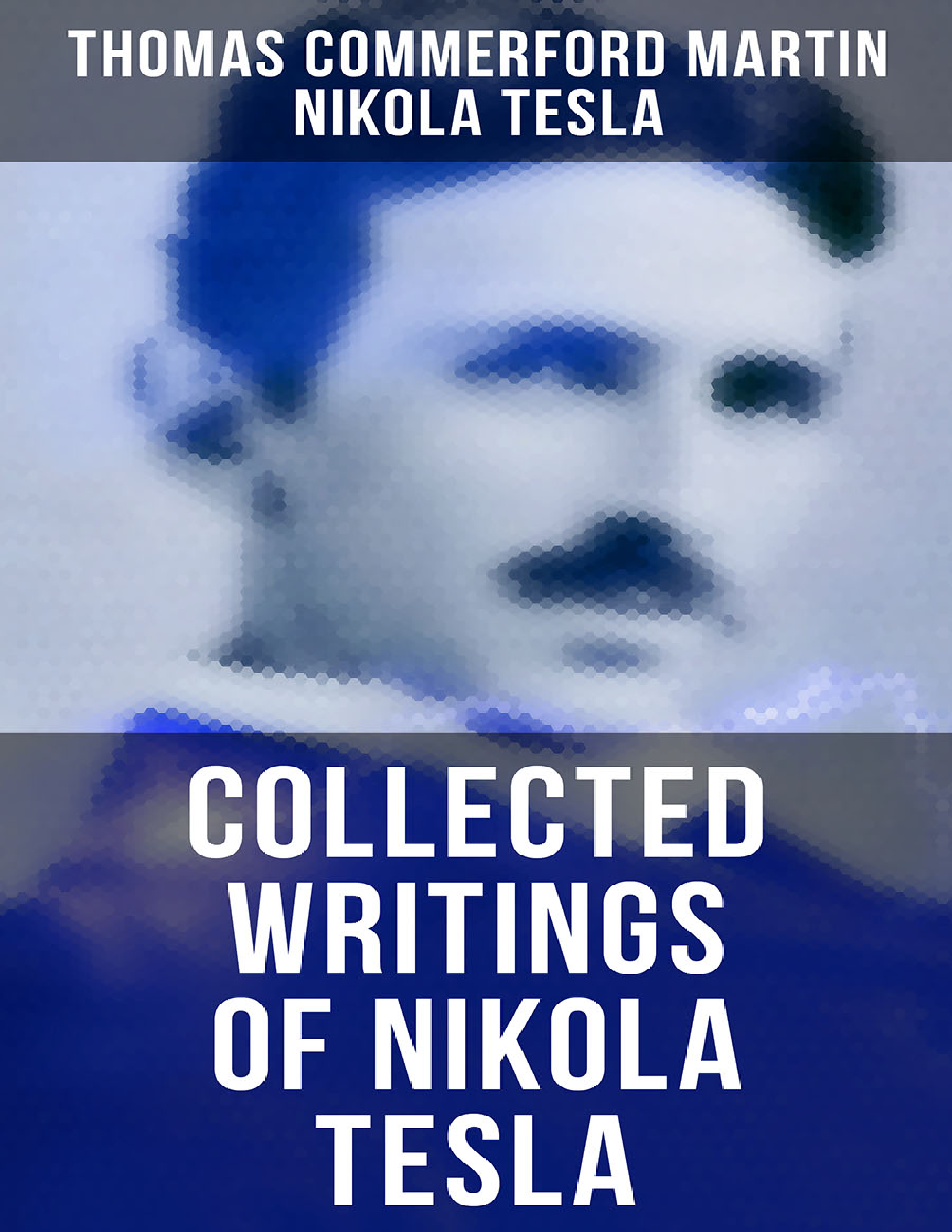
THOMAS COMMERFORD MARTIN
NIKOLA TESLA



COLLECTED WRITINGS OF NIKOLA TESLA

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Collected Writings of Nikola Tesla

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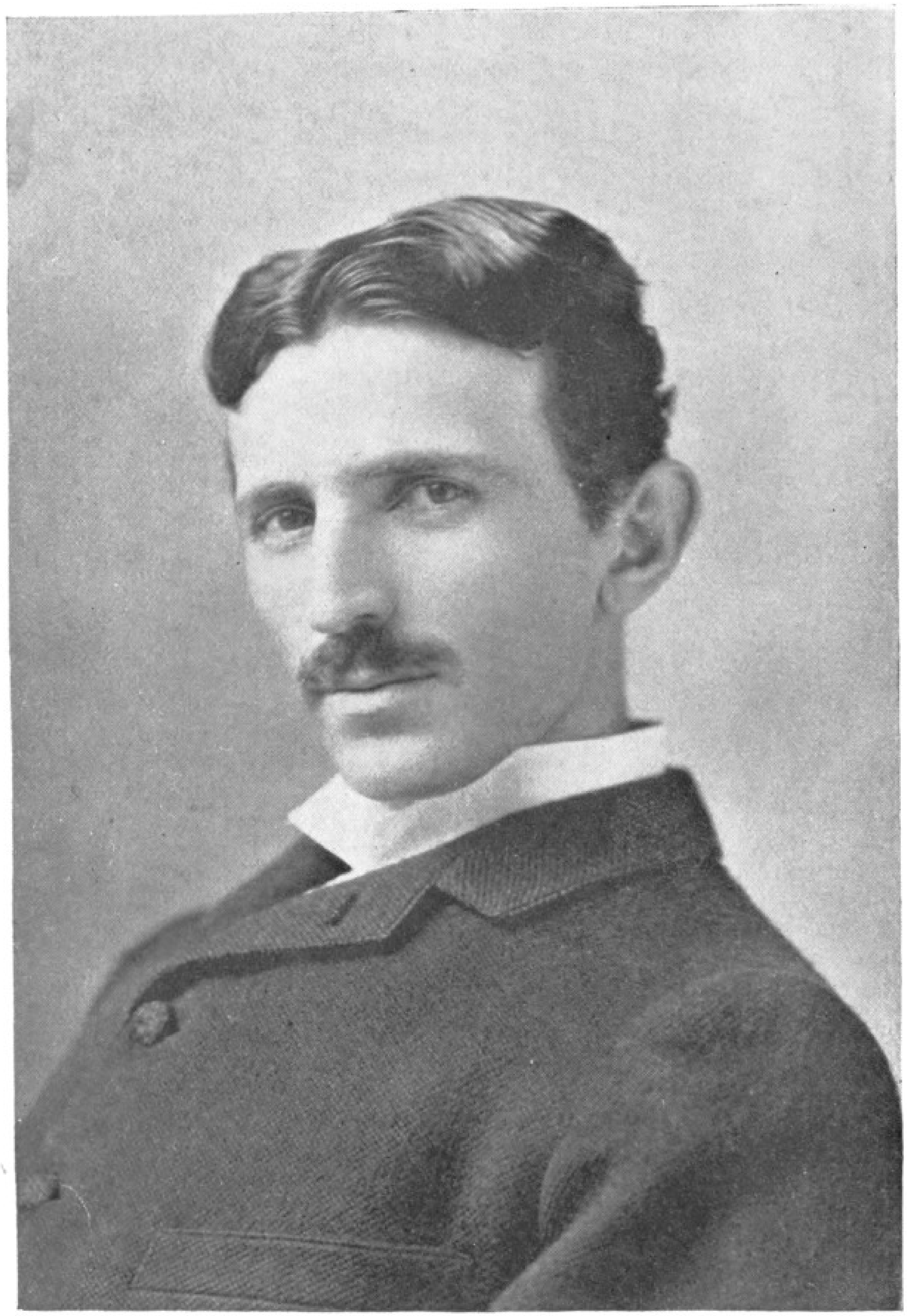
Table of Contents

The Inventions, Researches and Writings of Nikola Tesla

Table of Contents



Nikola Tesla

PREFACE.

Table of Contents

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 re-publication 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.

Table of Contents

CHAPTER I.
Biographical and Introductory.

Table of Contents

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.

Table of Contents

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.

Table of Contents

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 automatically, 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.

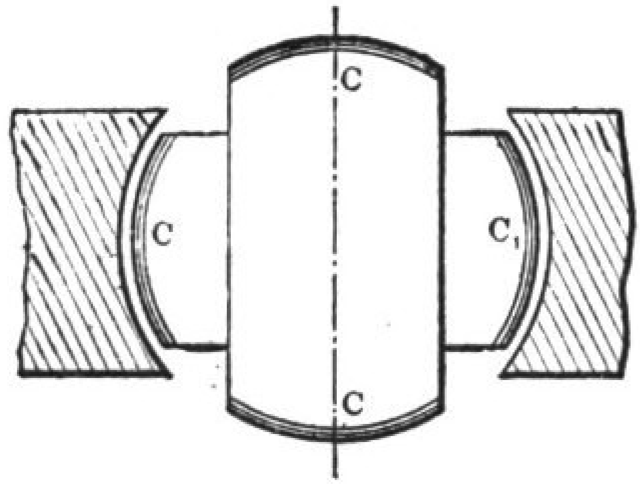


Fig. 1.

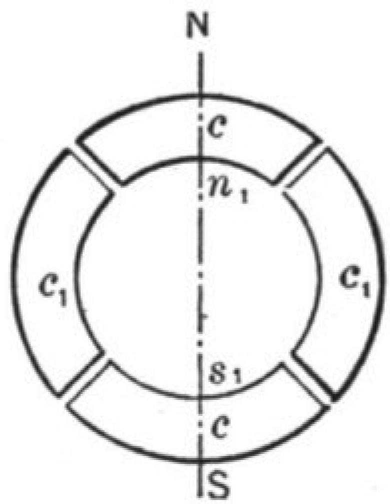


Fig. 1a.

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.

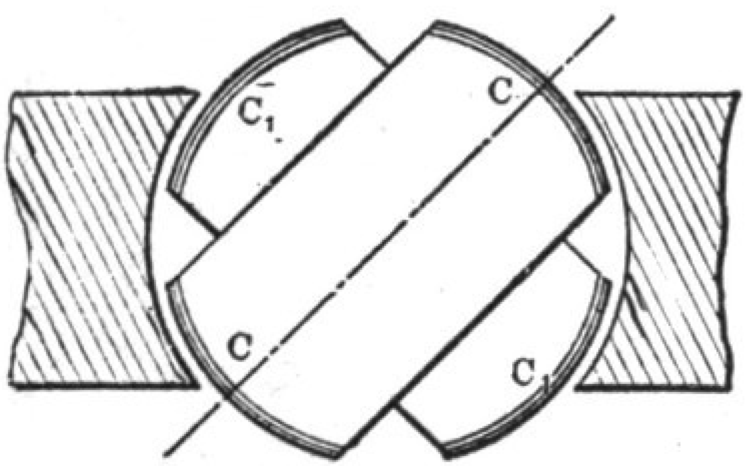


Fig. 2.

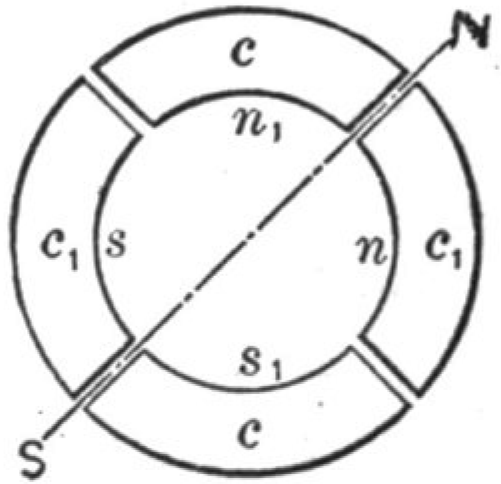


Fig. 2a.

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.

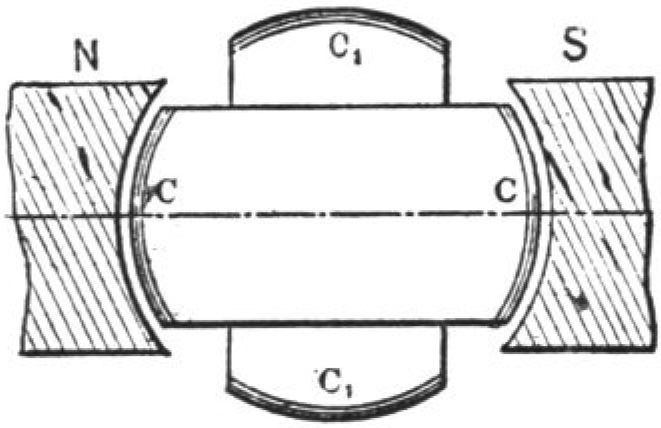


Fig. 3.

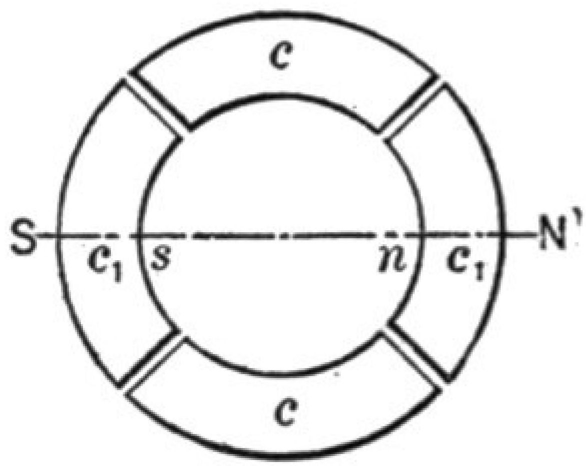


Fig. 3a.

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.

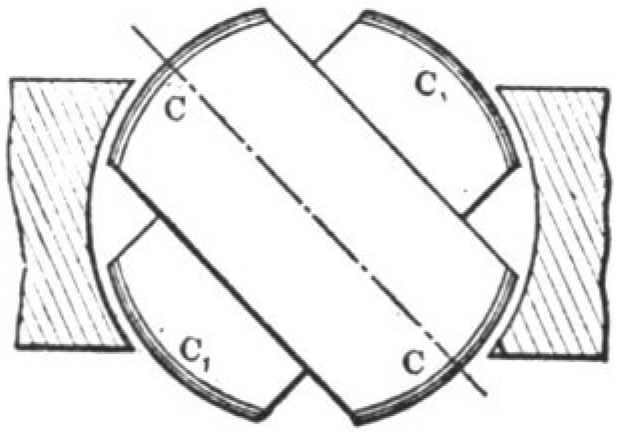


Fig. 4.

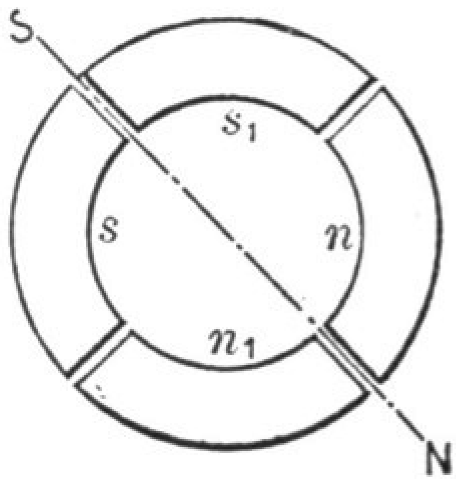


Fig. 4a.

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.

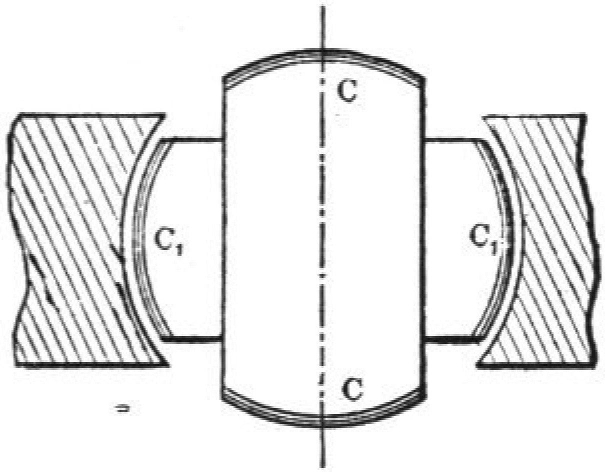


Fig. 5.

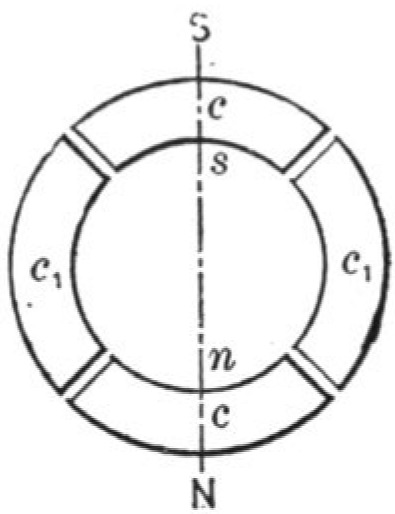


Fig. 5a.

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*.

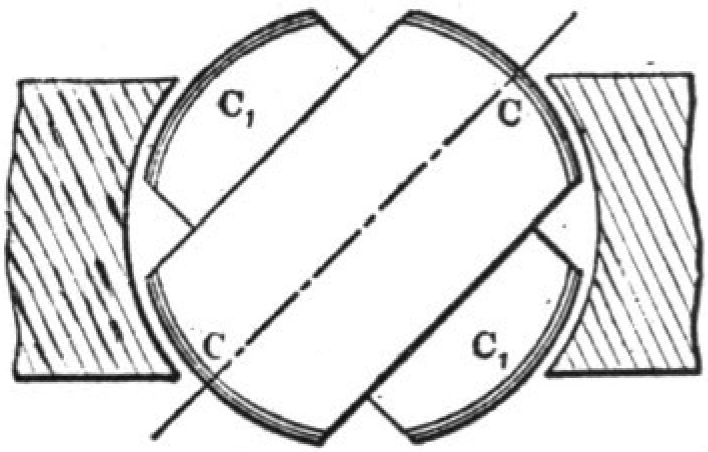


Fig. 6.

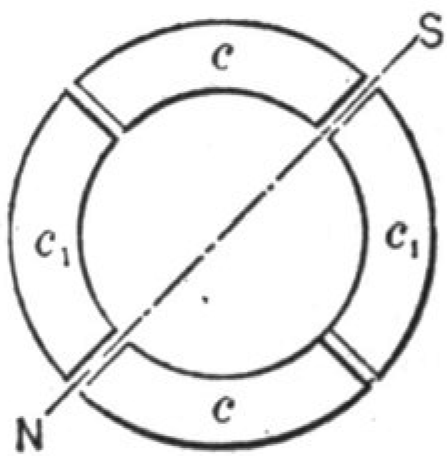


Fig. 6a.

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.

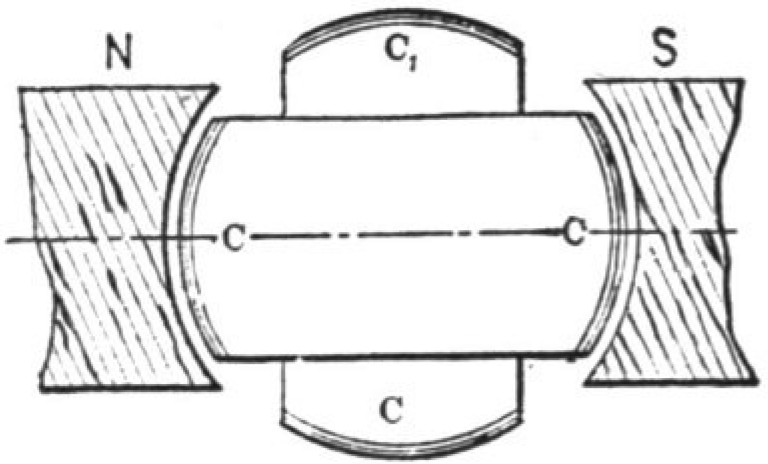


Fig. 7.

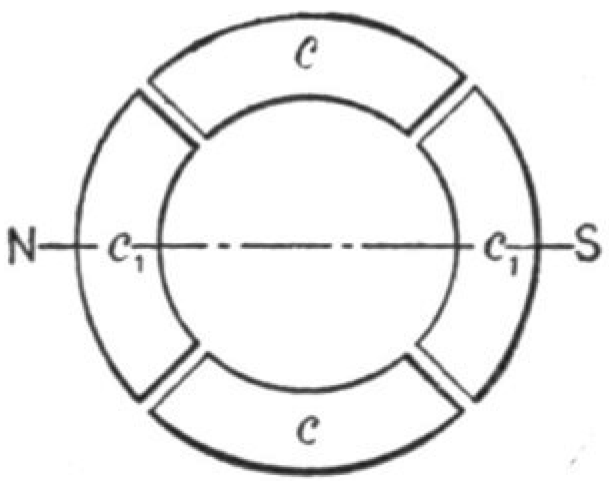


Fig. 7a.

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