C. MACMILLAN.

INDUCTION MOTOR.

APPLICATION FILED MAY 31, 1917.

1,356,936.

Patented Oct. 26, 1920.

5 SHEETS—SHEET 1.

Fig. 1.

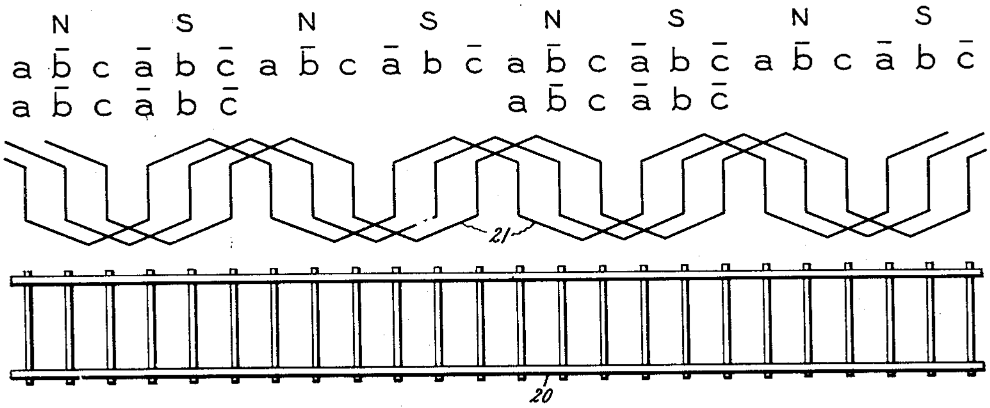


Fig. 5.

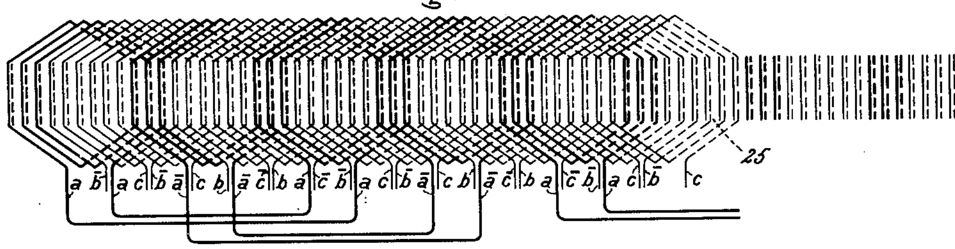
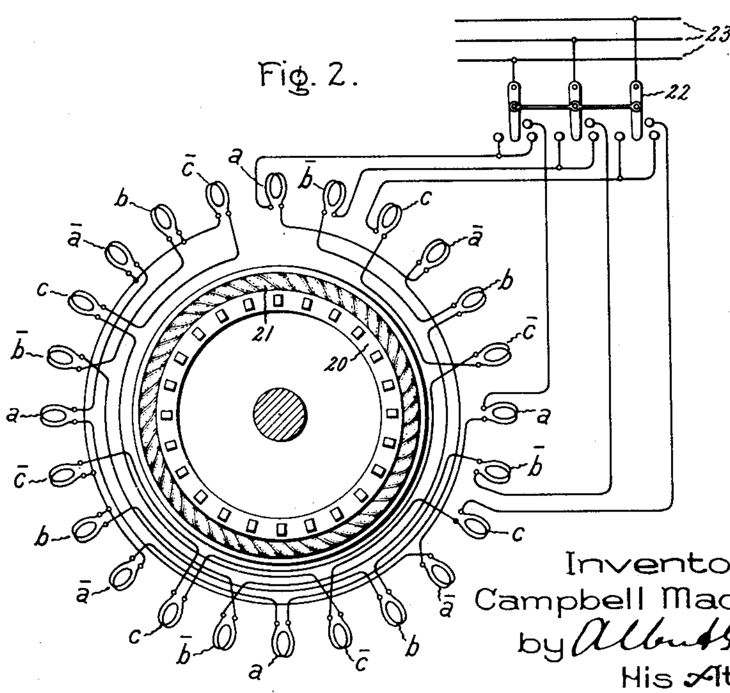


Fig. 2.



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5 SHEETS—SHEET 2.

Fig. 3.

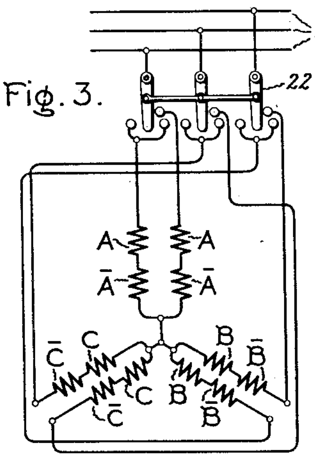


Fig. 4.

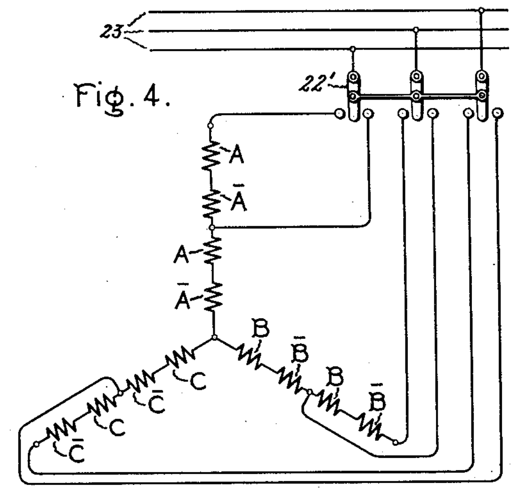
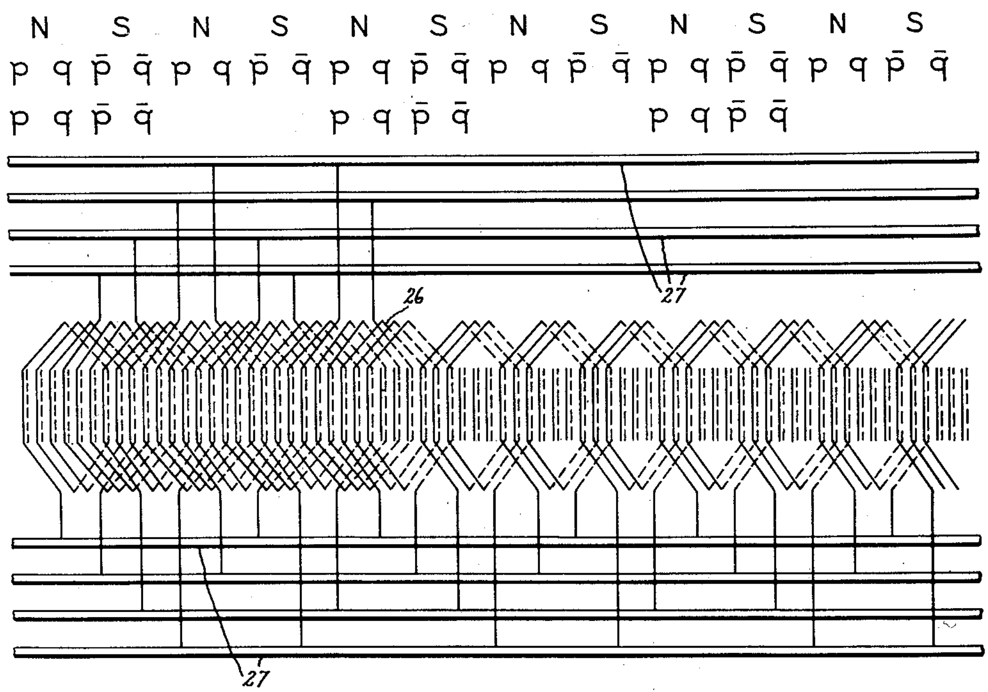


Fig. 6.



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5 SHEETS—SHEET 3.

Fig. 9.

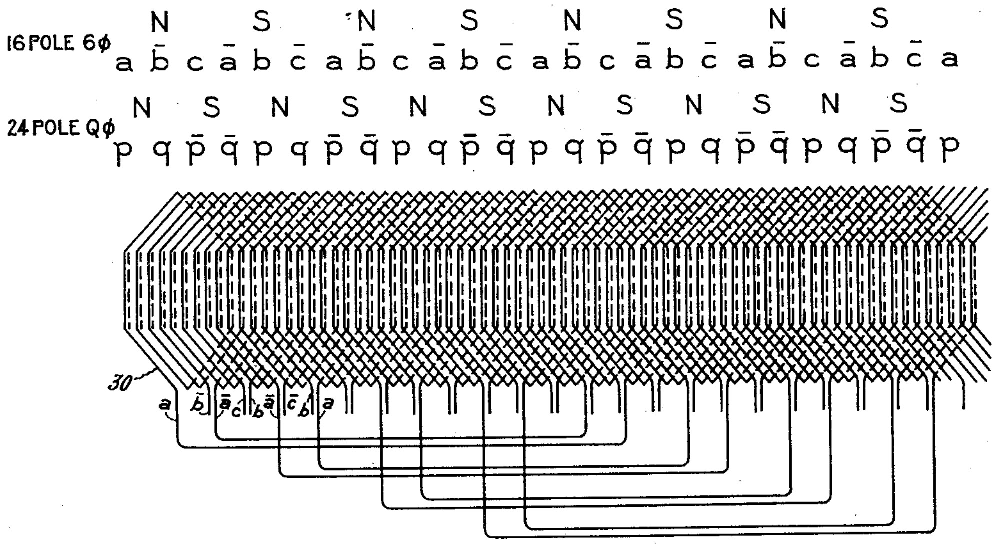
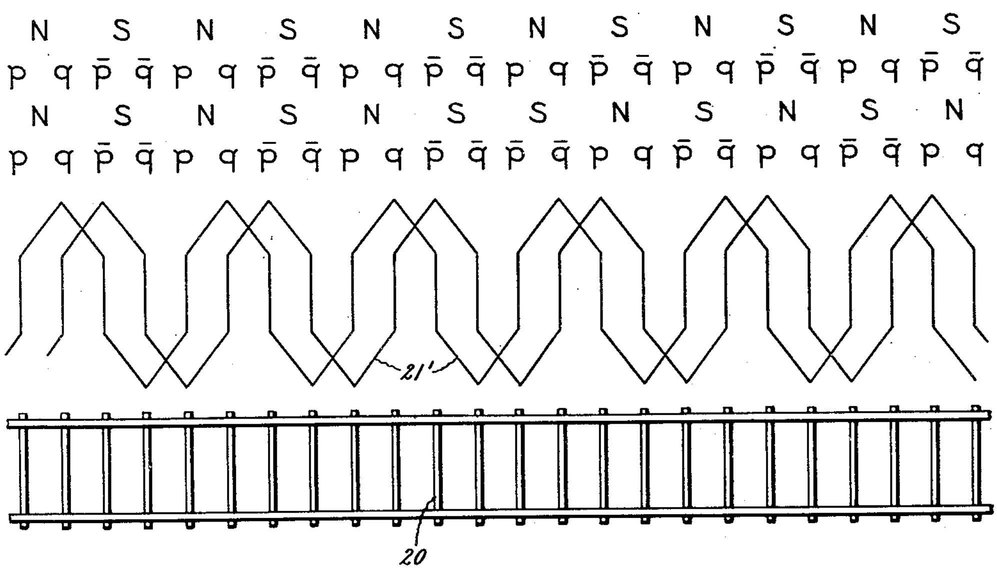


Fig. 7.



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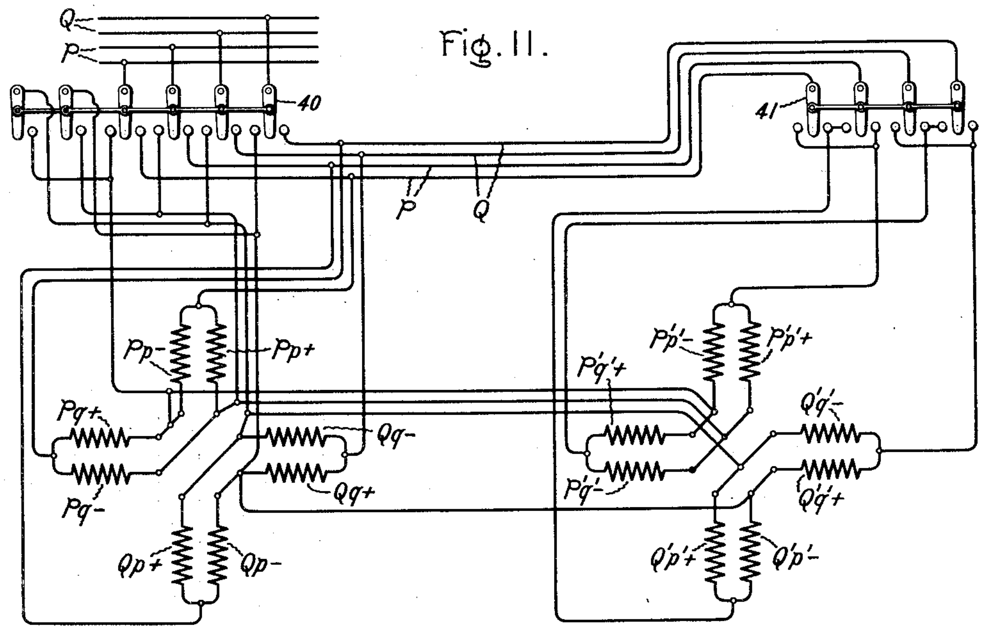

Fig. 11.

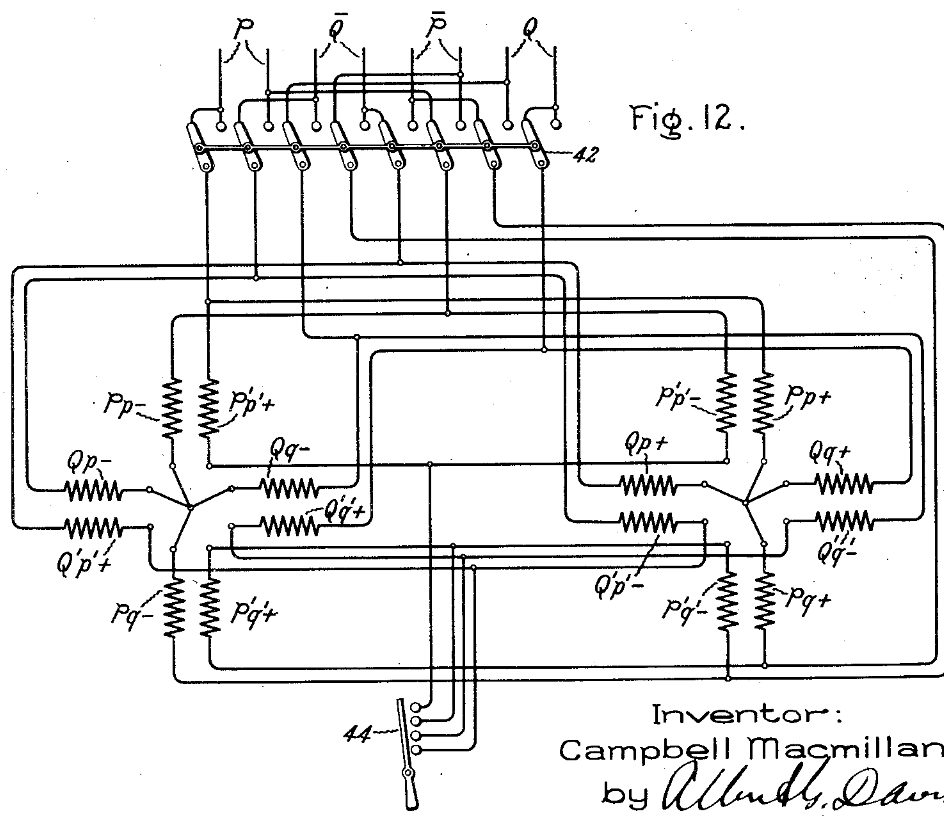

Fig. 12.

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5 SHEETS—SHEET 5.

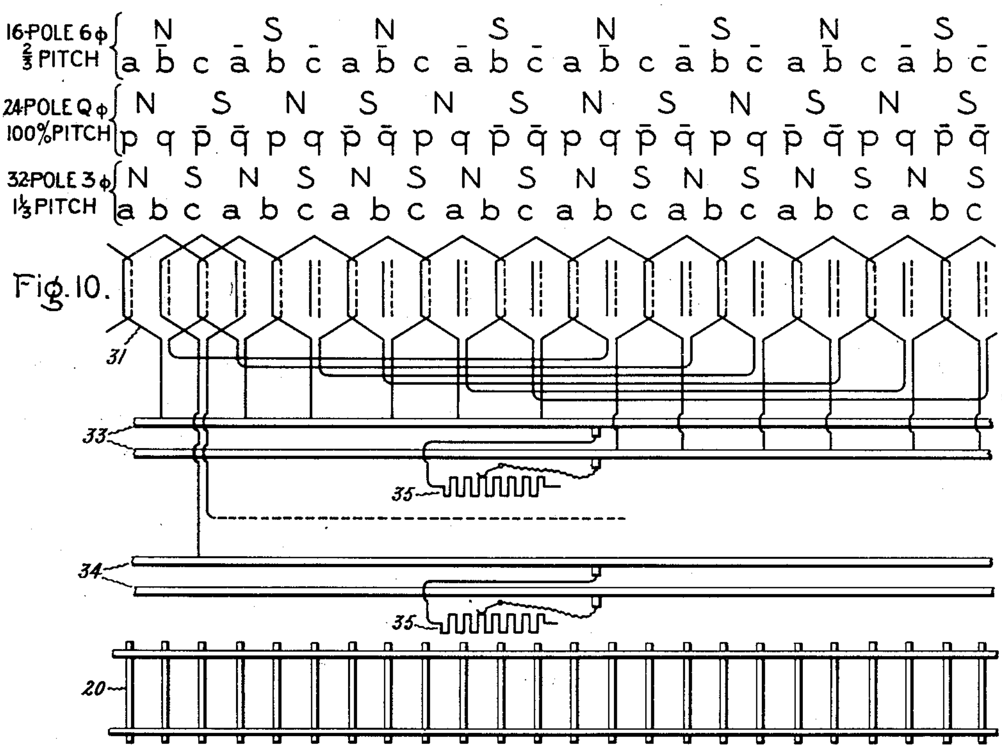


Fig. 10.

Fig. 8.

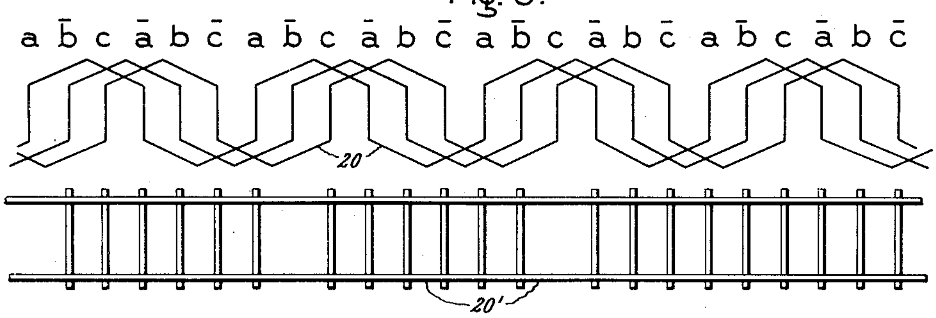
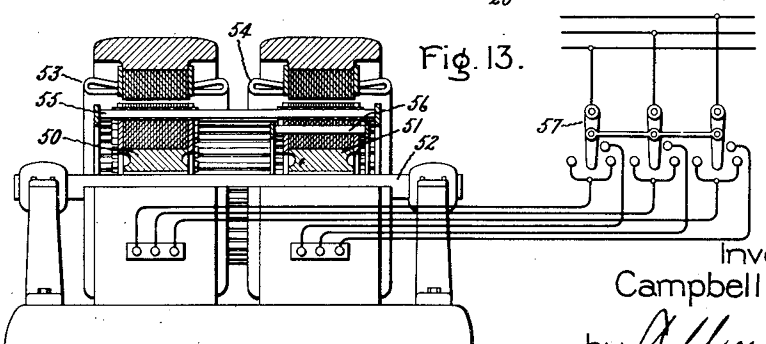


Fig. 13.



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UNITED STATES PATENT OFFICE.

CAMPBELL MACMILLAN, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INDUCTION-MOTOR.

1,356,936. Specification of Letters Patent. Patented Oct. 26, 1920.

Application filed May 31, 1917. Serial No. 171,917.

To all whom it may concern:

Be it known that I, CAMPBELL MACMILLAN, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Induction-Motors, of which the following is a specification.

My invention relates to induction motors and has for its object the provision of an induction motor having improved means for obtaining increased torque. The invention also relates to multi-speed induction motors and aims in this connection to provide simple and convenient means for obtaining increased torque for any pole number of the motor without interfering with the efficient operation of the motor under normal conditions. Other objects of the invention will be brought out in the course of the following description:

The ordinary polyphase induction motor with a low resistance secondary winding does not possess sufficient starting torque for many purposes. The particular object of the present invention is to provide improved means for conveniently increasing when necessary the starting torque of a polyphase induction motor without impairing its desirable operating characteristics under normal conditions. As is well understood in the art, the torque of an induction motor is most effectively modified by changing the effective resistance of the secondary circuit of the motor. However, while increased torque at starting can be obtained by increasing the effective resistance of the secondary circuit, still, for efficient operation at speeds near synchronism, the resistance of the secondary circuit should be relatively low, and, accordingly, the increase in the effective resistance of the secondary winding should be maintained only as long as the necessity for increased torque prevails. In carrying out my present invention, I provide means for increasing the effective resistance of the secondary circuit of an induction motor by a simple change in the connections of the primary winding, which change in connections can be conveniently made at starting or whenever increased torque is required without affecting the efficient operation of the motor under normal conditions when the primary winding is connected to produce a primary magnetic field of the usual type. The motor of my present invention therefore includes an improved secondary winding so constructed as to provide a path of relatively low effective resistance for a normal magnetic field and a path of relatively high effective resistance for an irregular primary magnetic field such as results when the connections of the primary winding are changed to obtain increased torque. The irregular primary magnetic field may be produced in various ways, but I prefer to obtain this result by disconnecting a part of the primary winding from the source of supply so that the resulting primary magnetic field consists of alternate active and inactive belts. Therefore, in the preferred form of the invention, the primary winding is divided into two components one of which is adapted to be independently disconnected from the source of supply thereby producing alternate active and inactive primary belts. The secondary winding is arranged so that the secondary currents induced by the alternate active belts of the primary winding are caused to flow through conductors of the secondary winding corresponding to inactive belts of the primary winding and thereby to induce by transformer action secondary currents in adjacent high resistance conductors of the secondary winding. The secondary winding is preferably a compound or double winding consisting of a low resistance winding comprising a plurality of closed circuits each of which includes in series relation one or more conductors influenced by active primary belts and one or more conductors under the influence of inactive primary belts and a high resistance winding having conductors inductively related to the conductors of the low resistance winding under the influence of inactive primary belts. The secondary currents induced in low resistance conductors by active primary belts are thus caused to flow by conduction through low resistance conductors under the influence of inactive primary belts and thereby induce by transformer action secondary currents in the inductively related high resistance conductors.

The novel features of my invention which I believe to be patentable are definitely set forth in the appended claims. The principles of the invention together with the practical embodiment of these principles will be best understood from the following description taken in conjunction with the accompanying drawings, in which several modifications and applications of the invention are illustrated, and in which;

Figure 1 is an explanatory diagrammatic view of a polyphase induction motor embodying the invention, Fig. 2 is a conventional diagram of the same motor; Figs. 3 and 4 are conventional diagrams of two modifications of the primary winding connections; Fig. 5 shows a modified type of the low resistance component of the secondary winding; Fig. 6 diagrammatically represents a quarter-phase induction motor embodying the invention and having a modified low resistance winding; Fig. 7 diagrammatically represents a motor in which the primary winding is changed or distorted by reversal in part instead of by open-circuiting sections or belts thereof; Fig. 8 illustrates a modification of the secondary winding; Figs. 9 and 10 illustrate the application of the invention to multi-polar motors; Figs. 11 and 12 illustrate the application of the invention to a quarter-phase motor having an eight-circuit primary winding arranged to be connected for two different pole members; and Fig. 13 illustrates the invention embodied in a motor combination having two separate motor units.

The fundamental principles of my invention will be best understood by reference to Fig. 1. The legends a, $\bar{b}$, c, $\bar{a}$, b and $\bar{c}$ at the top of the figure represent the six different phase-belts of an ordinary three-phase primary winding. The primary winding of the so-called three-phase induction motor is usually wound six-phase with six phase-belts or coil-sections per pair of poles. This result is obtained by providing per pair of poles two phase-belts in which the direction of current flow is relatively opposite or displaced in phase by 180 electrical degrees for each of the three phases of the source of supply. The currents in adjacent phase-belts are then displaced in phase by 60 electrical degrees, and the winding may be called a 60° six-phase primary winding. Such an 8-pole winding is diagrammatically represented by the first complete row of legends a, $\bar{b}$, c, $\bar{a}$, etc., of Fig. 1. Thus, a and $\bar{a}$ represent the phase-belts or coil-sections connected to phase A in which the currents are relatively opposite in direction of 180° out of phase, b and $\bar{b}$ represent the corresponding phase-belts connected to phase B, and c and $\bar{c}$ the corresponding phase-belts connected to phase C. All of the phase-belts of the same phase may be electrically connected together in any suitable manner, for example, in series, in parallel, or partly in series and partly in parallel, as will be understood by those skilled in the art. The first row of legends N, S, etc., of Fig. 1 designates the polar distribution of the primary winding.

The motor diagrammatically represented in Fig. 1 has a double or two-part secondary winding. One part or component of this secondary winding is a high resistance squirrel cage winding 20. The second part or component of the secondary winding is a low resistance multiple wave winding 21. The low resistance winding 21 has as many multiple circuits as there are slots per pole, and since in Fig. 1 I have shown only three slots per pole, the winding has only three multiple circuits. Each circuit is a wave winding including in series all bars or conductors which are similarly situated under successive poles.

In accordance with my present invention, the primary winding of the motor is so arranged that certain coils or circuits thereof may be independently connected to or disconnected from the source of supply in such a way as to leave alternate active and inactive or open belts. For example, all phase-belts of two adjacent poles may be active while all phase-belts of the succeeding pair of poles are idle. This condition I have diagrammatically represented by the last row of legends of Fig. 1. It will be noted that the primary winding over alternate pairs of poles is inactive, so that the active torque-producing portion of the primary winding consists only of the remaining alternate pairs of poles thereof. Under these circumstances, the active stator coils or conductors induce symmetrically disposed secondary currents which are of equal value under all active poles. Under idle or inactive poles, these currents will be opposed by impedance only, and will induce by transformer action substantially equal and opposite currents in the high resistance squirrel cage winding 20. In other words, these sections of the low resistance winding 21 which are located under inactive or open pairs of poles will act as the primary winding of a transformer, and the secondary currents flowing through such sections will induce currents in the adjacent conductors of the high resistance winding 20, which latter accordingly, acts as the secondary winding of the transformer. The high resistance winding 21 thus forms a material part of the active secondary circuit of the motor and the motor torque is correspondingly increased.

In Fig. 2 of the drawings, I have represented in a less diagrammatic way an induction motor embodying my present invention. This motor carries on its stator member a 60° six-phase primary winding of eight poles and the phase-belts are represented by the same letters as in Fig. 1. A switch 22 is arranged when thrown to its right-hand position to connect all of the coils of the primary winding to a three-phase source of supply 23, and when thrown to its left-hand position to connect only alternate pairs of poles to the source 23. The rotor of the motor carries the double secondary winding hereinbefore described comprising the high resistance component 20 and the low resistance component 21.

The primary winding is, therefore, in accordance with my present invention, divided into two sections or components in such a manner that when one section is disconnected from the source of supply the primary winding consists of alternate active and inactive belts or sections. For the sake of convenience, I shall hereinafter refer to that section of the primary winding which is always connected to the source as the basic component, while that section which is disconnected from the source for obtaining increased torque I will refer to as the disconnectible component. Similarly disposed coils or phase-belts may be electrically connected together in any suitable manner. In the motor represented in Fig. 2, the two similarly disposed phase-belts of each component winding are connected in series, while the groups of phase-belts differing in phase by 180 degrees are also connected in series. In other words, all of the phase-belts a and $\bar{a}$ of each component winding are connected in series, and so on for the other two phases of the primary winding.

The two components of the primary winding may be connected in parallel, or in series, or partly in series and partly in parallel. In Fig. 2, I have shown these two components connected in parallel. A different diagrammatic representation of the primary winding of this motor is shown in Fig. 3. Here, all of the individual phase-belts a of each component winding, connected together in series, in parallel, or in series-parallel, are represented by the winding A, all of the phase-belts $\bar{a}$ of each component winding are represented by the winding $\bar{A}$, and so on. The switch 22 in its right-hand position connects both components of the primary winding in parallel to the three-phase source of supply 23, and in its left-hand position connects only the basic component to the source. In Fig. 4, the two components of the primary winding are connected in series to the source when the switch 22′ is in its left-hand position, while only the basic component is connected to the source when the switch 22′ is in its right-hand position.

When the two component windings are connected in parallel, the same voltage is impressed on the basic component whether operating alone or in conjunction with the disconnectible component, whereas when the two component windings are connected in series a much higher voltage is impressed on the basic component when operating alone than when operating in conjunction with the disconnectible component. Any intermediate connection of the two component windings between straight series and straight parallel may of course be used.

The primary winding of an induction motor is usually a two layer lap winding. In such a winding each coil has two sides which are approximately 180 electrical degrees apart. When my present invention is applied to such a winding there will be intermediate spaces between the entirely active and entirely inactive belts in which one-half of the conductors per slot are active. The inclusion of the high resistance squirrel cage winding as a part of the secondary circuit by transformer action will be less effective beneath such sections than beneath entirely inactive sections. The net total effective result will, however, be the same as if the active and inactive sections were uniform and of just the width of a pair of poles, as will be clearly understood by those skilled in the art. While in the foregoing description of the invention I have assumed for the sake of clearness that the active and inactive belts of the primary winding were uniform, it will be well understood by those skilled in the art that my invention will usually be carried out with a two layer lap winding, in which event there will be intermediate spaces half active and half inactive as just described. It will further be seen that other distributions of the primary winding may be used, as for example, the proportion of active and inactive belts may be varied without preventing the formation of symmetrical groupings of all the coils, provided the total number of available circuits is sufficient.

The low resistance secondary winding may be divided into short sections, each end of which is connected to special end rings or to the end rings of the high resistance squirrel cage winding. In this way the maximum voltage of the secondary circuits may be limited. The low resistance secondary winding may also be a lap winding, and these modifications will be clearly understood by reference to Fig. 5 of the drawings. The winding 25 of this figure is to be considered as a substitute for the winding 21 of Fig. 1. Thus, the winding 25 coöperates with the high resistance squirrel cage winding 20 to form the double secondary winding for a primary winding of the character represented by the legends of Fig. 1. The winding 25 is the usual lap winding with two layers of conductors per slot assembled so that each coil has the conductors of one side in the top of a slot and the conductors of the other side in the bottom of a slot. In Fig. 5, the full lines indicate the top conductors and the dotted lines the bottom conductors. There are three slots per phase-belt of the primary winding and the three coils in these three slots are connected in series. The three series-connected coils of each phase-belt are connected in a local closed circuit with the three series-connected coils of the corresponding phase-belt of the next but one adjacent pole. The entire winding is thus composed of locally closed circuits, each consisting of six coils three of which are two poles removed from but otherwise correspond to the other three. The coils of the winding 25 beneath phase belts a and $\bar{a}$ are shown in heavier lines in Fig. 5 and only end connections for these coils are shown in order to better illustrate the principle of the arrangement. It will of course be understood that the coils beneath phase belts b and $\bar{b}$ and c and $\bar{c}$ are similarly connected to form short local circuits. When alternate pairs of poles of the primary winding are inactive or idle, it will be evident that each local circuit of the secondary winding 25 will be partly beneath an active section and partly beneath an inactive section, and, therefore, the high resistance secondary winding is effectively included by transformer action as a part of the secondary circuit of the motor.

As previously mentioned, the primary winding of the ordinary polyphase induction motor is generally a two-layer lap winding of the same type as the winding represented in Fig. 5. Diagrammatically the secondary winding 25 may thus be substantially a counterpart of the primary winding. The coils of the secondary winding 25 are, therefore, designated by the same legends as the corresponding phase-belts of the primary winding, the coils being designated by the legends of the primary phase-belts corresponding to the conductors in the top of the slots. If for the moment we assume that Fig. 5 represents the coils of a primary winding, it will be evident to those skilled in the art that the principles of the present invention may be applied to this winding by connecting the groups of coils in accordance with the corresponding diagram of Fig. 2. There will thus be obtained a two-layer lap winding arranged to produce a primary magnetic field of eight poles when supplied with three-phase electromotive force and embodying the principles of the present invention.

The conductor bars of the high resistance squirrel cage winding are preferably located in the same slots as the conductors of the low resistance winding. In Fig. 2, the conductor bars of the high resistance winding 20 are positioned in the bottom of the slots while the conductors of the wave winding 21 are positioned in the top of the slots. Where the winding 25 is substituted for the winding 21, the squirrel cage winding 20 preferably has as many conductor bars as there are rotor slots and there will then be three concentric rows or layers of conductors in the rotor slots.

In Fig. 6, I have illustrated my invention embodied in a quarter-phase induction motor. Reference letters p and $\bar{p}$ represent the phase-belts of the primary winding connected to phase P, and respectively 180 electrical degrees out of phase, while letter q and $\bar{q}$ represent the phase-belts of the primary winding connected to phase Q, also 180 electrical degrees out of phase with one another. In accordance with the present invention, this quarter-phase primary winding is divided into basic and disconnectible components, alternate pairs of poles being in the basic component, while the other alternate pairs of poles are in the disconnectible component. The short-circuited low resistance secondary winding 26 is of the same type as the winding 25 of Fig. 5. Instead of having a plurality of independent circuits as in winding 25, the winding 26 has all of its similar local circuits connected in parallel by four end rings or end-connections 27 at each end of the winding. In a quarter-phase winding of this type it will be evident that there are four different groups of local circuits. The first group includes the coils beneath phase belts p and $\bar{p}$ connected in series with similarly positioned coils beneath the next but one adjacent pair of poles. In other words, similarly positioned coils under the influence of active sections of the primary winding are connected to common end-connections while coils similarly positioned beneath corresponding parts of inactive or idle sections are connected in the reverse manner to the same common end-connections. It will of course be understood that a high resistance short-circuited secondary winding similar to the squirrel cage winding 20 will be used in conjunction with the low resistance winding 26. The pitch of the low resistance windings 21, 25 and 26 is in each case 100% or full pitch.

The improved double secondary winding of my present invention may be advantageously used in conjunction with primary windings in which an irregular or distorted primary magnetic field is obtained in other ways than by open-circuited alternate sections of the primary winding. In Fig. 7 of the drawings, I have shown how my improved secondary winding may be used in conjunction with a primary winding in which an irregular or distorted primary magnetic field is produced by reversing all phases of a particular section or component of the primary winding. The direction of the phase rotation of both components of the primary winding remains the same, because all phases of the distorting component are reversed, but the direction of current flow in the multiple circuits of a low resistance secondary winding embodying the principle of my present invention are reversed and the circuit for the secondary currents has a greater effective resistance. The first row of legends *p*, *q*, etc., represents such a primary winding under normal operating conditions, while the second row of legends *p*, *q*, etc., represents the primary winding distorted. The primary winding represented is normally a 12-pole quarter-phase winding. I distort this winding by reversing all phases of six consecutive poles thereof. The letters N and S above the two rows of legends *p*, *q*, etc., diagrammatically designate the polar distribution of the primary winding under normal conditions and when distorted. It will be observed that when one-half of the primary winding is reversed as represented in Fig. 7 substantially equal and opposite electromotive forces are induced in the multiple circuit low resistance winding 21′, and consequently all of the secondary current is forced to flow in the high resistance winding 20. The synchronous speed of the distorted primary winding will be somewhat different, usually higher, than the synchronous speed of the normal primary winding, because of the overlapping of the poles where the basic and distorted components of the primary winding join. It will be understood that less than half of the entire primary winding may be reversed, in which case more or less secondary current will flow in the low resistance secondary winding 21′.

The compound secondary winding of my present invention provides multiple circuits for the secondary currents, and in this respect is analogous to the double squirrel cage secondary winding in which one squirrel cage has low resistance and high inductance and the other high resistance and low inductance. A multiple circuit winding of the double squirrel cage type operates to flatten the top of the torque curve at maximum torque, thereby making the torque more uniform, or more nearly uniform, over a larger range of speed. This flattening of the torque curve is sometimes of advantage. The multiple circuit secondary winding of my present invention probably possesses this characteristic to a slight degree, but the characteristic can be emphasized by increasing the reactance of the low resistance winding, and this may be very effectively accomplished by omitting some of the high resistance squirrel cage conductor bars. The omission of a high resistance bar of the squirrel cage winding increases the reactance of the conductors of the low resistance winding occupying the same slot, and consequently increases the reactance of the circuit of which this conductor is a part. Preferably, the reactance of each multiple circuit of the low resistance winding is correspondingly increased by omitting one or more high resistance conductor bars for each multiple circuit. In order that the effective resistance of the secondary winding may not be so increased by the omission of high resistance conductor bars as to make the operation of the motor inefficient during the interval of operation at low slip prior to the restoration of the primary connections to normal, I prefer to increase the size of the high resistance conductor bars of the same series circuit in which one or more bars are omitted. This modification of the invention is illustrated in Fig. 8 of the drawings. The row of legends represents an 8-pole, six-phase primary winding having a basic component and a disconnectible component. The high resistance squirrel cage winding 20′ has three conductor bars omitted, one in each circuit corresponding to the three multiple circuits of the low resistance winding 21. Thus, the first conductor bar omitted is in the same slot as one of the conductors of phase-belt *a*, the second bar omitted is in the same slot as one of the conductors of phase-belt *b*, while the third omitted bar bears the same relation to phase-belt *c*. The symmetry of the winding is preserved as far as possible in omitting these three bars. The other bars of the squirrel cage winding are of slightly less resistance than if certain bars were not omitted. In this way one slot increases the reactance of the secondary circuit, by the omission of a high resistance conductor bar, while another slot reduces the resistance of the secondary circuit, by the substitution of a low resistance for a high resistance squirrel cage conductor bar. In this way the power factor of the circuit may be reduced without necessarily increasing its impedance if desired.

My present invention is adapted to be embodied in multi-speed induction motors. Such a motor is diagrammatically represented in Fig. 9 of the drawings, and the following description of this figure will indicate the manner of applying the invention to any multi-speed motor. The primary winding of the motor represented in Fig. 9 is adapted to be connected to a three-phase source of supply as a 16-pole winding, and to be connected to a quarter-phase source of supply as a 24-pole winding, as indicated by the legends at the top of the figure. An inspection of the legends will show that those coils which are similar in phase and direction of current flow for both pole numbers are four and six poles apart on the 16- and 24-pole windings, respectively. In applying the principle of the present invention to this primary winding, the basic and disconnectible components are four and six poles apart for the 16- and 24-pole numbers respectively, and, therefore, the active and inactive or idle sections of the primary winding embrace four and six poles for the 16- and 24-pole numbers, respectively. In other words, the basic component of the primary winding consists of alternate sections of four and six adjacent poles on the 16- and 24-pole arrangement, respectively, while the disconnectible component of the primary winding consists of the other alternate sections of four and six poles. The minimum number of poles for magnetic symmetry with such a combination of 4 and 6 poles is 16 and 24 poles.

In Fig. 9 of the drawings, I have shown a low resistance lap winding 30 embodying the principles of my present invention. The coils of this winding are connected to form a short-circuited secondary winding of low resistance for either the 16- or the 24-pole connection of the primary winding, and also to coöperate by transformer action with a high resistance secondary winding when alternate sections of four or six adjacent poles for either the 16- or 24-pole primary winding are inactive or idle. The coils beneath phase-belt a are connected in a closed circuit with coils similarly positioned beneath phase belt a, four poles removed with respect to the 16-pole arrangement. For the sake of clearness, only the circuits of the coils beneath phase-belts a and $\bar{a}$ are completed in Fig. 9, but it will be understood that the other coils of the winding are similarly connected in local short-circuits. It will also be understood that each local circuit may include more than two groups of coils. The high resistance squirrel cage winding to be used in conjunction with the low resistance winding 30 has been omitted in Fig. 9 in order to simplify the drawings. It will be noted that the pitch of the low resistance secondary winding 30 is 100% for the 16-pole arrangement of the primary winding and 150% for the 24-pole arrangement. If the secondary winding 30 is laid out as 100% of a full pitch winding with respect to 24 primary poles, it will be $66\frac{2}{3}\%$ of full pitch with respect to 27 primary poles. The pitch of the winding 30 should be selected to best meet the particular requirements of the case in hand.

An external resistance may be included in circuit with the low resistance secondary winding if desired. Such an arrangement is illustrated in Fig. 10 of the drawings. The primary winding of the motor diagrammatically represented in this figure is adapted to be connected for three different pole numbers as indicated by the legends. Thus, the winding can be connected to a three-phase source of supply as either a 16-pole winding or as a 32-pole winding, and to a quarter-phase source of supply as a 24-pole winding. The pitch at the left of the legend-diagrams indicates the pitch of the primary winding and also of the low resistance secondary winding 31 with respect to that particular polar arrangement of the primary winding. For the sake of clearness I have illustrated the winding 31 as having only one conductor per phase-belt, but in practice there will generally be a plurality of such conductors per phase belt. The primary winding of the motor as well as the secondary winding 31 are laid out with 100% pitch with respect to 24 primary poles, and, therefore, have a pitch of $66\frac{2}{3}\%$ and $133\frac{1}{3}\%$ with respect to 16 and 32 primary poles, respectively.

The coils of the winding 31 are connected to two sets of collector rings 33 and 34, so that with respect to 24 primary magnetic poles this secondary winding has twelve circuits connected in parallel between the collector rings 33, and similarly twelve circuits connected in parallel between the rings 34. For the sake of clearness, only the connections to the collector rings 33 have been fully indicated in the drawings. Every coil or group of coils beneath phase-belts p and $\bar{p}$ are connected in series to the similarly positioned coil or coils six poles removed with respect to the 24-pole arrangement, and the terminals of these series-connected coils or groups of coils are connected to the collector rings 33. The coils beneath phase-belts q and $\bar{q}$ are similarly connected to the collector rings 34. For the motor of 24 poles, there will, therefore, be twelve of these series-connected coils or groups of coils connected to each set of collector rings 33 and 34. The transformer action between the low resistance winding 31 and the high resistance squirrel cage winding 20 is obtained by open-circuiting alternate sections of the primary winding embracing six adjacent poles, just as described in connection with Fig. 9. It will be observed, however, that the winding 31 is effectively open-circuited for a primary magnetic field of 24 poles. This winding might, therefore, be entirely inactive for this polar arrangement, and all of the secondary current may then be forced to flow in the high resistance winding 20. Generally, however, it will be more desirable to provide external resistances 35 arranged to be connected between the collector rings 33 and 34, respectively, and thus to complete the circuits of the winding 31. The resistances 35 may be adjustable and when entirely cut out so as to short-circuit the rings 33 and 34, respectively, the winding becomes electrically equivalent to the winding illustrated in Fig. 9.

Although the winding 31 is effectively open-circuited for 24 poles, it is internally short-circuited for either 16 or 32 poles.

For the 16-pole arrangement, the coils beneath phase-belts a, b and c are connected to the collector rings 33 to form in effect a short-circuited star-connected winding and the coils beneath phase belts $\bar{a}$, $\bar{b}$ and $\bar{c}$ are similarly connected to the collector rings 34. For the 32-pole arrangement, the winding is similarly a short-circuited star-connected winding. The only difference between the short-circuits for the 16- and 32-pole arrangements is that for 32 poles the "p" and "q" circuits connected to the collector rings 33 and 34, respectively, carry currents in the same direction, while for 16 poles the currents in these "p" and "q" circuits are 180 electrical degrees apart. In addition to permitting a connection to an external resistance for the 24-pole arrangement, this winding has a simpler system of end-connections consisting of involutes spanning groups 4, 6 or 8 poles with respect to the 16-, 24-, or 32-pole arrangement.

The application of my present invention to a multi-speed motor of the type described in the copending application of Ernst F. W. Alexanderson, Ser. No. 67,387, filed December 17, 1915, patented April 23, 1918, No. 1,263,992, is illustrated in Figs. 11 and 12. The Alexanderson motor represented in these figures has a quarter-phase primary winding consisting of eight circuits. These eight circuits normally have one of their two terminals connected to a common neutral, while their other eight terminals are connected to a suitable switch for altering the connections of the circuits to the quarter-phase source of supply in order to obtain two different pole numbers. The eight circuits of the primary winding are designated Pp+, Pp—, Qq+, Qq—, Pq+, Pq—, Qp+ and Qp—. The capital letters designate the phase in which the circuits are connected for one pole number, while the small letters designate the phase in which the circuits are connected for the other pole number. Letters P and p represent phase I, while letter Q and q represent phase II. The circuits having a positive (+) sign have the same relative terminal connections with respect to the direction of current flow in both polar arrangements, while the circuits having the negative sign (—) have their terminal connections relatively reversed in the two polar arrangements. Each circuit of the primary winding is divided into two parts so as to form the basic and disconnectible components of my present invention. I have designated the disconnectible components in both Figs. 11 and 12 by prime marks (′).

Referring now particularly to Fig. 11, I will take a general case of an n- and m-pole motor. The capital letters will be taken to represent the connections for n poles, and the small letters the connections for m poles. The circuits are vectorially arranged in Fig. 11 for the m-pole connection. A source of quarter-phase current supply is designated by the four conductors marked P and Q. The primary winding has a circuit-controlling device consisting of two switches 40 and 41. The last two blades on the left end of switch 40 constitute a neutral-closing switch for the n-pole connection. I shall call the switch 40 the main switch, and the switch 41 the maneuvering switch. When the main switch 40 is in its left-hand position both the basic and disconnectible components of the primary winding are connected to the source P—Q as an n-pole winding. When the main switch 40 is thrown to its right-hand position, the basic component of the primary winding is connected to the source as an m-pole winding, and the disconnectible component is connected to coöperate therewith when the switch 41 is in its left-hand position. If the switch 41 is now thrown to its "off" position, the disconnectible component of the primary winding will be inactive or idle, while if the switch 41 is thrown to its right-hand position, the disconnectible component of the primary winding will be reversed with respect to the basic component, substantially as explained in connection with Fig. 7. It will of course be understood that a suitable compound or two-part secondary winding of the general character previously described will be provided for the motor represented in this figure.

A somewhat simpler circuit-controlling mechanism can be used in the arrangement shown in Fig. 12. Each phase of the source of supply is represented by two positive terminals P and Q and two negative terminals P and Q. When the main switch 42 is thrown to its left-hand position, both the basic and disconnectible components of the primary winding are connected to the source as an n-pole winding. When the switch 42 is thrown to its right-hand position, the circuits Pp—, Pp+, Qq—, Qq+, Qp+, Qp—, Pq+ and Pq— of the basic component are alone connected to the source so as to form complete circuits and carry currents and these circuits will produce a primary magnetic field equivalent to m poles. The circuits P′p′—, P′p′+, Q′ q′—, Q′q′+, Q′p′+, Q′p′—, P′q′+, and P′q′— of the disconnectible component are in effect open-circuited. When the auxiliary switch 44 is now closed a neutral is provided for the circuits of the disconnectible component and the machine will then operate as a normal m-pole motor.

The manner of distributing the coils of the primary winding of the Alexanderson eight-circuit motor, or in fact of any motor, into the basic and disconnectible components will, it is believed, be understood from the foregoing description. The polar width of the alternate active and idle belts or sections of the primary winding will first be determined by the ratio of the different pole numbers, n, m, etc., for which the primary winding is to be connected. In the case of the eight-circuit motor of Figs. 11 and 12, and generally in the case of other motors, all of the coils in active sections undergoing the same electrical change in passing from one pole number to the other will be grouped to form the circuits $Pp+$, $Pp-$, etc, of the basic component, while all of the coils in inactive or idle sections undergoing the same electrical change in changing pole numbers will be grouped to form the circuits $P'p'+$, $P'p'-$, etc. It is believed that the design of a suitable low resistance secondary winding for the motors of Figs. 11 and 12 will be obvious in view of the foregoing explanations. It will be seen that these motors may operate as normal high efficiency induction motors for both pole numbers n and m, but that a secondary winding of high effective resistance may be provided for the m-pole connection by distorting the primary winding in accordance with the principles of my present invention.

In Fig. 13 of the drawings, I have illustrated a double or two-part motor combination embodying the principle of the present invention. The combination includes two rotor cores 50 and 51 mounted on a common shaft 52. Polyphase primary windings 53 and 54 are electrically associated with the rotors 50 and 51, respectively. The secondary winding is a duplex winding consisting of a low resistance squirrel cage winding 55 common to both primary windings 53 and 54 and a high resistance squirrel cage winding 56 mounted on the rotor 51. The primary winding 54 is the disconnectible component of the motor combination, and a switch 57, corresponding to the switch 22 of Figs. 2 and 3, is provided for connecting the two primary windings 53 and 54 in parallel to the source or for connecting only the primary winding 53 to the source. When the primary winding 53 is alone connected to the source, the electromotive forces induced in the bars of the common squirrel cage winding 55 cause currents to circulate therethrough. In the slots of the rotor core 51 the long bars of this winding are lying side by side with the short bars of the independent high resistance squirrel cage winding 56 which latter consequently acts as the short-circuited secondary winding of a transformer and carries a current equivalent to its transformer primary current. In such a 1:1 ratio transformer, resistance in the secondary is exactly equivalent to resistance in the primary. Let R_1 and R_2 represent the relative resistances of the two squirrel-cage windings in one rotor, where R_1 refers to the winding 55 and R_2 to the independent winding 56. Then the total resistance of the winding 55 in both motor units is $2R_1$. By the 1:1 ratio transformer action in the rotor core 51, the independent squirrel-cage winding 56 is virtually connected in series with the winding 55. Therefore, the total virtual resistance of the secondary winding relatively to the active motor unit is $2R_1+R_2$.

The magnetizing current for the transformer formed by the secondary windings of the disconnected motor unit in the apparatus of Fig. 13 will be drawn from the source of supply as an additional wattless current, but at the reduced voltage required for starting, the sum of the two magnetizing currents relatively to the energy currents at starting will not be at all excessive. The operation of the apparatus with the primary winding of one motor unit unexcited is particularly favorable for the condition encountered when relatively large amounts of heat are generated. Both rotor cores are in this case available for the storage and dissipation of heat. By such efficient transformer action between the secondary conductors of the unexcited motor unit a considerable amount of electrical energy is transferred to the high resistance secondary winding of the unexcited motor unit, where the thermal and mechanical conditions are most favorable for the storage and dissipation of the heat into which this energy is converted. The effective resistance of the secondary winding is thus increased and its power of energy dissipation is also increased without varying its electrical connections.

I have herein shown and particularly described certain embodiments of my invention for the purpose of explaining its principles and showing its applications, but numerous modifications of the details of construction and arrangement of these embodiments and other applications will present themselves to those skilled in the art. I, therefore, wish to cover by the following claims all modifications within the spirit of the invention.

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

1. An induction motor having a polyphase primary winding arranged in two components such that a normal primary magnetic field is produced when the two components act in conjunction and an irregular primary magnetic field is produced when the electrical connections of one of the components undergo a predetermined change, a low resistance secondary winding having conductors corresponding to both components of the primary winding included in the same series circuit, and a high resistance secondary winding having conductors inductively related to conductors of

the low resistance winding corresponding to the irregular field-producing component of the primary winding.

2. An induction motor having a polyphase primary winding divided into two components one of which is adapted to be disconnected from the source of energy supply thereby producing alternate active and idle primary belts, a low resistance secondary winding having conductors corresponding to both active and idle belts of the primary winding included in the same series circuit, and a high resistance secondary winding having conductors inductively related to conductors of the low resistance winding corresponding to idle belts of the primary winding.

3. An induction motor having a polyphase primary winding arranged in two components such that a normal primary magnetic field is produced when the two components act in conjunction and an irregular primary magnetic field is produced when the electrical connections of one of the components undergo a predetermined change, a low resistance secondary winding having a plurality of closed series circuits inductively related to both components of said primary winding, and a high resistance short-circuited secondary winding.

4. An induction motor having a two-part primary winding, a low resistance secondary winding common to both parts of said primary winding, means for electrically disconnecting one part of said primary winding from the source of energy supply while the other part of the primary winding is connected to such source, and a high resistance secondary winding adapted to be included by transformer action between said secondary windings as a part of the effective secondary circuit of the motor when only one part of the primary winding is connected to the source of supply.

5. An induction motor having a two-part primary winding, a low resistance secondary winding having a plurality of closed series circuits including conductors which are inductively related to both parts of said primary winding, means for electrically disconnecting one part of said primary winding so that only the other part of the primary winding is connected to produce a magnetic field, and a high resistance squirrel cage secondary winding adapted to be included by transformer action between said secondary windings as a part of the effective secondary circuit of the motor when only one part of the primary winding is connected to produce a magnetic field.

6. An induction motor having a polyphase primary winding of two components which coöperate when acting together to produce a normal polyphase primary magnetic field, means for changing the electrical connections of one component of said primary winding so that the resulting magnetic field produced by the entire primary winding is irregular, and a secondary winding including a high resistance component and a low resistance component inductively related to said primary winding, the components of said secondary winding being so arranged that a relatively greater proportion of the total secondary current flows in the high resistance component when said primary winding produces an irregular magnetic field than when the primary winding produces a normal magnetic field.

7. An induction motor having a polyphase primary winding of two components, said components being adapted to act together to produce a normal polyphase primary magnetic field when both components are electrically connected to a source of energy supply, means for electrically disconnecting one of said components from the source of supply so that the primary magnetic field of the motor is produced by the other component acting alone, a low resistance secondary winding having a plurality of closed series circuits including one or more conductors inductively related to each component of said primary winding, and a high resistance secondary winding arranged to be included by transformer action between said secondary windings as a part of the effective secondary circuit of the motor when only one component of the primary winding is electrically active, the connections of said high resistance winding being identical for both connections of said primary winding.

8. An induction motor having a polyphase primary winding of two components adapted to act together to produce a normal polyphase primary magnetic field, each component of said primary winding consisting of alternate sections embracing one or more pairs of primary magnetic poles, a low resistance secondary winding having closed circuits including in series relation one or more conductors inductively related to each component of said primary winding, means for electrically disconnecting one component of said primary winding so that the primary magnetic field of the motor is produced by the other component acting alone whereby secondary current is induced in at least one of the conductors of each closed secondary circuit and flows by conduction through at least one conductor of the same circuit, and a secondary winding having high resistance conductors inductively related to the low resistance conductors through which secondary current flows by conduction when one component of the primary winding is inactive.

9. An induction motor having a polyphase primary winding of two components

one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that when only one component is connected to the source of supply the primary winding of the motor consists of active belts alternating with inactive belts, each of said active and inactive belts embracing one or more pairs of poles, a low resistance secondary winding having a plurality of series circuits including two or more conductors similarly situated under said active and inactive belts of the primary winding, and a high resistance secondary winding having conductors inductively related to low resistance conductors situated under inactive belts of the primary winding.

10. An induction motor having a polyphase primary winding arranged to be connected so as to produce a plurality of primary magnetic fields of different pole numbers, said primary winding comprising two components one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that when only one component is connected to the source of supply the primary winding of the motor consists of active belts alternating with inactive belts, each of said active and inactive belts embracing one or more pairs of poles for any polar arrangements for which said primary winding is arranged to be connected, a low resistance secondary winding having a plurality of series circuits including two or more conductors similarly situated under active and inactive belts of the primary winding for any polar arrangement for which said primary winding is arranged to be connected, and a high resistance secondary winding having conductors inductively related to low resistance conductors situated under inactive belts of the primary winding.

11. A multi-speed induction motor having a primary winding, means for connecting said winding as an n-pole six-phase primary winding and as a $\frac{3n}{2}$-pole quarter-phase primary winding and as a $2n$-pole three-phase primary winding, said primary winding being divided into two components one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that a normal primary magnetic field is produced when the two components act in conjunction and an irregular primary magnetic field is produced when only one component is connected to the source of supply, a low resistance secondary winding having conductors corresponding to both components of the primary winding included in the same series circuit, and a high resistance secondary winding inductively related to the low resistance secondary winding and adapted to be included by transformer action between said secondary windings as a part of the effective secondary circuit of the motor when said primary winding produces an irregular primary magnetic field.

12. A multi-speed induction motor having a primary winding adapted to be connected as an n-pole six-phase winding and as a $\frac{3n}{2}$-pole quarter-phase winding and as a $2n$-pole three-phase winding, said primary winding being divided into two components one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that when only one component is connected to the source of supply the primary winding of the motor consists of uniform active belts alternating with uniform inactive belts, each of said uniform active and inactive belts embracing one or more pairs of poles for any one of the polar arrangements for which said primary winding is adapted to be connected, a low resistance secondary winding having a plurality of series circuits including two or more conductors similarly situated under active and inactive belts of the primary winding for any one of the polar arrangements for which said primary winding is adapted to be connected, and a high resistance secondary winding having conductors inductively related to low resistance conductors situated under inactive belts of the primary winding.

13. An induction motor having a polyphase primary winding arranged to be connected so as to produce a plurality of primary magnetic fields of different pole numbers, said primary winding comprising a plurality of circuits each of which contains conductors which carry current relatively in the same way when the primary winding is connected for any of the pole numbers for which it is arranged, said primary winding being divided into two components one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that when only one component is connected to the source of supply the primary winding is arranged to produce a primary magnetic field consisting of alternate active and inactive belts embracing one or more pairs of poles for any polar arrangement for which the primary winding is adapted to be connected, a low resistance secondary winding comprising a plurality of closed circuits each of which includes in series relation one or more conductors influenced by active primary belts and one or more conductors under the influence of inactive primary belts for any of said polar

arrangements of the primary winding, and a high resistance secondary winding having conductors inductively related to said conductors under the influence of inactive primary belts.

14. An induction motor having a primary winding arranged in two components one of which is adapted to be independently connected and disconnected from the source of energy supply, said components being so arranged that when only one component is connected to the source of supply the primary winding is arranged to produce a primary magnetic field consisting of alternate active and inactive belts embracing one or more pairs of poles, a low resistance secondary winding comprising a plurality of closed circuits each of which includes in series relation one or more conductors influenced by active primary belts and one or more conductors under the influence of inactive primary belts, and a high resistance secondary winding having conductors in the same slots with said conductors under the influence of inactive primary belts.

15. An induction motor comprising a two part primary winding, a low resistance secondary winding common to both parts of said primary winding, said primary and secondary windings being arranged for relative rotation, means whereby a predetermined change may be made in the electrical connections of one part of said primary winding, and a high resistance winding mechanically fixed with respect to said low resistance secondary winding arranged in inductive relation to conductors of said low resistance secondary winding.

In witness whereof I have hereunto set my hand this 29th day of May, 1917.

CAMPBELL MACMILLAN.