No. 613,204. Patented Oct. 25, 1898.

M. HUTIN & M. LEBLANC.

ALTERNATING CURRENT ASYNCHRONOUS MACHINE.

(Application filed May 4, 1897.)

(No Model.) 4 Sheets—Sheet 1.

Fig. 2

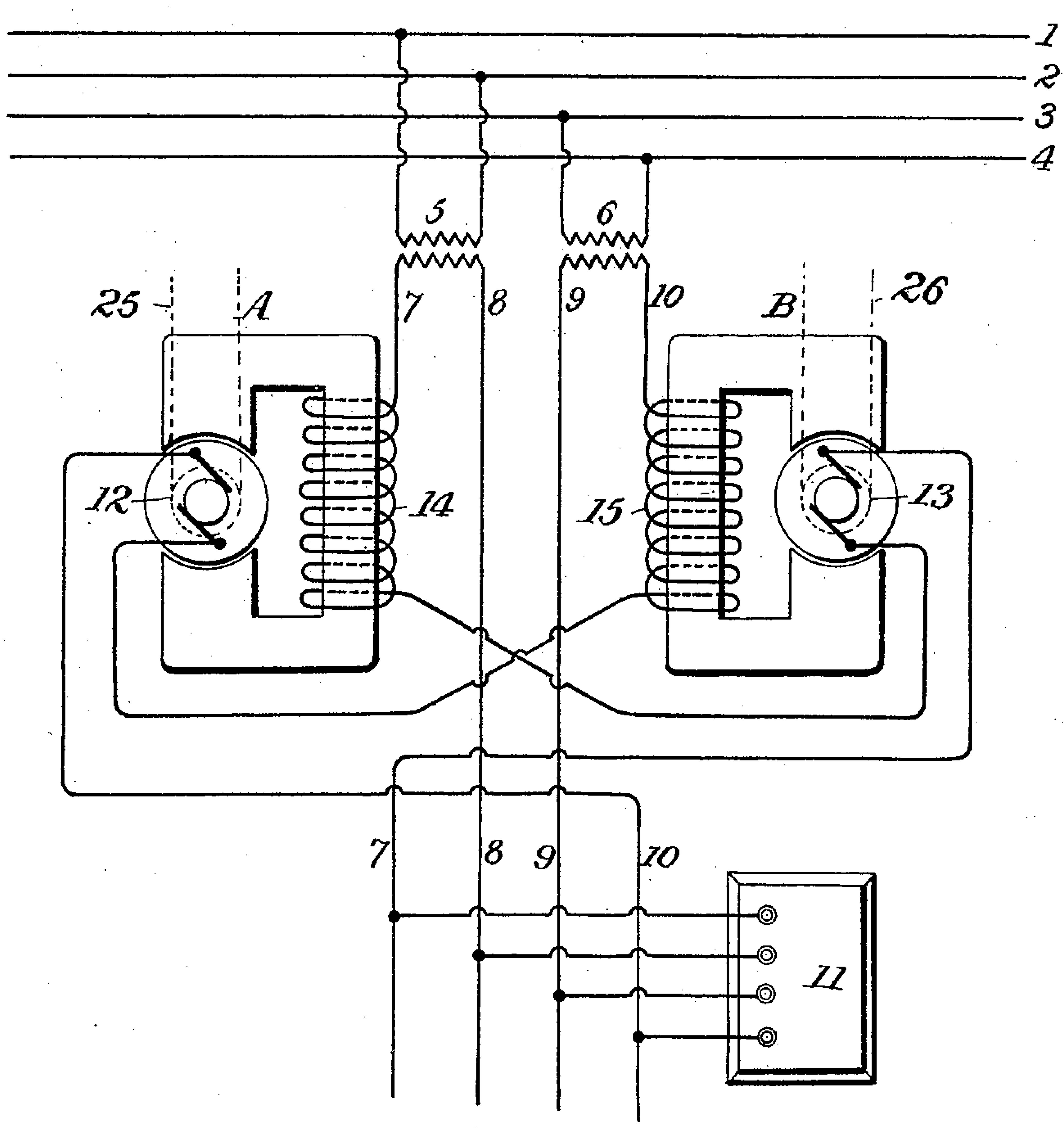


Fig. 4.

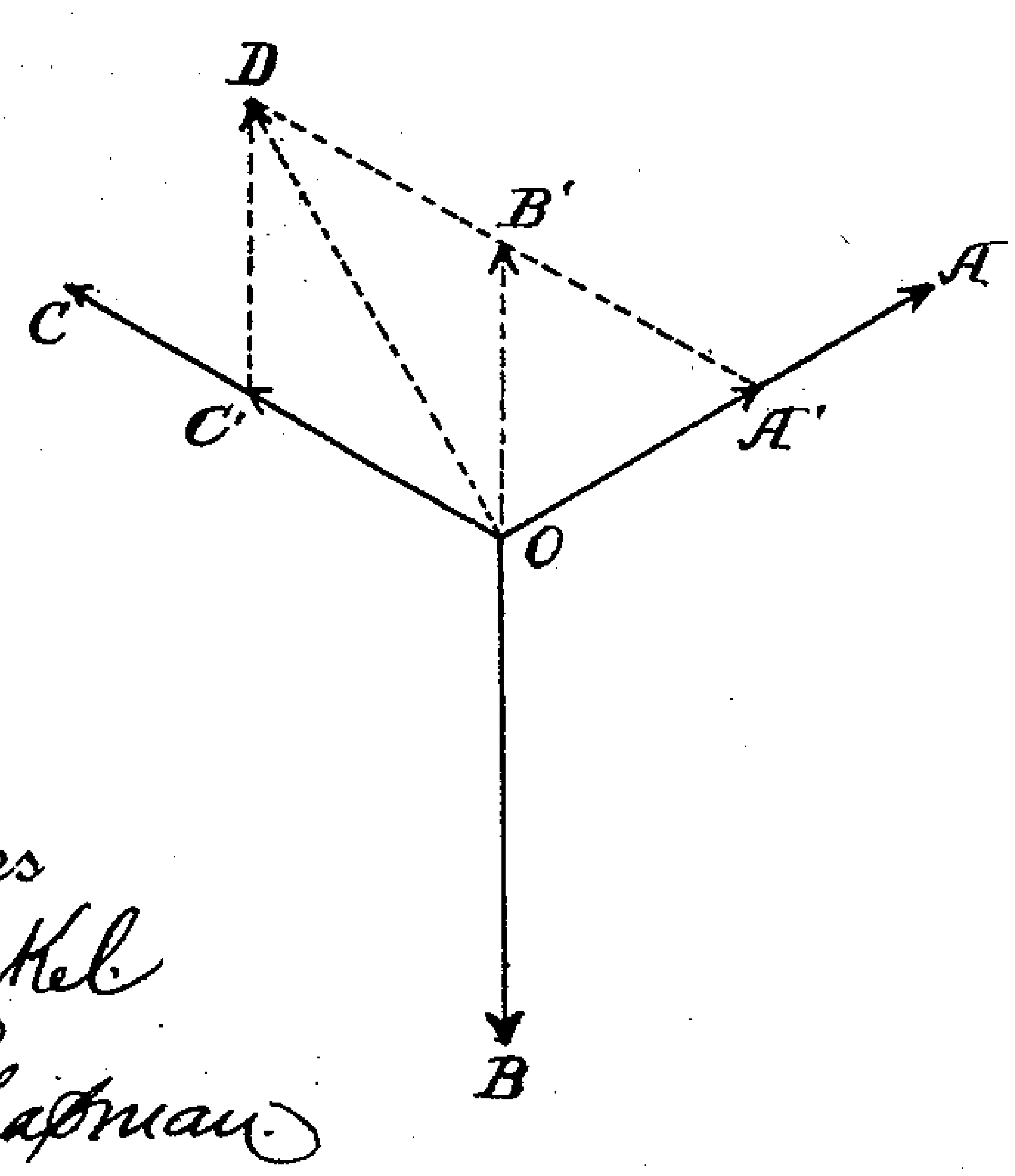
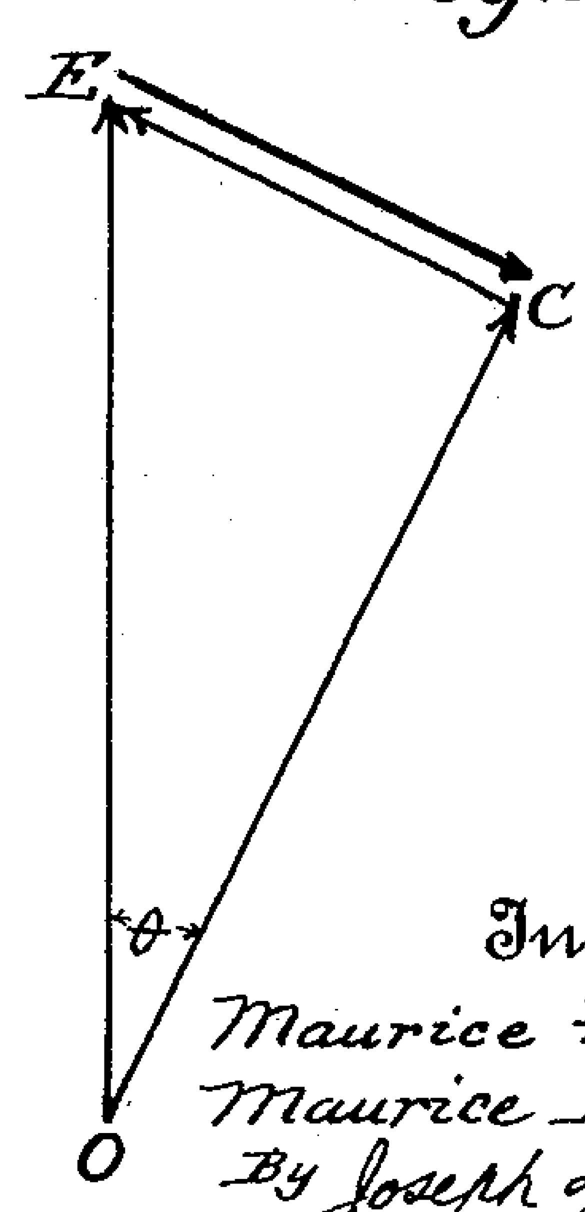


Fig. 1.



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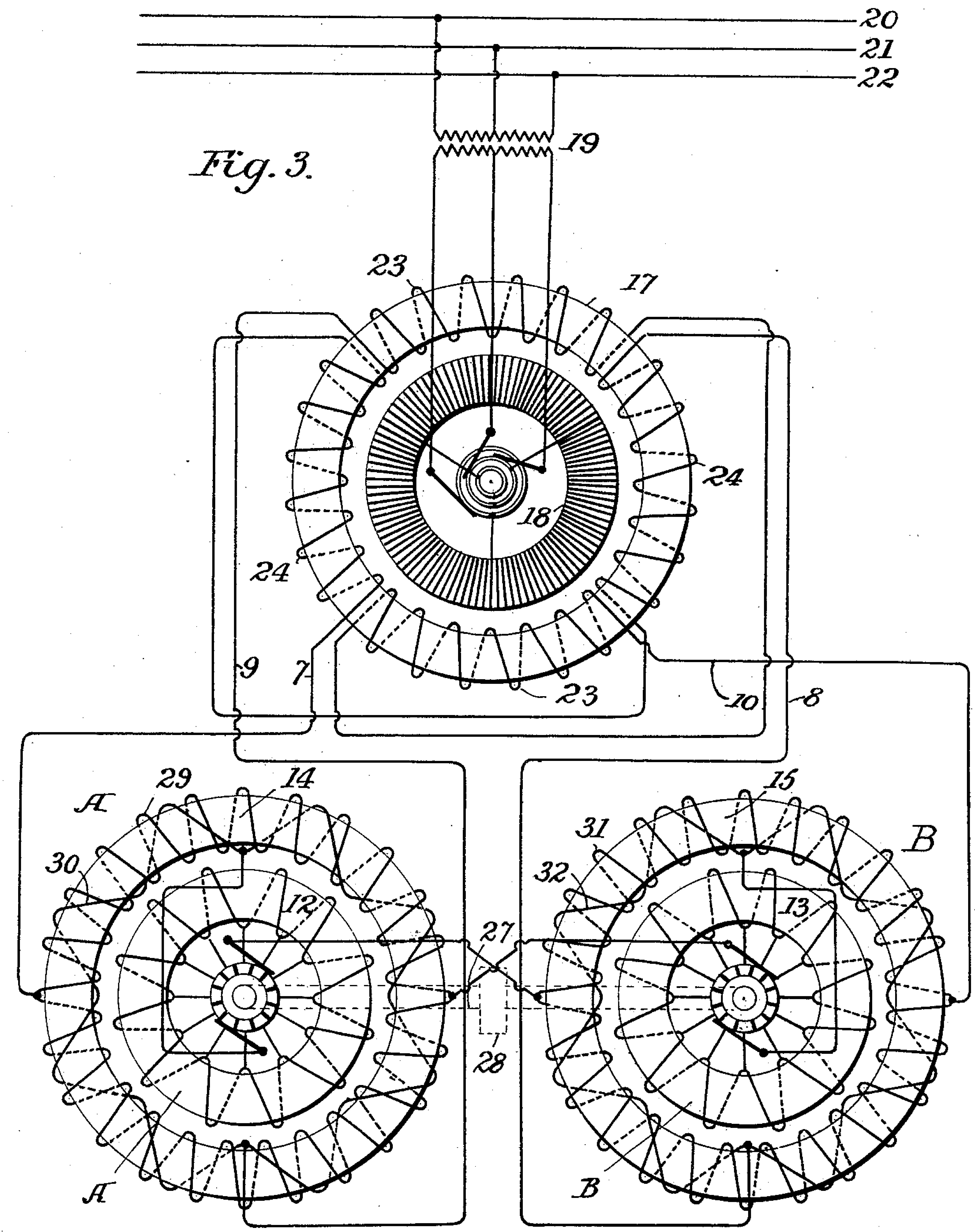

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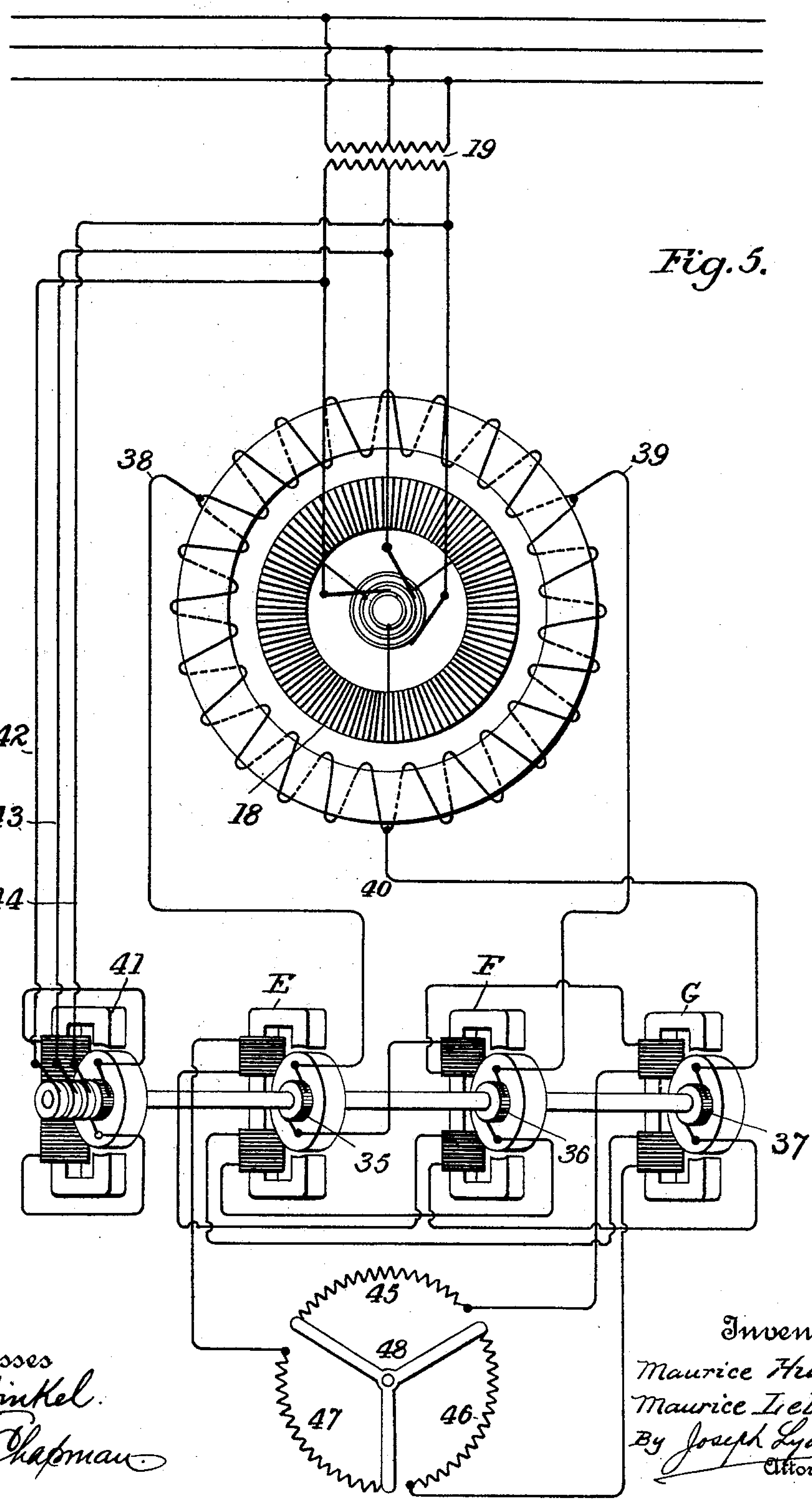
ALTERNATING CURRENT ASYNCHRONOUS MACHINE.

(Application filed May 4, 1897.)

(No Model.) 4 Sheets—Sheet 3.



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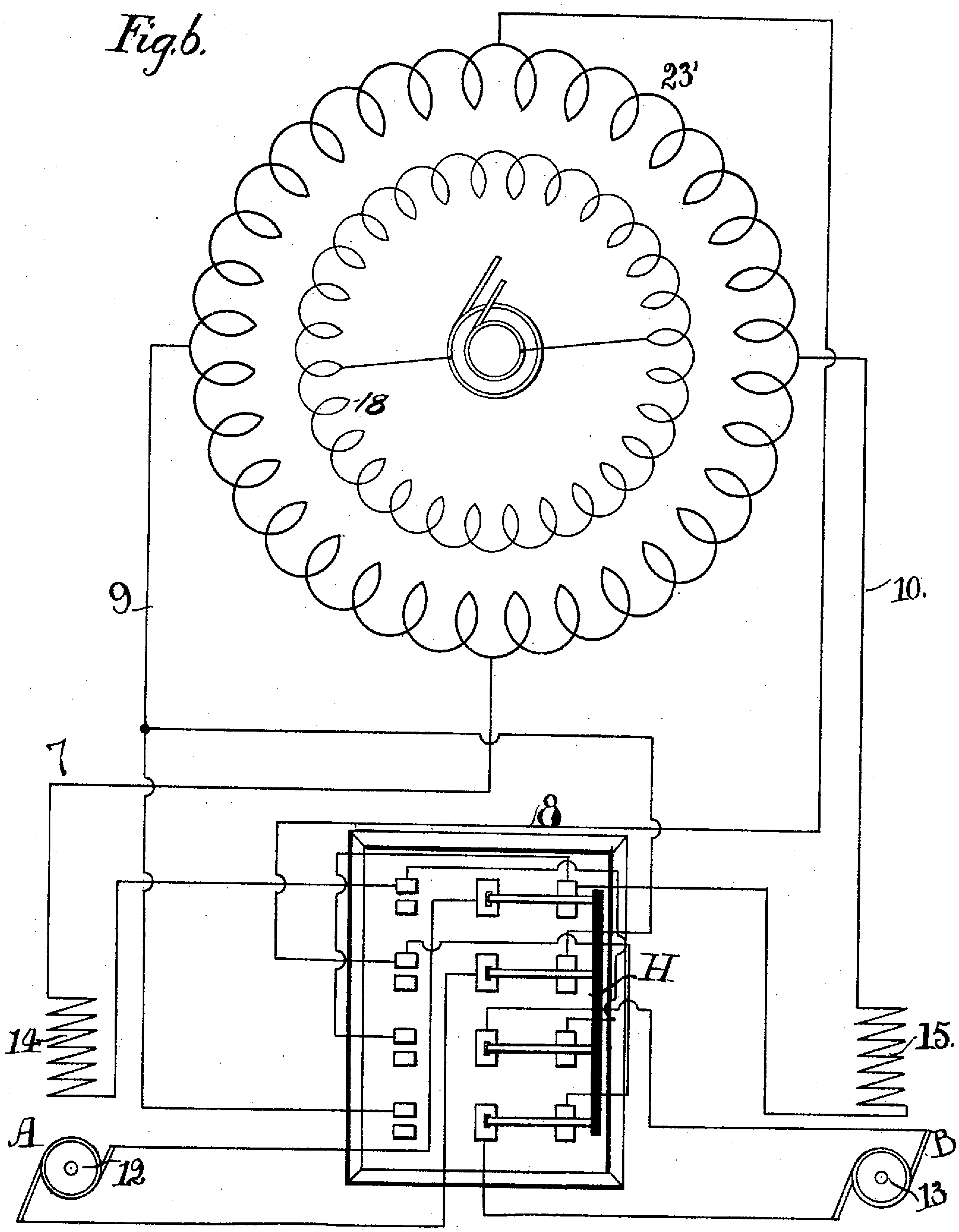
(No Model.) 4 Sheets—Sheet 4.

Fig. 6.



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UNITED STATES PATENT OFFICE.

MAURICE HUTIN AND MAURICE LEBLANC, OF PARIS, FRANCE, ASSIGNORS TO THE SOCIÉTÉ ANONYME POUR LA TRANSMISSION DE LA FORCE PAR L'ÉLECTRICITÉ, OF SAME PLACE.

ALTERNATING-CURRENT ASYNCHRONOUS MACHINE.

SPECIFICATION forming part of Letters Patent No. 613,204, dated October 25, 1898.

Application filed May 4, 1897. Serial No. 635,035. (No model.) Patented in France July 20, 1895, No. 249,036; in England August 16, 1895, No. 15,470; in Italy August 26, 1895, No. 39,633/425; in Belgium August 27, 1895, No. 117,175; in Hungary August 30, 1895, No. 5,566; in Spain September 9, 1895, No. 17,926, and in Switzerland November 29, 1895, No. 11,501.

To all whom it may concern:

Be it known that we, MAURICE HUTIN and MAURICE LEBLANC, citizens of the Republic of France, and residents of Paris, France, have invented certain new and useful Improvements in Alternating-Current Asynchronous Machines, of which the following is a specification, and for which Letters Patent have been granted in France, dated July 20, 1895, No. 249,036; in Hungary, dated August 30, 1895, No. 5,566; in Belgium, dated August 27, 1895, No. 117,175; in Switzerland, dated November 29, 1895, No. 11,501; in Italy, dated August 26, 1895, No. 39,633/425; in England, dated August 16, 1895, No. 15,470, and in Spain, dated September 9, 1895, No. 17,926.

Our invention relates particularly to alternating-current asynchronous machines, whether used as motors or as generators, and has for one of its objects to increase the power factor of such machines.

To this end it comprises a method of and apparatus for bringing the current in any circuit of the machines, but particularly in the induced circuits, into such phase relation with the impressed electromotive force that the output will be a maximum and the amount of wattless current taken from or fed to the lines will be a minimum.

Our invention also comprises a new and useful method of and apparatus for controlling the phase relation between current and electromotive force in any alternating current whatever, a new method of and apparatus for superposing on any given alternating wave a second wave having any desired relation to the first wave, and a new method of and apparatus for starting and running alternating-current motors.

In the drawings attached to this specification, Figure 1 is a diagram representing the relations between the various electromotive forces in a lagging circuit and showing the magnitude and phase of the corrective wave required in the particular case where the power factor is to be made unity. Fig. 2 is a view of our improved phase-regulator applied to a two-phase system of distribution. Fig. 3 is a view of an alternating-current motor with our improved phase-regulator applied to its induced circuits. Fig. 4 is a diagram showing the method of exciting the field-magnets of one of our improved phase-regulators from a three-phase circuit. Fig. 5 is a diagram similar to Fig. 3, but showing a motor with a three-phase secondary with the corresponding phase-regulators. Fig. 6 is a diagram of a single-phase machine having a two-phase field excitation in accordance with our invention.

In any alternating circuit the translating device or devices will have a certain effective or resultant self-induction or capacity, more commonly the former, which will cause the current to be out of phase with the impressed electromotive force. The result is that a considerable idle or wattless current flows, which detracts from the output.

In Fig. 1 the vector OE represents in magnitude and phase the electromotive force impressed upon an alternating circuit. Then if the angle of lag of the current be θ the effective electromotive force will be represented by OC and the reactive electromotive force by EC, the angle OCE being inscribed in a semicircle, and therefore a right angle. If now we superpose on the circuit the electromotive force CE, of equal magnitude to the reactive electromotive force and opposite to it in phase, the side EC of the triangle OEC will become zero and OC will coincide with OE. The reactive electromotive force, which is always ninety degrees behind the current, will then be ninety degrees behind the impressed electromotive force OE, and the leading electromotive force impressed on the circuit for the purposes of regulation should preferably be one hundred and eighty degrees from the reactive electromotive force which is to be overcome. In this way it is possible to make the power factor of the circuit or cos. θ equal to unity. It is not always necessary in the use of our improvements to make cos. θ exactly equal to unity; but the more completely this result is obtained the more perfect will be the conditions of the transmission. It is obviously possible, by making CE of the proper value, to give the angle θ any value desired, either positive or negative.

In Fig. 2 are shown the mains 1 2 3 4 of a four-wire two-phase system. 5 6 are the transformers. 7 8 9 10 are the secondary leads, and 11 is a translating device of any nature whatever. As above explained, the translating device or devices will usually have a resultant self-induction, which will cause the current in each of the circuits to lag. To generate the leading current necessary to overcome this lag or to generate the lagging current necessary to overcome a lead, if any exists, we insert in each circuit, preferably in series, the armature of a machine of the direct-current type, serving as a phase-regulator, as will be presently explained. These armatures are shown at 12 13. The direction and amount of the electromotive force generated by any generators of the ordinary direct-current type depend, the speed being constant, on the excitation of its field-magnets. If the field-magnets are excited by direct current of constant volume, the potential difference at the brushes is unidirectional and practically constant at all commercial outputs, though it drops slightly as the load comes on. If a is the exciting-current, then $a\ c$, where c is a constant, is the potential difference at the brushes, neglecting slight variations due to changes in the permeability of the field-magnets. If the exciting-current becomes periodic—as, for instance, if $a = a'$ cos. x, where x is some simple time function—the armature electromotive force will have the value $c\ a'$ cos. x, neglecting the time lag of the magnetic flux, which may be made small by proper design. It follows that by inserting in any electric circuit the armature of such a machine we are able to impress upon the circuit any wave whatever by simply exciting the field-magnets in the proper phase. The voltage of the wave thus impressed will be independent of the frequency and will depend only on the speed of revolution and on the amount of the excitation. This result is particularly important when the current to be regulated is of low frequency, for in that case the ordinary phase-regulators, such as condensers, become very expensive, as is well known. It will be seen that our improved phase-regulator is independent of the frequency; but this method of regulation or phase control requires that the field-magnet of each regulator be excited by a current dephased from the current whose phase is to be controlled, and as in most commercial circuits the current lags behind the electromotive force the regulating-wave, and therefore the current of excitation, should lead, preferably, by about ninety degrees. This result may be reached in many ways, remembering always that the magnetism due to any current may be reversed or dephased one hundred and eighty degrees by reversing the connections between the terminals of the exciting-coil and the line. With a two-phase system we prefer to make each current excite the field-magnet of the regulator which controls the other current.

Referring again to Fig. 2, it will be seen that the circuit 7 8 passes around the field-magnets 14 of one of the direct-current machines A and through the armature 13 of the other direct-current machine B, while the circuit 9 10 passes around the field-magnet 15 of machine B and through the armature 12 of machine A. The armatures 12 13 are driven at the proper speed in any way whatever, as by the belts 25 26, and the field-magnets are so wound and connected that the electromotive force impressed on each of the circuits by the corresponding armature is ninety degrees ahead of the current therein. In this way, as explained above with reference to Fig. 1, a wave will be impressed on each circuit, which may by proper adjustment be made of such magnitude as to make the power factor of the circuit unity.

The principal defect of any asynchronous machine, whether running as a generator or as a motor, is its apparent self-induction. This is due to the fact that it is necessary to get up a field of force in the machine, and this field is in general generated by the inducing-currents—that is to say, by the currents flowing from or to the system of distribution, according to whether the machine is running as a motor or as a generator.

It is known that the current lag caused by the reaction of a magnetic field upon the current which creates it increases rapidly with the frequency of the current. It is also a fact that the frequency of the currents in the induced member of an asynchronous machine is in general very much less than the frequency of the line-currents. The ratio of these two frequencies may be as low as one to fifty. It follows that if we can make the induced currents excite the machine, instead of the line-currents, the retarding effect of the field will be greatly reduced.

If the machine has $2n$ poles and is running at the speed of rotation w and if $\frac{1}{\mathrm{T}}$ is the line frequency, $\frac{1}{\mathrm{T}} - n\ w$ will be the frequency of the current in the induced circuits and of the flux generated by the same. The speed of the rotary field, if the machine is of the multiphase type, will be $\frac{1}{n\ \mathrm{T}}$. The speed with which the field generated by the induced current rotates with reference to the induced member is equal to one nth of the frequency of the induced current, or $\frac{1}{n}\left(\frac{1}{\mathrm{T}}-n\,w\right)$. This field will rotate with relation to the inducing-circuits with a speed equal to $\frac{1}{n}\left(\frac{1}{\mathrm{T}}-n\,w\right)$ plus the actual mechanical rotation of the machine, or

$$w+\frac{1}{n}\left(\frac{1}{\mathrm{T}}-n\,w\right)=\frac{1}{n\,\mathrm{T}}.$$

This shows that the induced member is able, by a current of the frequency $\frac{1}{\mathrm{T}}-n\,w$, to generate the same flux which the inducing member generates by means of a current of the frequency $\frac{1}{\mathrm{T}}$; but the lag due to the production of such a field will be very much smaller when it is generated by the current of lower frequency. Our improved phase-regulator, the action of which is as great at low frequencies as at high, enables us to effect the regulation of the machine by bringing the induced current into phase with its electromotive force with great ease and economy. This matter may be expressed in different language by saying that the currents in the induced and inducing members tend to lag, owing to the fact that they have to generate a magnetic field. The resultant current in either of these circuits will then consist of a current in phase with the electromotive force and a second wattless current at right angles to it. This wattless current may be neutralized by superposing on the circuit to be regulated an advanced wave, as explained with reference to Fig. 1. Owing to the reaction and interaction between the induced and inducing members, this regulation may take place in either of these members; but now that we have available a phase-regulator whose action is independent of the frequency we find it preferable to attain the regulation by acting upon the induced circuits.

In Fig. 3 the induced member of an asynchronous machine is indicated at 17, and 18 is the inducing member, taking currents from or feeding currents to a transformer 19 and mains 20 21 22. The inducing member (shown in this case as three-phase) may be of any approved form and need not be further described here. The induced member is of the two-phase type, wound with two windings 23 24. These two windings are connected to the phase-regulating armatures 12 13 and the fields 14 15 through the conductors 7 8 9 10, as are the secondaries of the transformers 5 6 in Fig. 1. The phase-regulators A B (shown in this figure) are similar to those in Fig. 1 as far as principle of operation is concerned. They consist of two ring armatures 12 13 on the shaft 27, driven by the pulley 28 within the inductive influence of the field-magnets 14 15. The field-magnets are supplied with two windings 29 30 and 31 32, respectively. The windings 29 31 are the ordinary field-magnet-exciting coils and are connected to their inducing or exciting circuits, in this case the induced circuits of the main motor or generator, at points ninety degrees from the line of the brushes. The field-winding 29 and the armature 13 are in series with the winding 24, while the field-winding 31 and armature 12 are in series with the winding 23. Each phase-regulator is thus excited by a current dephased ninety degrees from its armature-current, as before, and the relations of the field and armature windings on each regulator are made such that the wave impressed by each armature on the circuit to which it is connected is in advance of the current in that circuit. In addition we prefer to place on the field-magnets of the regulators the compensating windings 30 32. These are in this case of the ring type, preferably having as many turns as there are turns in the armature, and are connected in series with their respective armatures, the points of entrance and exit of their currents being in line with the brushes. The effect of these windings is to produce poles which oppose and neutralize the poles produced by the armatures, thus preventing disturbances due to armature reaction and neutralizing the self-induction of the armatures. The action of this system is as follows: Supposing the main machine to be running as a motor, in which case current enters from the transformer 19 and creates a field in the rotor, if the motor is multiphase, as shown, this field will rotate with respect to the iron of the rotor. This will induce two-phase currents in the windings 23 24, which pass, respectively, through the field-magnet winding 31, armature 12, and compensating winding 30 and through the field-magnet winding 29, armature 13, and compensating winding 32. Each current thus passes through one of the armatures and has superposed upon it an advanced wave, while in turn it excites the field-magnet of the regulator which controls the phase of the other current. The advanced waves thus impressed upon the circuits of the windings 23 24 serve to magnetize the main machine, thus relieving the line of the duty of furnishing the wattless currents for the excitation, or, in other words, these waves neutralize the effect of the self-induction in the armature-circuit, with the advantage above explained.

If the machine is running as a generator driven above synchronism by external power, the action is very similar. Current flowing through the winding of the rotor 18 generates, as before, secondary currents in the windings 23 24, the phase of which is controlled by the armatures 12 13. These currents in turn act to reinforce the currents in 18 in a manner described and claimed in our Patent No. 606,761, dated July 5, 1898.

It is thus apparent that our improvements are applicable to motors, generators, and distribution systems generally.

For simplicity we have shown machines in which the inducing member rotates and in which there is but one polar line; but it is obvious that our improvements are applicable to any induction-machines whatever; nor do we restrict ourselves to the use of any particular number of phases either in the induced or in the inducing member, though we prefer to wind the induced member for multiphase currents and find in most cases that a two-phase winding gives the best results. Whatever may be the number of phases used in the induced member, it will obviously be useful to provide a regulator for each separate phase of the current. Each of these regulators should have its field excited with a magnetism ninety degrees in advance of the current which it is to carry in its armature. The diagram Figs. 4 and 5 show how this excitation may be produced in a three-phase system.

In Fig. 4, OA, OB, and OC are three vectors, representing the magnitudes and phases of the currents in a symmetrical three-phase system. Suppose, for example, that it is desired to create a magnetism represented by the line OD ninety degrees in advance of OA and equal to it in magnitude. It is obvious that neither of these currents will serve to excite such a magnetism; but if we place on the field-magnet in question a winding that will take current in series with the current represented by OC and of such a number of turns that its magnetizing force is represented in magnitude by the line OC′ and a second winding of the same number of turns fed with a current which may be represented by OB, but reversely connected, so that its magnetizing effect may be represented by OB′, the resultant magnetic motive force will be represented in magnitude and phase by the vector OD ninety degrees in advance of OA and equal to it in magnitude. This method is not restricted to three phases, nor to the particular arrangement shown. In general it is possible to produce from any two dephased currents a magnetomotive force having any desired phase relation to a third current or to either of the two currents in question. For example, the magnetomotive force OD might be produced from the currents OA and OC by making the magnetomotive force due to OA equal to OA′ and the magnetomotive force due to OC equal to OC′, as will be evident from the diagram.

Fig. 5 represents a three-phase machine composed of an inducing member 18 and an induced member 33. 38 39 40 are the leads from the induced winding, each connected in series with one of the armatures 35 36 37 of the regulators E F G. The field of E, whose armature is connected with the lead 38, is excited by the currents of 39 and 40, and so on. The excitation of the field of each regulator is thus furnished by two of the currents, as required by the diagram Fig. 4, while the armature serves to regulate the third current. We have in this figure shown the regulators driven by the small self-excited synchronous motor 41, fed with current through the branch wires 42 43 44, connected to the secondary of the transformer 19. This method is convenient where the main machine is to be run as a motor and other power is not available. When the machine is used as a generator driven by external power above synchronism, as explained in our Patent No. 606,761, dated July 5, 1898, the induced currents in the secondary winding 33 are, as in the case of the arrangement shown in Fig. 3, regulated in phase by the auxiliary machines, so that the excitation is again obtained from the latter instead of from the line, which is thus relieved of the duty of furnishing wattless currents. We have also shown in this figure resistances 45 46 47, one in series with each of the wires 38 39 40. These resistances may be adjusted by the three-armed spider 48 and serve to prevent the current in the induced member of the motor from attaining excessive values while the machine is starting and also to control the speed and torque.

The regulating machines or exciters A and B, Fig. 3, are, as has been seen, ordinary generators of the direct-current type, with an additional compensating winding. They may therefore act as such by connecting them so that each excites its own field-winding. In this case each of these machines A and B will generate direct current to excite the induced member of the main machine, which will then become synchronous in its action and the currents flowing in the wires 7 8 9 10 will become direct. It follows that our invention enables us to provide a dynamo-electric machine which will run either snychronously or asynchronously, according to the connections of its induced circuits. Such an arrangement we have shown in Fig. 6, where 18 is the inducing-winding and 23′ the induced winding of the main machine, shown in this case as of the single-phase type. The wires 7 8 9 10 lead from the induced winding 23′ to the regulating-machines or exciters A and B through the switch H. With the switch in the position shown the connections are similar to those in Fig. 3—that is to say, the wire 7 is connected in series with the field 14, armature 13, and wire 8, while the wire 10 is connected in series with the field 15, armature 12, and wire 9. The main machine is then asynchronous and possesses all the advantages of asynchronous machines in addition to the advantages conferred by the use of our improved phase-regulators; but if the switch H is thrown to the left the circuits will be from the wire 7 through field 14 and armature 12 to wire 8 and from wire 10 through field 15 and armature 13 to wire 9. The machines A and B will then run as direct-current generators, exciting the winding 23′ as an ordinary field-magnet winding. The main machine will then run as a synchronous motor or generator, as the case may be. We are thus enabled to start the main machine as an asynchronous machine and then continue to run it as a synchronous machine. We have in this figure and in Fig. 5 shown the winding of the induced member of the main machine as of the continuous-ring type, while in Fig. 3 we have shown independent circuits. It will be obvious that either of these windings or any other approved winding may be used in connection with our invention in any of its forms.

It should be understood that our invention is susceptible of many modifications and that we do not limit ourselves either to the single-phase or the two-phase or the three-phase system in either the induced or the inducing member of the main machine or in the systems of distribution to which our improvements may be applied. Nor do we limit ourselves to any particular number of polar-lines in the main machine or in the regulating-machines, though we have for simplicity shown but one polar-line in each case.

We therefore claim as our invention and desire to secure by Letters Patent—

1. The method of impressing a wave of current or electromotive force on any circuit, which consists in connecting the circuit to the brushes of a generator of the direct-current type, and separately exciting the field of the latter in accordance with the wave desired.

2. The method of advancing or retarding the phase of an alternating current, which consists in passing the current through the armature of a dynamo-electric machine of the continuous-current type, and exciting the field-magnets of the dynamo-electric machine so as to have alternating magnetism in advance or retard of the current whose phase is to be controlled.

3. The method of controlling the phase relation between current and electromotive force in a multiphase system, which consists in using one of the currents to generate a wave of current or electromotive force, and impressing the said wave upon another of the currents.

4. The method of varying and controlling the phase relation between current and electromotive force in an alternating-current circuit, which consists in superposing on said circuit a wave of electromotive force by the action of a generator of the direct-current type whose field-magnets are excited by currents leading or lagging to the required extent with respect to the current whose phase is to be controlled.

5. The method of starting and running an alternating-current dynamo-electric machine, which consists in first closing the circuit of a winding on its induced member, and thereafter connecting the said winding to a source of direct current, whereby the machine runs first as an asynchronous machine, and then as a synchronous machine.

6. The method of starting and running an alternating-current dynamo-electric machine which consists in first short-circuiting the induced member through a phase-regulator, advancing the phase of the induced current to such an extent that the said induced current furnishes the field excitation for the machine, and thereafter connecting the said induced member to a source of direct current, and running the machine as a synchronous motor.

7. The method of reducing the apparent self-induction of an asynchronous dynamo-electric machine at all speeds of the rotor, which consists in impressing upon the induced circuit of the machine an advanced wave of current or electromotive force by the reaction between an armature of a generator of the direct-current type and an alternating field of force, substantially as described.

8. In an alternating-current circuit, the combination of a source of alternating current, a generator of the direct-current type with its armature in series with the circuit, and means for generating in the field-magnets of the generator a periodic flux.

9. The combination of a source of alternating current, a generator of the direct-current type having its armature electrically connected to the said source, means for driving the generator, and means for exciting its field-magnet with an alternating current of the same frequency as the alternating current from the said source.

10. In a multiphase system of distribution, the combination of a plurality of armatures, and a plurality of field-magnets, each field-magnet being in inductive relation to one of the armatures, corresponding fields and armatures being connected to different sides of the system.

11. In an asynchronous dynamo-electric machine, the combination with the inducing member, of an induced member and a phase-regulating dynamo-machine of the direct-current type, having an alternating field of force, connected thereto.

12. The combination with an alternating-current circuit, of a phase-regulator connected thereto, consisting of a generator of the direct-current type having means for generating in its field-magnets an alternating flux.

13. A phase-regulator for a multiphase circuit, consisting of a plurality of armatures connected to the circuit and so arranged as to run at the same speed, a corresponding number of field-magnets, and means for exciting the field-magnets with alternating currents bearing such phase relation to the currents in the circuits as to produce the regulation desired.

14. In an alternating-current dynamo-electric machine, the combination of an inducing-winding, and an induced winding, means for closing the circuit of said induced winding through a phase-modifier, and means for supplying it with direct current.

15. The method of operating an alternating-

current motor which consists in conveying alternating currents to the primary winding generating, by external power, multiphase electromotive forces and conveying the same to the circuits of the induced winding of the motor in opposition to the electromotive forces of self-induction in the same, substantially as described.

16. The combination of an alternating-current induction-motor, with a separate dynamo-electric source of current-supply driven by external power for impressing multiphase electromotive forces on the induced winding, to excite the machine and thereby reduce its effective self-induction.

17. The method of starting and running an electric motor which consists in supplying its inducing member with alternating currents, inducing thereby currents in the induced member, supplying said induced currents to an auxiliary dynamo-electric source of current-supply and, by the action of said auxiliary source, impressing upon the induced member multiphase electromotive forces and currents for the excitation of the motor.

18. The method of starting and running an electric motor which consists in supplying its inducing member with alternating currents, generating thereby currents in a plurality of circuits on the induced member of said motor, supplying said induced currents to corresponding auxiliary circuits on an auxiliary apparatus, and generating by external power multiphase electromotive forces in said auxiliary circuits.

19. An alternating-current dynamo-electric induction-machine in combination with an independently-driven dynamo-electric source of current-supply for charging its induced member with exciting-currents having the frequency of the slip, whereby wattless currents for the excitation of the machine are dispensed with on the line, substantially as described.

20. An alternating-current dynamo-electric machine composed of stator and rotor circuits, one of these circuits being adapted to be connected with a line carrying alternating currents of a given frequency, in combination with a separate dynamo-electric source of current-supply furnishing to the other circuit alternating currents having the frequency of the slip whereby when the rotor is allowed to run below synchronism, the machine acts as a motor taking watt-currents from the line, and when the rotor is driven above synchronism the machine acts as a generator, furnishing currents to the line, substantially as described.

In testimony whereof we have signed our names to this specification in the presence of subscribing witnesses.

MAURICE HUTIN.
MAURICE LEBLANC.

Witnesses as to signature of Maurice Hutin:
HENRY J. WEHLE,
FRED. P. WARREN.

Witnesses as to signature of Maurice Leblanc:
EDWARD P. MACLEAN,
PAUL BOUR.