergyman in the Greek Church. An uncle is to-day Metropolitan in Bosnia. His mother was a woman of inherited ingenuity, and delighted not only in skilful work of the ordinary household character, but in the construction of such mechanical appliances as looms and churns and other machinery required in a rural community. Nikola was educated at Gospich in the public school for four years, and then spent three years in the Real Schule. He was then sent to Carstatt, Croatia, where he continued his studies for three years in the Higher Real Schule. There for the first time he saw a steam locomotive. He graduated in 1873, and, surviving an attack of cholera, devoted himself to experimentation, especially in electricity and magnetism. His father would have had him maintain the family tradition by entering the Church, but native genius was too strong, and he was allowed to enter the Polytechnic School at Gratz, to finish his studies, and with the object of becoming a professor of mathematics and physics. One of the machines there experimented with was a Gramme dynamo, used as a motor. Despite his instructor's perfect

demonstration of the fact that it was impossible to operate a dynamo without commutator or brushes, Mr. Tesla could not be convinced that such accessories were necessary or desirable. He had already seen with quick intuition that a way could be found to dispense with them; and from that time he may be said to have begun work on the ideas that fructified ultimately in his rotating field motors.

In the second year of his Gratz course, Mr. Tesla gave up the notion of becoming a teacher, and took up the engineering curriculum. His studies ended, he returned home in time to see his father die, and then went to Prague and Buda-Pesth to study languages, with the object of qualifying himself broadly for the practice of the engineering profession. For a short time he served as an assistant in the Government Telegraph Engineering Department, and then became associated with M. Puskas, a personal and family friend, and other exploiters of the telephone in Hungary. He made a number of telephonic inventions, but found his opportunities of benefiting by them limited in various ways. To gain a wider field of action, he pushed on to Paris and there secured employment as an electrical engineer with one of the large companies in the new industry of electric lighting.

It was during this period, and as early as 1882, that he began serious and continued efforts to embody the rotating field principle in operative apparatus. He was enthusiastic about it; believed it to mark a new departure in the electrical arts, and could think of nothing else. In fact, but for the solicitations of a few friends in commercial circles who urged him to form a company to exploit the invention, Mr. Tesla, then a youth of little worldly experience, would have sought an immediate opportunity to publish his ideas, believing them to be worthy of note as a novel and radical advance in electrical theory as well as destined to have a profound influence on all dynamo electric machinery.

At last he determined that it would be best to try his fortunes in America. In France he had met many Americans, and in contact with them learned the desirability of turning every new idea in electricity to

practical use. He learned also of the ready encouragement given in the United States to any inventor who could attain some new and valuable result. The resolution was formed with characteristic quickness, and abandoning all his prospects in Europe, he at once set his face westward.

Arrived in the United States, Mr. Tesla took off his coat the day he arrived, in the Edison Works. That place had been a goal of his ambition, and one can readily imagine the benefit and stimulus derived from association with Mr. Edison, for whom Mr. Tesla has always had the strongest admiration. It was impossible, however, that, with his own ideas to carry out, and his own inventions to develop, Mr. Tesla could long remain in even the most delightful employ; and, his work now attracting attention, he left the Edison ranks to join a company intended to make and sell an arc lighting system based on some of his inventions in that branch of the art. With unceasing diligence he brought the system to perfection, and saw it placed on the market. But the thing which most occupied his time and thoughts, however, all through this period, was his old discovery of the rotating field principle for alternating current work, and the application of it in motors that have now become known the world over.

Strong as his convictions on the subject then were, it is a fact that he stood very much alone, for the alternating current had no well recognized place. Few electrical engineers had ever used it, and the majority were entirely unfamiliar with its value, or even its essential features. Even Mr. Tesla himself did not, until after protracted effort and experimentation, learn how to construct alternating current apparatus of fair efficiency. But that he had accomplished his purpose was shown by the tests of Prof. Anthony, made in the of winter 1887-8, when Tesla motors in the hands of that distinguished expert gave an efficiency equal to that of direct current motors. Nothing now stood in the way of the commercial development and introduction of such motors, except that

they had to be constructed with a view to operating on the circuits then existing, which in this country were all of high frequency.

The first full publication of his work in this direction—outside his patents—was a paper read before the American Institute of Electrical Engineers in New York, in May, 1888 (read at the suggestion of Prof. Anthony and the present writer), when he exhibited motors that had been in operation long previous, and with which his belief that brushes and commutators could be dispensed with, was triumphantly proved to be correct. The section of this volume devoted to Mr. Tesla's inventions in the utilization of polyphase currents will show how thoroughly from the outset he had mastered the fundamental idea and applied it in the greatest variety of ways.

Having noted for years the many advantages obtainable with alternating currents, Mr. Tesla was naturally led on to experiment with them at higher potentials and higher frequencies than were common or approved of. Ever pressing forward to determine in even the slightest degree the outlines of the unknown, he was rewarded very quickly in this field with results of the most surprising nature. A slight acquaintance with some of these experiments led the compiler of this volume to urge Mr. Tesla to repeat them before the American Institute of Electrical Engineers. This was done in May, 1891, in a lecture that marked, beyond question, a distinct departure in electrical theory and practice, and all the results of which have not yet made themselves fully apparent. The New York lecture, and its successors, two in number, are also included in this volume, with a few supplementary notes.

Mr. Tesla's work ranges far beyond the vast departments of polyphase currents and high potential lighting. The "Miscellaneous" section of this volume includes a great many other inventions in arc lighting, transformers, pyro-magnetic generators, thermo-magnetic motors, third-brush regulation, improvements in dynamos, new forms of incandescent lamps, electrical meters, condensers, unipolar dynamos, the conversion of alternating into direct currents, etc. It is needless to say

that at this moment Mr. Tesla is engaged on a number of interesting ideas and inventions, to be made public in due course. The present volume deals simply with his work accomplished to date.

CHAPTER II.

A New System of Alternating Current Motors and Transformers.

The present section of this volume deals with polyphase currents, and the inventions by Mr. Tesla, made known thus far, in which he has embodied one feature or another of the broad principle of rotating field poles or *resultant attraction* exerted on the armature. It is needless to remind electricians of the great interest aroused by the first enunciation of the rotating field principle, or to dwell upon the importance of the advance from a single alternating current, to methods and apparatus which deal with more than one. Simply prefacing the consideration here attempted of the subject, with the remark that in nowise is the object of this volume of a polemic or controversial nature, it may be pointed out that Mr. Tesla's work has not at all been fully understood or realized up to date. To many readers, it is believed, the analysis of what he has done in this department will be a revelation, while it will at the same time illustrate the beautiful flexibility and range of the principles involved. It will be seen that, as just suggested, Mr. Tesla did not stop short at a mere rotating field, but dealt broadly with the shifting of the resultant attraction of the magnets. It will be seen that he went on to evolve the "multiphase" system with many ramifications and turns; that he showed the broad idea of motors employing currents of differing phase in the armature with direct currents in the field; that he first described and worked out the idea of an armature with a body of iron and coils closed upon themselves; that he worked out both synchronizing and torque motors; that he explained and illustrated how machines of ordinary construction might be adapted to his system; that he employed condensers in field and armature circuits, and went to the bottom of the fundamental principles, testing, approving or rejecting, it would appear, every detail that inventive ingenuity could hit upon.

Now that opinion is turning so emphatically in favor of lower frequencies, it deserves special note that Mr. Tesla early recognized the importance of the low frequency feature in motor work. In fact his first motors exhibited publicly—and which, as Prof. Anthony showed in his tests in the winter of 1887-8, were the equal of direct current motors in efficiency, output and starting torque—were of the low frequency type. The necessity arising, however, to utilize these motors in connection with the existing high frequency circuits, our survey reveals in an interesting manner Mr. Tesla's fertility of resource in this direction. But that, after exhausting all the possibilities of this field, Mr. Tesla returns to low frequencies, and insists on the superiority of his polyphase system in alternating current distribution, need not at all surprise us, in view of the strength of his convictions, so often expressed, on this subject. This is, indeed, significant, and may be regarded as indicative of the probable development next to be witnessed.

Incidental reference has been made to the efficiency of rotating field motors, a matter of much importance, though it is not the intention to dwell upon it here. Prof. Anthony in his remarks before the American Institute of Electrical Engineers, in May, 1888, on the two small Tesla motors then shown, which he had tested, stated that one gave an efficiency of about 50 per cent. and the other a little over sixty per cent. In 1889, some tests were reported from Pittsburgh, made by Mr. Tesla and Mr. Albert Schmid, on motors up to 10 h. p. and weighing about 850 pounds. These machines showed an efficiency of nearly 90 per cent. With some larger motors it was then found practicable to obtain an efficiency, with the three wire system, up to as high as 94 and 95 per cent. These interesting figures, which, of course, might be supplemented by others more elaborate and of later date, are cited to show that the efficiency of the system has not had to wait until the present late day for any demonstration of its commercial usefulness. An invention is none the less beautiful because it may lack utility, but it must be a pleasure to any inventor to know that the ideas he is advancing are fraught with substantial benefits to the public.

CHAPTER III.

The Tesla Rotating Magnetic Field.—Motors With Closed Conductors.—Synchronizing Motors.—Rotating Field Transformers.

The best description that can be given of what he attempted, and succeeded in doing, with the rotating magnetic field, is to be found in Mr. Tesla's brief paper explanatory of his rotary current, polyphase system, read before the American Institute of Electrical Engineers, in New York, in May, 1888, under the title "A New System of Alternate Current Motors and Transformers." As a matter of fact, which a perusal of the paper will establish, Mr. Tesla made no attempt in that paper to describe all his work. It dealt in reality with the few topics enumerated in the caption of this chapter. Mr. Tesla's reticence was no doubt due largely to the fact that his action was governed by the wishes of others with whom he was associated, but it may be worth mention that the compiler of this volume—who had seen the motors running, and who was then chairman of the Institute Committee on Papers and Meetings—had great difficulty in inducing Mr. Tesla to give the Institute any paper at all. Mr. Tesla was overworked and ill, and manifested the greatest reluctance to an exhibition of his motors, but his objections were at last overcome. The paper was written the night previous to the meeting, in pencil, very hastily, and under the pressure just mentioned.

In this paper casual reference was made to two special forms of motors not within the group to be considered. These two forms were: 1. A motor with one of its circuits in series with a transformer, and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator, and the field coils closed upon themselves. The paper in its essence is as follows, dealing with a few leading features of the Tesla system, namely, the rotating magnetic

field, motors with closed conductors, synchronizing motors, and rotating field transformers:—

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems, and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now, the currents so directed cannot be utilized in the motor, but they must—again by means of a similar unreliable device—be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by, such currents.

But the operation of the commutator on a motor is twofold; first, it reverses the currents through the motor, and secondly, it effects auto-

matically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the systems, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself—How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

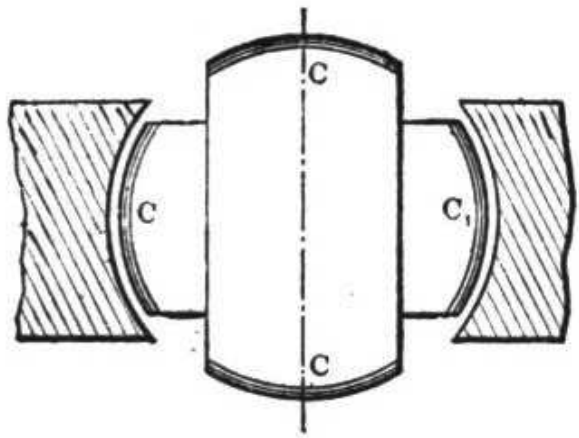


Fig. 1.

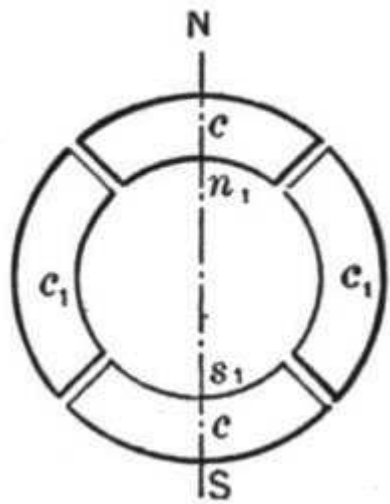


Fig. 1a.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet-iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in Fig. 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, Figs. 1 to 8*a*. The field of the generator being independently excited, the rotation of the armature sets up currents in the coils C C_1, varying in strength and direction in the well-known manner. In the position shown in Fig. 1, the current in coil C is nil, while coil C_1 is traversed by its maximum current, and the connections may be such that the ring is magnetized by the coils c_1 c_1, as indicated by the letters N S in Fig. 1*a*, the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil C.

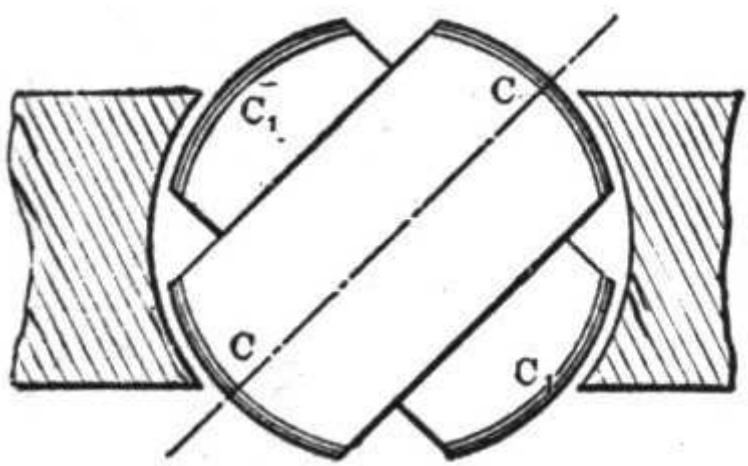


Fig. 2.

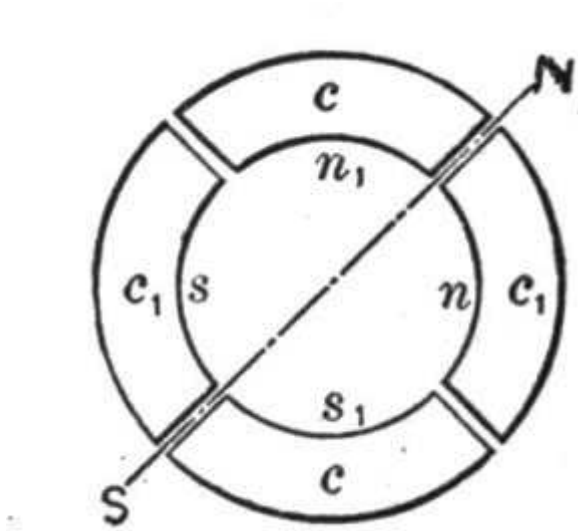


Fig. 2a.

In Fig. 2, the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Fig. 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil C_1 generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil C also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s*, as shown in Fig. 2*a*. The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

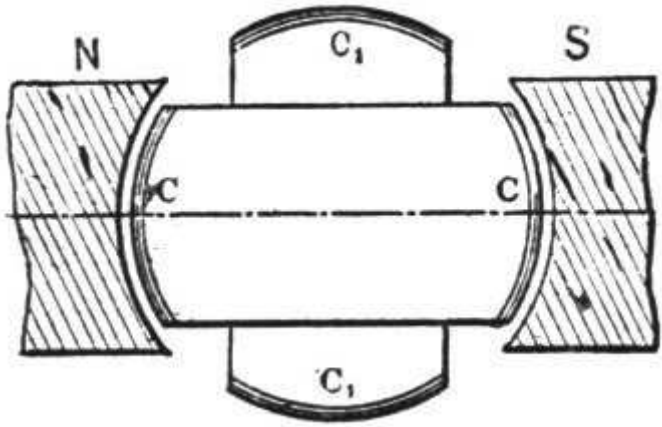


Fig. 3.

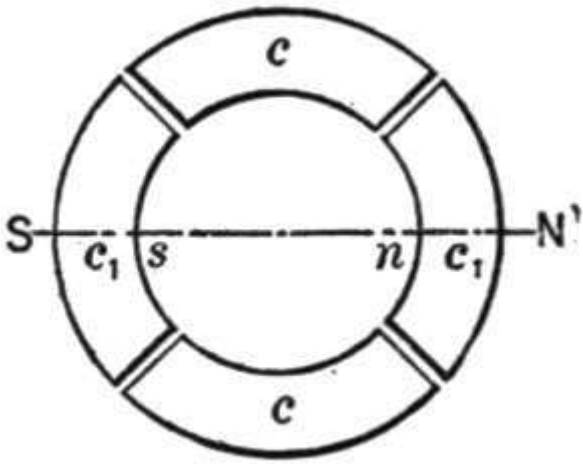


Fig. 3a.

In Fig. 3 the armature has completed one quarter of one revolution. In this phase the current in coil C is a maximum, and of such direction as to produce the poles N S in Fig. 3*a*, whereas the current in coil C_1 is nil, this coil being at its neutral position. The poles N S in Fig. 3*a* are thus shifted one quarter of the circumference of the ring.

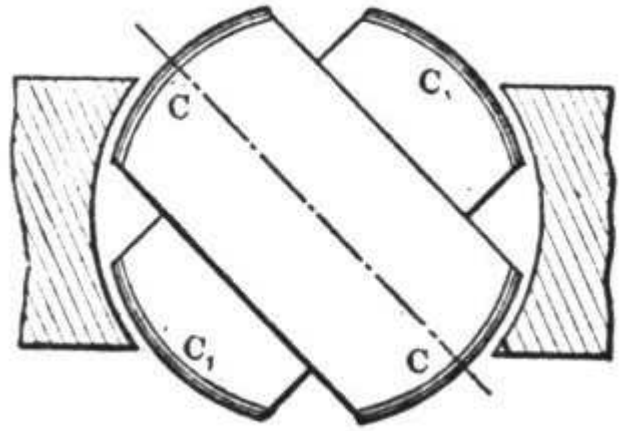


Fig. 4.

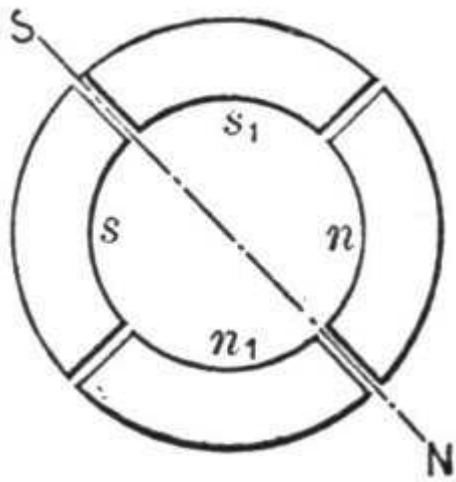


Fig. 4a.

Fig. 4 shows the coils C C in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil C still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in Fig. 4*a*. The current in the coil C_1 is of the same strength, but opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 s_1, as indicated, and a polarity, N S, results, the poles now being shifted three-eighths of the periphery of the ring.

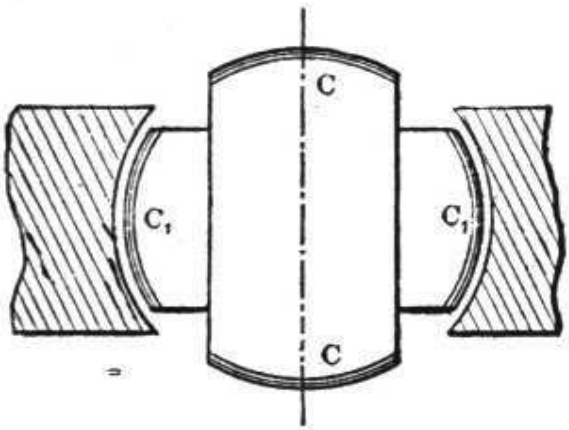


Fig. 5.

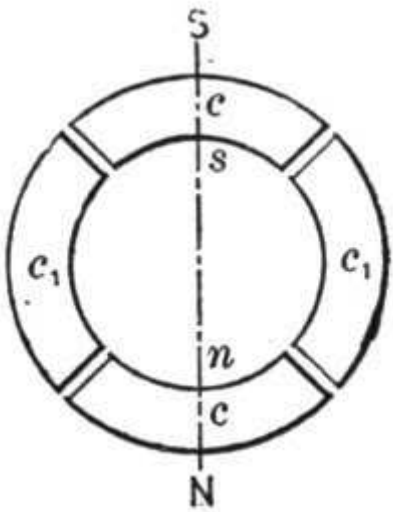


Fig. 5a.

In Fig. 5 one half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in Fig. 5*a*. Now the current in coil C is nil, while the coil C_1 yields its maximum current, which is of the same direction as previously; the magnetizing effect is, therefore, due to the coils, c_1 c_1 alone, and, referring to Fig. 5*a*, it will be observed that the poles N S are shifted one half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the Figs. 6 to 8*a*.

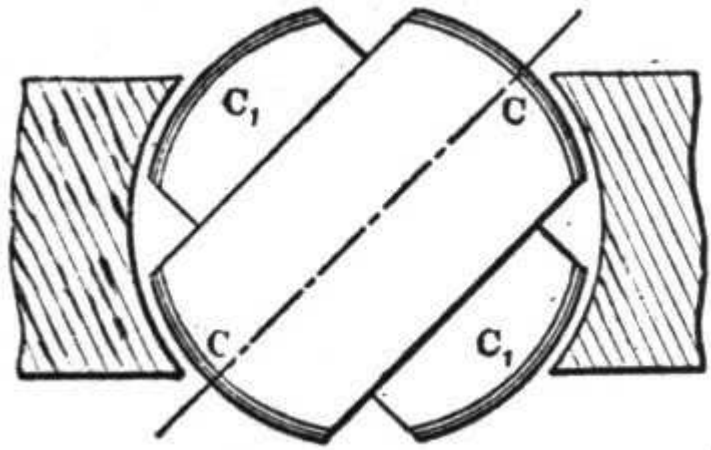


Fig. 6.

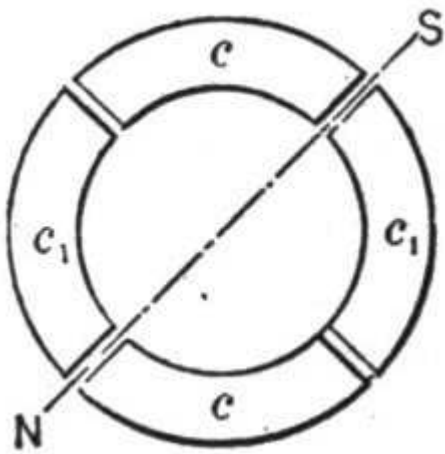


Fig. 6a.

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and, each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically the same. Instead of using four wires,

with like result, three wires may be used, one forming a common return for both circuits.

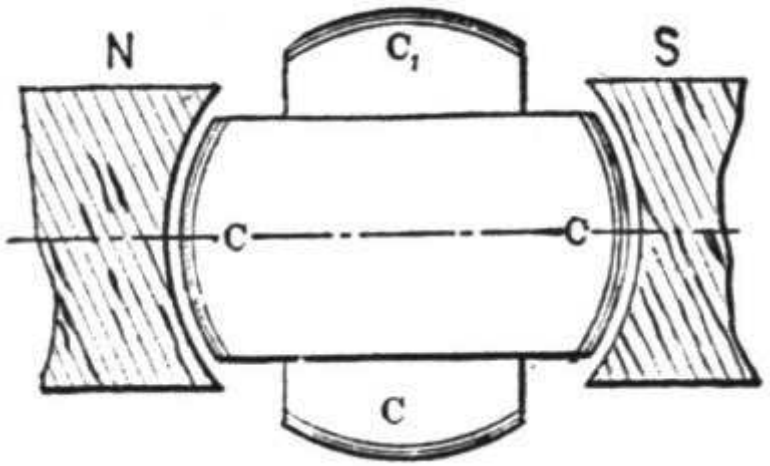


Fig. 7.

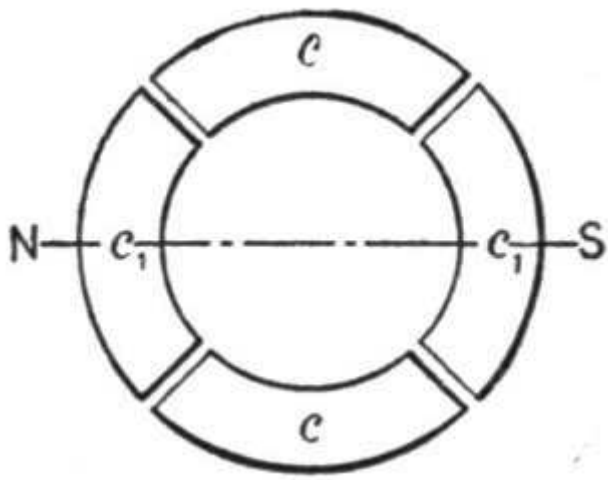


Fig. 7a.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance,

noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a position symmetrical to the ring. This is easily explained. Each time that a pole approaches, it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions, Fig. 9. When placed symmetrically to the ring, the pull on the opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investigations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring, they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may easily be observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects and may be utilized to generate currents in a closed con-

ductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils forming respectively the primary and secondary circuits, as shown in Fig. 10. In order to secure the most economical results the magnetic circuit should be completely closed, and with this object in view the construction may be modified at will.

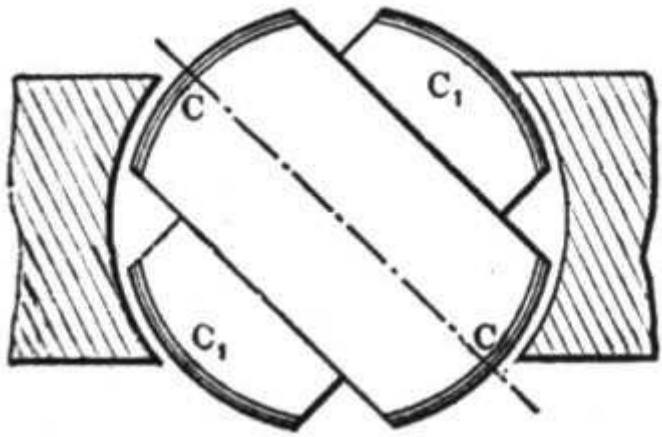


Fig. 8.

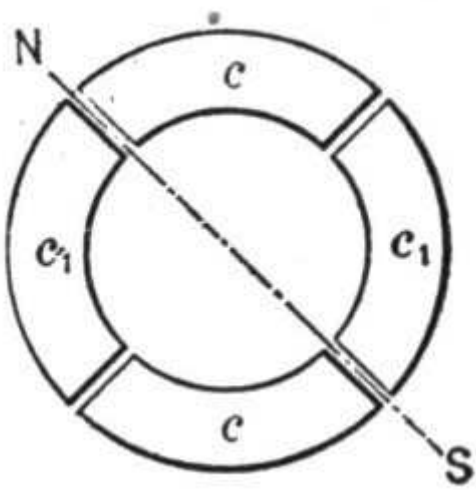


Fig. 8a.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils, the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the co-ordinates both of its components. These are then respectively the sine and cosine of the angle α between the radius and one of the axes (*O X*). Referring to Fig. 11, we have $r^2 = x^2 + y^2$; where $x = r \cos \alpha$, and $y = r \sin \alpha$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current—which may be admitted for weak degrees of magnetization—then $x = Kc$ and $y = Kc^1$, where K is a constant and c and c^1 the current in both sets of coils respectively. Supposing, further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin \alpha$ and $c = K^1 \sin (90° + \alpha) = K^1 \cos \alpha$, where K^1 is a constant. See Fig. 12.

Therefore,

$$x = K\,c = K\,K^1 \cos \alpha;$$
$$y = K\,c^1 = K\,K^1 \sin \alpha; \text{ and}$$
$$K\,K^1 = r.$$

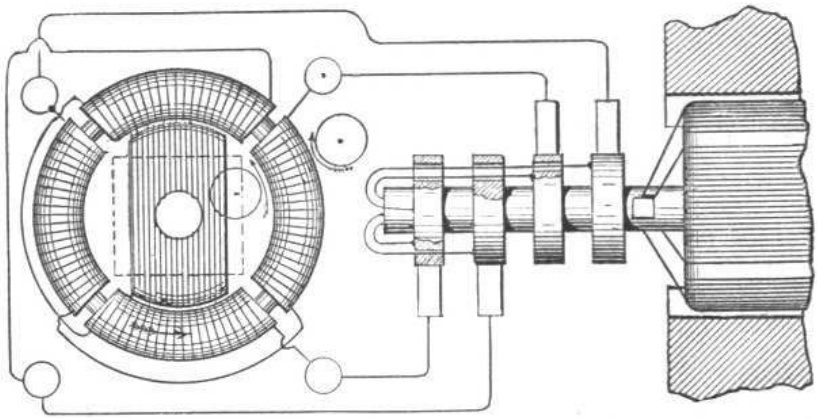


Fig. 9.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for $y = 0$, $r = x$; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways:

1. By the alternate currents of the source only.

2. By a combined action of these and of induced currents.

3. By the joint action of alternate and continuous currents.

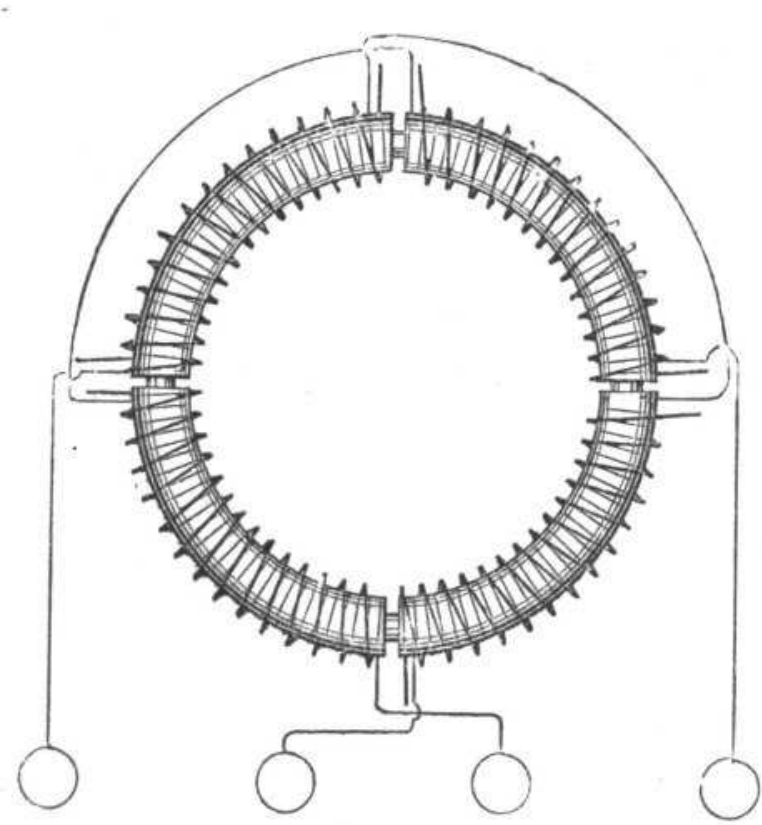


Fig. 10.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in Fig. 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in Fig. 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is pro-

duced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and currents being generated in the coil as long as the speed of the armature is inferior to that of the poles, considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous current the motor may not be able to start, but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating, it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

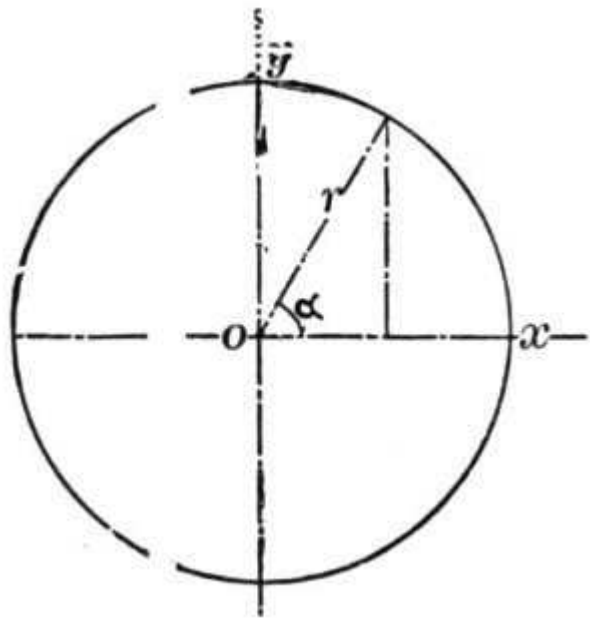


Fig. 11.

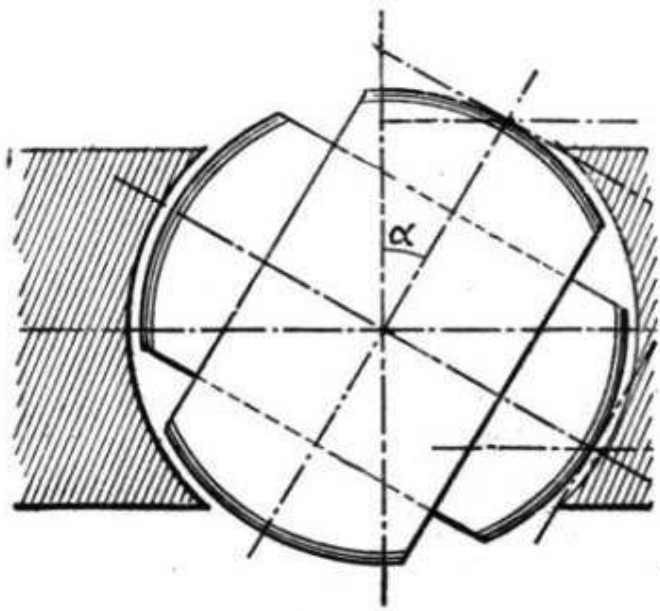


Fig. 12.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in Fig. 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed positions relatively to the field magnet, and the same is magnetized by induction, exhibiting a distinct pole on each of the pole-pieces. If a piece of soft iron is approached to the field magnet, it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases, the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that synchronism is reached and the field magnet energized by induction.

The disc may also be used for the experiment. If held quite close to the armature it will turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

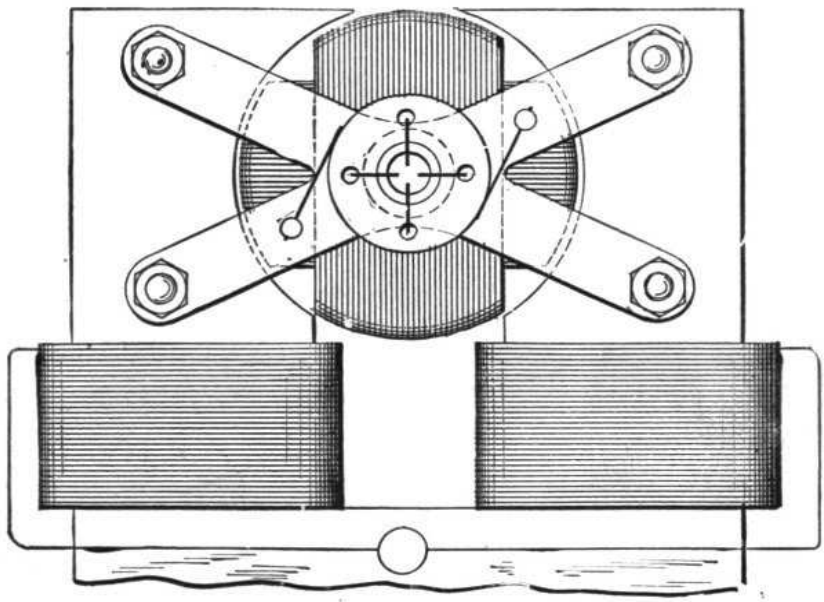


Fig. 13.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed. A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the

other elements should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

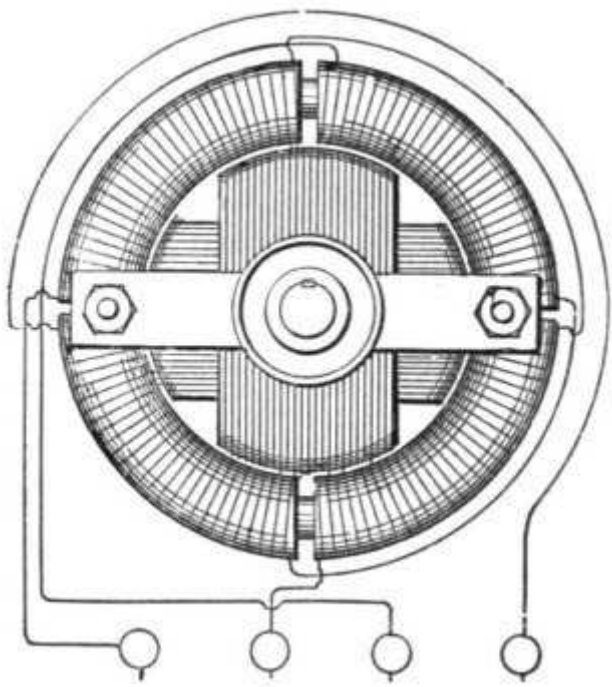


Fig. 14.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two coils at right angles as in Fig. 14, are sufficient, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since this action is entirely independent of the speed—that is, as far as the location of the poles is concerned—a continuous pull is exerted upon the pe-

riphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energizing coils, thus increasing the effort. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energizing coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

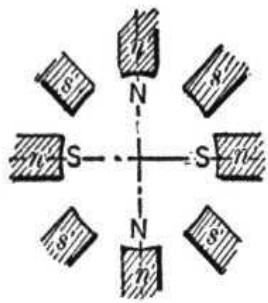


Fig. 15.

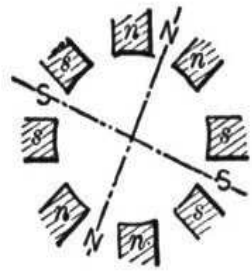


Fig. 16.

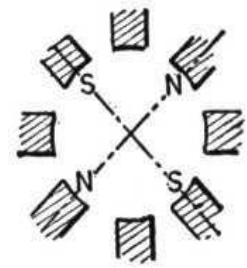


Fig. 17.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their property of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles.

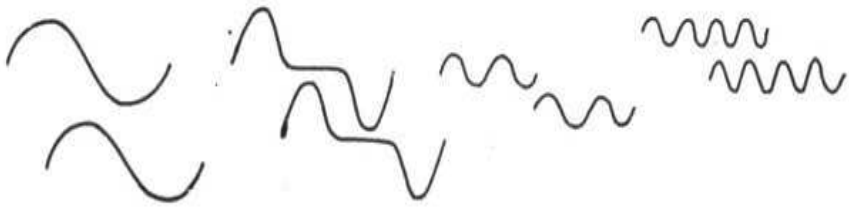


Fig. 18. **Fig. 19.** **Fig. 20.** **Fig. 21.**

If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for that reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action, namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electromotive force. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, this result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft and any desired preponderance may be given to either one, or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is

best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as used in the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is, 1, 3, 5 ... in one, and 2, 4, 6 ... in the other, and the coils of each set of series may be connected all in the same manner, or alternately in opposition; in the latter case a motor with half the number of poles will result, and its action will be correspondingly modified. The Figs. 15, 16, and 17, show three different phases, the magnet coils in each circuit being connected alternately in opposition. In this case there will be always four poles, as in Figs. 15 and 17; four pole projections will be neutral; and in Fig. 16 two adjacent pole projections will have the same polarity. If the coils are connected in the same manner there will be eight alternating poles, as indicated by the letters $n' s'$ in Fig. 15.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current sys-

tem, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still, exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case, the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles, and it would be desired to obtain a speed equal to 12/7 of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this, the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in

the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by n/n_1.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuit or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, Figs. 18, 19, 20 and 21, which are self-explanatory. Fig. 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in Fig. 9 is employed, one complete wave in each circuit will produce one revolution of the motor. In Fig. 19 the same result will be effected by one wave in each circuit, the impulses being successive; in Fig. 20 by four, and in Fig. 21 by eight waves.

By such means any desired speed may be attained, that is, at least within the limits of practical demands. This system possesses this advantage, besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:

In a transformer, as constructed at present, we produce the currents in the secondary circuit by varying the strength of the primary or excit-

ing currents. If we admit proportionality with respect to the iron core the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are employed; from this practice various disadvantages result. These are: Increased cost and diminished efficiency of the generator; more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in a transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

CHAPTER IV.

Modifications and Expansions of the Tesla Polyphase Systems.

In his earlier papers and patents relative to polyphase currents, Mr. Tesla devoted himself chiefly to an enunciation of the broad lines and ideas lying at the basis of this new work; but he supplemented this immediately by a series of other striking inventions which may be regarded as modifications and expansions of certain features of the Tesla systems. These we shall now proceed to deal with.

In the preceding chapters we have thus shown and described the Tesla electrical systems for the transmission of power and the conversion and distribution of electrical energy, in which the motors and the transformers contain two or more coils or sets of coils, which were connected up in independent circuits with corresponding coils of an alternating current generator, the operation of the system being brought about by the co-operation of the alternating currents in the independent circuits in progressively moving or shifting the poles or points of maximum magnetic effect of the motors or converters. In these systems two independent conductors are employed for each of the independent circuits connecting the generator with the devices for converting the transmitted currents into mechanical energy or into electric currents of another character. This, however, is not always necessary. The two or more circuits may have a single return path or wire in common, with a loss, if any, which is so extremely slight that it may be disregarded entirely. For the sake of illustration, if the generator have two independent coils and the motor two coils or two sets of coils in corresponding relations to its operative elements one terminal of each generator coil is connected to the corresponding terminals of the motor coils through two independent conductors, while the opposite terminals of the respective coils are both connected to one return wire. The following description deals with the modification. Fig. 22 is a diagrammatic illus-

tration of a generator and single motor constructed and electrically connected in accordance with the invention. Fig. 23 is a diagram of the system as it is used in operating motors or converters, or both, in parallel, while Fig. 24 illustrates diagrammatically the manner of operating two or more motors or converters, or both, in series. Referring to Fig. 22, A A designate the poles of the field magnets of an alternating-current generator, the armature of which, being in this case cylindrical in form and mounted on a shaft, C, is wound longitudinally with coils B B'. The shaft C carries three insulated contact-rings, *a b c*, to two of which, as *b c*, one terminal of each coil, as *e d*, is connected. The remaining terminals, *f g*, are both connected to the third ring, *a*.

A motor in this case is shown as composed of a ring, H, wound with four coils, I I J J, electrically connected, so as to co-operate in pairs, with a tendency to fix the poles of the ring at four points ninety degrees apart. Within the magnetic ring H is a disc or cylindrical core wound with two coils, G G', which may be connected to form two closed circuits. The terminals *j k* of the two sets or pairs of coils are connected, respectively, to the binding-posts E' F', and the other terminals, *h i*, are connected to a single binding-post, D'. To operate the motor, three line-wires are used to connect the terminals of the generator with those of the motor.

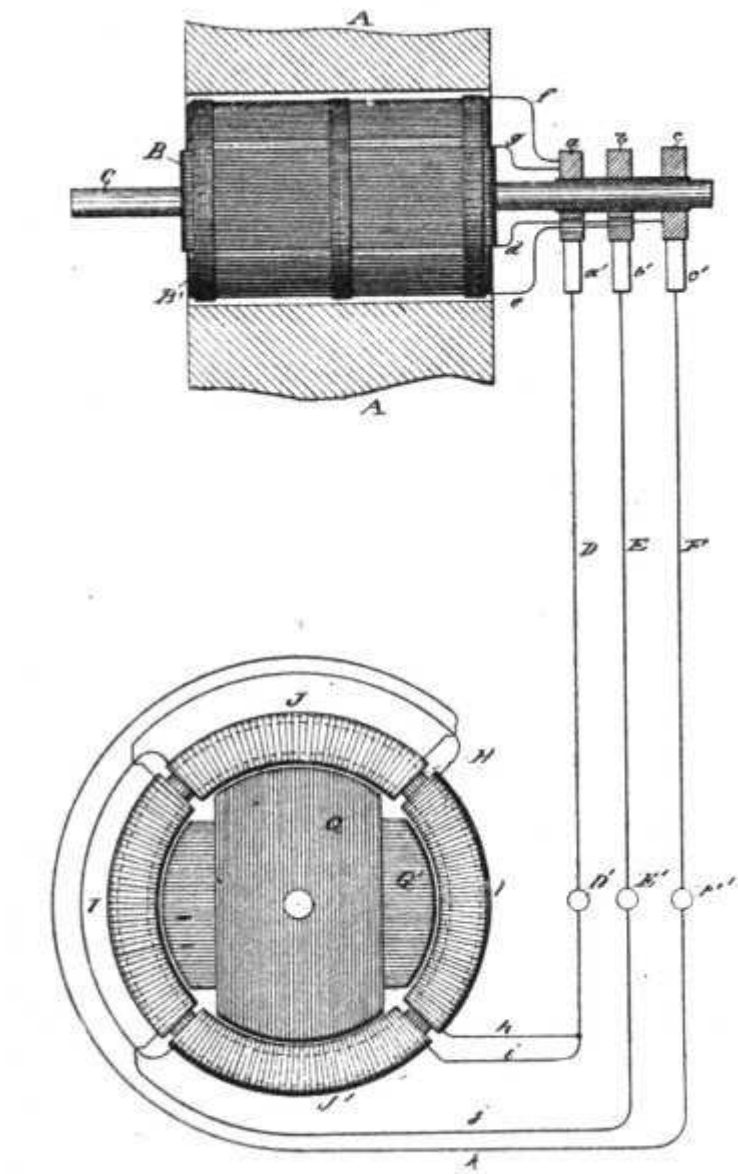


Fig. 22.

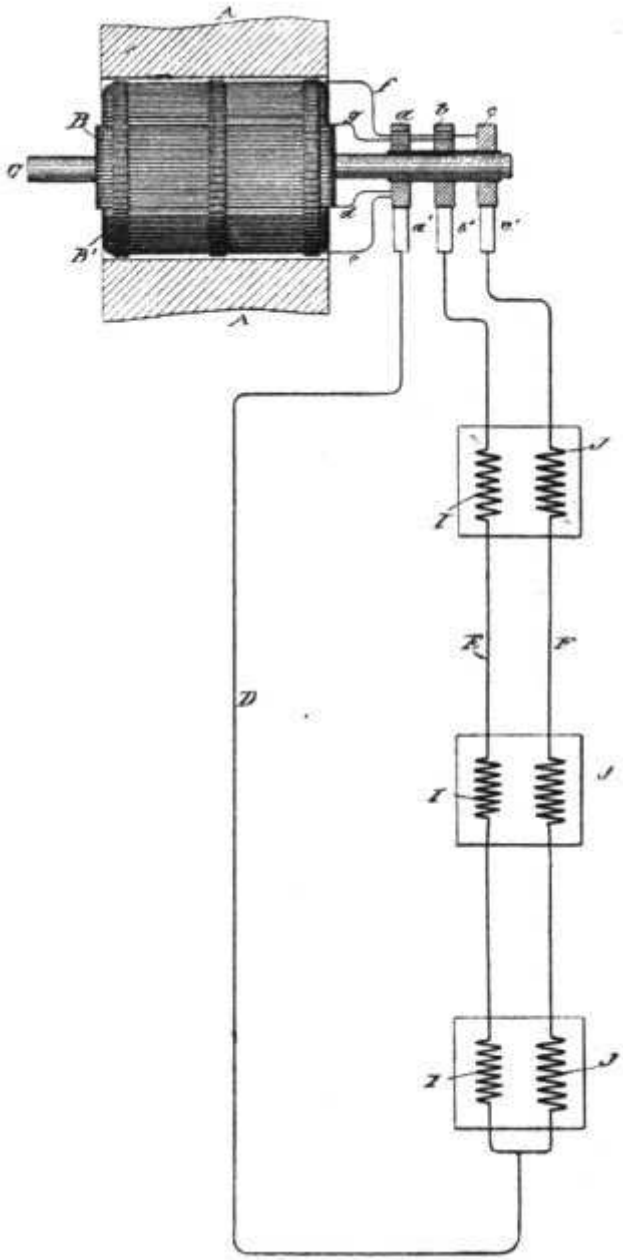


Fig. 24.

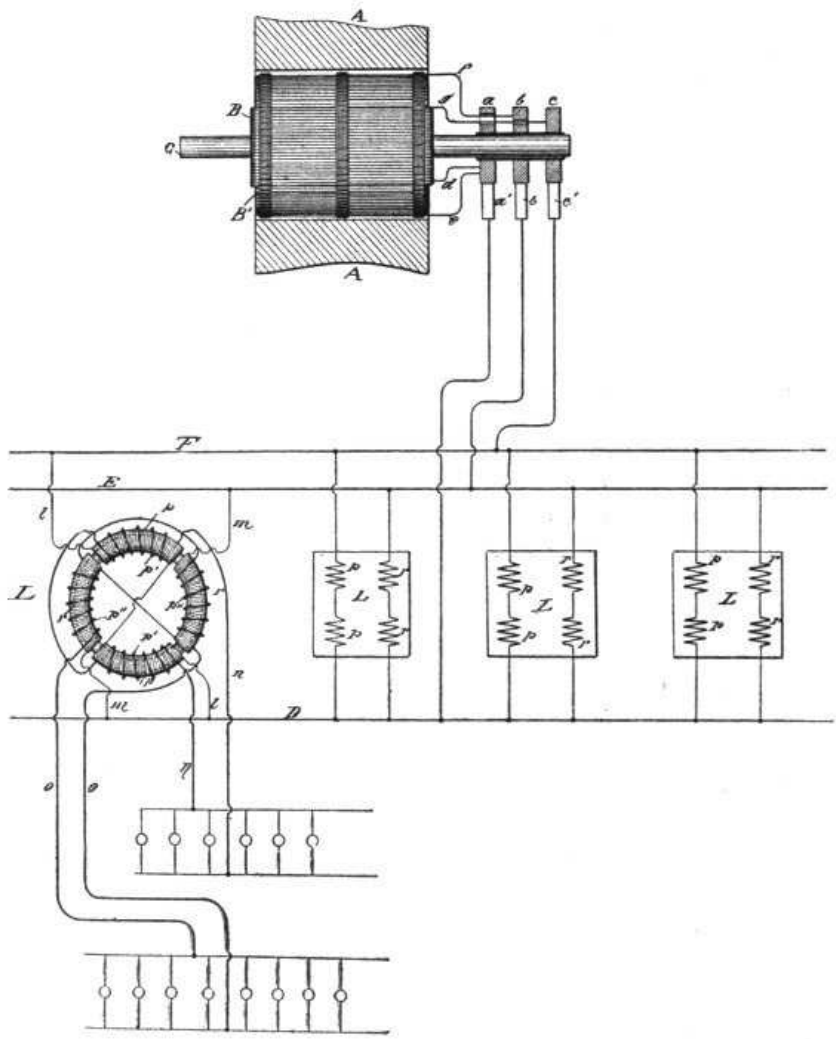


Fig. 23.

So far as the apparent action or mode of operation of this arrangement is concerned, the single wire D, which is, so to speak, a common return-wire for both circuits, may be regarded as two independent wires. In the illustration, with the order of connection shown, coil B' of the generator is producing its maximum current and coil B its minimum; hence the current which passes through wire *e*, ring *b*, brush *b'*, line-wire E, terminal E', wire *j*, coils I I, wire or terminal D', line-wire

D, brush *a'*, ring *a*, and wire *f*, fixes the polar line of the motor midway between the two coils I I; but as the coil B' moves from the position indicated it generates less current, while coil B, moving into the field, generates more. The current from coil B passes through the devices and wires designated by the letters *d*, *c*, *c'* F, F' *k*, J J, *i*, D', D, *a'*, *a*, and *g*, and the position of the poles of the motor will be due to the resultant effect of the currents in the two sets of coils—that is, it will be advanced in proportion to the advance or forward movement of the armature coils. The movement of the generator-armature through one-quarter of a revolution will obviously bring coil B' into its neutral position and coil B into its position of maximum effect, and this shifts the poles ninety degrees, as they are fixed solely by coils B. This action is repeated for each quarter of a complete revolution.

When more than one motor or other device is employed, they may be run either in parallel or series. In Fig. 23 the former arrangement is shown. The electrical device is shown as a converter, L, of which the two sets of primary coils *p r* are connected, respectively, to the mains F E, which are electrically connected with the two coils of the generator. The cross-circuit wires *l m*, making these connections, are then connected to the common return-wire D. The secondary coils *p' p''* are in circuits *n o*, including, for example, incandescent lamps. Only one converter is shown entire in this figure, the others being illustrated diagrammatically.

When motors or converters are to be run in series, the two wires E F are led from the generator to the coils of the first motor or converter, then continued on to the next, and so on through the whole series, and are then joined to the single wire D, which completes both circuits through the generator. This is shown in Fig. 24, in which J I represent the two coils or sets of coils of the motors.

There are, of course, other conditions under which the same idea may be carried out. For example, in case the motor and generator each has three independent circuits, one terminal of each circuit is connect-

ed to a line-wire, and the other three terminals to a common return-conductor. This arrangement will secure similar results to those attained with a generator and motor having but two independent circuits, as above described.

When applied to such machines and motors as have three or more induced circuits with a common electrical joint, the three or more terminals of the generator would be simply connected to those of the motor. Mr. Tesla states, however, that the results obtained in this manner show a lower efficiency than do the forms dwelt upon more fully above.

CHAPTER V.

Utilizing Familiar Types of Generator of the Continuous Current Type.

The preceding descriptions have assumed the use of alternating current generators in which, in order to produce the progressive movement of the magnetic poles, or of the resultant attraction of independent field magnets, the current generating coils are independent or separate. The ordinary forms of continuous current dynamos may, however, be employed for the same work, in accordance with a method of adaptation devised by Mr. Tesla. As will be seen, the modification involves but slight changes in their construction, and presents other elements of economy.

On the shaft of a given generator, either in place of or in addition to the regular commutator, are secured as many pairs of insulated collecting-rings as there are circuits to be operated. Now, it will be understood that in the operation of any dynamo electric generator the currents in the coils in their movement through the field of force undergo different phases—that is to say, at different positions of the coils the currents have certain directions and certain strengths—and that in the Tesla motors or transformers it is necessary that the currents in the energizing coils should undergo a certain order of variations in strength and direction. Hence, the further step—viz., the connection between the induced or generating coils of the machine and the contact-rings from which the currents are to be taken off—will be determined solely by what order of variations of strength and direction in the currents is desired for producing a given result in the electrical translating device. This may be accomplished in various ways; but in the drawings we give typical instances only of the best and most practicable ways of

applying the invention to three of the leading types of machines in widespread use, in order to illustrate the principle.

Fig. 25 is a diagram illustrative of the mode of applying the invention to the well-known type of "closed" or continuous circuit machines. Fig. 26 is a similar diagram embodying an armature with separate coils connected diametrically, or what is generally called an "open-circuit" machine. Fig. 27 is a diagram showing the application of the invention to a machine the armature-coils of which have a common joint.

Referring to Fig. 25, let A represent a Tesla motor or transformer which, for convenience, we will designate as a "converter." It consists of an annular core, B, wound with four independent coils, C and D, those diametrically opposite being connected together so as to cooperate in pairs in establishing free poles in the ring, the tendency of each pair being to fix the poles at ninety degrees from the other. There may be an armature, E, within the ring, which is wound with coils closed upon themselves. The object is to pass through coils C D currents of such relative strength and direction as to produce a progressive shifting or movement of the points of maximum magnetic effect around the ring, and to thereby maintain a rotary movement of the armature. There are therefore secured to the shaft F of the generator, four insulated contact-rings, *a b c d*, upon which bear the collecting-brushes *a′ b′ c′ d′*, connected by wires G G H H, respectively, with the terminals of coils C and D.

Assume, for sake of illustration, that the coils D D are to receive the maximum and coils C C at the same instant the minimum current, so that the polar line may be midway between the coils D D. The rings *a b* would therefore be connected to the continuous armature-coil at its neutral points with respect to the field, or the point corresponding with that of the ordinary commutator brushes, and between which exists the greatest difference of potential; while rings *c d* would be connected to two points in the coil, between which exists no difference of potential.

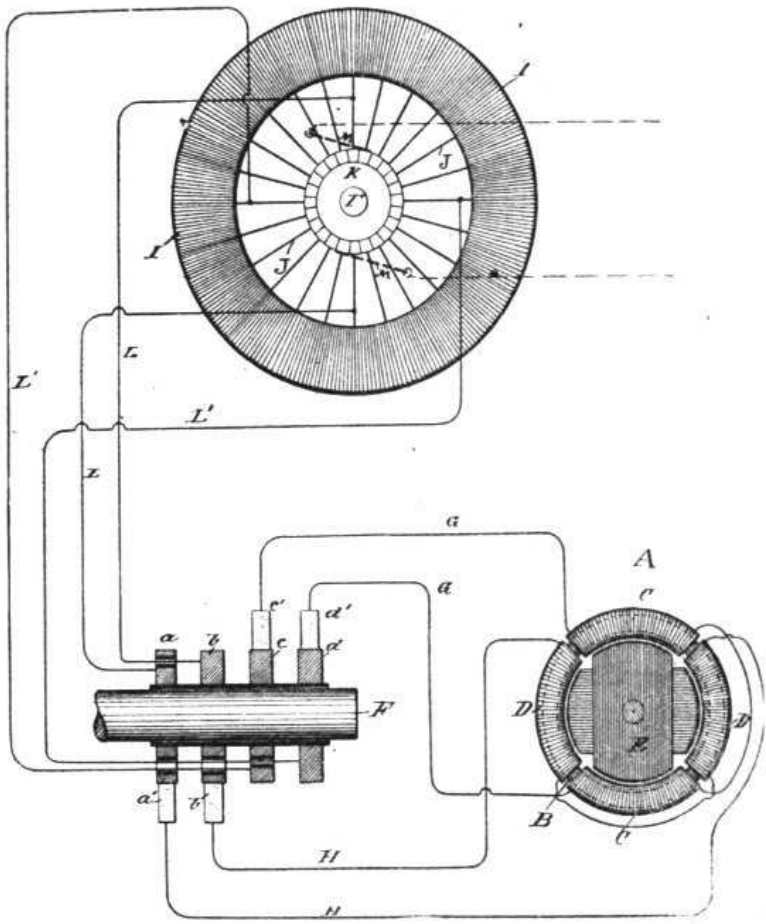


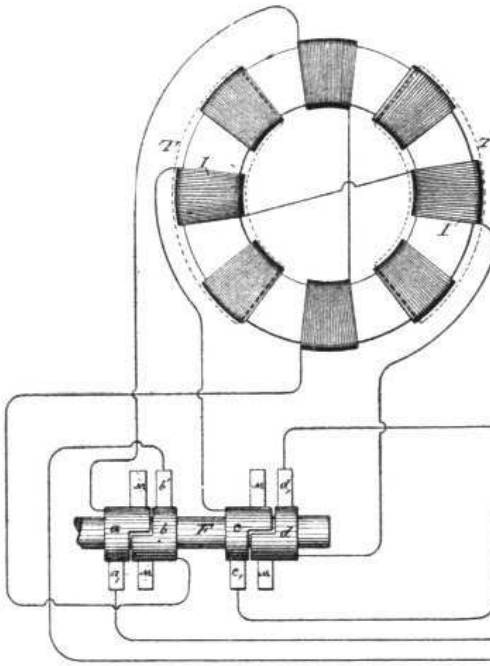
Fig. 25.

The best results will be obtained by making these connections at points equidistant from one another, as shown. These connections are easiest made by using wires L between the rings and the loops or wires J, connecting the coil I to the segments of the commutator K. When the converters are made in this manner, it is evident that the phases of the currents in the sections of the generator coil will be reproduced in the converter coils. For example, after turning through an arc of ninety degrees the conductors L L, which before conveyed the maximum current, will receive the minimum current by reason of the change in the position of their coils, and it is evident that for the same reason the cur-

rent in these coils has gradually fallen from the maximum to the minimum in passing through the arc of ninety degrees. In this special plan of connections, the rotation of the magnetic poles of the converter will be synchronous with that of the armature coils of the generator, and the result will be the same, whether the energizing circuits are derivations from a continuous armature coil or from independent coils, as in Mr. Tesla's other devices.

In Fig. 25, the brushes M M are shown in dotted lines in their proper normal position. In practice these brushes may be removed from the commutator and the field of the generator excited by an external source of current; or the brushes may be allowed to remain on the commutator and to take off a converted current to excite the field, or to be used for other purposes.

In a certain well-known class of machines known as the "open circuit," the armature contains a number of coils the terminals of which connect to commutator segments, the coils being connected across the armature in pairs. This type of machine is represented in Fig. 26. In this machine each pair of coils goes through the same phases as the coils in some of the generators already shown, and it is obviously only necessary to utilize them in pairs or sets to operate a Tesla converter by extending the segments of the commutators belonging to each pair of coils and causing a collecting brush to bear on the continuous portion of each segment. In this way two or more circuits may be taken off from the generator, each including one or more pairs or sets of coils as may be desired.



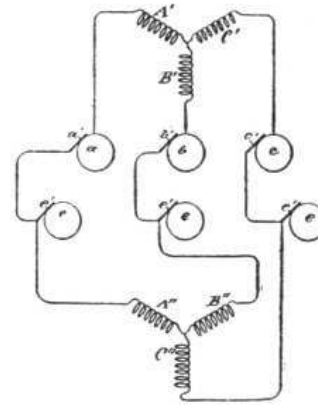


Fig. 26. **Fig. 27.**

In Fig. 26 I I represent the armature coils, T T the poles of the field magnet, and F the shaft carrying the commutators, which are extended to form continuous portions *a b c d*. The brushes bearing on the continuous portions for taking off the alternating currents are represented by *a′ b′ c′ d′*. The collecting brushes, or those which may be used to take off the direct current, are designated by M M. Two pairs of the armature coils and their commutators are shown in the figure as being utilized; but all may be utilized in a similar manner.

There is another well-known type of machine in which three or more coils, A' B' C', on the armature have a common joint, the free ends being connected to the segments of a commutator. This form of generator is illustrated in Fig. 27. In this case each terminal of the generator is connected directly or in derivation to a continuous ring, *a b c*,

and collecting brushes, *a′ b′ c′*, bearing thereon, take off the alternating currents that operate the motor. It is preferable in this case to employ a motor or transformer with three energizing coils, A" B" C", placed symmetrically with those of the generator, and the circuits from the latter are connected to the terminals of such coils either directly—as when they are stationary—or by means of brushes *e′* and contact rings *e*. In this, as in the other cases, the ordinary commutator may be used on the generator, and the current taken from it utilized for exciting the generator field-magnets or for other purposes.

CHAPTER VI.

Method of Obtaining Desired Speed of Motor or Generator.

With the object of obtaining the desired speed in motors operated by means of alternating currents of differing phase, Mr. Tesla has devised various plans intended to meet the practical requirements of the case, in adapting his system to types of multipolar alternating current machines yielding a large number of current reversals for each revolution.

For example, Mr. Tesla has pointed out that to adapt a given type of alternating current generator, you may couple rigidly two complete machines, securing them together in such a way that the requisite difference in phase will be produced; or you may fasten two armatures to the same shaft within the influence of the same field and with the requisite angular displacement to yield the proper difference in phase between the two currents; or two armatures may be attached to the same shaft with their coils symmetrically disposed, but subject to the influence of two sets of field magnets duly displaced; or the two sets of coils may be wound on the same armature alternately or in such manner that they will develop currents the phases of which differ in time sufficiently to produce the rotation of the motor.

Another method included in the scope of the same idea, whereby a single generator may run a number of motors either at its own rate of speed or all at different speeds, is to construct the motors with fewer poles than the generator, in which case their speed will be greater than that of the generator, the rate of speed being higher as the number of their poles is relatively less. This may be understood from an example, taking a generator that has two independent generating coils which revolve between two pole pieces oppositely magnetized; and a motor

with energizing coils that produce at any given time two magnetic poles in one element that tend to set up a rotation of the motor. A generator thus constructed yields four reversals, or impulses, in each revolution, two in each of its independent circuits; and the effect upon the motor is to shift the magnetic poles through three hundred and sixty degrees. It is obvious that if the four reversals in the same order could be produced by each half-revolution of the generator the motor would make two revolutions to the generator's one. This would be readily accomplished by adding two intermediate poles to the generator or altering it in any of the other equivalent ways above indicated. The same rule applies to generators and motors with multiple poles. For instance, if a generator be constructed with two circuits, each of which produces twelve reversals of current to a revolution, and these currents be directed through the independent energizing-coils of a motor, the coils of which are so applied as to produce twelve magnetic poles at all times, the rotation of the two will be synchronous; but if the motor-coils produce but six poles, the movable element will be rotated twice while the generator rotates once; or if the motor have four poles, its rotation will be three times as fast as that of the generator.

These features, so far as necessary to an understanding of the principle, are here illustrated. Fig. 28 is a diagrammatic illustration of a generator constructed in accordance with the invention. Fig. 29 is a similar view of a correspondingly constructed motor. Fig. 30 is a diagram of a generator of modified construction. Fig. 31 is a diagram of a motor of corresponding character. Fig. 32 is a diagram of a system containing a generator and several motors adapted to run at various speeds.

In Fig. 28, let C represent a cylindrical armature core wound longitudinally with insulated coils A A, which are connected up in series, the terminals of the series being connected to collecting-rings *a a* on the shaft G. By means of this shaft the armature is mounted to rotate between the poles of an annular field-magnet D, formed with polar projections wound with coils E, that magnetize the said projections. The

coils E are included in the circuit of a generator F, by means of which the field-magnet is energized.

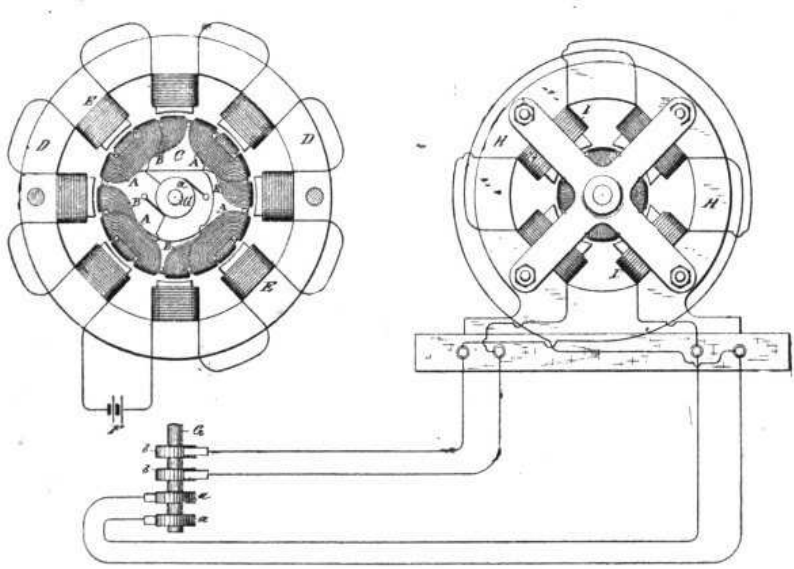


Fig. 28. **Fig. 29.**

If thus constructed, the machine is a well-known form of alternating-current generator. To adapt it to his system, however, Mr. Tesla winds on armature C a second set of coils B B intermediate to the first, or, in other words, in such positions that while the coils of one set are in the relative positions to the poles of the field-magnet to produce the maximum current, those of the other set will be in the position in which they produce the minimum current. The coils B are connected, also, in series and to two connecting-rings, secured generally to the shaft at the opposite end of the armature.

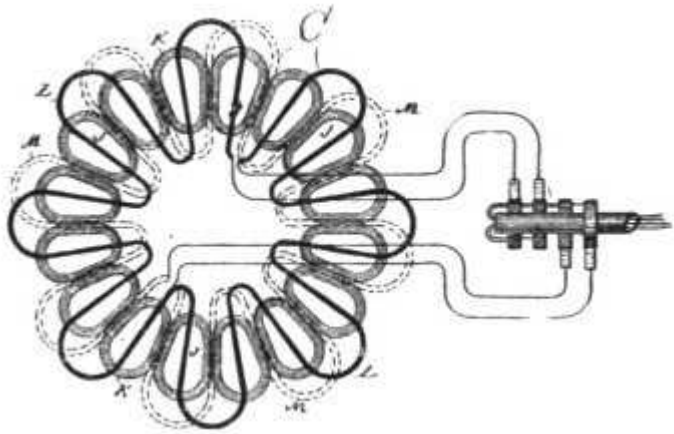


Fig. 30.

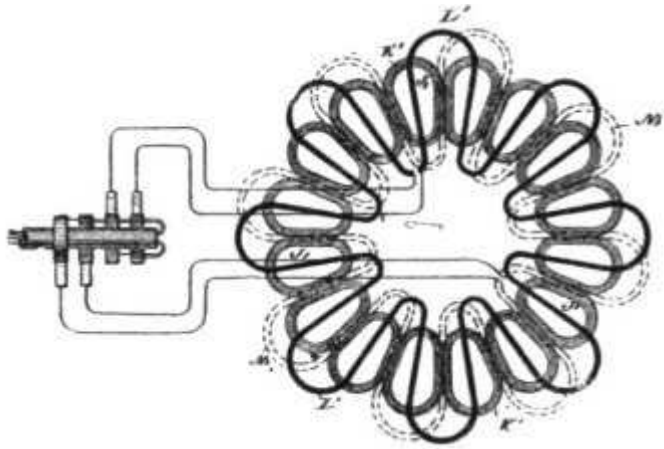


Fig. 31.

The motor shown in Fig. 29 has an annular field-magnet H, with four pole-pieces wound with coils I. The armature is constructed similarly to the generator, but with two sets of two coils in closed circuits to correspond with the reduced number of magnetic poles in the field. From the foregoing it is evident that one revolution of the armature of the generator producing eight current impulses in each circuit will produce two revolutions of the motor-armature.

The application of the principle of this invention is not, however, confined to any particular form of machine. In Figs. 30 and 31 a generator and motor of another well-known type are shown. In Fig. 30, J J are magnets disposed in a circle and wound with coils K, which are in

circuit with a generator which supplies the current that maintains the field of force. In the usual construction of these machines the armature-conductor L is carried by a suitable frame, so as to be rotated in face of the magnets J J, or between these magnets and another similar set in front of them. The magnets are energized so as to be of alternately opposite polarity throughout the series, so that as the conductor C is rotated the current impulses combine or are added to one another, those produced by the conductor in any given position being all in the same direction. To adapt such a machine to his system, Mr. Tesla adds a second set of induced conductors M, in all respects similar to the first, but so placed in reference to it that the currents produced in each will differ by a quarter-phase. With such relations it is evident that as the current decreases in conductor L it increases in conductor M, and conversely, and that any of the forms of Tesla motor invented for use in this system may be operated by such a generator.

Fig. 31 is intended to show a motor corresponding to the machine in Fig. 30. The construction of the motor is identical with that of the generator, and if coupled thereto it will run synchronously therewith. J' J' are the field-magnets, and K' the coils thereon. L' is one of the armature-conductors and M' the other.

Fig. 32 shows in diagram other forms of machine. The generator N in this case is shown as consisting of a stationary ring O, wound with twenty-four coils P P', alternate coils being connected in series in two circuits. Within this ring is a disc or drum Q, with projections Q' wound with energizing-coils included in circuit with a generator R. By driving this disc or cylinder alternating currents are produced in the coils P and P', which are carried off to run the several motors.

The motors are composed of a ring or annular field-magnet S, wound with two sets of energizing-coils T T', and armatures U, having projections U' wound with coils V, all connected in series in a closed circuit or each closed independently on itself.

Suppose the twelve generator-coils P are wound alternately in opposite directions, so that any two adjacent coils of the same set tend to produce a free pole in the ring O between them and the twelve coils P' to be similarly wound. A single revolution of the disc or cylinder Q, the twelve polar projections of which are of opposite polarity, will therefore produce twelve current impulses in each of the circuits W W'. Hence the motor X, which has sixteen coils or eight free poles, will make one and a half turns to the generator's one. The motor Y, with twelve coils or six poles, will rotate with twice the speed of the generator, and the motor Z, with eight coils or four poles, will revolve three times as fast as the generator. These multipolar motors have a peculiarity which may be often utilized to great advantage. For example, in the motor X, Fig. 32, the eight poles may be either alternately opposite or there may be at any given time alternately two like and two opposite poles. This is readily attained by making the proper electrical connections. The effect of such a change, however, would be the same as reducing the number of poles one-half, and thereby doubling the speed of any given motor.

It is obvious that the Tesla electrical transformers which have independent primary currents may be used with the generators described. It may also be stated with respect to the devices we now describe that the most perfect and harmonious action of the generators and motors is obtained when the numbers of the poles of each are even and not odd. If this is not the case, there will be a certain unevenness of action which is the less appreciable as the number of poles is greater; although this may be in a measure corrected by special provisions which it is not here necessary to explain. It also follows, as a matter of course, that if the number of the poles of the motor be greater than that of the generator the motor will revolve at a slower speed than the generator.

In this chapter, we may include a method devised by Mr. Tesla for avoiding the very high speeds which would be necessary with large

generators. In lieu of revolving the generator armature at a high rate of speed, he secures the desired result by a rotation of the magnetic poles of one element of the generator, while driving the other at a different speed. The effect is the same as that yielded by a very high rate of rotation.

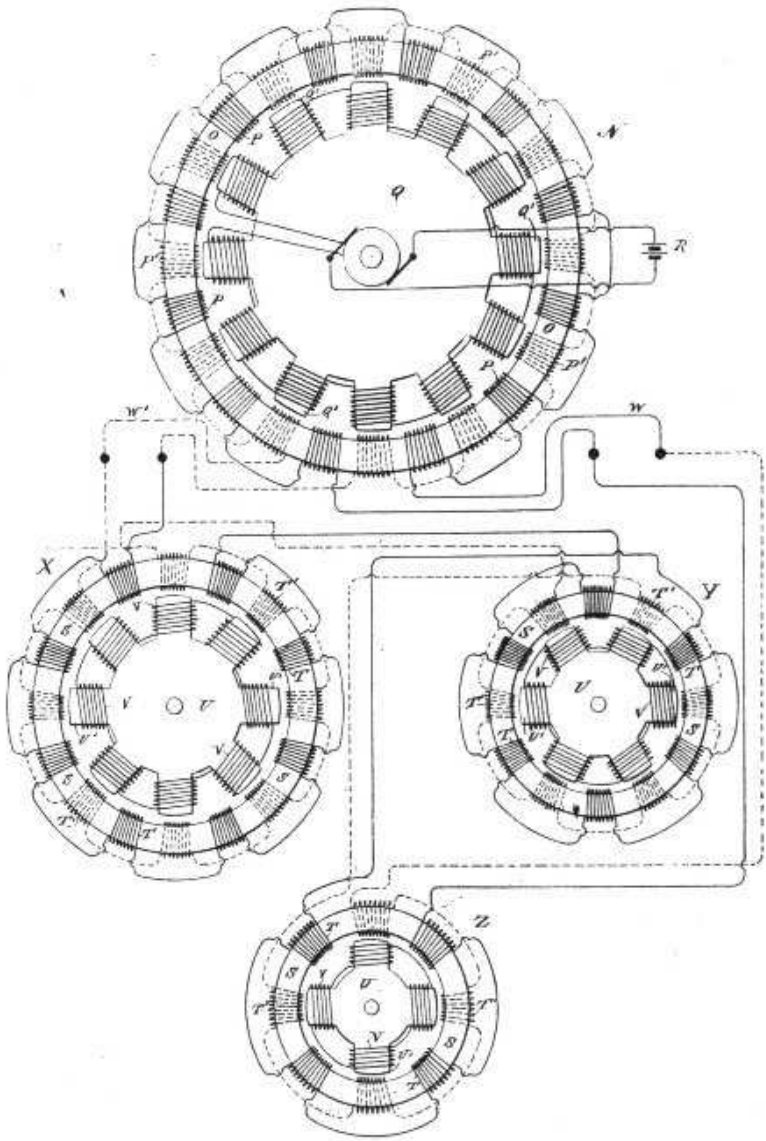


Fig. 32.

In this instance, the generator which supplies the current for operating the motors or transformers consists of a subdivided ring or annular core wound with four diametrically-opposite coils, E E', Fig. 33. Within the ring is mounted a cylindrical armature-core wound longitudinally with two independent coils, F F', the ends of which lead, respectively, to two pairs of insulated contact or collecting rings, D D' G G', on the armature shaft. Collecting brushes *d d′ g g′* bear upon these rings, respectively, and convey the currents through the two independent line-circuits M M'. In the main line there may be included one or more motors or transformers, or both. If motors be used, they are of the usual form of Tesla construction with independent coils or sets of coils J J', included, respectively, in the circuits M M'. These energizing-coils are wound on a ring or annular field or on pole pieces thereon, and produce by the action of the alternating currents passing through them a progressive shifting of the magnetism from pole to pole. The cylindrical armature H of the motor is wound with two coils at right angles, which form independent closed circuits.

If transformers be employed, one set of the primary coils, as N N, wound on a ring or annular core is connected to one circuit, as M', and the other primary coils, N N', to the circuit M. The secondary coils K K' may then be utilized for running groups of incandescent lamps P P'.