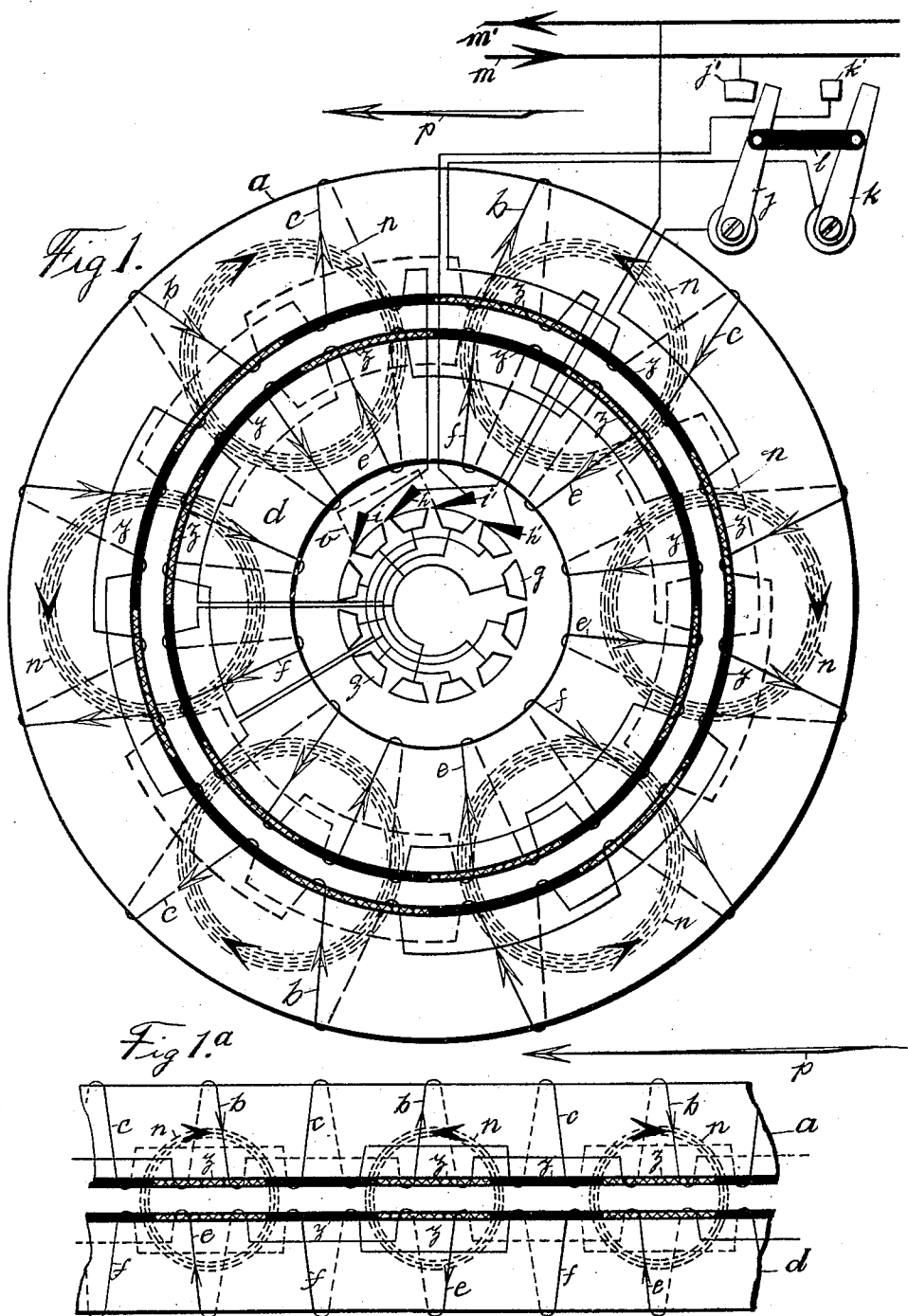


A. W. SMITH.
ELECTRIC MOTOR.

No. 552,337.

Patented Dec. 31, 1895.



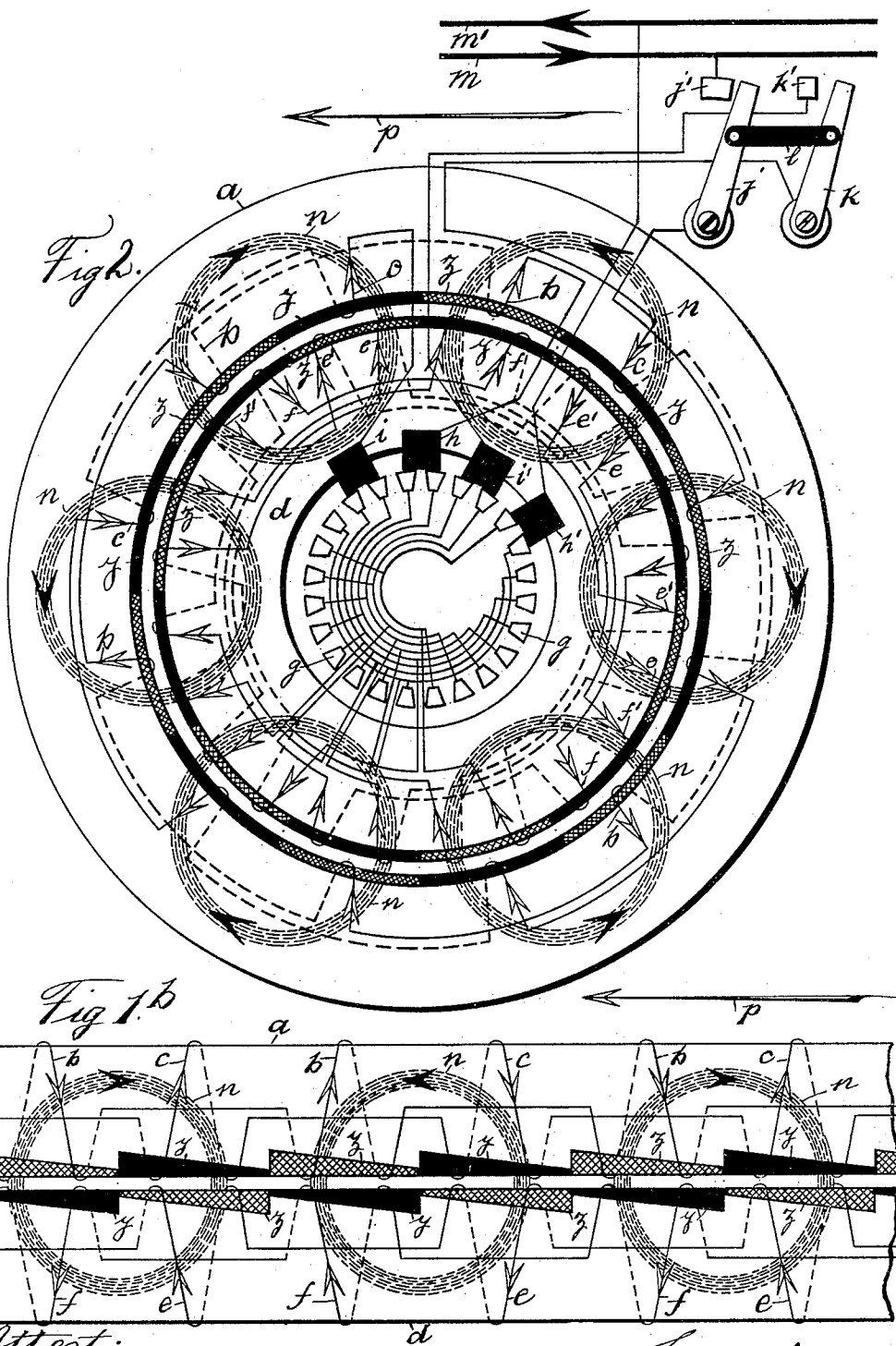
Attest:
Fred A. Schmidt
Robt. T. Platt

Inventor:
Albert W. Smith

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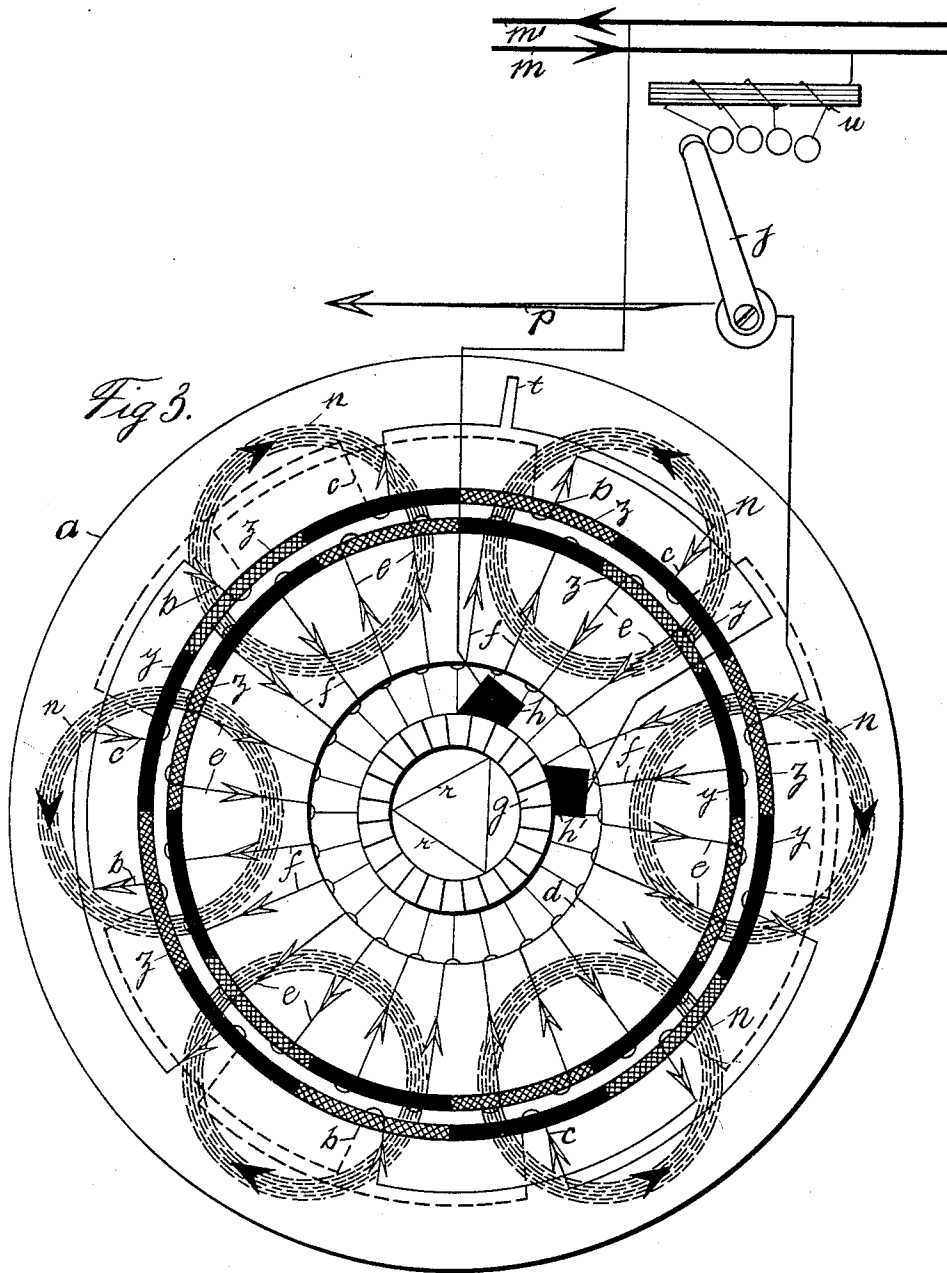
(No Model.)

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UNITED STATES PATENT OFFICE.

ALBERT W. SMITH, OF WASHINGTON, DISTRICT OF COLUMBIA.

ELECTRIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 552,337, dated December 31, 1895.

Application filed July 23, 1895. Serial No. 556,855. (No model.)

To all whom it may concern:

Be it known that I, ALBERT W. SMITH, a citizen of the United States, residing at Washington, in the District of Columbia, have invented a new and useful Improvement in Electric Motors, of which the following is a specification.

The object of this invention is to produce an efficient, simple, and cheap alternating-current induction-motor employing both the principles of attraction and repulsion in its operation, and one that will be self-starting with several times its normal load without the need of extraneous or auxiliary starting devices, and may be run at either a synchronizing or a variable speed, as desired, and be capable of being economically operated by a single high-pressure alternating current of high or low frequency without the usual intermediary of pressure-reducing transformers and with an electrical efficiency equal to that of the best stationary induction-transformers.

To these several ends my invention consists in the employment of a fixed and a movable magnetic system, one of which systems is wound with non-commutable primary and secondary coils angularly displaced from each other, and the other system of which is wound with two or more independent and angularly-displaced sets of commutable coils having their working or torque-producing portions wound in parallel direction with and in inductive relation to the non-commutable coils on said other magnetic system, and a commutator adapted to place said commutable coils in the primary circuit during those portions of each revolution during which attraction in the direction of rotation exists between them and the non-commutable primary coils, and to place said commutable coils in the secondary circuit during those portions of each revolution during which repulsion in the direction of rotation exists between them and the non-commutable primary coils.

It also consists in other details to be hereinafter more fully described.

In the drawings herewith, Figure 1 is a conventional diagram of my invention. Figs. 2 and 3 show modifications thereof. Figs. 1^a and 1^b are detail views.

In all the views the same letters refer to like or corresponding parts.

a is the fixed magnetic system, and *d* is the movable magnetic system.

b b are primary coils, and *c c* are secondary coils on the fixed magnetic system *a*.

In Fig. 1 the movable magnetic system *d* has two sets of coils. The set *e e* are for the time being primaries, and set *f f* are secondaries. All the coils in Fig. 1 are shown as ring-coils of one and one-half turns each. In practice, however, each coil consists of many turns. The form of cross-section and angular width of those portions of the primary coils which are in the air-gap is shown by the cross-hatched spaces *z z*, and the form of cross-section and angular width of the secondary coils is shown by the full black spaces *y y y*. The spaces *y y y* and *z z z* also serve to graphically indicate the character of the coils, the black spaces *y y y* indicating secondary coils and the light or cross-hatched spaces *z z z* representing primary coils.

In Fig. 1 the commutator *g* has twelve segments connected in four groups of three in each group. Each group forms one terminal of one set of commutable coils, alternate segments being connected to opposite terminals of the same set of coils.

h and *h'* are primary brushes, and *i* and *i'* are secondary brushes. The switch *j* is adapted to close the primary circuit, and switch *k* is adapted to close the secondary circuit. Link *l*, of insulating material, mechanically connects switches *j* and *k*. The two sets of non-commutable coils *b b* and *c c* are each connected in a separate series, as shown by full lines on the front and dotted lines on the back. Likewise the two sets of commutable coils *e e* and *f f* are each connected in a separate series.

In Fig. 1 the circuit through the motor is as follows: Starting at the supply-wire *m* it passes through the non-commutable primary coils *b b* in series to brush *h*, then through commutable coils *e e* in series to brush *h'*, and via switch *j* out to supply-wire *m'*. The secondary circuit starting at switch *k* passes through non-commutable coils *c c* in series to brush *i*, then through commutable coils *f f* in series to brush *i'* and out to terminal-plate *h'*.

If the supply-wires *m* and *m'* are assumed to have for the time being a current of the polarity indicated by arrow-heads thereon, and switches *j* and *k* are assumed to be closed,

then a primary current will flow through all the primary coils in series, as shown by arrow-heads thereon, and a secondary current will flow through all the secondary coils in series, as shown by arrow-heads thereon. The current is simultaneously reversed in all the coils when the polarity of the current in the mains is reversed.

The operation of the motor is as follows:

- 10 Assuming the motor to be at rest with the movable magnetic system in the position shown in Fig. 1, then the circuit through the commutable coils has just been commutated and the coils *ee*, which for the time being are
- 15 in the primary circuit, are angularly displaced backward from those of the non-commutable primaries *bb*, having the same direction of current therein. When in this position the non-commutable and commutable primary
- 20 coils jointly generate the circular magnetic fluxes *nn*, which, as shown in Figs. 1, 2 and 3, cut across those portions of the primary and secondary coils lying in the air-gap, and also thread through some of the turns of the
- 25 primary and secondary coils. When the coils are in this position the self-induction of the motor is small, because the entire magnetic flux cannot thread through all the turns of the primary coils, and also because currents
- 30 of opposite and counter inducing direction are flowing in the non-commutable and commutable secondary coils. A large current is therefore permitted to flow through the motor, producing a powerful torque always in
- 35 the same direction, because the non-commutable and commutable primaries in their effort to inclose the entire magnetic flux and thus obtain greater self-induction tend to move into alignment with each other, thus producing attraction; and the non-commutable and
- 40 commutable secondaries in their effort to avoid the magnetic flux and obtain positions of less or no self-induction tend to move out of alignment with the primary coils, and thus
- 45 produce repulsion, the commutable secondaries tending to move out of line with the non-commutable primaries, and the non-commutable secondaries tending to move out of line with the commutable primaries, but being
- 50 fixed, reacting against and repelling the commutable primaries.

It will thus be seen that all the coils jointly tend to produce motion in the direction of the arrow *p* until they reach the relative positions shown in Fig. 1^a, which is a diagram showing the fixed and movable magnetic systems *a* and *d* developed. In this position the non-commutable and commutable primary coils coincide in angular position with each other, and therefore the motor is producing no torque, but has the greatest possible self-induction, and only a small magnetizing-current in the primary coils is required to produce the necessary counter electromotive force, because the entire magnetic flux now threads

- 55
- 60
- 65

through all the turns of the primary coils, and

also because no currents are being induced in the secondary coils for the reason that they are being threaded in opposite directions by adjoining magnetic fluxes. When this position is reached the circuit through the commutable coils is again commutated, coils *ff* becoming primaries and coils *ee* becoming secondaries.

While the motor is being started and is accelerating in speed there is very little or no sparking at the moment of commutation, because even when the commutation happens to coincide with the highest point on the current-wave the sparking can only be slight, as there is during the commutating positions of the coils only a small magnetizing-current flowing through the motor, and when the commutation happens to coincide with the zero-point on the current-wave there is no sparking whatever.

When the motor is running at synchronism the commutation always coincides or nearly coincides with the zero or no-current point on the current-wave, and hence no sparking whatever is possible when running at synchronism.

It will be seen by comparing the position of magnetic fluxes *nn* in Fig. 1^a with those in Fig. 1 that the fluxes *nn* in Fig. 1^a have moved forward with relation to the non-commutable coils *bb* and *cc*, and that the commutable coils *ee* and *ff* have moved forward with relation to the fluxes *nn*. It is therefore obvious that all the non-commutable and commutable coils are subject to translation induction, or that induction resulting from the relative mechanical movement between the coils and fluxes *nn*, and also to self-induction, or that induction resulting from an increase and decrease of the magnetic fluxes *nn*.

The translation induction in all the primary coils is in the same direction as the self-induction and co-operates with or adds itself thereto, and they together oppose the flow of the primary current through the motor. It will thus be seen that the counter electromotive force in the primary coils is produced by combined and co-operating self and translation induction, and not by self-induction alone, as is the case in transformers.

The electromotive force of self-induction in each of the secondary coils has the same direction as in those of the primary coils to whose flux they are subject; but as the magnetic fluxes have in those positions where they are being cut by the secondary coils opposite directions to that where they are being cut by the primary coils, therefore the translation induction in the secondaries is opposite in direction to and opposes their self-induction. This fact makes it possible to place the secondary coils on short circuit, their self-induction and the currents due thereto being limited by their opposing translation induction, and thus the secondary coils are prevented from being destroyed by excessive current flow therethrough, as would be the

case in a transformer if its secondary coils were short-circuited, because no opposing translation induction is present therein.

To minimize self-induction the primary and secondary coils have their active or torque-producing parts which pass through the air-gap wound in parallel direction with each other, as shown in all the views. Referring to Fig. 1, which shows the relative positions of the coils just after the moment of commutation, and when producing the greatest torque, it will be seen that the commutable secondaries $f f$ coincide in angular position with the non-commutable primaries $b b$, and that the commutable primaries $e e$ coincide in angular position with the non-commutable secondaries $c c$, and as the induced currents in the secondaries are opposed in direction to and inductively counteract the currents in the primaries the self-induction in the primaries is minimized and a large current is permitted to flow through the motor-coils. The motor is, however, in no danger of being destroyed by excessive current flow there-through, as would be the case with a transformer if its secondary were short-circuited, because when running all the coils are when in these positions subject to translation induction, and thus the current flow therein is limited.

It will thus be seen that when the coils are in the relative positions shown in Fig. 1, and the self-induction is at its lowest, as above explained, then the translation induction in all the coils is at its highest, and the motor depends almost entirely upon translation induction for its counter electromotive force; but when the coils are in the relative positions shown in Fig. 1^a there is no translation induction in the primary coils and the motor depends altogether upon self-induction for its counter electromotive force. It is therefore obvious that while the motor is being started its counter electromotive force is small and inadequate, because its coils are then not subject to the full amount of translation induction and its normal self-induction alone is adequate only in the commutating positions of its coils. It is therefore desirable to temporarily increase the self-induction of the motor until partial or full speed has been reached and translation induction becomes available and adequate to limit the current flow. To attain this result the primary circuit only is closed while starting by moving the switches j and k until switch j closes against the extended contact-point j' , the secondary circuit being left open until partial or full speed has been reached. In this condition the motor has sufficiently augmented self-induction, due to the fact that the secondary coils are inoperative by reason of being open-circuited and the consequent absence of secondary currents therein, to prevent destructive current flow therethrough. Its torque is, however, directly proportional to the current flowing, as is the case in a di-

rect-current series motor, and several times the normal load can be started with the primary coils alone.

When partial or full speed has been reached and translation induction becomes available and adequate for limiting the current-flow through the coils, then the secondary circuit is closed by moving the switches j and k until switch k contacts with switch-terminal k' .

When the motor is intended to run in one direction only its coils are wound for minimum self-induction, as shown in Fig. 1^b, which is a diagram of a portion of the fixed magnetic system a and the movable magnetic system d developed. In Fig. 1^b the cross-hatched spaces $z z$ and black spaces $y y$ show the form of cross-section and the angular area of those portions of the motor-coils which are wound through the air-gap.

It will be seen that the non-commutable coils $b b$ and $c c$ are wound thickest at their front portions in the direction of arrow p , and the commutable coils $e e$ and $f f$ are wound thickest at their back portions. Therefore the centers of mass of coils $b b$ and $c c$ are situated forward in advance of their geometrical centers and the centers of mass of coils $e e$ and $f f$ are situated backward from their geometrical centers. It will thus be seen that any two co-operating primary coils $b b$ and $e e$ have their centers of mass farther removed from each other than have the two corresponding secondary coils $c c$ and $f f$.

It is a well-known fact that the ampere turns in the secondary coils of any inductive apparatus are nearly equal to those of the primary coils. It follows, therefore, that if the centers of mass of the secondary coils are placed closer together than the centers of mass of the primary coils, as is the case in Fig. 1^b, and the magnetic fluxes $n n$ are prevented from threading through all the turns of the coils by adjacent and opposing fluxes, then the secondary coils, although having a less number of ampere turns than the primary coils, but being more advantageously placed relatively to the magnetic fluxes, are nearly as effective as the primary coils, and thus the self-induction of the motor is greatly reduced. This method of winding can also be applied to Fig. 2, but in Fig. 3 can only be applied to the non-commutable coils, because the commutable coils do not move as a whole with relation to the non-commutable coils, but are progressively commutated by sections, as in direct-current machines.

When the motor is running at synchronism, its several sets of commutable coils are successively and alternately placed in the primary and secondary circuit synchronously with the current alternations, the sets of coils being commutated each time the current-wave reaches its zero-point. It follows, therefore, that a slower speed is obtained than has heretofore been realized with synchronizing motors.

When running at synchronism with a fre-

quency of eight thousand per minute, a six-pole motor having twelve commutable coils in two sets, as shown in Fig. 1, makes thirteen hundred and thirty-three and one-third turns per minute. The motor tends very strongly to maintain synchronism, and must be very much overloaded before it falls out of synchronism, which it immediately regains when the overload is reduced.

The motor can be run at variable speed by placing a variable inductive resistance in the primary circuit, thus supplying a portion of the counter electromotive force, which before had to be generated in the motor-coils, and thus permitting a reduced speed of the motor.

The motor can be reversed by reversing the circuit connections of either the non-commutable coils or the commutable coils.

In Fig. 2 all the coils are shown as drum-wound coils. Each coil consists of a single lap or crossing in the air-gap. The movable magnetic system d has four sets of coils. The two sets ee and $e'e'$ are for the time being in the primary circuit, and sets ff and $f'f'$ are in the secondary circuit. The commutator g has twenty-four segments connected in eight groups of three in each group. The several brushes each contact with two segments of the commutator, thus placing the two sets of commutable primary coils in parallel circuit relation with each other and in series with the non-commutable primary coils. Likewise the two sets of commutable secondary coils are in parallel circuit relation with each other and in series with the non-commutable secondary coils. It is obvious that at the moment of commutation but one set of primary and one set of secondary coils is commutated, the other set remaining in circuit. It follows from this that the circuit through the motor is never interrupted, as is the case in Fig. 1. This motor is therefore well adapted to be run at variable speed, because its demand on the supply-circuit is under these conditions more uniform than that of Fig. 1.

On a circuit having a current frequency of eight thousand per minute this motor will make six hundred and sixty-six and two-thirds turns per minute. To run this motor at variable speed an inductive resistance in the primary circuit must be used. Otherwise the motor tends very strongly to maintain synchronism.

It is obvious that if a still greater number of coils is placed on the movable magnetic system a still slower synchronizing speed can be obtained.

In Fig. 3 the fixed magnetic system a is shown wound with drum-wound coils b and c having each a single lap or crossing in the air-gap. The movable magnetic system is wound with a closed-circuit-ring winding. The commutator g is cross-connected, as shown by lines rr , thus requiring but a single pair of brushes h and h' . The brushes h and h' each cover an angle of the commutator equal to the secondary coils or sections, and

are adapted to individually short-circuit the commutable coils or sections to form secondaries, and they also form primary circuit-terminals for the movable magnetic system. The field secondaries are short-circuited on themselves, as shown at t .

In this motor the self-induction is constant and quite small, because the commutable primaries do not as a whole move into alignment with the non-commutable primaries, but are progressively commutated by sections as in direct-current machines. The motor therefore depends almost entirely upon translation induction for its counter electromotive force.

This motor does not synchronize, but will run at a nearly constant speed with variable load, regulating similar to a shunt-wound motor.

This motor is especially adapted for variable-speed work if a variable inductive resistance is placed in the primary circuit.

To start the motor it is necessary to use an inductive resistance u in the primary circuit, as otherwise the current flow would be too large, and the torque, which is directly proportional to the current, whether at rest or in motion, would be so great as to endanger the motor itself or the machinery with which it is connected. With small motors, however, having little inertia, and being therefore able to accelerate quickly in speed, the inductive resistance u may be dispensed with.

Having described my invention in detail, I will now briefly summarize its principal features and point out their advantages.

In practice the magnetic fluxes nn fill or permeate, when the coils are in their greatest torque positions, as shown in Figs. 1, 2, and 3, the entire circumference of the air-gap, thus both threading through and cutting across the primary and secondary coils, and therefore rendering every turn of wire on the motor active both in the production of magnetic fluxes nn and in the production of rotary effort or torque, the primary coils directly producing fluxes nn , and producing torque by reason of their attraction for each other, and the secondary coils, by reason of the contrary direction of currents therein, lowering the self-induction in the primary coils and thus permitting an increased current flow there-through, and so conducing to the production of fluxes nn , and also producing torque, by reason of their repulsion for the magnetic fluxes nn . The magnetic fluxes nn , being circular in form, are of the shortest possible length, and therefore require for their production the fewest possible ampère turns, thus obtaining the lowest possible self-induction and consuming the least possible magnetizing energy.

As the motor is adapted to work with a single current, and as all its primary coils can be placed in a single series, motors of quite small size can be directly connected to high-pressure mains, and pressure-reducing trans-

formers can be dispensed with, thus enhancing the efficiency of power transmission by the amount otherwise lost in the transformers, as well as saving the first cost and maintenance of transformers.

As the torque is directly proportional to the current flowing through the motor, whether the same is at rest or in motion, therefore the motor is self-starting from a state of rest with several times its normal load, and has a high electrical efficiency under all operative conditions.

As the self-induction of the motor is very small, owing to short-length magnetic circuits, the entire absence of magnetic leakage, and the consequent small number of ampere turns necessary to generate the magnetic fluxes, as well as to the inductive action between the parallel-disposed primary and secondary coils, therefore it is well adapted to be operated with higher current frequencies than have heretofore been used, and the output or weight efficiency is therefore very high.

Having now specifically described my invention, I desire to state that many modifications thereof are possible without departing from the spirit or essential principle of the invention, which consists in the employment of fixed and movable non-commutable and commutable primary and secondary coils having their active or torque-producing portions wound in parallel direction with each other and the method of and means for maintaining the commutable coils in torque-producing circuit relation with the non-commutable coils.

In the drawings and specification herewith I have shown and described what I believe to be the best organization of the elements of my invention, viz: a circular fixed magnetic system *a* without pole-pieces, wound with coils, and a movable magnetic system *d*, also of circular form and wound with coils, all of said coils being arranged where they pass through the air-gap at right angles both to the direction of rotation and to the direction of flow of the magnetic fluxes. It must be understood, however, that my invention can also be used with other magnetic structures.

What I therefore claim as my invention, and desire to secure by Letters Patent, is—

1. In an alternating current motor, a fixed magnetic system and a movable magnetic system, both having circularly arranged primary elements, and both also having circularly arranged secondary elements, a portion of said total number of elements being commutable, and a commutator for maintaining the commutable elements in effective or torque producing circuit relation with the non commutable elements, as set forth.

2. In an alternating current motor, a fixed magnetic system and a movable magnetic system, both having circularly arranged primary elements, and both also having circularly arranged secondary elements, one half

of said total number of elements being commutable, and a commutator for maintaining the commutable elements in effective or torque producing circuit relation with the non commutable elements, as set forth.

3. In an alternating current motor, a fixed magnetic system wound with wire having those of its portions which pass through the air gap disposed at substantially right angles both to the direction of rotation and to the direction of flow of the magnetic fluxes, and a movable magnetic system wound with wire having its air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said wire on said fixed magnetic system, alternate coils or sections of said wire on both the fixed and movable magnetic systems being placed in the primary circuit, and the alternate coils or sections between said primaries on both the fixed and movable magnetic systems being placed in the secondary circuit, the coils on one of said systems being commutable, and a commutator whereby the commutable coils are maintained in effective or torque producing circuit relation with the non-commutable coils, as set forth.

4. In an alternating current motor, a circular fixed magnetic system without pole pieces, and wound with equally spaced and angularly displaced primary and secondary coils alternating with each other, and having their air gap portions disposed at substantially right angles to the direction of rotation and to the direction of magnetic flow, in combination with a movable magnetic system wound with two or more sets of independent and angularly displaced sets of commutable coils, as set forth.

5. In an alternating current motor, a movable magnetic system wound with two or more independent sets of commutable coils, said sets of coils being angularly displaced from each other, and a commutator for placing said sets of coils in the primary circuit during positions of attraction, and in the secondary circuit during positions of repulsion, as set forth.

6. In an alternating current motor, a fixed magnetic system and a movable magnetic system, one of said systems being wound with non commutable coils having their air gap portions disposed at substantially right angles to the direction of rotation, and the other magnetic system being wound with commutable coils having their air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said non commutable coils on said other magnetic system, and a commutator for placing said commutable coils in the primary circuit during positions of attraction, and in the secondary circuit during positions of repulsion, as set forth.

7. In an alternating current motor, a fixed magnetic system and a movable magnetic sys-

tem, one of said systems being wound with non commutable coils having their air gap portions disposed at substantially right angles to the direction of rotation, and the other system being wound with two or more angularly displaced sets of commutable coils having their air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said non-commutable coils on said other magnetic system, and a commutator for placing said sets of commutable coils in the primary circuit in those positions of each revolution where their self induction is least, and their attractive torque is greatest, and to take them out of the primary circuit in those positions where their self induction is greatest, and their torque is *nil*, as set forth.

8. In an alternating current motor, a fixed magnetic system and a movable magnetic system, one of said systems being wound with angularly displaced non commutable primary and secondary coils having their air gap portions disposed at substantially right angles to the direction of rotation, and the other system being wound with commutable coils having their air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said non commutable coils on said other magnetic system, and a commutator for placing said commutable coils in the primary circuit during positions of attraction, and in the secondary circuit during positions of repulsion, as set forth.

9. In an alternating current motor, a fixed magnetic system and a movable magnetic system, one of said systems being wound with angularly displaced non commutable primary and secondary coils having their air gap portions disposed at substantially right angles to the direction of rotation, and the other system being wound with two or more angularly displaced sets of commutable coils having their air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said non commutable coils on said other magnetic system, and a commutator for placing said sets of commutable coils in the primary circuit in those positions of each revolution where their self induction is least, and their attractive torque is greatest, and to take them out of the primary circuit in those positions of each revolution

where their self induction is greatest and their torque is *nil*, as set forth.

10. In an alternating current motor, a fixed magnetic system and a movable magnetic system, one of said systems being wound with angularly displaced non commutable primary and secondary coils having their air gap portions disposed at substantially right angles to the direction of rotation, and the other magnetic system being wound with two or more angularly displaced sets of commutable coils having their air gap portions disposed in parallel direction with and in inductive relation to the air gap portions of said non commutable coils on said other magnetic system, and a commutator for placing said sets of commutable coils in the secondary circuit in those positions of each revolution where their self induction and repelling torque are greatest, and to take them out of the secondary circuit in those positions where their self induction and torque are *nil*, as set forth.

11. In a synchronizing alternating current motor, a movable magnetic system wound with two or more sets of commutable coils angularly displaced from each other, and a commutator for successively and alternately placing said sets of coils in the primary and secondary circuit synchronously with the current alternations, as set forth.

12. In an alternating current motor, a fixed magnetic system wound with coils whose centers of mass are displaced forward in the direction of rotation from their geometrical centers, as set forth.

13. In an alternating current motor, a movable magnetic system wound with coils whose centers of mass are displaced inversely to the direction of rotation from their geometrical centers, as set forth.

14. In alternating current motor, the combination with a fixed and a movable magnetic system, each of said magnetic systems having both primary and secondary coils thereon, of means for closing the circuit through said primary coils only while starting, and rendering the secondary coils inoperative until partial or full speed has been reached, as set forth.

ALBERT W. SMITH.

Witnesses:

H. N. JENKINS,

H. S. WETMORE.