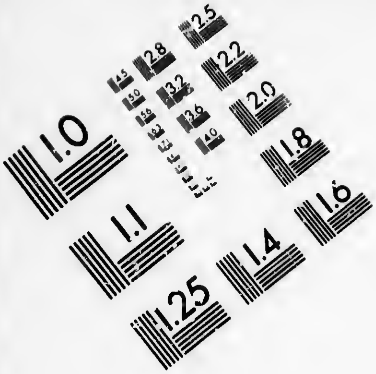

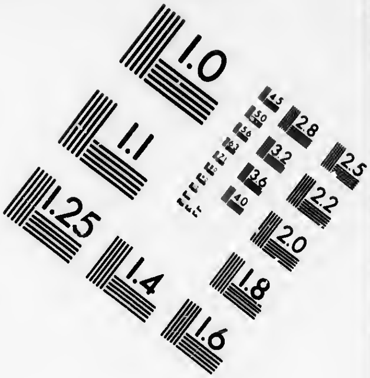

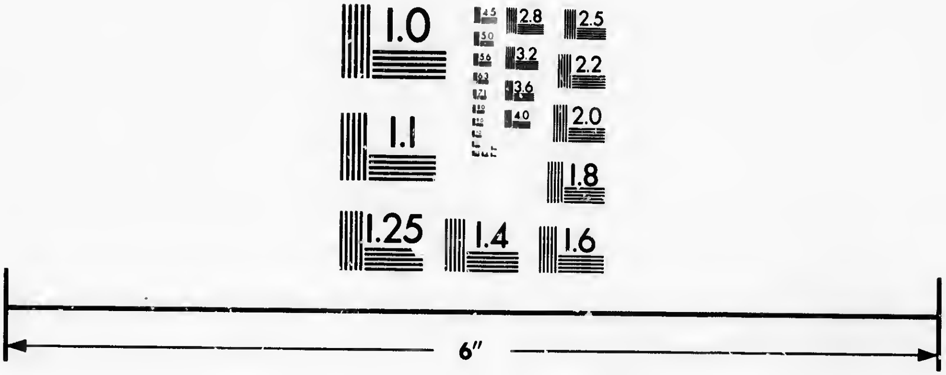
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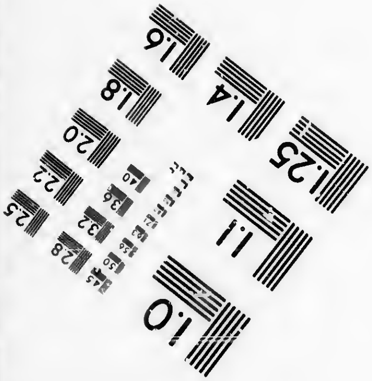

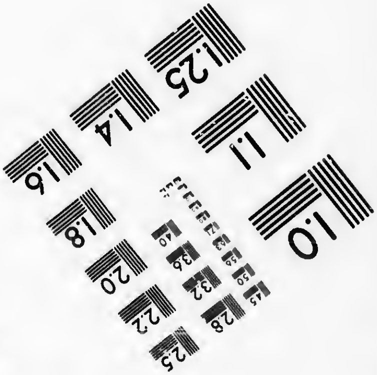

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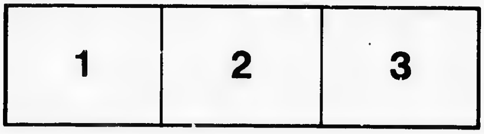
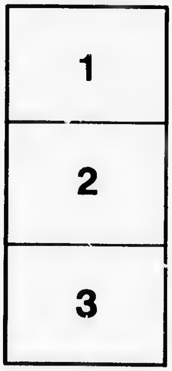
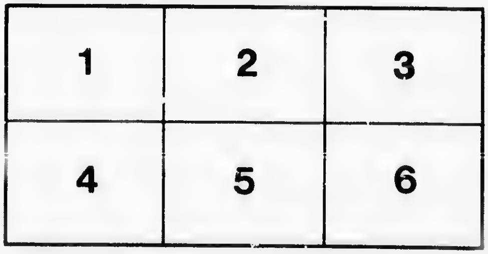






Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

MULTIPHASAL ALTERNATING CURRENTS.

By Arthur Edward Childs, B.Sc.

Graduate of the London Central Institution.

To be read Friday, March 25th, 1892.

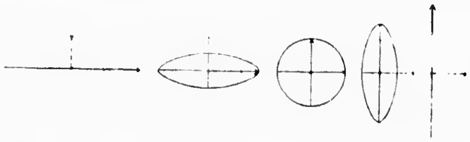
The analytical treatment of multiphasal alternating currents has not yet been so fully developed as that of the simple alternating current. Experimental work has, however, been much more fruitful of results. This paper is an attempt to bring under notice, as briefly as possible, the present state of experimental knowledge on this latest of all subjects of interest to electrical engineers.

Alternating electric current distribution has gained a considerable footing and would certainly increase to a greater extent than continuous current distribution if we possessed a fuller knowledge of how to utilize it in connection with electro-chemical and electro-dynamic operations. Further, could we store the electric energy of alternating currents, and transform into mechanical energy, a greater impulse would be given this branch. For such work the continuous current has taken the lead. In spite of this lack of knowledge alternating current systems have been largely adopted because of simplicity, cheapness of construction of alternators, the easy attainment of high potentials, the simple transformation of currents by apparatus containing no moving parts, and the high efficiency obtainable. Although we cannot deny the many good qualities of the continuous current, experience has shown that the alternating current is alone suited for the distribution of power on a large scale over long distances. Until recently no practical alternating motor has been put forward, and it is to this subject that the attention of engineers and scientists has been directed.

All their efforts produced no results until 1888, the year of the birth of the distribution of power by alternating currents. The discovery of Ferraris and the experiments of Tesla were published in that year. Many others also worked on the use of alternating currents differing in phase, without any practical result being reached. Tesla's motor, which attracted so much attention when it came out, has not fulfilled anticipations, as no commercial application of it has yet been made. Tesla's arrangement with two quite independent currents, differing 90° in phase, possessed little advantage. Its faults were avoided by others, and less than two years ago motors with a larger number of alternating currents were worked out by Bradley, Hasselwauder, Wenstrom and Von Dolivo-Dobrowolsky. Brown of the Oerlikon Machinenfabrik, also worked out an alternating current motor, which has lately been employed with success at Frankfort. Prior to 1886 no progress in this branch was made because of the low efficiency and insecurity of dynamos of that date, but from 1886 to 1888 the English school of electrical engineers made such improvements in dynamos as to render possible the transmission of power on a large scale. During this time, the Oerlikon Machinenfabrik did good service in this direction, but continuous currents, on account of the delicacy of the commutator and the difficulty of transformation, being little suited for distribution and transmission of power over long distances, the hopes of engineers have hitherto remained unfulfilled. The construction of a continuous current machine to supply energy at 10,000 to 20,000 volts to single motors or to lamps, is practically an impossibility and will certainly remain so. Engineers, therefore, watch with interest the progress which alternating current work is making toward this point.

The employment of two or more alternating currents differing in phase in a motor has the effect of making the resultant magnetic field rotate relatively to the machine, as will shortly be seen, instead of remaining stationary as in the case of the continuous current dynamo. The resultant of two or more alternating currents, upon which this rotating magnetic field depends, has been called a *rotary current*. In order to show how this rotation comes about let us turn to an analogy which has been used in this connection, viz; that of elliptical and circular polarization of light. An atom of ether simultaneously performs two simple sinusoidal oscillations of equal period, the directions of which are perpendicular to each other. For each phase the radius vector of the resulting movement is the diagonal of a parallelogram, the components of which are the two distances from the centre which the atom would have reached, at that phase, if it performed only one or the other of the two simple oscillations. If the phase difference of the two simple oscillations be made $\frac{0}{8}$, $\frac{1}{8}$, $\frac{2}{8}$, $\frac{3}{8}$, $\frac{4}{8}$, of a period, and the amplitudes equal, then in this case, we obtain the curves of Fig. 1.

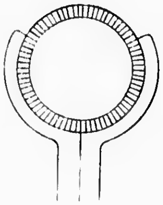
If, on the other hand, the phase difference between the component oscillations be fixed, at say $\frac{2}{8}$ of a period or 90°, and the amplitudes successively varied, we obtain for half a period the curves of Fig. 2.



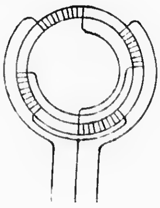
Clerk-Maxwell proved mathematically and Dr. Hertz experimentally, that optical and electromagnetic phenomena were identical. Doubtless the similarity of elliptical and circular polarization and electromagnetic phenomena led Mr. Ferravis to prosecute his experiments on the phenomena of electromagnetic rotation produced by rotary currents. If we substitute the two superimposed oscillations of the atom by the variations of two superimposed magnetic fields, we obtain a resulting field the direction and intensity of which is defined by the direction and length of the radius vector of the corresponding curves of optical oscillation. In employing such a rotary field to drive electromotors, its intensity and angular velocity ought to be as nearly as possible constant. This corresponds to perfectly circular polarization in the optical analogy. To attain this has been the special aim of those working at this subject. The theoretical conditions deserve particular attention. It is only when the amplitudes of the two component oscillations are equal and have a phase difference of 90°, that the oscillation curve becomes a true circle as shown in Fig. 1. We cannot, however, apply this case to electromagnetic rotation because circular polarization is only obtained when the directions of the two components enclose a fixed angle of 90°, whereas in a rotary current motor using more than two alternating currents, this angle requires to be other than 90°. To obtain perfectly circular polarization the amplitudes of the two components must be made equal, and the angle which their directions contain must be the supplement of the angle of phase difference. In Fig. 1 we have the case of equal amplitudes and varying angle of phase difference. Fig. 3 is obtained from it by making the angle contained by the components equal to the supplement of the phase difference.

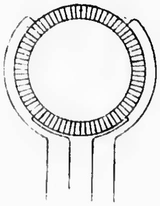
These circles, whose diameters represent the intensities of the rotary magnetic fields, have not their diameters equal to the amplitudes, as in Fig. 1, but equal respectively to the product of the amplitudes into the sines of the angles contained by the components. This electro-optical method gives a representation of rotary magnetic fields easily followed. The case where more than two component oscillations are combined gives rise to a number of modifications which need not be followed up.

There are several methods of obtaining rotating magnetic fields. Consider a continuous magnetisable ring wound with a series of coils in such a way that separate electrical connection exists between the coils of each section. Such a ring is shown in Fig. 4.

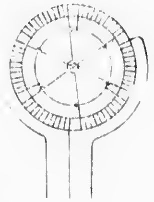


By using three wires from the generator it is possible to employ currents of equal periodicity, lagging behind one another by one-third of a period. By taking advantage of the employment of three currents retarded in this way, the algebraical sum of the currents at any instant can be made zero, and one of the three wires can always serve as a return to the currents traversing the other two. We may have four sections with three or four leads as shown in Figs. 5 and 6.

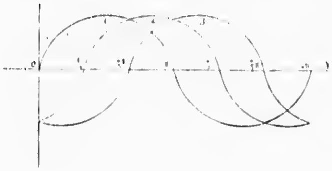




Still further we may have a large number of sections as shown in Fig. 7.



Using the line curve to represent the alternating current, with ordinates as amplitudes and abscissae as periodic time, we can in any particular case represent the action of the current graphically. In the case of three currents we have Fig. 8.



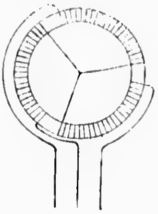
While current 1 is increasing from 0 to a positive maximum, current 2 is increasing from a negative maximum to 0. While current 1 is decreasing from a positive maximum to 0 current 2 is increasing to a positive maximum, and current 3 is passing from a negative maximum to a positive maximum, and so on. Here the difference of phase between any two currents is $\frac{\pi}{3}$.

There are several methods of obtaining, from a single alternating current, two alternating currents differing in phase, producing a rotating magnetic field. The single current is split up into two branches, into one of which is inserted a small resistance and great inductance, into the other a large resistance and small inductance. The phase difference in this case may approach 90°, but will always be smaller. Let us assume it to be 45°, for instance, then the resulting curve will be the ellipse of Fig. 1, supposing, of course, that the ampère windings in both coils have been made equal. This method gives great fluctuation in intensity of magnetism of the rotating field, a thing to be avoided. Another method, upon which the writer has spent considerable time in endeavouring to develope, is to split the single current into two and introduce into one branch a condenser. This has the effect of giving an advance difference of phase of 90°. The difficulty with this method, which has not as yet been overcome, lies in the fact that a condenser of sufficient capacity and insulation has not been brought forward. Mr. Tesla, in his later motors, makes use of the first of these methods, but the conditions for constancy of velocity and intensity of the rotating field are very imperfectly fulfilled. In his latest design of rotary current motor a four pole machine is chosen. Eight radial electromagnets are placed at equal distances on the inside of an iron ring, and are wound in such a way that every second bobbin has a low resistance and high inductance and *vice versâ*. Each set of bobbins is connected in a series and both sets in parallel. As we cannot even freely choose the values of inductance and resistance, a phase difference of 45° between the two currents will hardly be attained. In this case the resulting field would be illustrated by the stretched ellipse in Fig. 2. A similar result is obtained in all motors in which only one current is used to obtain a rotary field whether the first, second, or any other method be employed.

In 1891, Messrs. Siemens and Halske made a series of experiments on motors of the types given in Figs. 4, 6 and 7. Interesting results were obtained for the three-coil motor showing that, whatever the position of the rotating magnetic field, the magnetic axis was generally curved, and the lines of force contracted at one pole and spread out at the other, that is, the intensities of the two poles were never the same. The four-coil motor gave a considerably better result. The magnetic axis was always straight, and both poles had equal intensities. The six-coil showed a still more equal resulting field. The intensities of the rotary field was obtained by hanging a coil in the centre of the ring, in such a way that its magnetic axis was perpendicular to the measured direction of the resulting magnetic axis of the ring. The coil was then excited by a constant continuous current, and was kept in its position by a spring. The tongue of the spring served as a measure of the intensity. The horiozontal compound of the magnetism of the earth was neglected because the ring surrounding the measuring coil effectually served as a magnetic screen. In this way they found that the mean intensities in the three, four, and six-coil motors were as 117 : 127 : 136. The fluctuations of intensity were not appreciable in the six-coil motor. In the four-coil motor those fluctuations did not quite reach 13 per cent. of their minimum value. In the three-coil motor the measurements of the intensities were not very valuable because the resulting axis was generally bent. The fluctuations of the angular velocity of the resulting axis were much longer than the fluctuations of the intensity in all three motors. In the three-coil motor it was found that the two poles always moved without different velocities. Since the velocity of the poles themselves chiefly influence the armature, it follows that this type is certainly not very advantageous. In the four-coil motor the variations of velocity are very much smaller, and are still smaller in the six-coil type. These experiments are of great value in that they throw a good light on the fluctuations of the rotary current field.

The result of a rotating magnetic field in the interior of a ring act almost as if a constant magnetic field were mechanically revolved in it. On this principle extremely simple motors, without either sliding contacts or brushes, can be built, and the usefulness of large motors, having these advantages, has been one of the strongest reasons for experimental work in this branch. It has been stated that the conditions for constancy of velocity and intensity of the rotating field are very imperfectly fulfilled in the Tesla motor. In fact the excitation of the motor varies as much as 40 per cent of its minimum value, so that the magnetic field is not merely rotating, but also pulsating to a very considerable extent. The action of the motor is accordingly far from being simple. The type of alternating current motor designed by Elihu Thomson affords us an example where the two properties of the rotating field may be considered separately. This motor consists of a magnetic field due to an alternating current, and an armature of which the windings form closed circuits. Like all synchronous alternating current motors, it must be brought up carefully to the proper number of revolutions per minute before the alternating current takes up the work. If the work be thrown on too soon, or if the motor be overloaded, the effect is to stop the machine. As the pulsations of the field only serve to turn the armature when it is going at a particular speed, and as the currents induced in the closed circuit armature do not correspond properly in time and direction to those of the field, it is very difficult to start such an armature in its alternating field. When a two-phase motor, with closed circuit armature such as Tesla's is not running synchronously the torque is only equal to the difference between the effect of its rotating field and the checking due to the pulsations of the magnetism. The motor, therefore, does not run well under load. At full speed it has a tendency to synchronism up to a certain load, beyond which its speed and torque rapidly diminish. The usefulness of such a motor is limited, and it can only be regarded as an improvement on the perfectly synchronous motor of Thomson, by reason of its power to start under a heavy load.

To produce a good motor we must diminish the amplitude of the pulsations of the alternating magnetism of the field. An ideal field would be without magnetic pulsations. This ideal is approached by increasing the number of currents, of which the phases are made to follow one another. In the case of three currents, Fig. 8, it will be seen that the algebraic sum is sufficiently constant, the tops of the curves representing approximately the values of the fluctuations. A simple calculation shows that the pulsation of this field is only 15 per cent instead of 40 per cent as in Tesla's motor. Since the number of alternations is relatively small, the saturation of the iron can be carried up to a high degree without impairing the efficiency, so that for a variation of 15 per cent in the ampere turns, the total quantity of magnetism remains practically constant. With four alternating currents differing in phase the value of the pulsations would be still further reduced. But here we are met by the fact that the increased number of conducting wires constitutes an obstacle to the practical application of their transmission. Even in the case of three currents we would require at least four wires, which would still be too costly. Von Dolivo-Dobrowolsky has worked out an arrangement by which three currents can be conveyed by three conductors. He supplies three currents differing by 120° instead of 60° in phase, and reverses the connections of the bobbin which supplies one current. To each of the circuits in the motor correspond at least two oppositely wound coils producing opposite poles, so that he is able to add the currents obtained by reversing their signs. This results in a figure quite analogous to Fig 8, which represents the currents differing in phase by 120° instead of 60°. He has two methods of joining the sections on his ring, one similar to Fig. 4, which he calls a *closed* connection, and the other similar to Fig. 9, which he terms an *open* connection.

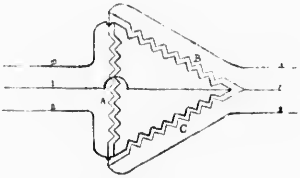


These connections render possible the conveyance of the three currents through three conductors, in that the current flowing in one conductor finds its way back by the other two. A similar system can also be employed in the case of more than three currents. Von Dolivo-Dobrowolsky states that in the course of careful experiments carried out by him with the *Allgemeine Elecktricitäts Gesellschaft*, and while working out the details of his system, there appeared many cogent reasons for abondoning this simple arrangement. Amongst these were the small output and consequent low efficiency, the heavy cost of dynamos and motors, and the difficulty of regulating, controling, and measuring the currents in the three connected circuits.

In March of 1888, Professor Ferraris first made public the principle of rotary current motors, the development of which now seems likely to cause a revolution both in long distance transmission work and in the distribution of electric energy for small motors. The following is the principle established by Ferraris:—*When two alternating currents of the same period, lagging* *one behind the other by a quarter period, are passed through two circuits arranged at right angles, the result is a constant rotary magnetic field revolving at a constant speed, making one complete revolution per period. If now a closed magnetic circuit is placed in this rotary field it will be the seat of induced currents, and these induced currents will tend to turn the induced circuit in the same direction as the rotary field.* In fact it will be seen that the rotary current motor works in virtue of Foucault currents which are induced in the rotating closed magnetic circuit. These Foucault currents would be zero if the circuit were stationary with regard to the field, that is to say, if the circuit revolved at the same speed as the field; and it is the effort of the circuit to fulfil this condition of relative immobility that makes it turn within the field, and in the same direction. In short, the circuit runs after the field. Although of relatively recent invention, rotary field motor systems are already very numerous and varied in design and arrangement of circuits. They are distinguished amongst themselves chiefly by the mode of producing the rotary field, and by the generator which supplies current to the motor.

The transmission of power over long distances has been the special end aimed at in all developments relating to rotary current work. High efficiency is to be gained in the use of the alternating current due to its easy transformation and adaptability for long distance transmission. The problem has yet to be completely solved, but those working at it have lately received a great impulse from the success obtained in the Lauffen-Frankfort transmission, to be described later on. The methods described above are applicable principally to the case of distribution of comparatively small motors. For the purpose of long distance transmission on a considerable scale, it is preferable to have recourse to special generators, no longer producing ordinary alternating currents, but several currents lagging a fraction of a phase one behind the other, that is to say, a multiphial alternating current. We may employ two currents and four wires, or two currents and three wires (using one as a common return), or three currents and three wires. Systems using either of the first two combinations have been developed by Ferraris, Tesla, Shallenberger, Huntin and Leblanc. Developments in the last combination are due to Von Dolivo-Dobrowolsky, Brown, Haselwander, Bradley and Wenström.

To use a three-phase current with a system of transformers it is only necessary to have three leads if the primaries are arranged as in Fig. 10



The primary A of the transformer is traversed by currents over the leads III and II, from the first section of the coils on the armature. Similarly, primary B is fed with currents from the second section, and C from the third section. Lead I goes to the common junction of the primaries B and C. Lead III is thus the common wire for current impulses from the end of the first section of coils and beginning of the second section; lead I for impulses from end of second and beginning of third sections; and lead II for impulses from end of third and beginning of first sections. The same order prevails for the secondaries of the transformer. In this arrangement no current impulses act against each other in any part of the circuit. As the current in A increases, the magnetisation also increases; after the maximum has been reached both decrease in A, but increase in B, and so on. Briefly, the magnetism travels from A over B to C, thus completing the cycle.

Here, then, we have a transformer which depends upon the rotation, by means of the rotary current, of a magnetic field inside a closed iron ring without poles, whilst the compound current supplied from the machine excites in the secondary coils similar current impulses following behind one another. The transformation corresponds to the action that takes place in a rotary current dynamo, except that in the transformer the field rotates about fixed coils, whilst in the dynamo the armature is mechanically rotated in a fixed field. In this transformer we have three connected currents differing by 120° in phase, producing a rotary field, and this has led to the idea that the same loss will occur that takes place in the case of the currents in a motor. This actually does occur to the extent of about 15 per cent loss in pressure, because the ratio of transformation is not the ratio of the number of turns on the primary to those on the secondary, but it is only necessary to increase the number of turns in the secondary by 15 per cent in order to fully utilize the primary currents. The efficiency of the transformer is consequently only very slightly affected. As a general rule, the loss in the transformation and the cost of transformers are not of great importance, since it is generally preferable to build machines for a relatively low voltage, and to transform the energy to a high voltage before supplying it to the conducting wires. In the case of very high pressures, exceeding 1,000 volts, it is much cheaper and safer to build a dynamo with a terminal voltage of from 50 to 100, and transform up to the required line potential. It is, in fact, so much cheaper that a transformer pays for itself, and the low pressure machine works so much more economically that the three or four per cent loss in the transformer is balanced.

When at the second transformation at the receiving station the currents are to be used for running large motors or lamps it will be well to resolve the combined currents, for reasons similar to those which apply to dynamos.

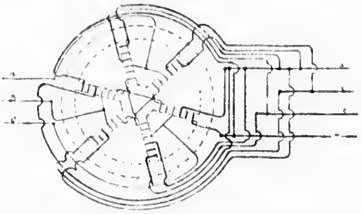


Fig. 11 shows one of many methods of doing this. A, B, C represent the long distance leads carrying high pressures and small currents. The letters a, b, c, d refer to the low pressure leads running directly to motors, etc. The transformer ring is shown dotted. The behavior of the currents of the secondary winding is a reproducting of that of those in the separate primary circuits, so that the regulation of current and tension is comparatively simple. By connecting the secondary currents we also secure the advantage that the long and expensive conductors need only be three instead of four in number.

It can readily be proved that *the weight of the conductor required for equal energy, is not greater for the three wires of the rotary current system than for the two wires of the ordinary system.* In determining the section of the conductor for a combined rotary current, such as is used in transmitting power over a long distance, it is necessary to obtain a clear idea as to the amount of energy conveyed. The determination is made in the same way as in the case of an ordinary alternating current, with the assumption that there is no self-induction, i.e., no difference of phase between current and electromotive force. Should self-induction exist, the same modifications that occur with an alternating current also present themselves with a rotary current. The three conductors should be considered as equally loaded, since only the full normal load need be considered in determining the section of the conductor. As the last of these three conditions never, or very seldom, holds good, the determination of the sectional area of the conductor would not be sufficiently correct for practical work, though of course the general proposition holds true. In a central station the rotary currents would usually be uncombined and independent, so that the control of the loads could be very easily effected by the electrician in charge. In taking measurements of the total consumption at the receiving station, the combined current being there resolved into its components, care should be taken, when self-induction exists in the circuits, to obtain readings from separate ammeters and voltmeters, and not from wattmeters. In the latter case the watts obtained would be too small. All lamps should be placed on some two particular mains, and account taken of them by simple recording apparatus. Large motors should be placed on separate circuits and their consumption measured by suitable wattmeters. For small motors supplied with the combined rotary current one measurement is sufficient without any correction for the difference of load in the separate circuits.

Reference has been made to experiments carried out by Messrs. Siemens and Halske on certain motors. In the same year the *Allgemeine Electricitäts Gesellschaft* published the results of tests on a two horse-power motor built for low pressures, such as is used in the mains of a town, transformation being avoided. The arrangement of the motor was practically an inversion of the Tesla motor, the magnet rotating inside the closed circuit armature. The motor required 70 volts and 35 complete periods per second. The tests were carried much higher than the normal allowable load in order to determine the behavior of the machine under excessive load and abnormal conditions. The weight of the motor was about 1¾ tons, and, from several trials, it appeared that a load of 2 horse-power, after a long run only heated it slightly. This was fixed as the normal load, which, it is claimed, was by no means relatively low. The motor was entirely devoid of synchronism, the number of revolutions when running at no load being below that calculated from the number of alternations. Between no load and the maximum, the number of revolutions fell about 6 per cent, an amount which for a 2 horse-power motor is similar to that which occurs in any direct current motor of equal power. The speed fell off more quickly, however, as the load increased, although at 150 per cent overload the speed was still fairly high, showing that the property that alternating motors have of coming to rest when overloaded is quite done away with. From the curve of efficiency obtained it was seen that the utilizable work rose nearly in proportion with the electrical energy consumed, up to three horse-power, from which point the proportion fell off. The losses in the motor due to ohmic resistance, hystresis, Foucault currents and friction were all separately determined and plotted as functions of the total watts consumed. The most important of these losses, viz, that in the copper, increased pretty rapidly, thus tending to make the curve of efficiency fall off with increased load. All the other losses were found to be approximately constant. It was found that at half-load the efficiency reached 75 per cent, at normal load, 2 horse-power, over 80, reaching its maximum 81.4 at about 2.3 horse-power. From the flatness of the curve obtained it was shown that the economical regulation of the motor was very good, and that momentary overloading, which is unavoidable in practice, has very little effect on its efficiency. A comparison with direct current motors shows clearly that rotary current motors of the same size are a distinct advance in point of capacity and efficiency and, further, as rotary current motors can start from any position with considerable force, no friction or other coupling is necessary.

Certain rotary currents systems have been very fully worked out and are, at the present time, giving satisfactory evidence of their great usefulness. The *Allgemeine Electricatäts Gesellchaft* has developed a system in which the dynamos supply several perfectly independent currents, usually six, although any number may be adopted. A large number of currents enables the dynamos to be used to the best advantage, in that the whole circumference of the armature can be covered with active turns which, as is well known, cannot be effected with ordinary alternators. An increase in the output in relation to size is also rendered possible from the fact that a multiple phase machine gives out energy continuously, while ordinary alternators only pulsate. The energy flowing in the conductors is also constant, since the arithmetical sum of the separate currents is practically constant, as in the case of the continuous current. The distinct unconnected currents supplied by the machine are carried separately through switches, regulators and measuring instruments, and then combined by suitable transformers into three connected currents, differing by 120° in phase. These are conveyed wherever they are required, and finally again split up in order to be utilized. In their system they generally use a type of motor employing a transformer, fed by three wires carrying the three combined high pressure rotary currents, which supplies from its secondary double the number of currents of low voltage, the phases of which follow closely after one another.

The Oerlikon Machinenfabrik have always devoted a good deal of attention to electrical power transmission. Their engineer, Mr. C. E. L. Brown, who has given special study for a long time to the multiphase system, has created a type of machine which utilizes in an excellent manner the characteristic qualities of the system. In his 300 horse-power multiphasal alternator the armature circuits are arranged to give three alternating currents lagging 120° behind one another, so that they may be combined so as to supply a three wire system. He avoids rubbing contacts by making the armature stationary and the field magnets revolve. The armature conductors are bars of copper, insulated inside asbestos tubes, and buried in holes punched out of the iron close to the internal periphery. Eddy currents, which would attain enormous values in the copper conductors, if they were arranged in the ordinary way, are by this device avoided. Experiments made with buried conductors do not show that any power is lost by these heating currents. This method of arranging the armature conductors is mechanically strong, and, as it enables asbestos to be used as an insulator, results in an armature which is absolutely incombustible. The reduction in the air space, and the consequent improvement of the magnetic circuit reduces the exciting current. Corresponding to the number of poles of the field magnet each of the three circuit of the armature has an equal number of copper bars, connected in series by transverse pieces. There are, therefore three times as many bars on the armature as there are magenetic poles. The three circuits are joined up to each other in a manner similar to the three circuits of the Thompson-Houston arc machine. The exciting circuit is coiled around a sort of cast-iron pulley. Two steel rings, each armed with horns for ..ing pole-pieces, are bolted on to the pulley, one on either face. The spacing between the horns on each steel rim allows the horns of the opposite one to intersect, thus giving an alternating series of poles. This machine can work equally well as a synchronizing motor, and can be made to start without difficulty. It is claimed for this design that the total weight of copper on the field-magnet is very much less than is required for other machines of the same size. To excite the machine on open circuit only one-twentieth per cent. of the output is required. At full load, owing to the reaction of the armature, this amount is slightly increased. At full speed and with normal volts, the friction losses amount to about 1·6 per cent. of the maximum output. The loss due to heating, (C^2R), by the currents is a little less than this. When all losses are taken into account it is claimed that the machine has a commercial efficiency of 96 per cent.

The dynamo used in the Lauffen-Frankport transmission, to be described further on, was of this type and was constructed by Mr. Brown's company. They have been so successful that very shortly similar generators with vertical spindles, for coupling direct to turbines, and motors with horizontal spindles, are to be employed to drive the whole of the machinery at the Oerlikon Machinenfabrik from a waterfall 15 miles distant.

A system which is not properly a rotary current system, but a transition from the ordinary alternating current to the rotary current has been developed by the Schuckert Company of Nuremberg. The generator used for the development of a two-phase alternating current is the same as a continuous current machine, with a difference in the connections of the armature coils, and the addition of four collector rings. The armature is a flat Gramme ring, the connections of the coils with the commutator bars being made in the usual way. The machine thus resembles a self-exciting alternating current machine, with the difference that two alternating currents are obtained with a phase difference of 90°. In this way its efficiency as an alternating current generator is greatly increased. If a continuous current machine were to be used as an alternator, by omitting the ordinary commutator and substituting two collector rings, the efficiency would be about 30 per cent. less in the latter than in the former. With this double arrangement the machine delivers at once, alternating currents for one or two circuits and a continuous current for a third. The motor is a machine similar to the generator. The armature, when fed with the two phase current, will begin to rotate by means of the cyclic shifting of the magnetic polarity around the ring, and the corresponding action of the iron of the field magnets magnetised by induction. It is not necessary to have synchronism, although the machine attempts to attain it. If the field were excited by an alternating current it would necessitate it being constructed of laminated iron, and there would be loss due to hysteresis. The field of the generator is excited by a continuous current, either from a separate source or from its own commutator. This self-excitation is usually begun when the motor has attained synchronism. The method adopted is to bring the machine up to synchronism, at which moment the brushes are placed on the commutator, and the motor becomes self-exciting. The peculiar construction adopted gives great flexibility to the system, and the machine may be used as a continuous current dynamo, a self-exciting alternator furnishing currents of one or two phases, a continuous current motor, an alternating current motor, or as a transformer of continuous into alternating currents or vice versâ. As no results as to the efficiency of generation, transmission, or transformation have yet been published it is impossible to say whether this system will attain any considerable commercial importance or not.

The summer of 1891 saw great advances in the transmission of electric power by means of multiphasal alternating currents. The transmission of power from the waterfall at Lauffen-on-the Neckar to Frankport-on-the-Main, by means of these currents is one of the greatest achievements yet obtained in this direction. The dynamo-machine at Lauffen generated a three-phase alternating current, each component of which had a pressure of 50 volts and 1,400 amperes. The potential difference was then raised from 50 to 18,000 volts by means of transformers placed in oil to secure sufficient insulation. (Towards the end of the experiments the pressure was raised to 30,000 volts). From the transformers the currents passed along three No. 8 S.W.G. bare copper wires to Frankfort 112 miles distant. The line consisted of wooden poles 26 feet high, placed about 195 feet apart. The porcelain insulators used with the line were constructed with the lower edge turned up inside so as to form an oil bath. This bath was filled with resin oil so that no leakage could take place except across its surface. At Frankfort the high-tension currents were again transformed to 100 volts with corresponding current. Half the power transmitted, i.e., about 100 horse-power, was employed to light an illuminated sign. The remaining half was used to run a motor working a centrifugal pump. This pump raised water for an artificial waterfall 32 feet high. Thus a complete cycle was made from the waterfall at Lauffen to that at Frankfort. The generator and part of the oil transformers were built by the *Oerlikon Machinenfabrik,* while the motor working the pump, and the remaining transformers were built by the *Allgemeine Electricitäts Gesellschaft.* The special committee appointed to test this insulation has not yet sent in their report, so that no very certain figures can be obtained regarding the working of this line. Mr. Huber, director of the former company has, however, put forward a few figures relating to it. Only one insulator broke down under 30,000 volts. Two slight disturbances took place caused by the breaking of a wire and by a defective insulator, both due to faulty manufacture. The cost of installation was $300 per effective horse-power, of which $210 were for the line construction. According to Mr. Huber, the efficiency of transmission was 77 per cent. He further states that rain and fog had no effect whatever upon the insulation of the line. If these figures are substantiated by the official report of the commission, then the Lauffen-Frankfort experiment will place electric transmission of power on a very much firmer basis.

Since the economic transmission of power by electricity has been generally established, the question of the distribution of energy to great distances assumes more and more prominence, especially the distribution from remote waterfalls. In such cases it is, of course, especially necessary to work with higher tensions than have been customary heretofore. The direct current does not permit the employment of these high tensions, while the alternating current, owing to the fact that it is easily transformed, affords a very suitable medium for this purpose. It must be possible in such systems to drive motors of any desired size, a demand which at present the simple alternating current is less able to meet than the direct current, whereas the multiphasal alternating current is fully adapted to satisfy it.

The chief aim of the present paper has been to draw attention to the rotary current as a new means of transmitting power, and to give a general idea of the systems employed and experimental results arrived at.

The foregoing rapid enumeration of the methods employed, or now being investigated, for the convenient transformation of the energy of alternating currents for mechanical purposes shows that we may consider the problem as practically solved. Alternating currents will soon assume a commercial importance superior to that of continuous currents, and a new evolution of electric systems will be observed pending that which will be ultimately arrived at by the employment of multiphasal alternating currents.