No. 621,924. Patented Mar. 28, 1899.

K. E. F. KNAUTH.

MEANS FOR SPEED REDUCTION OF ASYNCHRONOUS ALTERNATING MOTORS.

(Application filed Jan. 6, 1896.)

(No Model.) 2 Sheets—Sheet 1.

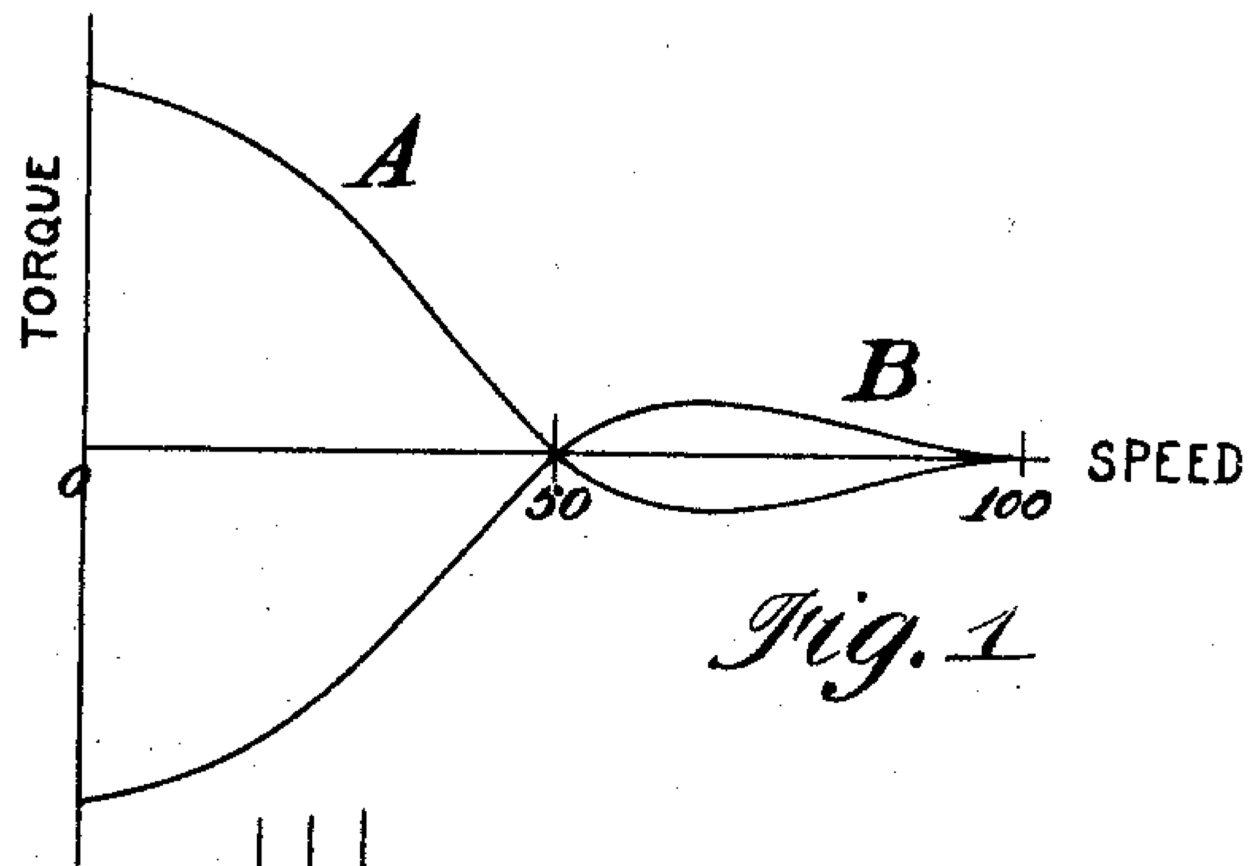

Fig. 1

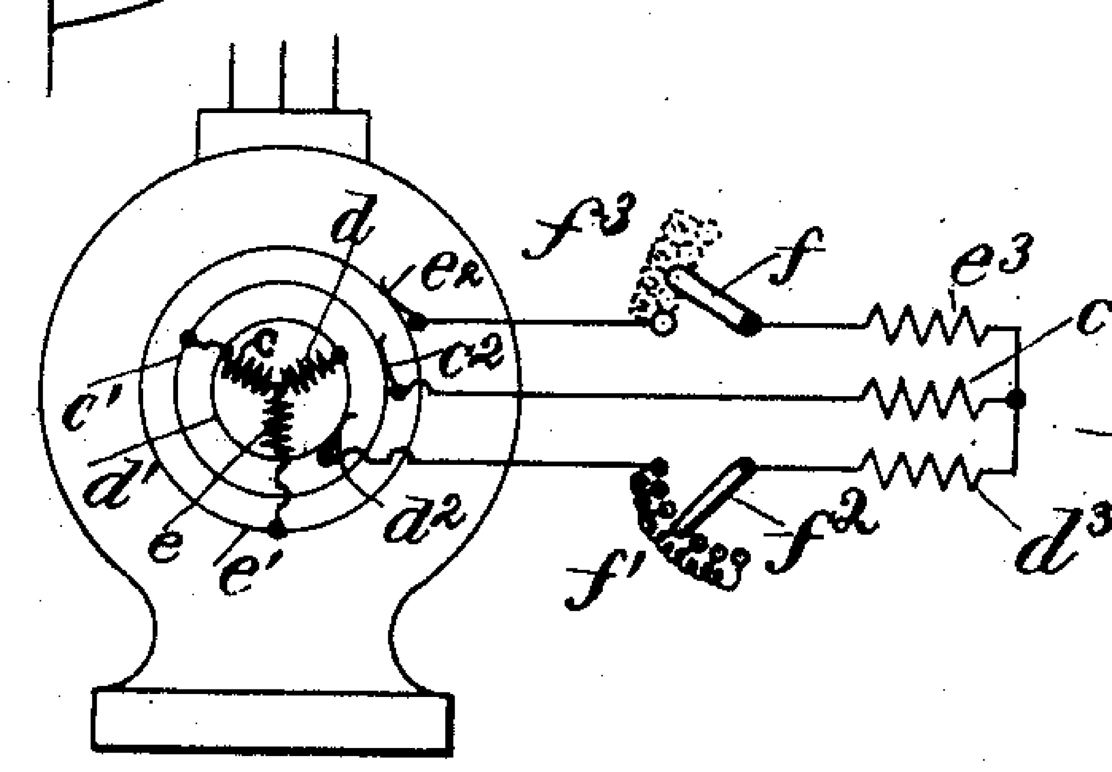

Fig. 2.

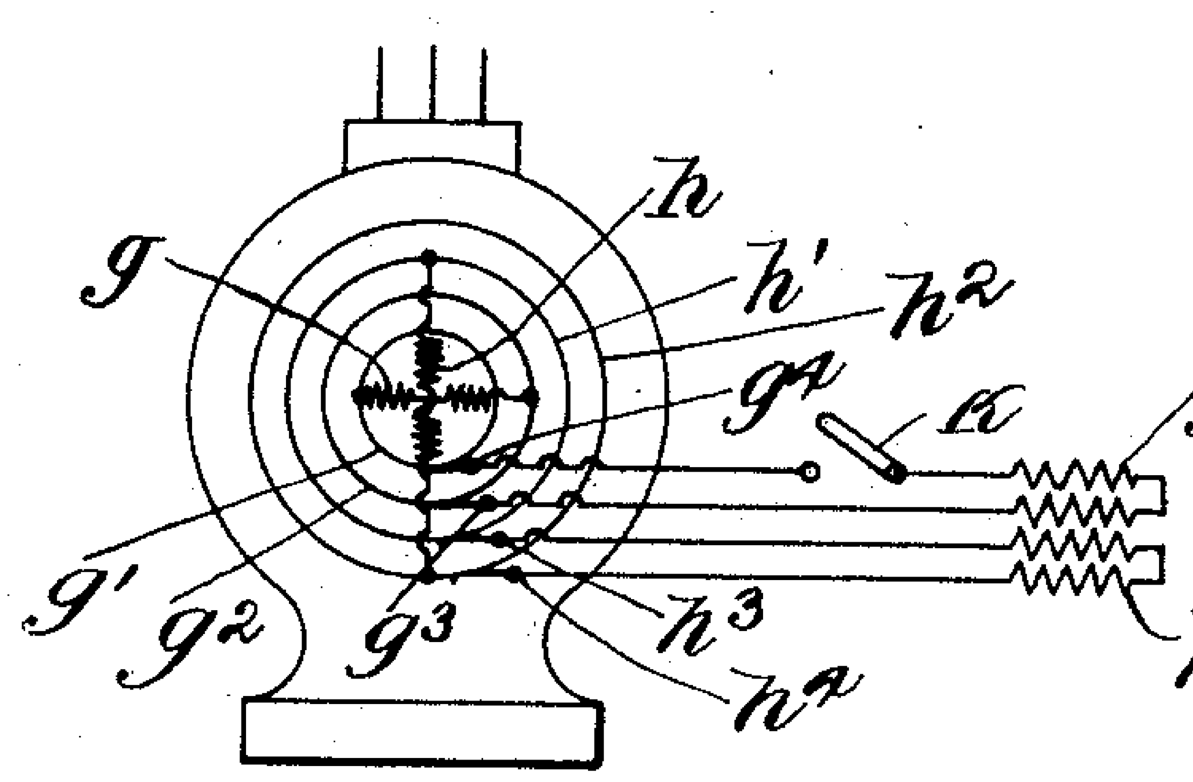

Fig. 3.

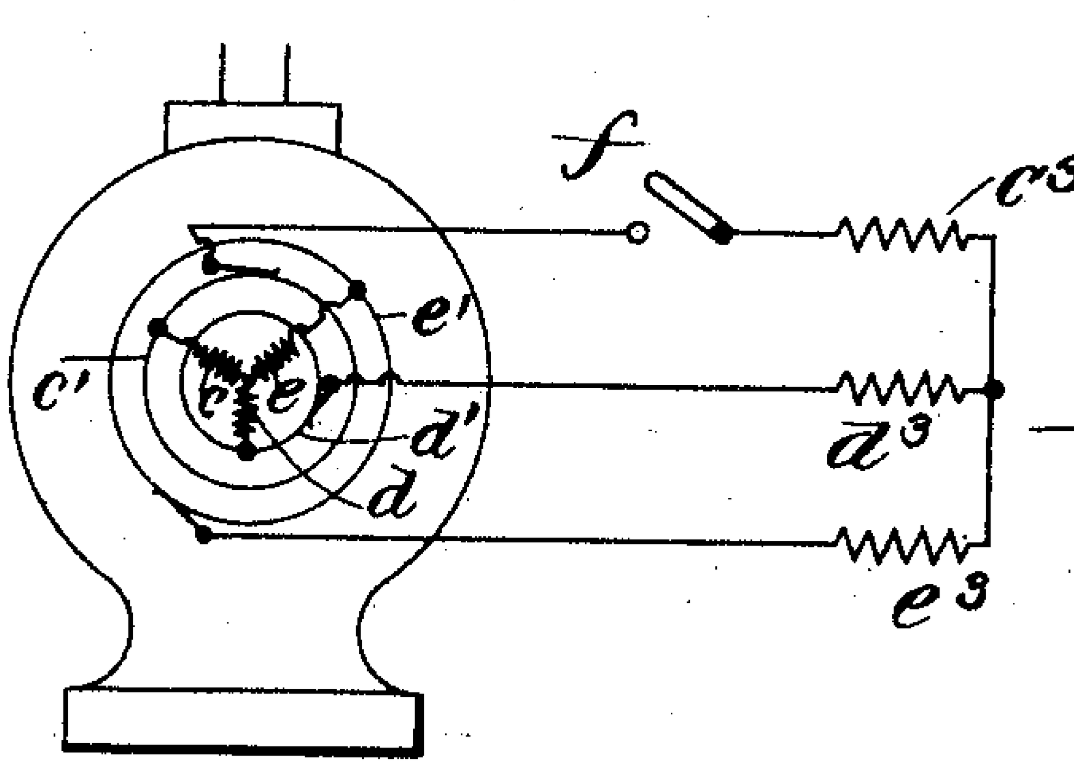

Fig. 4.

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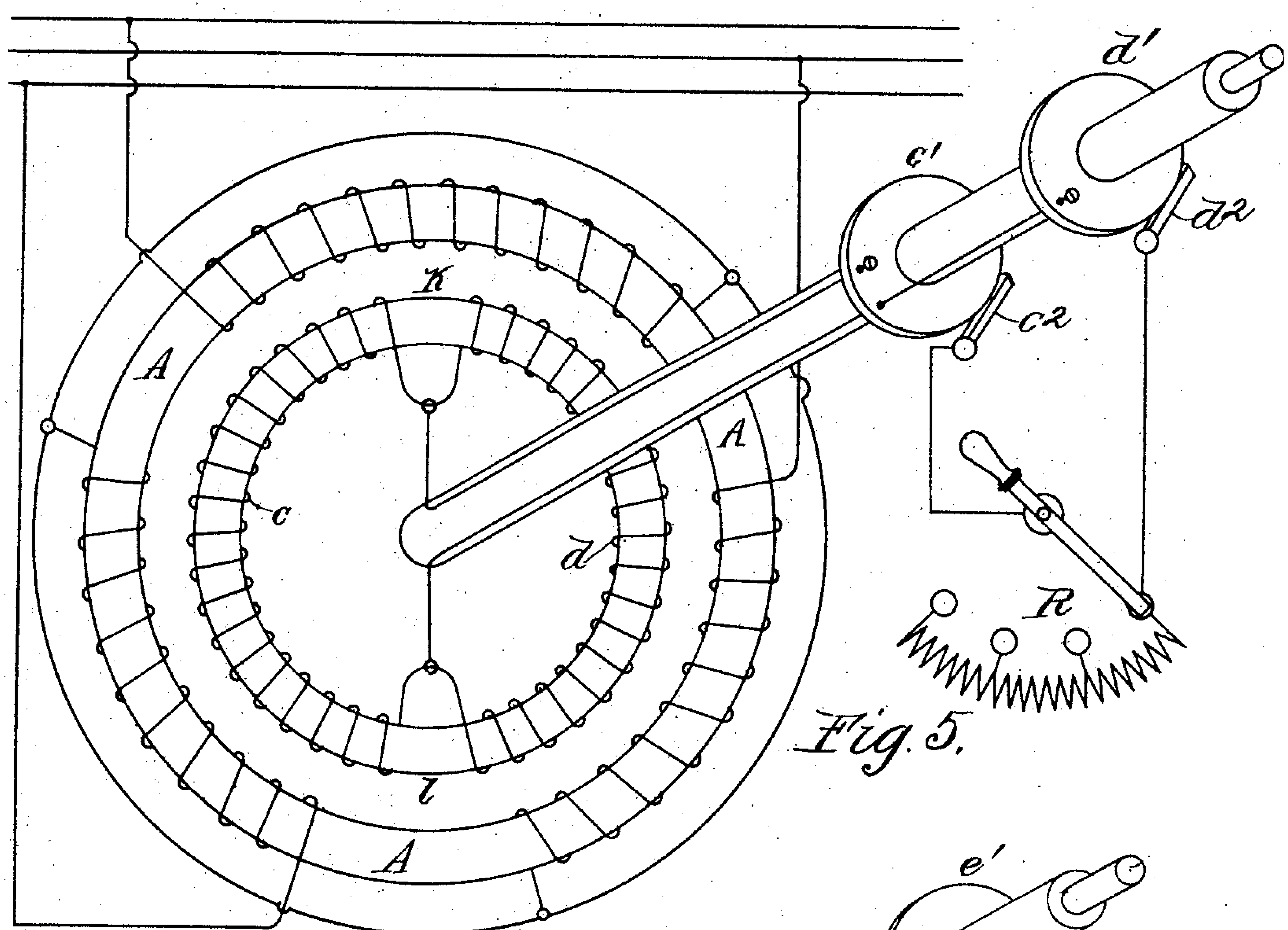

Fig. 5.

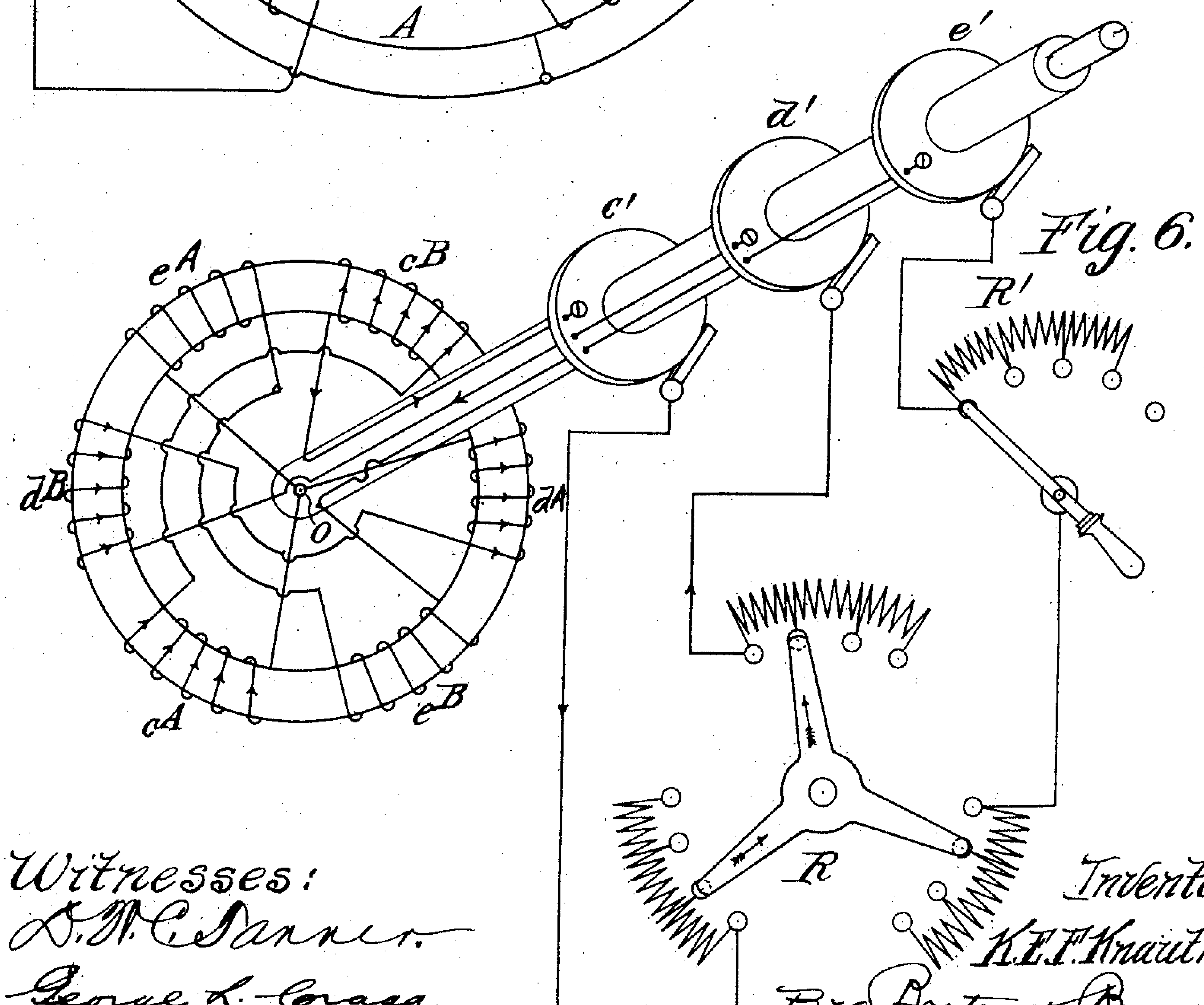

Fig. 6.

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UNITED STATES PATENT OFFICE.

KARL ERNST FRANZ KNAUTH, OF CHARLOTTENBURG, GERMANY, ASSIGNOR TO THE SIEMENS & HALSKE ELECTRIC COMPANY OF AMERICA, OF CHICAGO, ILLINOIS.

MEANS FOR SPEED REDUCTION OF ASYNCHRONOUS ALTERNATING MOTORS.

SPECIFICATION forming part of Letters Patent No. 621,924, dated March 28, 1899.

Application filed January 6, 1896. Serial No. 574,526. (No model.)

To all whom it may concern:

Be it known that I, KARL ERNST FRANZ KNAUTH, a subject of the Emperor of Germany, residing at Charlottenburg, near Berlin, Germany, have invented new and useful Improvements in Alternating-Current Motors and Methods of Operating the Same, (Case No. 71,) of which the following is a specification.

My invention relates to means for speed reduction of asynchronous alternating motors, my object being to provide means whereby the speed of the motor may be varied without materially reducing the efficiency.

Asynchronous motors supplied with either single-phase or pluriphase currents tend under normal conditions to run at a speed at or near synchronism, and in order to decrease the speed two methods have been principally employed. By the first of these methods the number of periods of the alternating current supplied is reduced, thus decreasing the speed of synchronism. By the second method resistance is introduced into the circuit of the induced member of the motor, the speed depending upon the degree of resistance encountered by the currents traversing the induced winding. The latter method may be employed to advantage in cases where the speed is to be reduced only temporarily; but by this method the motor operates at the reduced speeds at a greatly-decreased efficiency, and for this reason the method is objectionable for continued use. Another objection is that when resistance is introduced into the circuit the motor runs at variable speeds, depending upon the load, and therefore as the load varies the motor requires constant regulation in order to maintain it at a constant speed.

In accordance with the present invention the motor may be run with high efficiency at or near synchronous speed or at a speed approaching half-synchronous speed, while through the agency of speed-reducing means, as above described—for instance, by the introduction of resistance into the circuit of the induced winding—the speed may be still further decreased.

My invention is based upon a peculiar property of asynchronous motors. If the stationary member or ring system of a pluriphase-current motor be supplied with a pluriphase current, thus producing a rotary field, and a single-phase induced winding is subjected to the action of the rotary field, the motor will run at a speed very near synchronism with moderate torque. The torque first increases as the speed decreases. Then the torque decreases with decrease of speed and is zero at half the speed of synchronism. At still decreasing speed the curve runs below zero, thus indicating that under these conditions for speeds below half the speed of synchronism the torque is negative, or, in other words, the motor is developing electrical energy. If the motor be started from rest, we find that at slow speeds the torque is considerable, but decreases with increasing speed and becomes zero at half the speed of synchronism. As the speed of the motor is increased above half the speed of synchronism the curve of torque runs below zero, thus indicating that for such speeds the motor runs as a generator, developing electrical energy. This peculiar action is dependent upon the position of the armature for any particular position of the rotating magnetic field. If the motor furnishes mechanical work in one position, it would at the same speed furnish electrical work if the armature should be turned suddenly through an angle defined by the distance between adjacent poles. If now the motor be running at a speed near synchronism with moderate load and the load be increased, so that the torque is greater than that which the motor is capable of developing between synchronous speed and half-synchronous speed, the speed will immediately drop to a point below half-synchronous speed, at which the torque developed by the motor will carry the load. In passing from the speed near synchronism to the speed slightly below half-synchronous speed, the motor passes the point where the torque is zero and the slippage of the induced member takes place, so that the poles change position and the curve of torque instead of becoming negative now follows the positive curve of torque. With the motor running at a speed near half-synchronous speed it cannot increase in speed above half the speed of synchronism, because, as above stated, the curve of torque becomes negative above half-synchronous speed. The losses for the development of the same torque at synchronous and half-synchronous speed are about the same. The commercial efficiency is therefore lower for half-synchronous speed; but if the motor is of good design it is not objectionable. Where, as in practice, the efficiency at full speed is from eighty-five to ninety per cent., the efficiency at half-speed is from seventy to seventy-five per cent. The variations in speed when the motor is running at half-speed are very small, because the torque of the motor increases very fast at decreasing speed for speeds below half the speed of synchronism. Since a motor provided with a single-phase induced winding thus runs efficiently and with considerable torque at half-speed, I am enabled to produce a motor that will run with considerable torque either at full speed or at half-speed by providing a pluriphase induced winding which may be employed when it is desired to run at full speed, while when it is desired to run at half-speed the pluriphase winding may be changed to a single-phase winding by opening a portion of the pluriphase winding or by other change of the circuits. If the motor be in operation with the pluriphase induced winding in circuit, a considerable torque is developed at full speed. When the pluriphase induced winding is changed to a single-phase winding, the torque at full speed, as above explained, is decreased, and consequently at great load the motor immediately drops to half-speed, at which the torque is considerable, and the motor continues to rotate at half-speed. The change from a pluriphase to a single-phase induced winding may be accomplished in a variety of ways. For instance, in a two-phase system one of the windings may be opened, or where brushes and collecting-rings are employed for conveying the current of the induced winding to controlling devices outside the machine brushes may be lifted from the rings to thus open the circuit through some of the windings.

In the above explanation I have referred to a motor provided with a pluriphase inducing-winding adapted to be supplied with pluriphase currents; but my invention is equally applicable to a motor in which the inducing-winding is supplied with a single-phase current, while the induced winding may be connected in circuit either as a pluriphase or as a single-phase winding.

I will describe my invention more in particular by reference to the accompanying drawings, in which—

Figure 1 is a diagram showing the curves of torque of a pluriphase motor with single-phase induced winding. Fig. 2 is a diagram illustrating my invention in connection with a three-phase induced winding. Fig. 3 is a similar view illustrating a two-phase induced winding. Fig. 4 is a view illustrating a motor supplied with single-phase currents instead of pluriphase currents. Fig. 5 is a diagrammatic view showing in detail the circuits and connections of my invention as applied to a motor with a single-phase induced winding. Fig. 6 is a view similar to Fig. 5, illustrating a three-phase induced winding.

Like letters refer to like parts in the several figures.

In Fig. 1 the ordinates represent torque, while the abscissas represent speed. If a motor be provided with a pluriphase inducing-winding and with a single-phase induced winding, it will start from rest with a considerable torque, as illustrated by curve A. The torque decreases as the speed increases until at half-synchronous speed the torque is zero. For further increase in speed the curve of torque passes below the zero-line and is again zero at synchronous speed—that is, if the motor be rotated above half-synchronous speed by any means the machine will act as a generator and continue to generate a current until synchronous speed is reached, when the current becomes zero. If then the driving-power be removed, the machine will rotate as a motor at a speed slightly below synchronous speed. As the speed decreases the torque increases, as indicated by curve B, and then decreases until at half-synchronous speed the torque is zero. If the motor continues to rotate under these conditions the curve of torque passes below the zero-line, the motor thus becoming a generator and giving out electrical work. If, however, when half-synchronous speed is reached and no torque is being developed the induced member be suddenly shifted in position, the motor will continue to develop a torque, increasing with decrease of speed, the torque following the curve A.

If a motor provided with a pluriphase induced member be rotating at synchronous speed, it will develop a considerable torque, and if now it be desired to change the speed to half-speed the pluriphase winding may be changed to a single-phase winding, and immediately the speed of the motor will fall to a point below half-synchronous speed, as determined by the load which the motor is carrying—that is, the speed will fall to the speed corresponding to the point upon the curve A at which the required torque is being developed.

In Fig. 2 the induced member is illustrated as provided with a three-phase winding, the three coils c d e being connected with rings c' d' e', upon which rest brushes c^2 d^2 e^2, connected through starting-resistances c^3 d^3 e^3. When it is desired to change from a three-phase to a single-phase winding, the lever f may be moved to open the circuit. A rheostat f' may be provided, whereby the resistance of the circuit through the single-phase winding may be varied by the movement of the contact-arm f^2 to further decrease the speed. Likewise, a rheostat f^3 may be included in circuit with the winding adapted to be thrown on open circuit, as illustrated in dotted lines, whereby resistance may be gradually introduced into the circuit to change gradually from a pluriphase winding to a single-phase winding.

In Fig. 3 a two-phase winding is illustrated, the coil g being connected between collecting-rings g' g^2, upon which rest brushes g^3 g^4, connected to starting-resistance g^5, while coil h is connected between collecting-rings h' h^2, upon which rest the brushes h^3 h^4, connected to a starting-resistance h^5. By opening the switch k the circuit through coil g may be opened to thus convert the winding into a single-phase winding.

In Fig. 4 is illustrated a motor provided with a single-phase inducing-winding and a three-phase induced winding similar to that illustrated in Fig. 2, the winding being converted into a single-phase winding by the opening of the switch f.

Referring to Fig. 5, the stator portion (represented by the external annular body A A A) is made of insulated iron sheets and provided with a winding which when fed by a pluriphase current is capable of producing in the ring a rotating magnetic field. For simplicity's sake there are shown only three coils, whose terminals are separated one hundred and twenty degrees from each other and which are connected to the three main conductors of the three-phase system, while the three terminals are connected together. A ring-shaped rotor portion is mounted on an axle inside of the external iron ring. This rotating part consists also of insulated iron sheets and is provided with a winding which can produce poles only at certain stationary points of the body. In Fig. 5 the rotating part is shown as a ring which is wound with two coils c d, which are of equal length and located opposite each other. These coils are connected in parallel and can produce poles only at points k l of the rotating ring whenever they are traversed by a current. The terminals of the coil c are connected with the terminals of the coil d, and from the junctions of these terminals connection is led to the contact-rings c' d', from which rings the induced current is led by means of brushes c^2 d^2 through a regulating-resistance R. This winding of the rotor portion is called a "one-phase" winding in counterdistinction to that of the stator portion, because the former can be fed only by means of a single-phase current and because it is not capable of producing a rotating field in the ring. If now there is generated in the external stationary ring a rotating field by connecting its coils to a three-phase generating-system the internal part commences to move. Preferably when starting the resistance R is all cut in the induced circuit and is gradually cut out subsequently. The rotating part, however, will assume only about one-half the speed with which the field rotates. If the motor is permitted to run with greater than one-half the velocity with which the field rotates, which is accomplished by driving the motor by an external source of energy, then the motor furnishes electrical energy, because it opposes a mechanical resistance to the rotation. If now the motor is adjusted to the same velocity with which the poles of the field rotate and if the motor is left entirely to itself, it is then again capable of doing mechanical work, because its speed is a little less than that of the rotating magnetic field. The motor, however, at this speed develops considerably less torque than when running at half-speed, so that this combination constitutes an asynchronous pluriphase motor which has the important capacity of operating both at half and full speed without changing its connections. If the motor is running approximately at the same velocity as that with which the poles of the rotating magnetic field revolve and if the motor is doing mechanical work, then when load is put upon the motor the speed thereof would decrease very rapidly to about half-speed, at which point, as the motor now develops much greater torque than before, the load is carried and the motor continues to rotate at approximately half-speed. From the foregoing it results that the rotating part of an ordinary motor may be provided with a switching arrangement by which the motor may be changed into one having the above-described properties. Taking, for example, a motor whose rotating part is provided with a three-phase winding, as shown in Fig. 6, the diametrically opposite coils are connected in series with each other. The six coils then form three groups, which are connected in a well-known manner in star connection. The three terminals of this winding are connected with the three contact-rings c' d' e', from which the current passes through a starting-resistance R. This resistance is short-circuited when the motor is operating normally. In the circuit from contact-ring e' to resistance R there is located a special resistance R', which is so arranged that this part of the circuit may be left entirely open. When the motor is running as a regular pluriphase motor, then both resistance R and resistance R' are short-circuited. If now the resistance R' is inserted, the current in the two coils eA eB is diminished. Current in this section and in the circuit including R' may be entirely cut off. At a certain instant, then, the current will pass from the point o, through the coils cA cB, to the contact-ring c', to the resistance R, thence to contact-ring d', thence through coils d A d B to the point o. The current thus circulating is a single-phase alternating current which forms poles always at those two points of the ring where the coils eA and eB are located. If the resistance R' is removed, the motor runs with full torque at a speed which is only a little less than the speed with which the poles rotate. If we open the circuit through the coils *eA eB* at R′, the motor continues to run at less torque with the same speed. At greater load, however, its speed will fall suddenly to one-half, and, finally, at a very great load the motor will stop altogether. If, on the other hand, the motor is started with R′ open and resistance R inserted, the motor will start with a great torque, but will reach half-speed easily even when R is entirely removed, and it is then necessary to employ external mechanical power in order to bring the motor above half-speed. If, however, R′ is removed gradually, the motor may be brought up to its full load easily by using resistance R.

It is immaterial how the rotating field in the stationary external part is produced. It is therefore also possible to use three-phase current. I have found in practice that the external ring may be fed also with a single-phase current arranged to produce a rotating field and that in this manner a motor is produced which is capable of running both with half and with full speed.

It is obviously immaterial whether the inducing or the induced portion is stationary or which of the two parts is external.

By a "single-phase winding" as the term is used herein is meant one in which the axis of the magnetizing force set up thereby is fixed with relation to the winding or where a plurality of coils make up the winding the axis of each magnetizing force is fixed with relation to the coil setting up the magnetizing force, the magnetizing forces set up by the different coils of the winding being coincident in phase.

Having described my invention, what I claim as new, and desire to secure by Letters Patent, is—

1. The herein-described method of changing the speed of alternating-current motors, which consists in changing the character of the currents in the induced windings from pluriphase to single phase to cause the motor to rotate at near half-synchronous speed, substantially as described.

2. The herein-described method of changing the speed of alternating-current motors, which consists in changing the character of the currents in the induced winding from single phase to pluriphase to cause the motor to rotate at near synchronous speed, substantially as described.

3. In an alternating-current motor, the combination with an inducing-winding adapted to be energized by single-phase or pluriphase currents, of an induced winding, and means for connecting said induced winding into circuit as a pluriphase or as a single-phase winding; substantially as described.

4. In an alternating-current motor, the combination with an inducing member adapted to be energized by single-phase or pluriphase currents, of an induced member having a pluriphase winding, and means for converting said pluriphase winding into a single-phase winding; substantially as described.

5. In an alternating-current motor, the combination with an inducing member adapted to be energized by single-phase or pluriphase currents, of an induced member having a pluriphase winding, and means for opening some of the circuits of said pluriphase winding to convert the same into a single-phase winding; substantially as described.

6. In an alternating-current motor, the combination with an inducing member adapted to be energized by pluriphase or single-phase currents, of an induced member having a pluriphase winding, and resistance adapted to be interposed in the circuit of said pluriphase winding to change the character of the pluriphase currents generated in the winding more and more into the character of single-phase currents; substantially as described.

7. In a system of electrical distribution, the combination with distributing-mains for conveying alternating current from a suitable source, of a motor having two relatively-rotatable members, each provided with windings, the windings of one member being connected in circuit with said distributing-mains, and means for connecting the windings of the other member as pluriphase windings to secure one rate of speed and as single-phase windings to secure another rate of speed, substantially as described.

In testimony whereof I affix my signature in the presence of two witnesses.

KARL ERNST FRANZ KNAUTH.

Witnesses:
HERMANN RÖNNE,
OSCAR BIELEFELD.