AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, December 19th, 1894.

The 92d meeting was held this date at 12 West 31st Street, and was called to order at 8 P. M. by President Houston.

The Secretary read the minutes of the last meeting, which on motion were approved.

The Secretary read the following list of associate members elected and transferred at the Council meeting, held in the afternoon.

Name	Address	Endorsed by
BLACKALL, F. S.	N. Y. City Representative, Crocker-Wheeler Elec. Co., 126 Liberty St., N. Y. City.	Jos. Wetzler. Ralph W. Pope. T. C. Martin.
DERYCKERE, G.	Professor in Electrical Engineering, Gand University, residence, Boulevard Frere Orban 18, Gand Belgium.	A. G. Inrig. G. Sacco Albanese. R. W. Pope.
DEY, HARRY E.	342 Tenth Street, Brooklyn, N. Y.	H. Ward Leonard. Jos. Wetzler. Geo. W. Tuttle.
GRAHAM, GEORGE WALLACE	Secretary, Interior Telephone Co., 203 Broadway, N. Y.; residence, 163 Hicks Street, Brooklyn, N. Y.	Ralph W. Pope. T. C. Martin. Geo. M. Phelps.
LANE, VANCE	Manager and Supt. Construction, Nebraska Telephone Co., Omaha, Neb.	Thos. D. Lockwood. T. B. Doolittle. Wm. S. Ford.
LARDNER, HENRY ACKLEY	Instructor in Electrical Engineering, State College, Pennsylvania	J. P. Jackson. D. C. Jackson, J. G. White.
MOSES, PERCIVAL ROBERT	Student of Electrical Engineering, Columbia College, N. Y.; residence, 46 West 97th Street, New York.	F. B. Crocker. Geo. F. Sever. W. H. Freedman.
PRATT, CHARLES A.	Electrical Engineer, The Independent Elec. Co., 39th Street and Stewart Ave., Chicago.	Elmer A. Sperry. Chas. N. Black. E. P. Roberts.
PRIVAT, LOUIS	Electrician, Cicero Water, Gas and Electric Light Co., Oak Park, Ill.	Albert Scheible. Fred DeLann. Geo. Cutted.

SHEDD, JOHN C.	Professor of Physics and Applied Electricity, Marietta College; residence, 512 Fourth Street, Marietta, Ohio.	Ernest Merritt. Frederick Bedell. Harris J. Ryan.
VANDERSLICE, G. HAMILTON	Westinghouse Electric and Mfg. Co., P. O. Box 911, Pittsburgh, Pa.	L. B. Stillwell. Chas. F. Scott. Alex. J. Wurts.
Total, 11.		

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, October 5, 1894.

REIST, HENRY G.	Designing Engineer, General Electric Co., Schenectady, N. Y.
TRAFFORD, E. W.	Electrical Engineer, Richmond Railway and Electric Co., 104 N. 7th St., Richmond, Va.
JACKSON, HENRY	Telegraph Superintendent and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le-Moors, Lancashire, England.
ROUQUETTE, WILLIAM FREDERICK	BLAKEWAY, Proprietor Rouquette & Co., 47 Dey Street, N. Y.
UHLENHAUT, FRITZ, JR.	Electrical Engineer, Philadelphia Traction Co., Philadelphia, Pa.
Total, 5,	

Report of Meeting of Board of Examiners, December 17th, 1894.

Present—Messrs. G. A. Hamilton, *Chairman*; C. O. Mailloux and E. P. Thompson; R. W. Pope, Secretary, present *ex officio*.

	Approved.	Disapproved.	Laid over for further consideration.	Total Considered.
Applications for Transfer Reconsidered.	11		2	13
New Applications for Transfer Considered.				
Totals.	11		2	13

THE PRESIDENT:—There being no other business, the next matter as announced, will be a paper by Mr. Ludwig Gutmann of Chicago, entitled, "The Production of Rotary Magnetic Fields by a Single Alternating Current." As the author is not here, Dr. Pupin has kindly agreed to present the paper.

ON THE PRODUCTION OF ROTARY MAGNETIC FIELDS BY A SINGLE ALTERNATING CURRENT.

BY LUDWIG GUTMANN.

Since the first announcements of Prof. Ferraris and Mr. Tesla, that rotation can be accomplished by employing two or more alternating currents of displaced phase, the question has been raised by many an engineer as to the possibility of producing a rotary magnetic field by the use of a single circuit, carrying the ordinary alternating current, instead of requiring three or more wires or several independent circuits. So far it has been necessary to construct a special generator armature, the windings of which were rotated in a field of constant polarity, to produce two or more currents lagging in phase behind each other. To use the currents generated for establishing a progressive or rotary field, it was necessary to carry as many wires to the place of consumption as currents were employed differing in phase. Six years have passed, and quite rapid progress has been made in various directions. I wish now, to bring to your notice, a method of generating a rotary magnetic field by a single alternating current or its field, without condensers or choking coils. This is accomplished by a device brought out by me some three years ago. Its fundamental principle is hardly as yet appreciated; however, the World's Fair exhibits as well as literature of late, show that the device has attracted attention, and that several engineers have approached the principle involved.

I wish to refer to my motor and especially to its armature described in 1891.¹ Figures 1 and 2 show the device. The

¹ *Electrical Engineer*, vol. xii., Aug. 26, 1891, p. 230.

former is principally used in the American patents, while the latter is given in the English patent of the same year. The novelty of the armature construction, lies in a winding containing closed sub-circuits; and another point is, that the closed circuits do not coincide in number with the poles of the field magnet.

FIG. 1.

FIG. 2.

Before going into the action of this device, I will mention two simple experiments which are essential in order to understand the operation of this rotary magnetic field system.

If we have a closed coil moving in an alternating magnetic field, or better, between the poles of a *field magnet* as illustrated in Figs. 3 and 3a, energized by alternating currents; then the coil A, will be repelled from the pole, owing to the secondary field which it establishes, so long as it cuts, or is threaded by the lines of force of the field. The consequence is, that it will rotate, and place itself between the north and south pole, Fig. 4, where it reaches a *stable magnetic equilibrium*, as I

FIG. 3.

FIG. 3a.

like to term it, because in this position it acts like a pendulum properly suspended (Fig. 5). Any motion imparted causes the pendulum to make a few oscillations and come to rest, and similarly any attempt made to move the coil into an energized field will cause it to be repelled, and after a few oscillations it will re-

main at rest between the poles. It is repelled in either direction, because as soon as it approaches a strong magnetic flux, currents are induced in its windings and create an opposing field. The same coil can be in unstable magnetic equilibrium (Fig. 6), if it stands just in front of a pole, in which position it would act like a pendulum which is balanced with the weight above the point of support (Fig. 7). Both are in unstable equilibrium; the least motion to the left or right imparted to either, will cause them to accelerate in the direction of the impulse, and to assume a position of stability (Figs. 4 and 5). In this position, Fig. 4, the coil is therefore currentless. *This stable position, is the natural position of synchronous motors in operation.*

If such a synchronous motor is held behind the phase when rotating under load, a heavier current is induced in the spools

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

which accelerate the armature and keep it in step. If, however, the motor runs in harmony, and suddenly a great deal of the load is taken off, then the armature has a tendency to go more quickly, but in this case opposing currents are generated in the windings which retard the speed of the armature and keep it back, to remain in step, or in stability.

Let us look into the device before us, and consider first its quality as a motor. Returning to Figs. 1 or 2, preferably the latter, which is simpler and easier to explain, we find that if we send into the field magnet coil an alternating current, the armature will turn through a certain angle and stop. This motion depends upon the position of the three closed coils with respect to the two poles. This same device can itself be self-starting if we make the poles far enough apart and the energizing current sufficiently strong, so that at the initial speed the armature is repelled

at a certain rate. This initial speed changes with the number of poles, closed circuits and alternations. Let us take the first case and examine it. If we try to rotate the *armature* (as I shall call it hereafter), in a field of alternating polarity, we induce currents in the closed circuits, which establish poles,

FIG. 8.

but these poles are alternating in nature, and owing to the motion imparted, and owing further to the permanent connections in the winding, the poles move or travel, with the latter. This accounts for the fact that if the field poles are close together the armature consumes power during its rotation through the alternating field; it acts as a dynamo and does not start from a state of rest. If we impart by mechanical means an impulse to the armature, currents are generated whose sum has a variable and principally negative value. The armature makes a few revolutions and places itself in a stable magnetic equilibrium, viz., in such a position, symmetrical if possible, as not to generate any currents, and hence not to induce any reactionary¹ poles in the core. If, however, we impart to this armature a certain initial speed, which I shall call *the critical speed*, then it will continue to rotate, with a tendency to reach a certain fixed higher speed. This initial impulse may be given by mechanical or electrical means. I shall not state the results as yet, but prefer

FIG. 9.

to explore the action first, so that the same may be before us in various diagrams, and enable us to make any deduction desirable. First, let us assume that the armature rotates syn-

1. It is well to call the armature poles due to the armature currents, reactionary poles. The other armature poles are induced directly by the field poles, and contribute nothing to the torque.

chronously: It is evident that in order to have an armature with three closed-circuited coils, interconnected as shown, rotate in one direction, we must have currents induced whose sum has a positive value, viz., two of the coils must do work, in the same sense, while the third coil is either without a current, or has a smaller current in opposite direction, so that the value still remains positive. For true synchronism a closed-circuited coil reaches within a half-period the opposite pole, and consequently our diagram for one revolution would look as follows: (See Fig. 8).

The three diagrams, *a*, *b*, *c*, show the flow of currents and resultant poles. The closed-circuited coil 2, diagram *a*, is at this moment generating opposing currents to the others; coil, 1, is passing just in front of a pole. All three induced currents combined are developing poles as indicated, and rotating the armature

FIG. 10.

in counter-clockwise direction. The rotation being synchronous, diagram *b* shows the position of the armature when the polarity in the field has reversed; diagram *c* gives the position of the coils after the polarity has changed again. It will be noticed that the original position, as shown at *a*, has been reached again, and that the cycle will repeat itself. Without explaining these diagrams at this point, I wish to bring before you several other conditions, all of which will assist in reaching definite conclusions. Looking at the armature we see that it has a symmetrical winding, and as long as these closed circuits do not coincide with the number of poles of the field magnet (contrary to all synchronous motors built heretofore), other working positions are possible. The operation will take place as long as the sum of the armature currents have a positive value, since as far as the rotation is concerned it is indifferent which of the coils are doing the work. Let us assume that the armature does not run at a synchronous

rate, but at another fixed speed which may have a certain commensurable relation to the periods of the exciting field current, which speed I shall call the *harmonic speed*. Instead of showing the diagram with windings as in the first set, I have simplified them. In the following sets of diagrams, Fig. 9, I assume that the armature, on account of the load or other reasons, cannot reach synchronism, and that at each field reversal the position of the armature with respect to the field is the same, only the coils have changed places as indicated. You will notice that in this set of diagrams the armature, for each half-period, makes one-third of a revolution only, namely, coils 1, 3 and 2 exchange positions with the change of polarity. Let us step at once to another speed (Fig. 10), which you will no doubt admit as possible; viz;—let us assume that coils 1, 2 and 3 cannot arrive at synchronous speed, and that coil 2 reaches the position which 1 ought to occupy, it will be seen that owing to the symmetrical position, it is quite indifferent which of these coils arrives at a given position required for harmonic operation. This will be clear to you by referring to the third set of diagrams, Fig. 10.

We are now enabled to compare three sets of diagrams, Figs. 8, 9 and 10. The first set shows for this new type of synchronous motor that at synchronous speed the pole positions in the armature are practically stationary relatively to the coils and core, and rotate with it. The second set shows that during a complete revolution of the armature, the field has reversed three times, that is, an odd number of times, hence, when the armature returns to its original position, after a complete revolution, it finds the field magnetization of reversed polarity. The magnetic field of the armature rotates in the opposite sense, one and a-half times per revolution. In the third set, the armature makes but one-sixth of a revolution per half-period, and the magnetic field of the armature in a complete revolution rotates three times in the opposite direction. This statement may be startling, and my argument, so far, may not be entirely convincing, as on close inspection it will be found that the armature poles have to do considerable jumping. I will now explain the performance of the rotary magnetic field of this armature in a four-pole field, where the changes occur far more gradually, leaving no doubt whatever as to the assertion made. Fig. 11 shows diagrams illustrating synchronous speed. By the aid of these four diagrams we can more easily follow the pole positions in the arma-

ture core, and find them stationary in it. Inspecting now Fig. 12, in which the armature speed is reduced, we are able to obtain a clear picture of the main subject under consideration.

In this set of five diagrams we see five positions, which coil 1, for instance, occupies before it has made one-third of a revolution. Nevertheless, if we now look at the changing pole positions we can readily detect that they are progressively shifting, and we also see that they have made one whole revolution and that in opposite direction to the mechanical rotation, or in other words, the magnetic field would travel three times around the armature core during one revolution. In all armature diagrams described, and to be described, the resultant of the magneto-motive forces of the armature currents is given only. To complete the picture showing every one of the component magneto-motive forces act-

FIG. 11.

FIG. 12.

ing, it becomes desirable to plot a diagram of force (Fig. 13). These components act like three variable concurrent forces including an angle of 120 degrees with each other. These forces we may represent as equal, for the sake of convenience, as it does not influence the idea which we wish to illustrate. However, those two forces which are acting in the same direction are indicated by heavier lines.

Plotting the direction of the forces in order, as, for instance, in the last named set of diagrams (Fig. 12), where the coils act in the order 1, 2, against 3; 3, 1, against 2, and 2, 3, against 1, we obtain Fig. 13 for one cycle. The three figures marked *a*, *b*, and *c* indicate the direction in which the three forces are acting in the three positions of one cycle or revolution.

By drawing the resultant diagram of force from the predomi-

nating forces of each position, we obtain the accompanying figure (Fig. 14). These forces form a triangle, and the rotation resulting, may be seen from the direction of arrows on the circumference of the surrounding circle. However, the reactive forces should be considered and represented separately to obtain

FIG. 13.

FIG. 14.

the true picture, and we have to add them to find the total force applied, and the manner in which all the forces are acting. We, therefore, repeat the resultant diagram (Fig. 14), and add the opposing forces at their proper places. This diagram (Fig. 15) shows that the reactive forces, shown by dotted arrows, also have a common center, and that as regards time of maximum effect, they succeed each other in the direction of rotation of the armature, while they are acting in the opposite direction of the main force. If we now plot a diagram of these reactive forces alone, we obtain the smaller triangle shown (Fig. 15) inside the larger. It will be noticed that rotation is in the opposite direction; or, in other words, that in reality we have, with this disposition, to deal with two rotary magnetic fields in opposite direction; the useful work done will depend on the difference of the angular velocity of these two rotating fields and their relative intensity.

FIG. 15.

FIG. 15a.

FIG. 15b.

Looking now at the device as a generator (Fig. 12), we can account for the rotary magnetic field because we generate poly-phased currents in the coils 1, 2 and 3. They operate together in the following order: 1, 2; 3, 1; 2, 3; 1, 2, etc. If rotated, as shown, the coils will distribute three-phased currents over the

armature, and this will be understood when examining into the flow of currents of the closed-circuiting conductors which are here provided with arrows. At this particular harmonic speed, it will be further noticed that the simple alternating field of force has the identical qualities as a polyphase energizing field, as the poles in front of the closed-circuited coil seem to be traveling (for the armature) in clockwise direction. This is indicated by the shading of the pole of same sign in front of the coil most powerfully acted upon in the five positions, representing one revolution for the field. The currents displaced in phase, cause the armature to rotate harmoniously with the alternations, and prevent the armature from being easily thrown out of step.

Returning once more to the earlier diagrams, Figs. 9 and 10, we see that below synchronism there are two other speeds which are entitled to be called synchronous, because a certain fixed relation exists between the periods of field excitation and armature rotation.

It will be evident that the greater the number of closed circuits, the greater is the number of harmonic or synchronous speeds in which the armature can operate. If the armature contains ten closed circuits, and rotates in a two-pole field, it will be able to generate five currents, lagging 72 degrees behind one another in phase, and would have at least five speeds which are synchronous, and the armature owing to its peculiar construction, can operate at a slower speed than the synchronous speed as interpreted heretofore.

Looking at the device from a general standpoint, it will be clear that this particular armature construction embodies all the weak points of a synchronous, and all the strong points of the poly-phase motor. The weak points are :

1. that the machine will not start from state of rest in the form shown, because in Figs. 1, 2, and 12, the coils act on one another differentially and have a variable and negative value; they are in magnetic stability when at rest, hence, no rotation can result.

2. The device has a small starting torque when rotated, owing to the differential action of the coils, which cause, with a small number of closed circuits strongly oscillating or jumping poles, until a harmonic speed is reached.

3. The device when in rotation, is not reversible by simply changing circuit connections.

The strong points are :

First, that the motor develops polyphased currents in its own windings.

Second, that therefore it is more difficult to pull it out of step as it has the capacity to stand, what I would term, magnetic slippage.

Let us assume that a certain coil, which should reach a given point to run harmonically, remains behind owing to a slower motion of the armature; in this event the coil ahead has to perform the function at the expense of a heavier current. The loss of revolutions due to this action may be comparable to the slipping of a belt over a pulley. However, there is also a limit to the slipping. The armature should have some harmonic speed with respect to the alternations. Should it fall below the lowest harmonic speed, then it will come to a standstill just like any other overworked synchronous machine.

Synchronism in a motor means nothing more nor less than a magnetic flexible clutch, which may be represented mechanically as follows:

The old fashioned non-starting synchronous machine having equal armature coils and field poles, can be compared with the arrangement shown in Fig. 15*a*, giving side view and elevation. The disk 1 is provided with two projections; 2, imparts rotation to shaft 4 by means of the flexible arm, or spring 3, which enables the shaft 4 to be slightly behind or ahead of disk 1. However, if the work put on shaft 4 is in excess of the strength of spring 3, then it will break, and shaft 4 will speedily come to a standstill.

In contrast to this older form of synchronous motors stands the new one, which forms the subject of this paper and the machines operated by bi or polyphased currents. The mechanism for showing magnetic coupling for these latter types may be represented by Fig. 15*b*. In this case, 1 represents a crown-wheel the teeth marked 2; into these teeth meshes a catch 3 in a flexible manner, which catch is connected rigidly to shaft 4. Within the range of normal work, catch 3 would remain fixed between the two given teeth, but if the shaft 4 is overloaded, the flexibility of catch 3 will cause it to yield, and pull out of its position, drop in between some other two teeth, and continue to operate but at a slower speed. The greater the excess of work, the greater will be the slippage, and the more teeth will be jumped by the catch 3 in every revolution of disk 1. For the synchronous motor herein described, the overloading to the extent that it cannot reach

the lowest harmonic speed, would be equivalent to the breaking of spring 3'.

It will be remembered that Prof. Ferraris always, and Tesla sometimes obtained a rotary magnetic field and rotation by influencing one coil carrying a primary current, by another at right angles thereto carrying secondary currents. Here we have two phases from a single source, Fig. 16. To obtain a multiple of phases we may take two or three iron cores A, and surround them with coils B, like the links of a chain, Fig. 17, so that the secondary coil of transformer 1, is the primary of transformer 2, and so on; or we may design a special core for a transformer, and create a rotary magnetic field by applying to one coil a primary current from the line, and to another coil a secondary current from a transformer, whereupon by the rotary field obtained,

FIG. 16.

FIG. 17.

polyphased currents may be taken through other coils on the transformer. These methods have, however, one drawback, and that is that the phase will change more or less in lag with difference in load, while for many purposes it is most essential that for efficient working, the phase should remain at the same constant angle. This desideratum has been accomplished by the device under consideration, and any suitable number of currents lagging in phase may be obtained from a single alternating current.

To obtain a rotary magnetic field in or by a stationary body, at least two electric or electromagnetic forces of definite phase relations, acting at an angle to one another and changing at periods harmoniously, are essential requirements.

If, however, we allow the body, or part of the same, to be movable, we may substitute mechanical rotation primarily as an adjuster of the periodicity and phase of one of the two forces;

the fundamental relation between the two forces must in this case also be the same as in the other ; namely, they must work in harmony, and the periodicity and phase of one force determines the periodicity and phase of the other. If the second force is a current, it must be one of the same period or some harmonic of that period; if it is rotation, it has also to be synchronous or harmonic. We can now clearly understand why, when rotating the armature, Figs. 1 and 2, in an ordinary alternating current field, we have no system of polyphased currents and no rotary field, simply because the armature rotation does not stand in any relationship whatever to the alternations; but as soon as the speed does so, there are generated polyphased currents lagging in phase at a fixed angle, and a rotary magnetic field.

There is a difference whether the armature is influenced by a single alternating current, or by several, causing themselves a rotating energizing field. Nevertheless, in either condition the armature is in magnetic stability, and this state is the reason that it remains stationary in the first case, and that it rotates in the second. The reason that the motor starts in the second case is evidently because the inducing magnetic field is itself rotating in the stationary field magnet core. As said before, it is considered necessary for the proper operation of the armature for giving maximum torque, that if placed in an alternating current field of force, the armature rotation should have a definite relation to the alternations. Up to the publication of this device some three years ago, synchronous motors had as many armature coils as field coils, and hence to obtain the value of the synchronous speed, all that was necessary was to divide the alternations of the armature current n by the number of field poles p of the magnet employed. But if the number of armature coils are not the same as the field poles, then the speed may vary from this synchronous speed, and a modification is thought to be necessary. We would have to find the smallest common factor between field poles p and armature coils p^1 with which we have to divide the number of alternations to obtain the value of the lowest synchronous speed while the condition of slippage may allow for the lowest harmonic, the value $\frac{n}{p p^1}$.

It will now be clear that motors can be designed having any desired variation of speed, and have defined synchronous speeds or

approach the indifferent relation. I wish it understood, that I do not intend to treat the subject in all its details, and I am especially reluctant on the ground of having carried on but few experiments.

The few diagrams presented do not disclose many conditions of those possible. They show only one or two facts of conditions which frequently are of a complex nature. Evidently, the rotary magnetic fields in the device under consideration may have altogether different speeds from those shown in the diagrams; also, that the magnetic field may rotate with and ahead of the armature, and lastly, the speed of rotation of the rotary field of the armature may be synchronous, and opposite in direction to its rotation.

The device has been given in form of a diagram, and as it has been described as not self-starting, I wish now to state that it be-

FIG. 18.

comes self-starting as a series, a shunt or an induction motor in a field of single phase or polyphased alternating currents. Fig. 18 represents one of the earliest forms which have since been simplified to a considerable extent. The part A B, represents here a simple series motor whose armature B may be any drum or ring type, open or closed coil winding; the part C D, may be similarly constructed. Both armature windings B and D are connected electrically by 4 wires E at points of equal distance, which number of conductors E, may be reduced or increased, depending on the number of phase currents desired. Now send an alternating current into the series motor, part A B¹, then the armature will start from state of rest, and will send current impulses into the D part winding, which becomes the more regular the more the armature

1. Preferably so that no reaction takes place from part D.

has approached synchronous speed, where bi-phase currents will be established therein; these react on the field magnet core *c*, and for the purpose of maintaining the armature in this synchronous speed, the commutator *F* is applied to rectify the polyphase currents; which continuous current may be used to energize the magnet *c*.

The fundamental principle disclosed, opens to us a very wide field for work. Not only are we enabled to construct motors almost as cheap and simple as continuous current motors, but there is in this principle involved the germ for the ideal distribution of power, inasmuch as we are enabled to collect the polyphased currents generated, or commutate them immediately at will.

Finally I wish to call your attention to the fact, that the last figure is in reality a motor-generator, and it is therefore evident that the electrical energy supplied need not all to be transformed into mechanical power, but that a portion may be utilized in one of the modified forms named above.

DISCUSSION IN NEW YORK.

DR. M. I. PUPIN :—The author states in the introduction that his paper contains a discussion of a method of generating a rotary magnetic field by a single alternating current without condensers or choking coils, and its application to the construction of single phase alternating current induction motors.

Figs. 1 and 2 show diagrammatically the principle of the devices. An armature core, uniformly wound with wire and the winding divided into a number of closed sections, preferably equal to each other, but in such a way that the number of these sections is not equal to the number of poles of the exciting field. The field is an alternating field. Figs. 4 and 6 illustrate what the author calls the *stable* and the *unstable* positions of magnetic equilibrium of a coil in an alternating field. In the first place a slight displacement of the armature would cause it to oscillate about the line of symmetry between the two poles. In the second case such a displacement would cause the armature to flop over and rotate toward the position of stable equilibrium. An armature winding as that in Fig 2 has also a position of stable magnetic equilibrium about which it will oscillate if slightly displaced. So for instance the position represented in Fig. 2 is an unstable position. A mechanical impulse will start the armature to rotate toward the position of stable equilibrium, and during its journey toward that position it will be also acted upon by the repulsive force between the alternating field and the armature current induced by that field. The armature, therefore, reaches the position of stable equilibrium with a certain amount of kinetic energy which is equal to the energy of the mechanical impulse imparted to it, and the work done upon it by the repulsive force. With this stored up energy, the armature is enabled to continue its journey beyond the position of stable magnetic equilibrium although from this point on, it has to move *against* the electromagnetic forces, at the expense of its kinetic energy. How far it will continue this journey will depend entirely on the kinetic energy with which it started from the unstable position, how much work was done upon it by the variable field during its journey from the unstable to the stable position, and at what rate it has to expend its kinetic energy after passing this position.

Three cases must be carefully distinguished :

1st. The armature arrives at the position of stable magnetic equilibrium with less kinetic energy than the amount required to carry it beyond this position and up to the next position of unstable magnetic equilibrium. In this case it will oscillate about the stable position and be finally reduced to rest.

2d. The armature arrives at the position of stable magnetic equilibrium with enough kinetic energy to carry it beyond this position and up to the next position of unstable magnetic equilibrium, but unfortunately it arrives there with less kinetic energy than it had in parting from the preceding unstable position. In

this case it will generally continue to rotate several times around, and be finally reduced to rest.

3d. The third possible case is the most important one and forms the groundwork on which Mr. Gutmann proposes to raise a new system of electrical distribution. It is this: Suppose the armature receives from some external source a certain initial speed, and is then left to take care of itself. Suppose again that this speed is such that the kinetic energy with which the armature passes through a position of stable magnetic equilibrium is considerably more than necessary to carry it to the next position of unstable equilibrium, so that the armature reaches this position with more kinetic energy than it had when it left the last position of unstable equilibrium. It is evident that in this case the armature will not only continue to rotate, but that it will rotate with continuously increasing angular velocity. This initial speed the author calls the *critical speed*.

The question arises now, how long will this continual increase in angular velocity go on? Evidently until synchronism is reached, that is if the armature does no appreciable external work during its rotation. In a bipolar machine with three armature coils, the synchronous rotation is illustrated in diagrams Fig. 8. During one reversal of the field the armature has moved through 180° , so that the triangle 1, 2, 3, in B has its sides parallel to the triangle 1, 2, 3 in A. During the next reversal the armature has reached its initial position again, as given in C. But if the armature cannot reach synchronism on account of the external load, or on account of too large frictional resistances, then the best it can do is to rotate at some other lower but constant speed, and the question arises, is any other speed possible? The answer is in the affirmative, for if you look at Fig. 9 you will see that if the speed of the armature under consideration is such that it will carry the armature through one-third of the circumference during one reversal of the field, that the armature can go on rotating at this constant speed. This speed Mr. Gutmann calls *harmonic speed*. Another harmonic speed is illustrated in Fig. 10. Here the armature passes through one-sixth of the circumference during one reversal of the field, so that during three reversals of the field the armature has gone through one-half revolution. The possible speeds of this armature are, therefore, 1, or 2, or 3 revolutions for the time interval corresponding to three complete periods of the exciting field. We can now generalize as follows:

An armature containing n coils will have n *harmonic speeds*, that is to say, it can rotate 1, 2, 3, . . . n times during the time interval corresponding to n complete periods of the exciting current. But it must be remembered that for a given value of the impressed electromotive force and a given mechanical force acting on the shaft of the armature there is, according to the Principle of Conservation of Energy, only one speed at which the armature can rotate uniformly, and if that speed is below the

lowest harmonic speed, the armature will stop. We can say, therefore, that the critical speed is equal to the lowest harmonic speed. If the lowest harmonic speed should be too high for practical working, we can evidently reduce it to any practical limit by using a multipolar field, as an inspection of Figs. 11 and 12 will show.

There is another way in which the forces acting between the field and the armature can be pointed out, and that is, by pointing out the reactions between the exciting alternating field and the magnetic field produced by the induced currents in the armature. It does not make the subject any clearer, and I shall consider it in so far only as necessary to bring out a rather interesting fact. Consider the armature in Fig. 2. Suppose we had one closed coil only, covering $1/n$ th part of the armature, and suppose, also, that the field is constant. If the armature is rotated, an alternating current is generated in it, whose frequency is equal to the frequency of rotation of the armature. If, however, while the armature is rotating uniformly, the field alternates uniformly also, then two alternating currents are generated in the coil, one whose frequency is equal to the sum of the frequencies of the armature and field, and the other whose frequency is equal to the difference of these two frequencies. The current of lower frequency has a smaller amplitude than the one of the higher. Its amplitude is zero when the field and the armature are in synchronism, and then the frequency of the other is equal to twice the frequency of the field. If now we cover the whole armature with n equal short-circuited coils by simply connecting, as Mr. Gutmann does in Fig. 2, n successive equidistant points to each other, we shall then have n pairs of alternating currents differing from each other in phase by $1/n$ th of the period. They will, therefore, give, theoretically, two rotary magnetic fields. One rotating with a frequency equal to the sum of the frequencies of the armature rotation and the frequency of the alternating field, and the other rotating with a frequency equal to the difference of these two frequencies. At synchronism the slower rotary field vanishes, and the speedier, rotates with twice the angular velocity of the armature. Mr. Gutmann evidently neglects the slowly rotating field, and he may be right. But, however that may be, it is certainly plain that a rotary magnetic field is established by Mr. Gutmann's device, and that we could obtain by a suitable arrangement polyphase currents from such armatures. It is also plain that such a motor could be employed as a motor generator. These appear to me to be the novel features of Mr. Gutmann's proposition. The proposition is certainly interesting. Let us hope that Mr. Gutmann will soon succeed in proving its practical value.

THE PRESIDENT:—Gentlemen, you have heard Dr. Pupin's able exposition of this paper. It is now open for discussion.

MR. WOLCOTT:—I would like to ask one or two questions. On page 841 it says the motor allows magnetic slippage; in other words, it works like an ordinary induction motor. In an ordinary induction motor, in synchronism, the torque is zero, or at all events, it is minimum. It is the same here. Put on a load and get the armature running at a little slower speed than synchronism, the polyphase principle begins—the current induced in the armature makes the pull stronger. Well, if I understand the thing, that is also true of the harmonic speeds. Therefore, starting from the synchronous speed, dropping down to the first harmonic speed, there must be a point where, after there is a certain amount of slip, it drops suddenly to the harmonic speed, because if the harmonic speed works in that respect like a synchronous speed, there must be a tendency either side of it to approach it. That is, if you are going a little faster than the harmonic speed, the tendency is to pull down, and as you go slower again the tendency would be to bring it up again. Is that correct?

DR. PUPIN:—I don't think so.

MR. WOLCOTT:—Would the torque go on increasing infinitely?

DR. PUPIN:—No, because as the armature increases its angular velocity the torque varies; it may diminish. The torque must have a certain value, otherwise it is not able to overcome the mechanical pull on the shaft.

MR. WOLCOTT:—That is very true. But, if I understand this motor, it has two separate components. That is, it works like the ordinary synchronous motor, and then, in addition, it works like the polyphase motor—induction motor.

DR. PUPIN:—Yes, that is right.

MR. WOLCOTT:—Considering the portion of the torque which is due to the synchronous action, the instant you get out of synchronism, as with an ordinary synchronous motor, it stops.

DR. PUPIN:—Not quite so.

MR. WOLCOTT:—Now with this one, as soon as you get out of absolute synchronism, then you depend on the induced currents in the armature.

DR. PUPIN:—The pull between the armature and field, changes rather suddenly; that is, it is a sort of harmonically varying function.

MR. WOLCOTT:—As the speed lags a little, the torque increases, does it not?

DR. PUPIN:—Not necessarily.

MR. WOLCOTT:—It does not do the work of an induction motor then? If it does not do that it seems to me that it is no good.

DR. PUPIN:—It has a fair torque at definite speeds only.

MR. WOLCOTT:—The author says it allows similar magnetic slippage.

DR. PUPIN:—Magnetic slippage from the synchronous speed to the next harmonic speed, and then to the next and next, and so on. It does not allow a gradual slippage.

MR. WOLCOTT:—I understand the author to say that it works like a polyphase motor.

DR. PUPIN:—In the sense that it has more than one speed at which it can work. It can work at two or three speeds, practically any number of speeds, if you increase the number of sections in the armature.

MR. KENNELLY:—If I understand the paper correctly, there are certain speeds called harmonic speeds at which the torque is a maximum. In the polyphase motor at certain speeds the torque is zero. So that this action is different altogether from the action of a polyphase motor.

DR. PUPIN:—That is my idea of it.

MR. WOLCOTT:—On page 841 he says: "Second, that therefore "it is more difficult to pull it out of step, as it has the capacity to "stand what I would term magnetic slippage." If that means anything it means that if you pull it a little out of step the torque increases. If the torque does not increase, I do not see how it is any more difficult to pull out of step than the ordinary synchronous motor.

DR. PUPIN:—Because, if you pull it out of one step you get it into another.

MR. WOLCOTT:—That may be what the author means, but if it is, I think that is a very poor foundation for his claim.

DR. PUPIN:—It has several chances; whereas the ordinary synchronous motor has only one.

DR. SAMUEL SHELDON:—I wish to say a word in reference to the currents generated in the different coils upon the ring of the armature. Suppose the armature to rotate n times in a second in a constant field of unit strength. At any instant of time t , the electromotive force generated in a single coil would be proportional to the sine $2\pi n t$. If the armature remain at rest and the bipolar field should alternate harmonically n' times per second, the electromotive force generated would be proportional to sine $2\pi n' t$. If now the armature should rotate and, at the same time, the field should alternate, the electromotive force produced would be proportional to the sine of $2\pi n t$ times the sine of $2\pi n' t$. Suppose the armature to rotate at that harmonic speed which makes the ratio of n to n' as 2 to 3. The graphic combination of two sine curves of these frequencies yields a third curve, which represents the time change of electromotive force generated in the coil. In this case there is a succession of alternations at two different frequencies. One complete alternation at a certain frequency is followed by another complete alternation at twice that frequency. I do not know what mechanical action would result from this.

DR. PUPIN:—I suspected the difficulty which Dr. Sheldon mentions. The two currents are of unequal amplitude. The one of lower frequency has a smaller amplitude than the one of higher frequency, and Mr. Gutmann seems to rely for the total

action upon the quicker field. Whereas, really, when you have two alternating currents of unequal frequencies, and they are magnetizing iron, then although the current of lower frequency may have a smaller amplitude, it may produce a stronger magnetic effect than the other current which has a higher frequency and larger amplitude and weaken considerably its magnetic effect. That may give Mr. Gutmann some difficulty. I must confess, however, that I have not examined the proposition thoroughly enough to speak with much definiteness.

THE PRESIDENT:—Is there any other discussion of this paper?

It may interest the members of the INSTITUTE to know that Council this afternoon took an action which resulted in the appointment of a committee consisting of Prof. Crocker as Chairman, Prof. Kennelly, Mr. Caldwell, Mr. Stine and Prof. Sheperdson to discuss and formulate a plan to determine whether or not it is advisable for the INSTITUTE to undertake the indexing of electrical literature. This grew out of the discussion which you remember we had at our last meeting here. I do not know whether the INSTITUTE would care to discuss the matter prior to the work of the committee. This committee is charged with the duty of determining whether such a thing is desirable, and second if it be desirable, to formulate a plan according to which it can best be carried out.

[Adjourned.]

DISCUSSION IN CHICAGO.

A meeting of the Western members of the INSTITUTE was held in Armour Institute on December 19. The meeting was called to order by Mr. Arnold, about thirty-five members and visitors being present. Mr. L. L. Summers was appointed Chairman.

Mr. Gutmann's paper was read in detail by the author.

MR. CARL K. MACFADDEN:—I have had the good fortune to witness a number of experiments that have been made on this system, and I would say that in this new plan, as is stated in the last clause of this paper, it will find a wide field of application. As far as I know there is no method of obtaining polyphased currents in any manner which will ensure a definite relation between the phases of the currents. The method here shown for getting a direct current from a single phase alternating current through a single machine is undoubtedly of great value. One of the drawbacks to the distribution of alternating current for power is the necessity for having more than two wires, and having special generators for furnishing such a current. If our simple single-phase apparatus could be used, and a current obtained which might then be converted into poly-phase or direct currents, I think that we would find it very desirable.

MR. L. L. SUMMERS:—In the rotary transformer it is evident