No. 630,418. Patented Aug. 8, 1899.

C. STEINMETZ.

METHOD OF AND MEANS FOR INDUCING MAGNETISM IN MAGNETIC CIRCUITS.

(Application filed Aug. 31, 1891.)

(No Model.) 4 Sheets—Sheet 1.

Fig. 1.

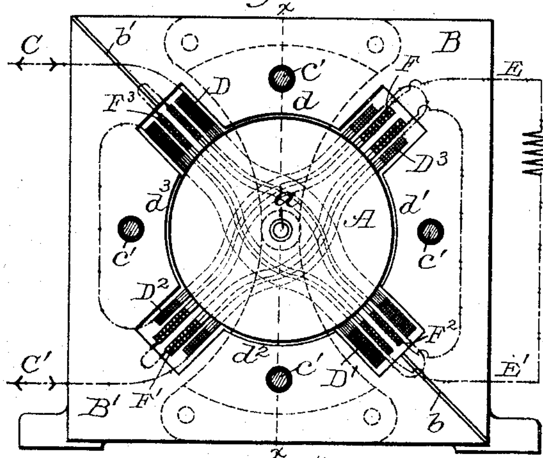


Fig. 2.

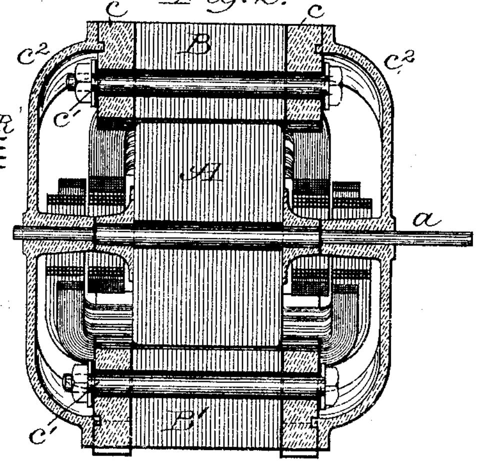


Fig. 3.

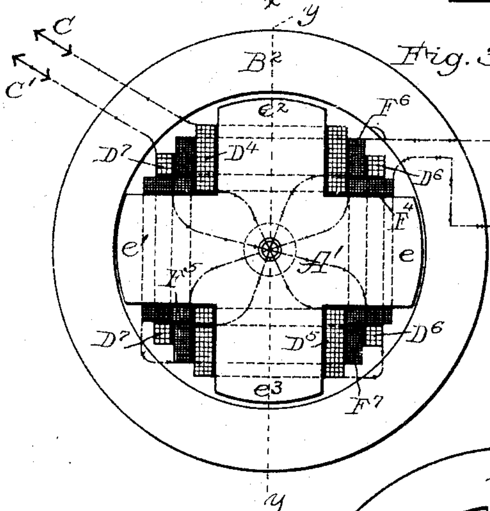


Fig. 4.

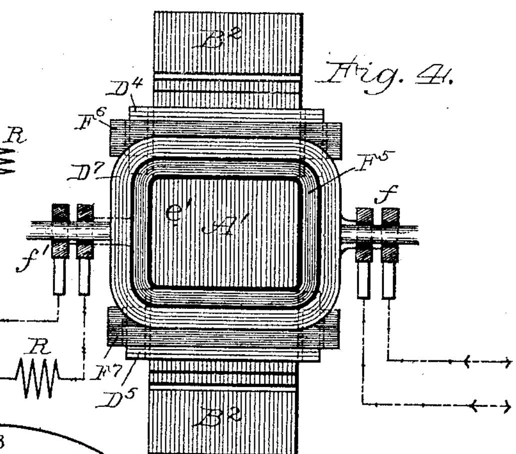
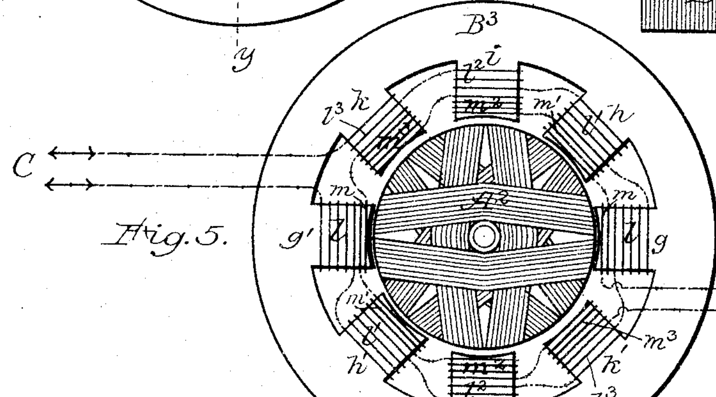


Fig. 5.



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(No Model.) 4 Sheets—Sheet 2.

Fig. 6.

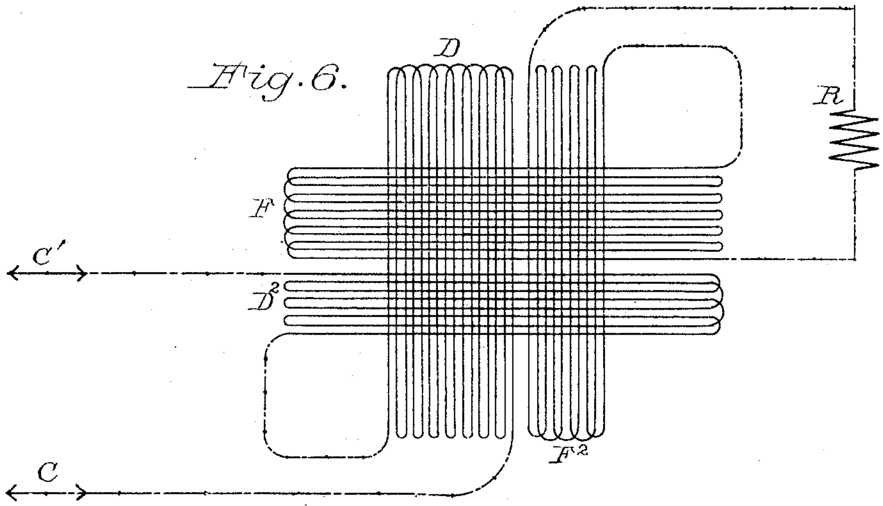
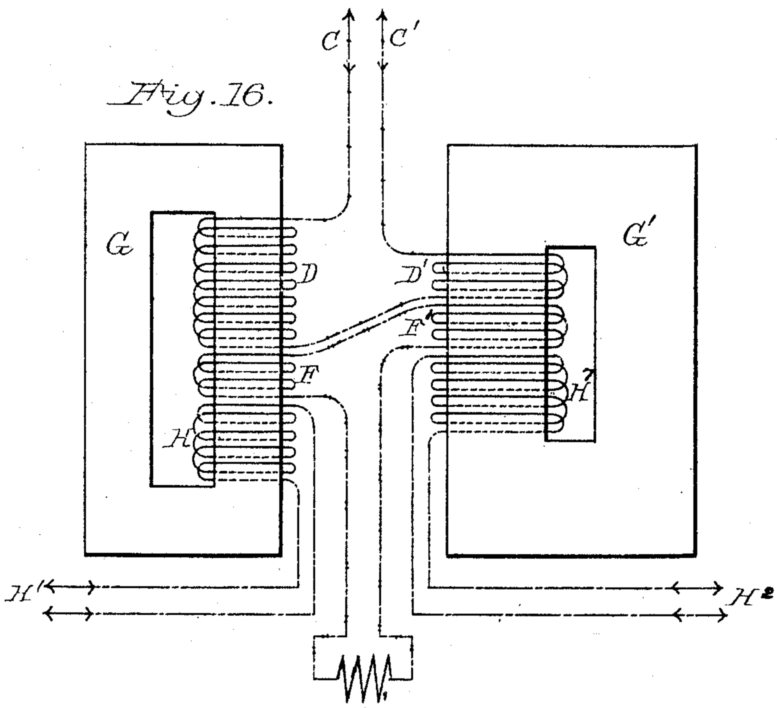


Fig. 16.



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4 Sheets—Sheet 3.

Fig. 7.

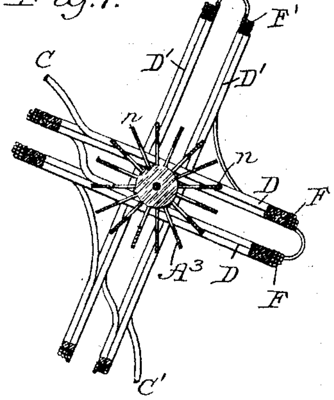


Fig. 9.

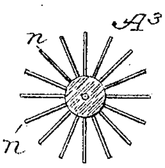


Fig. 8.

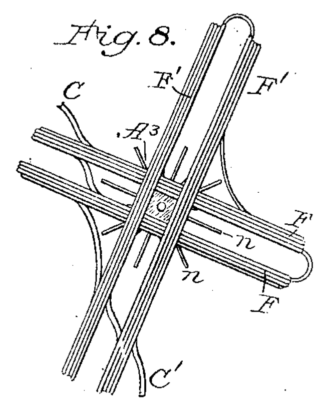


Fig. 10.

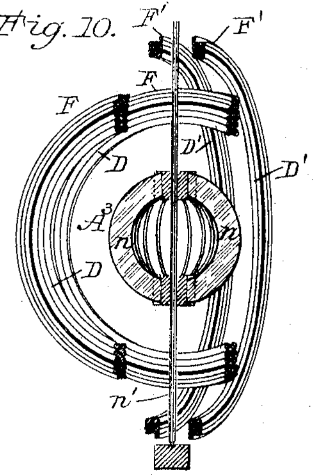


Fig. 12.

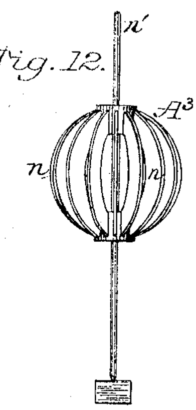


Fig. 11.

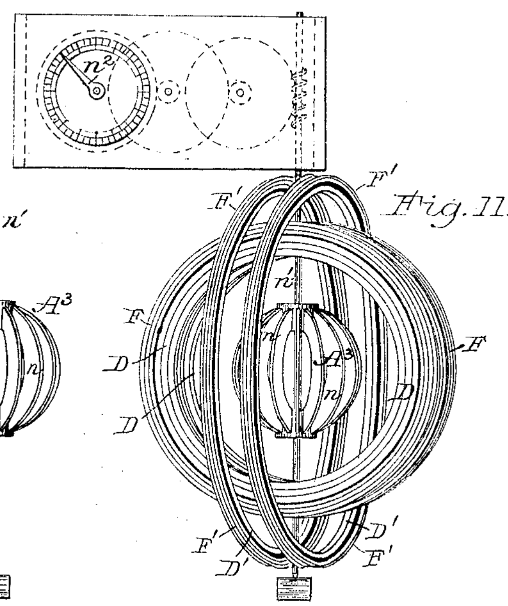


Fig. 13.

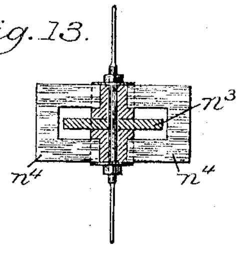


Fig. 14.

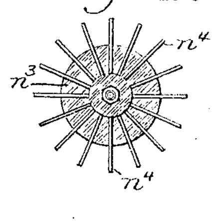
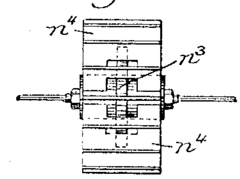


Fig. 15.



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(Application filed Aug. 31, 1891.)

(No Model.)

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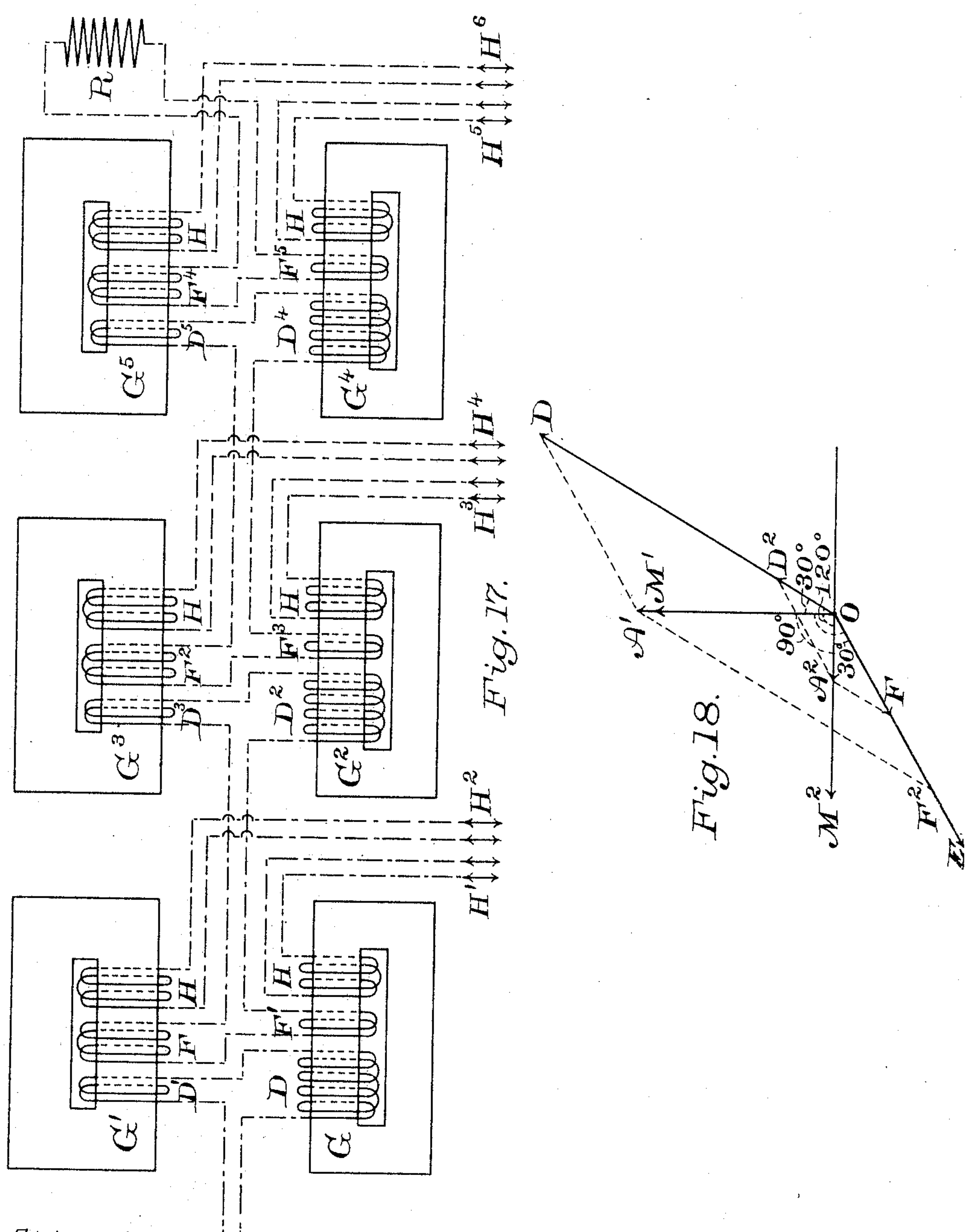

Fig. 17.

Fig. 18.

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UNITED STATES PATENT OFFICE.

CHARLES STEINMETZ, OF YONKERS, NEW YORK, ASSIGNOR TO THE GENERAL ELECTRIC COMPANY, OF NEW YORK.

METHOD OF AND MEANS FOR INDUCING MAGNETISM IN MAGNETIC CIRCUITS.

SPECIFICATION forming part of Letters Patent No. 630,418, dated August 8, 1899.

Application filed August 31, 1891. Serial No. 404,265. (No model.)

To all whom it may concern:

Be it known that I, CHARLES STEINMETZ, a subject of the Emperor of Germany, residing in Yonkers, in the county of Westchester and State of New York, have invented a certain new and useful Method of and Means for Inducing and Controlling Magnetic Circuits, of which the following is a specification.

The present invention relates to certain novel methods of and means for inducing magnetism in magnetic circuits and utilizing the magnetism so developed for producing rotation in alternating-current motive devices or for transforming alternating currents and at the same time changing the phase relation of the currents so transformed.

The invention will be hereinafter more particularly described as embodied both in a novel form of alternating-current motor and in special arrangements of transformers. In the particular apparatus of both of these types in which the invention is shown embodied magnetism is induced in two or more magnetic circuits by the combined magnetizing action of alternating single-phase electric currents, serving as a primary exciting medium, and secondary currents in a closed circuit in inductive relation to the circuit of the first-named currents, and the phases of magnetism in the magnetic circuits are controlled, adjusted, or varied by properly proportioning or varying the relative magnetizing powers of the currents upon the different magnetic circuits. In other words, I can and do vary the time of the maximum phases of magnetization in any one of the magnetic circuits so that it will occur at any predetermined time before or after the maximum electric phases of the electric currents fed into the apparatus, because the magnetic phases in the magnetic circuits will conform to the resultant of the magnetomotive forces induced by the different currents exciting the circuits, and this resultant will not conform in phase relation to either of the exciting-currents alone. The resultant magnetic phases can therefore be made to differ to any desired extent from the phases of the magnetizing-currents, such differences being established by suitably proportioning the magnetizing powers of the different currents upon the several magnetic circuits and by appropriately varying the magnetic resistance of the seveaal magnetic circuits, said resistance, with the lag of the electric phases of the secondary currents behind the electric phases of the primary currents, enabling me to provide, in a series of magnetic circuits, a rotation of the line of magnetization, as for certain types of alternating motors, or with alternating currents of a single phase or, indeed, any phase relation to induce alternating currents of different phase relation when said magnetic circuits are employed, as in transformers.

The novelty of the invention as set forth in the claims is, however, in many respects broader than the general description just given of the special embodiments of the invention hereinafter to be described, and I refer to the claims forming part of this specification as setting forth generically, as well as more specifically, what I believe to be the points of novelty in the present invention.

Referring to the drawings, Figures 1 and 2 illustrate in two sections at right angles to each other an alternating-current motor designed to operate in accordance with the present invention in which the armature is surrounded longitudinally by the field-coils. Fig. 2 is taken on the section-line *x x*, Fig. 1. Figs. 3 and 4 illustrate in two similar sectional views another form of alternating-current motor. Fig. 4 is taken on the section-line *y y* of Fig. 3. Fig. 5 is an end view of an alternating-current motor in which the armature is surrounded by a field-magnet having multiple field-poles provided with a suitable arrangement of field-coils. Fig. 6 is a diagrammatic view of the winding of the field-coils of an alternating motor of the type herein described. Figs. 7 to 12 illustrate the invention as applied to an alternating-current motor of small power—for example, one suitable for use in connection with an electric meter. Figs. 13, 14, and 15 illustrate an armature well adapted for use in such meters. Fig. 16 is a diagrammatic illustration of the manner of applying the invention to transformers. Fig. 17 is a diagrammatic illustration of a series of transformers connected in tandem, as will be hereinafter described; and Fig. 18 is an illustrative diagram which will be referred to later on in describing certain of the electrical actions involved in the invention.

I will first describe the form of motor illustrated in Figs. 1, 2, and 6. The armature A is in this machine the rotating element, and it may be widely varied in character. As here shown, it comprises a cylindrical mass of laminated magnetic metal mounted upon a suitable shaft *a*, which may be provided with a pulley or other means for transmitting its rotative power. The iron forming the field-magnets of this machine consists of two laminated masses B B′, separated from each other on a line parallel with the axis of the armature by spaces, as indicated at *b b′*. These masses of magnetic metal are supported in position by a suitable frame of non-magnetic material, (best seen in Fig. 2,) having end pieces *c c*, connected by cross-bolts *c′* and brackets c^2, affording bearings for the armature-shaft. Each of these masses of iron affords appropriate concave cheek faces or poles *d d′* and d^2 d^3. The cheek-faces *d d′* are separated by a rectangular recess for the reception of the sides of substantially rectangular field-coils, and the same is true of the faces d^2 d^3; but the faces *d′* and d^2 and d^3 and *d* are not only separated by similar recesses, but also by the air-spaces *b b′*. Assuming now that these masses of metal have been magnetized, it will be seen that there are four coöperating magnetic circuits, to wit: the first from *d* to *d′* to the rear of the intervening recess and including an appropriate portion of the magnetic metal of the armature A. In this circuit there is a minimum of magnetic resistance, the latter only resulting from the restricted annular air-spaces necessarily present between the cheek-faces and the armature. Second, in the magnetic circuit from *d′* to d^2 special magnetic resistance is afforded by the air-space *b*. Third, from d^2 to d^3 there is a minimum resistance, as in the first circuit, and in the last or fourth circuit, from d^3 to *d*, there is the same special resistance as in the second circuit, because of the air-space *b′*. There is therefore in this machine a series of magnetic circuits, each one of which is between two magnetic circuits which have either a greater or lesser magnetic resistance than it.

The magnetization of the field metal depends upon the currents supplied to the coils, which, as already stated, longitudinally surround the armature A and have their sides within the recesses between the cheek-faces. These coils are clearly indicated in Figs. 1 and 2, and they are divided into two groups at right angles to each other. Although each group includes four coils considered as separate structures, there are in substance but two coils in each group, the separation of each coil into two parts being merely for securing their symmetrical distribution across the ends of the armature and with relation to the armature-shaft. Two of these coils in each group are in circuit with a source of alternating single-phase currents, which, for example, entering at C, pass into one section of coils D and then directly to the other section D′, thence around to a smaller coil D^2 to the second section of this coil D^3, and thence out at C′. The other two coils of each group are secondary coils in a closed circuit having a resistance therein, as at R, the connections being from R, through E to the coil F, thence to coil F′, thence around to coil F^2, thence to coil F^3, and by E′ to resistance R.

The electrical organization of the field-coils is diagrammatically illustrated in Fig. 6, wherein the subdivision of the coils is not shown, but they are illustrated as divided into two groups of two coils each and arranged at right angles to one another. The alternating currents enter at C, traverse the large primary coil D, and thence through the small primary coil D^2 at right angles to D, and thence out at C′. The large secondary coil F is placed alongside of the small primary coil D^2 and the small secondary coil F^2 alongside the large primary coil D. The two secondary coils are in a closed circuit with the resistance R, as already described. These coils afford two sets of magnetizing-circuits whose axes are at right angles to one another, the large primary coil D and small secondary coil F^2 affording circuits having a magnetic axis in one direction and the large secondary coil F and the small primary coil D^2 circuits having a magnetic axis at right angles to that of coils D and F^2. Supplying alternating electric currents to the primary coils D and D^2 produces secondary currents in the coils F and F^2, and the strength of the secondary currents is regulated or determined by the resistance in the secondary circuit. For illustration I will assume that the secondary current in coils F F^2 will lag behind the primary or main current in coils D D^2 by one hundred and fifty degrees, or, in other words, five-twelfths of a three-hundred-and-sixty-degrees period. The magnetism in the two magnetic circuits will not follow or conform either to the primary or secondary currents, but it will follow or correspond with the resultant magnetomotive force of both currents, and therefore the maximum of the magnetic phases will occur between the maximum electric phases of the two currents. In other words, the resultant magnetism will reach its maximum succeeding the maximum action of the primary current and preceding the maximum of the secondary current.

By giving the primary coil of one magnetic circuit more ampere-turns, and hence more magnetizing power than the secondary coil acting on the same magnetic circuit and in the second circuit reversing the arrangement, so that the secondary coil has greater magnetizing power than the primary coil the magnetism in the first-named circuit will more nearly coincide in phase with the primary current, and in the second circuit the magnetism will more nearly coincide in phase with the secondary current. Now on the assumption that the secondary current lags one hundred and fifty degrees or five-twelfths of a period behind the primary current the number of ampere-turns in the different primary and secondary coils can be readily arranged so that the magnetic maximum in one circuit will occur one-fourth of a period after or before the maximum of magnetism in the other circuit. The two electromotive forces induced in the secondary coils F and F^2 will also differ correspondingly from each other in phase—that is, one-fourth of a period—and the said combined electromotive forces will yield a secondary current which lags behind the primary current five-twelfths of a period, as before stated.

To further illustrate, the large primary coil D in one magnetic circuit may have one hundred and fifty-six turns, and the adjacent secondary coil F^2 may have ninety turns, and with the currents in both circuits of equal strength (as may be insured by a resistance in the closed circuit) the maximum of the resultant magnetism will occur one-twelfth of a period or thirty degrees after the primary current and four-twelfths of a period or one hundred and twenty degrees before the secondary current. Now in the other magnetic circuit the primary coil D^2 having thirty turns and the secondary coil F fifty-two turns the resultant magnetism in this circuit will occur four-twelfths of a period or one-hundred and twenty degrees behind the primary current and one-twelfth of a period or thirty degrees before the secondary current, and therefore it will occur one-fourth of a period after the maximum of magnetism in the first circuit. That is to say, the magnetisms in the two circuits will differ by ninety degrees in phase. With these two circuits at right angles to each other and the primary coils fed with alternating single-phase currents the magnetic poles produced will be shifted correspondingly and make one revolution or rotation of the line of magnetization during each period of the alternating current. By providing in the first magnetic circuit D F^2 three times as much magnetic resistance as in the second magnetic circuit the magnetism afforded by the two circuits will be of equal strength, and the two electromotive forces induced in the secondary coils F and F^2 being proportioned to each other, as are the number of their turns, ninety to fifty-two, the secondary current lags behind the electromotive force in F^2 by one-twelfth of a period or thirty degrees, and this last electromotive force being ninety degrees behind the magnetism of D the resulting magnetism of D F^2 lags behind the primary current thirty degrees, and the secondary current lags behind the primary current one hundred and fifty degrees.

Reference is made to the diagram shown in Fig. 18 in order to further illustrate and explain the operation of the invention and to make more clear the illustration discussed in the immediately-preceding portions of this description. Assuming that the current in the secondary circuit lags one hundred and fifty degrees behind the primary current, then the line O D in the diagram may represent the primary current and the line O E the secondary current. The value of the secondary current can be made equal to that of the primary by a suitable adjustment of the resistance R in the secondary circuit. If the primary coil has one hundred and fifty-six turns in the first magnetic circuit, its magnetizing force can be thus represented in ampere-turns by the line O D. The secondary coil in the first magnetic circuit is assumed to have ninety turns, and thus its magnetizing force can be represented in the diagram by the line O F^2, O D and O F^2 being proportioned, respectively, to one hundred and fifty-six and ninety. O D and O F^2 combine by the parallelogram of forces to a resultant magnetizing force O A′, which under the conditions assumed will lag thirty degrees behind O D and is one hundred and twenty degrees in advance of O F^2. The magnetism of the first magnetic circuit is produced by the resultant magnetizing force O A′, and thus can be represented by the line O M′ in phase with O A′, (if we neglect hysteresis and other secondary reactions.) In the second magnetic circuit the primary coil of thirty turns can be represented in magnetizing power by O D^2 and the secondary coil of fifty-two turns by O F, O D^2 and O F being again proportioned, respectively, to thirty and fifty-two. O D^2 and O F combine to a resultant magnetizing force of the second magnetizing-circuit O A^2, which with the numerical values assumed is one-third as much as the resultant magnetizing force O A′ of the first magnetic circuit, and thus produces in the second magnetic circuit a magnetism O M^2, equal to that in the first-named circuit, since the magnetic resistance of the second magnetic circuit is one-third of that of the first magnetic circuit. The magnetism O M^2 of the second magnetic circuit is in phase with the resultant magnetizing force O A^2 of the second magnetic circuit, and thus with the numerical values assumed one hundred and twenty degrees behind O D^2 and thirty degrees in advance of O F. It is therefore apparent that O M^2 is ninety degrees behind O M′, or, in other words, that two equal magnetic waves or fluxes, which may be represented by O M′ and O M^2, displaced from each other by ninety degrees difference of phase, will be produced in the two magnetic circuits under the conditions assumed.

By the combined magnetizing influence of the single-phase alternating currents fed to the motor and the secondary currents induced as herein described and as represented in Figs. 1 and 2 an effective and highly-satisfactory conversion of electrical energy into mechanical motion is accomplished. In this machine the number of ampere-turns in the several coils are so proportioned and the variations of magnetic resistance are such that the magnetism produced by the coils in one circuit lags one-fourth of a period or ninety degrees behind the magnetism produced by the coils in the other circuit, and both magnetisms being of equal strength and perpendicular to each other cause a rotation of two oppositely-induced poles of the armature at regular and uniform speed.

As before stated, the armature may be widely varied so long as it can be rotated by rotating magnetic poles in the field. It may be of solid iron or laminated against eddy currents or laminated lengthwise, so that eddy currents flowing therein will be of such direction relatively to the magnetizing force of the field-poles and of such difference in phase as to cause electrodynamic repulsion between the field and the armature. So, also, may be the "H" or shuttle core used, and this is especially desirable when a motor is to be operated synchronously. An armature with wire coils in closed circuits may also be used or a laminated-iron core coated with copper or tin for affording a special path for induced currents. So, also, may the exterior magnetic metal be widely varied in its form, arrangement, and distribution—as, for instance, as shown in Figs. 3 and 4, wherein the rotative element A′ is the field-magnet, and it is within a stationary iron ring B^2, which may be termed the "armature." The core of the magnet is composed of laminated iron so disposed as to afford four arms convex at their outer ends. Two of these, diametrically opposite, as at e and e', have their convex faces closely adjacent to the coincident inner surface of the iron ring B^2, and the other two faces e^2 and e^3 are separated from said ring by wider spaces, thus affording variable magnetic resistance. Surrounding each of the arms e^2 and e^3 there are large primary coils D^4 D^5, and around the arms e and e' there are smaller primary coils D^6 and D^7, all of which are connected in circuit with the terminals C and C′, by which the alternating current is supplied by way of the brush-contacts f. Surrounding the arms e and e' there are also large secondary coils F^4 and F^5, and around the arms e^2 and e^3 there are other secondary coils F^6 and F^7, these all being in one closed circuit and including the resistance R, the latter being in connection by way of the brush-contacts at f'. In this machine, as in the one first described, one magnetic circuit is magnetized by the large primaries D^4 D^5 in conjunction with the small secondaries F^6 and F^7 and the other magnetic circuit by the large secondaries F^4 F^5 and the small primaries D^6 and D^7, and their resultant operation is such that the magnet is caused to rotate with great efficiency and at a speed corresponding with the speed of the alternations of the electric current supplied thereto. If, on the other hand, the magnet should be stationary and the ring B^2 provided with axial supports, then the line of magnetization would be rotated as before and the ring would become the rotative element.

In each of the two organizations thus far described the shifting phase is one-quarter of a period, or ninety degrees; but the shifting of phase in other proportions may be readily provided for—as, for instance, as illustrated in Fig. 5. In this organization the armature A^2 may be as before described; but, as shown, it has an iron core and a set of coils in closed circuit. The field metal B^3 is an annular mass of iron with inwardly-projecting cores paired with each other on diametrical lines, as at $g\,g'$, $h\,h'$, $i\,i'$, and $k\,k'$. These cores have concave faces, which are variably separated from the surface of the armature, the pair $g\,g'$ having the least spaces, the pair $h\,h'$ a little more, the pair $i\,i'$ still more, and the pair $k\,k'$ the greatest space, thus securing variable magnetic resistance in the magnetic circuits. The resistances of these different magnetic circuits are, as before in Figs. 1 and 2, proportioned relatively to the magnetomotive forces, so that displaced magnetisms of equal strength are maintained. Each of these cores carries a primary and secondary coil, and, as in the other machines, said coils are variably proportioned. The cores $g\,g'$ have the largest primary coils l and the smallest secondary coils m. The cores $h\,h'$ have the next smaller primary coils l' and the next larger secondary coils m'. The cores $i\,i'$ have still smaller primary coils l^2, and their secondary coils m^2 are larger than on the cores $h\,h'$. The cores $k\,k'$ have the smallest primary coils l^3 and the largest secondary coils m^3. The primaries are connected in series and are fed by way of the terminals at C, and the secondaries are all in one closed circuit containing the resistance R. These four pairs of magnet-poles when excited by single-phase alternating currents afford shifting magnetic phases displaced in phase. The magnetism of the circuits at $h\,h'$ reaches its maximum behind the magnetism at $g\,g'$ and that at $i\,i'$ reaches its maximum behind $h\,h'$, while at $k\,k'$ it reaches its maximum behind $i\,i'$, and therefore the line of magnetic polarity is successively shifted at uniform speed from $g\,g'$ over to $h\,h'$, to $i\,i'$, and then to $k\,k'$. In this machine the magnetism in each magnetic circuit is induced and controlled, varied, or adjusted, as in the previous machines, by the two electric currents, whose magnetizing powers are variably proportioned relatively to each other, and the lag of the secondary current can be varied by variations of the resistance in the closed circuit.

In extra light-duty motors the field-iron may be dispensed with, if desired. For instance, for driving the rotary element in an alternating-current meter the magnetic fields may be induced by currents flowing in coils arranged as already described, but without iron cores. In the meter shown in Figs. 7 to 12 the rotary element A^3 is an armature composed of a series of semicircular strips n of sheet-copper secured radially to suitable hubs and mounted upon a spindle n', provided with a worm, which by meshing with a worm-gear transmits slow rotary motion through a train of gearing to the indicating-handle n^2 of the meter. This armature is surrounded in the plane of its axis by a pair of complex coils, each of which includes a primary coil D and a secondary coil F, and at right angles to said coils and surrounding both of them and the armature are two other complex coils, each including a primary coil D′ and a secondary coil F′. The primary coils D and D′ are of coarse wire and variably proportioned, as before described, and they are connected in series with each other and are fed by a single alternating current by way of the terminals C C′, Figs. 7 and 8. The secondary coils F and F′ are of fine wire and all are in closed circuit, their terminals being soldered together at one side. The currents in these coils induce the required magnetic fields, the circuits of which vary in their magnetic resistance because of their varied proportions. In the coils D D the magnetizing power of the primary current is stronger than that of the secondary coils F F; but in the coils D′ D′ the power of the primary current is less than in the coils D and less than that of the secondary current in the coils F′ F′; and hence the magnetizing maximum in the coils D′ F′ will lag behind the maximum induced by the coils D F one-quarter of a period and cause the magnetic field to rotate, and this in turn will cause rotation of the armature and so operate the meter.

The rotative power of the meter-armature can of course be increased by the use of iron herein, as shown in Figs. 13, 14, and 15, wherein an iron disk n^3 is located between the copper hubs and within a series of radial copper strips n^4 of such a form as imparts to the armature a drum-like contour.

Now for describing the application of the main features of my invention for inducing alternating currents differing in phase I will refer to Fig. 16. Two transformers G G′ are connected in circuit and employed as a single translating device. The alternating currents are fed by way of the terminals C C′ to the transformers, and in this circuit there is a large coil D, wound on the transformer G, and connected in series therewith a small primary coil D′, wound on the transformer G′. A closed secondary circuit comprises a coil F on the transformer G and a similar coil F′ on the transformer G′, and a resistance R is included in this closed circuit, as already described. The transformer G is provided with a third coil H, in which alternating currents are induced and may be delivered from the transformer by way of the terminals shown at H′. In the transformer G′ there is also a coil H^7 for affording induced alternating currents by way of the terminals H^2. The cores of transformers G G′ are shown of different sizes, so that the magnetic circuits have different resistances, as in the case of the motor construction already described.

As already explained in connection with the description of the alternating motor, the phases of magnetism in the cores of the transformer do not conform with the currents in either of the coils D F of one transformer or D′ F′ of the second transformer, but rather to the resultant of the magnetomotive forces induced by the currents in these coils which, as already explained, are out of phase with one another. Hence the induced currents in the circuits H′ H^2 are of different phase relation from the currents in either of the other coils of the corresponding transformers and from each other—that is to say, the currents in the circuit H′, for example, are of different phase relation from the current in circuit H^2 and also have a different phase relation from the currents in the coils D and F of the transformer G.

The proportioning of the coils upon the transformers resembles that already described in connection with the alternating motor. The primary coil D of the transformer G is stronger than the secondary coil F—that is, its magnetizing influence is greater than the influence of the coil F—while in the transformer G′ the secondary coil F′ is stronger than the primary coil D′. The resistance R is here used, as before, to adjust the secondary current, but it is not always necessary, and even when the resistance is needed it may be afforded by lamps and the electrical energy utilized for lighting purposes. The arrangement just described affords a practical method of transforming the phase relation of alternating currents, for it will be observed that the magnetic phases in the transformers G and G′ do not conform with the electric phases of the alternating currents fed to the transformers. This result is secured by the modifying action upon the magnetic phases of the currents in the coils F and F′ which are out of phase with the currents in coils D and D′, and hence the energy fed to the transformers in the form of alternating currents is first converted into magnetism, and the currents in circuits H′ and H^2 induced by the magnetism in the transformers have a different phase relation from that of the supplied currents. For example, as a concrete illustration, single-phase currents may be fed to the transformers by circuit C C′ and quarter-phase currents may be taken from the transformers by circuits H′ and H^2. As already explained, the single-phase currents tend to induce magnetism in the transformers in phase with the currents; but the magnetic phases in the transformers are modified by the currents flowing in the other coils, so that the resultant magnetomotive forces may by proper calculations and proportioning of parts assume any desired relation. The electromotive forces in the closed circuits may be used for operating a series of translating devices of the kind herein shown in tandem, the resistance being inserted in the closed circuit of the last translating device of the series. By "tandem" I refer to an arrangement such as that shown in Fig. 17, where there are three sets of transformers. The transformers G G′, comprising the first set, are supplied with single-phase alternating currents through the terminals at C for exciting the primary coils D D′, respectively wound on the cores of the transformers. The secondary coils F F′ on said transformers, which coöperate with the primary coils, have their circuit closed through coils D^2 D^3 on a second set of transformers G^2 G^3, so that the current flowing in the coils F F′ of transformers G G′ serves to excite magnetism in the transformers G^2 G^3. The secondary coils F^2 F^3 are provided on transformers G^2 G^3, which in turn are closed through primary coils D^4 D^5 upon the third set of transformers G^4 G^5. This last set of transformers has secondary coils F^4 F^5, whose circuit is closed through resistance R. On each of these transformers a third coil H is shown, from which an independent induced alternating current can be taken by way of the terminals lettered H' H^2 H^3 H^4 H^5 H^6, and the currents in each of these circuits may have a phase of alternation peculiar to itself, or the currents in any number of said circuits may have the same phase relation.

Referring more particularly to Fig. 16, it will be seen that the coils D D′ F F′ form primary coils in the sense that they coact to produce electromotive forces in the coils H and H^7, though the coils F F′ are also secondary coils with respect to the coils D D′, as has been above explained. It will also be seen that the coils H H^7 may be regarded as secondary coils in the sense that they have electromotive forces induced in them by the joint action of the coils D D′ F F′. It is therefore obvious that one feature of my invention consists in a transformer or set of transformers G G′, having a plurality of independent magnetic circuits with primary and secondary windings thereon so arranged that the currents in one set of windings—as, for example, in the arrangement described in set D D′ F F′—induce magnetic waves or fluxes in the cores G G′, which in turn induce electromotive forces in the windings H H^7, the phase relation between electromotive forces and magnetic waves being such that the electromotive forces of one set of windings—for example, those induced in the windings H H^7—correspond in phase to the phase relation of the magnetic waves in the magnetic circuits G G′, while the electromotive forces of the other set of windings comprising those electromotive forces which cause current to flow in the coils D D′ and in the coils F F′ do not correspond in phase displacement to the phase displacement of the magnetic waves.

It is my intention to claim herein points of novelty alike present in the motors and stationary transformer systems herein set forth and also such further improvements or points of novelty as relate only to the transformers.

I reserve for a separate application, filed May 13, 1897, Serial No. 636,281, claims upon such improvements of the alternating motors herein set forth as relate only to the motors and are not applicable to the transformers. I also reserve for the said application claims upon that feature of my invention which relates to the connection of translating devices in tandem.

What I claim as new, and desire to secure by Letters Patent of the United States, is—

1. The method of transforming alternating electric currents from one number of phases to another, which consists in inducing in a series of magnetic circuits magnetic waves by the magnetizing action of the currents to be transformed, modifying the phases of the magnetic waves to correspond with the current phases desired, and inducing currents of the desired number of phases in a secondary circuit or circuits in inductive relation to such magnetic circuits.

2. The method of transforming alternating single-phase currents into currents of plural phases, which consists in inducing by the magnetizing influence of such single-phase currents magnetic waves in a series of stationary transformers, modifying the phase relation of the magnetic waves thus induced to correspond with the current phases desired, and inducing currents of different phases in the secondary circuits of the transformers.

3. The method of translating alternating electric currents from one number of phases to another, which consists in inducing in a series of stationary transformers magnetic waves by the magnetizing action of the primary currents to be transformed, inducing thereby secondary currents in a closed circuit in inductive relation to the different transformers, modifying the phases of the magnetic waves by the magnetizing influence of such secondary currents to correspond with the current phases desired, and finally, inducing currents of the desired number of phases in a secondary circuit or circuits leading from the transformers.

4. In an electric translating device supplied with alternating currents, the combination of primary magnetizing-coils connected in series and in exciting relation to a series of magnetic circuits having unequal magnetic resistance and an equal number of secondary magnetizing-coils connected in closed circuit and in inductive relation to the primary coils and also in magnetizing relation to each of the magnetic circuits.

5. In electric translating devices to be supplied with alternating electric currents, the combination, substantially as described, of magnetic metal affording varied magnetic resistance in the several magnetic circuits; primary exciting-coils connected in series, and supplied with alternating electric cur-

rents; secondary exciting-coils connected with each other in one closed electric circuit, the said secondary coils in one or more of said circuits having greater magnetizing power than the primary coils in the same magnetic circuits, and in the other magnetic circuits, the said secondary coils having less magnetizing power than the primary coils in the same magnetic circuit, whereby the maximum resulting magnetizing power of the combined primary and secondary coils in any one or more magnetic circuits, will be different in time from the maximum resulting power of the primary and secondary coils, in other magnetic circuits.

6. The combination of two or more stationary transformers having independent magnetic circuits in each of which magnetism is induced by the joint magnetizing action of alternating electric currents of displaced phase, whose relative magnetizing influences are so proportioned that the magnetic waves induced therein have a desired difference of phase.

7. The combination of magnetic material affording two or more magnetic circuits with conductors carrying out-of-phase currents, each acting to induce magnetism in all such circuits but not to the same relative extent, the action of one current preponderating in magnetizing one circuit and of another current in magnetizing another circuit, as described.

8. The combination in an electric translating device, of magnetic material affording two or more coöperating magnetic circuits of different magnetic resistance, with conductors carrying respectively primary and secondary alternating currents displaced in phase serving to induce magnetism in each of such magnetic circuits, the magnetizing influence of such currents being so proportioned relatively to each other, and with reference to the magnetic resistance of such circuits, that magnetic waves are induced in each, of substantially equal intensity but displaced in phase, as described.

9. The method hereinafter set forth, which consists in supplying to different transformers, or like induction apparatus, having separate magnetic circuits, alternating electric currents of a given number of phases, thereby converting the electric energy of such currents into magnetic energy in the form of magnetic waves induced in the magnetic circuits, and inducing in secondary work-circuits leading from such induction apparatus, secondary currents having a different number of phases from that of the primary currents supplied to the induction apparatus.

10. The method hereinafter set forth, which consists in supplying alternating electric currents having a given phase relation to the primary circuits of a series of transformers inducing electromotive forces in the secondary circuits of such transformers, and deriving from such electromotive forces secondary currents, in suitable electric circuits, having a different number of phases from the currents fed to the transformers.

11. The method hereinafter set forth, which consists in inducing out-of-phase magnetic waves in a series of transformers having independent magnetic circuits, by the inductive action of alternating dephased electric currents flowing in certain electric circuits, in inductive relation to said transformers, inducing alternating electromotive forces in certain other electric circuits likewise in inductive relation to said transformers, and deriving from said last-named electromotive forces alternating currents dephased from each other by an angle different from the angle of phase displacement of the first-named alternating currents.

12. The method of producing quarter-phase magnetic waves, which consists in generating alternating currents whose phase difference is not equal to ninety degrees, inducing by said currents magnetomotive forces in two magnetic circuits, and superposing said magnetomotive forces in the proper proportions, so that the resultant magnetic waves in the two circuits are dephased by ninety degrees.

13. The method of producing a magnetic wave of any phase desired intermediate between the phases of two electric currents, which consists in subjecting a magnetic circuit to the inductive influence of the two electric currents in the proper proportions to produce the result desired, substantially as described.

14. The method of producing a magnetic wave of any phase desired intermediate between the phases of two electric currents, which consists in subjecting a magnetic circuit to the inductive influence of the two electric currents, the inductive influence of the two currents on the magnetic circuit being different in amount, and so proportioned as to produce the magnetic phase desired.

15. The method of producing a magnetic wave intermediate in phase between the phases of two electric currents, and nearer in phase to one of them than to the other, which consists in subjecting a magnetic circuit to the inductive influence of the two currents in different relative amounts, so that the inductive influence of that current to whose phase it is desired that the phase of the magnetic wave shall more closely approximate, shall exceed in amount the inductive influence of the other current, substantially as described.

16. The method of producing dephased magnetic waves one of which is in magnitude and phase the resultant of a plurality of dephased electric currents, and all of which draw their energy from the said electric currents, which consists in subjecting a plurality of magnetic circuits to the inductive influence

of the said currents in such a way that at least one of the circuits is acted upon by a plurality of dephased currents, the said inductive influences of the different currents on the various magnetic circuits being so proportioned and adjusted as to produce in the magnetic circuits dephased magnetic waves of the desired phase and magnitude.

17. The method of producing dephased magnetic waves, which waves are in magnitude and phase the resultant of a plurality of dephased electric currents, which consists in subjecting a plurality of magnetic circuits each to the inductive influence of a plurality of dephased currents, the said inductive influences of the different currents on the various magnetic circuits being so proportioned and adjusted as to produce in the magnetic circuits dephased magnetic waves of the desired phase and magnitude.

18. The method of increasing the number of phases of an alternating current, which consists in producing by means of the energy of the said current dephased magnetomotive forces, combining the said magnetomotive forces in the proper proportions and relations, and generating by the said magnetomotive forces a secondary multiphase current of an order higher than the order of the original alternating current.

19. The method of generating quarter-phase currents which consists in producing in two magnetic circuits magnetomotive forces whose phase difference is not equal to ninety degrees, superposing the magnetic waves due to said magnetomotive forces so that the resultant phase difference of the magnetic waves is equal to ninety degrees, and inducing currents by said magnetic waves.

20. The method of producing quarter-phase currents, which consists in generating currents whose phase angle is not equal to ninety degrees, inducing in two magnetic circuits by said currents resulting magnetic waves whose phase angle is equal to ninety degrees, and generating by the action of said magnetic waves quarter-phase currents.

21. The method of deriving from a plurality of alternating currents dephased by any given phase angle a plurality of alternating currents dephased by any desired different phase angle, which consists in combining the effects of said first-named currents, as by subjecting to their magnetizing influence a plurality of magnetic circuits having secondary coils wound thereon, or in any equivalent way, in such a manner that one of the resulting currents shall be due to the joint influence of a plurality of the first-named currents acting in different relative proportions.

22. The method of obtaining from a single-phase current magnetic waves in qradrature, which consists in generating magnetomotive forces in two magnetic circuits by the influence of the said current, and reacting upon said magnetomotive forces by a corrective or modifying action to produce resultant magnetomotive forces of approximately ninety degrees phase displacement.

23. The combination of a plurality of cores forming magnetic circuits with primary and secondary windings in inductive relation thereto, so arranged that the electromotive forces due to one set of windings induce magnetic waves in said circuits and thereby induce electromotive forces in the other set of windings, the phase relation between electromotive forces and magnetic waves being such that the electromotive forces acting in one of said sets of windings correspond in phase displacement to the phase displacement of the individual magnetic waves, while the other set of electromotive forces do not correspond in phase displacement to the phase displacement of the individual waves.

24. The combination of a plurality of transformers having independent magnetic circuits with windings in inductive relation to said circuits, and two sets of leads for connecting windings on said transformers with different distribution systems, certain of said windings being wound on the different magnetic circuits separately and connected so that their electromotive forces and currents correspond in phase with the phase of the magnetic waves induced in the magnetic circuits, and the remainder of said windings being so distributed, arranged and connected that their electromotive forces and currents have a definite phase relation with respect to the said magnetic waves, such that the said windings and magnetic circuits become capable of transforming and altering the number of phases of alternating currents.

25. The combination with two magnetic cores or circuits, and means for generating magnetomotive forces therein, of a secondary coil or circuit inclosing each core, and additional coils on each core connected to work-circuits, the number of turns of said secondary coil enveloping each core being graduated to produce electromotive forces of a different phase displacement in said additional coils.

26. The combination with two magnetic circuits, of windings in inductive relation thereto, consisting of a plurality of inducing turns and a plurality of induced turns, so arranged that some of the inducing turns are in inductive relation to each of the magnetic circuits, and some of the induced turns are in inductive relation to each of the magnetic circuits; and an additional winding closed on itself, embracing each of said magnetic circuits, and adapted to be the seat of induced currents acting to dephase by a definite amount the magnetic waves in said circuits.

27. The method hereinafter set forth, which consists in setting up in suitable, non-identical paths, out-of-phase magnetic waves, by the inductive action of alternating, relatively-dephased, electric currents flowing in certain electric circuits, in inductive relation to

said paths, impressing on multiphase mains, alternating electromotive forces derived from certain electric circuits in inductive relation to said paths and having a relative phase displacement different from that of the aforesaid alternating currents, and maintaining the phase relation of said alternating electromotive forces different from the phase relation of said electric currents whether the multiphase mains be on open circuit or supplying current.

CHARLES STEINMETZ.

Witnesses:
R. EICKEMEYER,
H. RYDQUIST.