INDUCTION VOLTAGE REGULATOR

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This invention relates to electrical inductive apparatus and more particularly to induction voltage regulators.

A conventional induction voltage regulator comprises a primary winding disposed on a rotor member whose position can be varied with respect to an associated secondary winding disposed on a stationary stator core. The primary winding of the induction regulator is normally connected in parallel with an input circuit whose alternating current voltage is to be controlled or regulated and the secondary winding is normally connected in series with the output circuit of the regulator in order to introduce a voltage component which is either additive or opposing with respect to the input voltage of the regulator.

The construction of a conventional induction regulator and the means which have been employed in the past for controlling its operation have several important disadvantages. For example, in order to reduce the voltage drop introduced by a conventional induction regulator when the regulator is in the neutral position and the mutual inductance between the primary and secondary windings is at a minimum, a tertiary winding is provided on the rotor member which is short-circuited to reduce the effective impedance of the secondary winding of the regulator in the latter position. In addition, in a conventional induction regulator, it is well known that a vibratory torque of twice the frequency of the alternating current being carried by the regulator is developed in the rotor member of the regulator and may be transmitted to the stationary parts of the regulator to produce an objectionable or undesirable noise level.

It is therefore desirable to provide an improved construction for an induction voltage regulator and an improved means for controlling the operation thereof which either reduces, or substantially eliminates the above disadvantages and provides several other advantages.

It is an object of this invention to provide a new and improved induction voltage regulator.

Another object of the invention is to provide a new and improved means for controlling the operation of an induction voltage regulator.

A further object of this invention is to provide an improved induction regulator having primary and secondary windings in which the impedance of the secondary winding is reduced when the regulator is in the neutral position and which does not require the use of a tertiary winding.

A still further object of this invention is to provide an improved induction regulator in which the sound level is reduced.

A more specific object of the invention is to provide an improved bearing arrangement for induction voltage regulators.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings, in which:

FIGURE 1 is a diagrammatic view illustrating the manner in which an induction regulator of the type disclosed may be mounted and interconnected with an associated source of alternating current, such as a distribution transformer, in an electrical distribution system.

FIGURE 2 is a top plan view of the induction regulator shown in FIGURE 1 with the cover removed and certain other parts either partially shown or omitted.

FIGURE 3 is a front elevational view partly in section of the induction regulator shown in FIGURES 1 and 2.

FIGURE 4 is a partial side elevational view, partly in section, of the induction regulator shown in FIGURES 1 through 3 illustrating the details of construction of the rotor member of said regulator.

FIGURE 5 is a partial bottom plan view of the induction regulator shown in FIGURE 4, illustrating the manner in which the rotor member is driven by the associated driving means.

FIGURES 6 through 9 illustrate different bearing arrangements which may be employed with the induction regulator shown in FIGURES 1 to 5.

FIGURES 10 through 12 illustrate the construction of a conventional limit switch which may be employed with the induction regulator shown in FIGURES 1 through 5.

FIGURES 13 and 14 are diagrammatic views illustrating the principles of operation of the induction regulator shown in FIGURES 1 through 5 for different operating positions of the rotor member thereof.

FIGURE 15 is a set of curves illustrating the different voltages which result in the secondary winding of the induction regulator shown in FIGURES 1 through 5 for different operating positions of the rotor member thereof.

FIGURE 16 is an overall diagrammatic view illustrating the connection of the induction regulator shown in FIGURES 1 through 5, with the associated distribution transformer and with its associated control circuit or equipment.

Referring now to the drawings and FIGURES 1 and 16, in particular, there is illustrated an induction voltage regulator 30 which may be conveniently utilized with an associated source of alternating current, such as the distribution transformer 20, in an electrical power system or distribution system. In this instance, the induction regulator 30 is shown mounted adjacent to the associated distribution transformer 20 on a common utility pole 29 and interconnected therewith in order to maintain the voltage supplied to a load circuit by the distribution transformer 20 at substantially a predetermined value or within a substantially predetermined operating range. The transformer 20 may be of any conventional type and may include a primary or high voltage winding 21 and a secondary or low voltage winding 31, as shown schematically in FIGURE 16. The primary or high voltage terminals 22 and 23 at the ends of the primary winding 21 of the transformer 20 may be connected to an associated electrical power system or source of alternating current voltage (not shown), while the secondary or low voltage terminals 24 and 26 at the ends of the secondary winding 31 of the transformer 21 are connected to the input terminals 32 and 34, respectively, of the induction regulator 30, as shown in FIGURES 1 and 16. The mid-point or mid-tap of the secondary winding 31 of the transformer 20 is illustrated as being connected to a ground connection, as indicated at 27. The output terminals 36 and 38 of the induction regulator 30 are connected to a load circuit, as indicated at the load conductors L1 and L2, respectively. For three-wire operation of the latter load circuit, a third load conductor L3 may optionally be connected to the ground connection or neutral terminal 27 of the transformer 20.

In general, the induction voltage regulator 30 comprises a primary winding 37, which is disposed on an associated rotor member 39, and a secondary winding 35, which comprises the first and second secondary winding sections or coils 38A and 38B, respectively, and which is disposed on...
an associated stationary stator core which will be described in detail hereinafter. The primary winding 37 is connected across or in parallel with the input terminals 32 and 34 of the regulator 30 by the flexible leads 43. The first secondary winding section 35A is connected in series circuit relationship with the load conductor L1 between the terminals 32 and 36 of the regulator 30 by the leads S1 and S3, respectively, while the second secondary winding section of coil 35B is connected in series circuit relationship with the load conductor L2 between the terminals 34 and 38 of the regulator 30 by the leads or conductors S2 and S4, respectively, in order to permit substantially balanced regulation of the voltage of a three-wire load circuit when the induction regulator 30 is applied on a system of that type. The relative positions of the primary and secondary windings 37 and 35, respectively, is varied by energizing either the first or second drive motors 60 and 70, respectively, which are mechanically coupled to the rotor member 39 by the mechanical linkage indicated generally at ML in FIGURE 16. The energization of the drive motors 60 and 70, which may be of any conventional type, such as the shaded pole type, and which include the main windings 62 and 72, respectively, is controlled, in turn, in response to the output voltage of the induction regulator 30 at the terminals 36 and 38 by the control circuit or means 40, which is connected in circuit relation with the drive motors 60 and 70 through the disconnect plug member 80, as shown in FIGURE 16. In order to provide the necessary electrical energy for the operation of the drive motors 60 and 70, which are arranged to rotate the rotor member 39 in opposite directions and to provide a voltage signal to the control circuit 40 which is proportional to or varies with the output voltage of the induction regulator 30 at the terminals 36 and 38, the transformer 50 is connected in circuit relation with said regulator. In particular, the transformer 50 comprises, in this instance, a primary winding 52 which is connected across the output terminals 36 and 38 of the regulator 30 at the load conductors L1 and L2, respectively, the first and second secondary windings 54 and 56, respectively, which are connected in circuit relation with the drive motors 60 and 70, respectively, and a third secondary winding 58 which is connected in circuit relation with the control circuit 40 through the disconnect plug member 80 to supply a voltage sensing signal to said control circuit.

In the event of the failure of the rotor member 39 when either the drive motor 60 or the drive motor 70 is energized by the control circuit 40 from the secondary windings 54 or 56, respectively, of the transformer 50, the first and second limit switches 51 and 52, respectively, shown diagrammatically in FIGURE 16 are actuated by the movement of the mechanical linkage or coupling ML to prevent the control circuit 40 from further energizing either the drive motor 60 or the drive motor 70 when the travel of the rotor member 39 has reached predetermined operating positions in either direction of rotation.

In general, the control circuit 40 operates to maintain the output voltage of the induction regulator 30 at substantially a predetermined value or within substantially a predetermined operating range or bandwidth by energizing either the drive motor 60 with the drive motor 70 to rotate the rotor member 39 whenever the output voltage of the induction regulator 30 deviates from substantially a predetermined desired value or from a predetermined desired operating range.

Referring to FIGS. 2 through 5 and 13 and 14, the overall construction and arrangement of parts of the induction regulator 30 is illustrated. In general, the regulator 30 comprises the stator magnetic core 59 on which the secondary winding 35 is disposed, the rotor member 39 on which the primary winding 37 is disposed and which is adapted for angular rotation with respect to the stator core 90, the control circuit 40, the disconnect plug member 60, the transformer 50 and the drive motors 60 and 70, which are all disposed and assembled in the casing 28 and substantially immersed in a fluid dielectric, such as the insulating oil whose level is indicated at 133 in FIG. 3.

In particular, the casing 28 includes a cover member 66 which is removably secured to the side wall portion of the casing 28 by the lifting eye bolt member 152 and the beam member 154, the lower portion of the eye bolt member 152 being adapted to engage a threaded portion of the beam member 154. In order to removably secure the beam member 154 to the inside of the casing 28, the bracket members 156 are secured or welded to the inside of the casing 28 adjacent to the upper end of the side wall portion thereof and include recess portions to accommodate the ends of the beam member 154. The bracket members 156 cooperate with the cotter pins or bolts 158 to restrain any movement of the ends of the beam member 154. In order to provide means for mounting the induction regulator 30 on an associated utility pole or other location, the bracket member 42 may be secured to the side wall portion of the casing 28, as best shown in FIGS. 2 and 3. In order to insulate the input terminals 32 and 34 and the output terminals 36 and 38 of the induction regulator 30 as said terminals pass through the side wall portion of the casing 28, the latter terminals may include conventional bushing members of any suitable type, as indicated in FIGS. 2 and 3. The flexible leads 43 of the primary winding 37 and the leads S1 and S4 of the secondary winding sections 35A and 35B are connected to the inner ends of the conductor portions of the respective terminals 32, 34, 36 and 38 of the induction regulator 30, as best shown in FIGS. 2 and 3.

Referring now to FIGS. 3, 4, 13 and 14, the stator magnetic core 90 is generally cylindrical in configuration and includes a central opening or bore 53 in which the rotor member 39 is disposed for angular rotation and which in this instance is substantially circular in cross section. The stator magnetic core 90 comprises a plurality of stacked laminations or punchings formed from a suitable magnetic material, such as sheets of hot rolled silicon steel or sheets of silicon-iron and aluminum-iron alloys containing from 1 to 7% silicon and from 1 to 10% aluminum, respectively, the sheets of the latter alloys having a cube texture, either doubly-oriented or randomly oriented wherein the major volumetric proportion of the grains have their cube faces parallel to the facing sheets, and the cube edges of the cube grains are parallel to the rolling direction and transverse thereto in the doubly oriented material or the cube grains may have their edges randomly distributed in the randomly oriented material. One such doubly oriented cube textured silicon-iron alloy is that disclosed in copending application Serial No. 681,333, filed August 30, 1957, which is assigned to the same assignee as the present application.

After the laminations which form the stator magnetic core member 90 have been stacked or assembled, as best shown in FIGS. 3 and 4, the laminations are preferably impregnated with a suitable thermosetting resin, such as an epoxy resin, which is then cured in place to bond said laminations together and form a unitary member. The latter method has been found to insure proper alignment of the different laminations which make up the stator magnetic core 90. The stator magnetic core 90 includes a plurality of substantially rectangular longitudinal slots 64 in which are disposed the first and second secondary winding sections 35A and 35B, respectively, of the secondary winding 35 and which are circumferentially displaced from one another by substantially equal distances around the inner opening 63 of the stator magnetic core 90. In this instance, the stator magnetic core 90 includes four symmetrically disposed slots 64 which are displaced from one another by an angle of substantially 90° with respect to a central longitudinal axis of the opening 63 in said stator magnetic core. As indicated in FIGS. 13 and 14, the first and second secondary winding sections or coils
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35A and 35B, respectively, are each disposed in a pair of the stator slots 64 at opposite sides of the stator magnetic core 90 to form first and second magnetic poles in said stator core whenever current flows through said secondary winding sections.

Each of the secondary winding sections 35A and 35B comprises a plurality of conductor turns which may be in any suitable form, such as conductor strap, to provide the necessary current carrying capacity in said winding sections. The conductor turns of each of the secondary winding sections 35A and 35B form individual closed loops which may be preformed and then assembled in the stator slots 64 of the stator core 90. As previously mentioned, the ends of the secondary winding section 35A are brought out of the casing 28 to the terminals 23 and 26, while the ends of the secondary winding section 35B are brought out of the casing 28 to the terminals 34 and 38. It is to be noted that during the operation of the induction regulator 30 when current flows through the secondary winding section 35A, the current instantaneously flows in opposite directions through the active portions of the conductor turns which are disposed in the upper and lower stator slots 64 associated with the secondary winding section 35A. Similar current directions exist in the different active portions of the secondary winding section 35B.

Referring to FIGS. 13 and 14, it is to be understood that the secondary winding sections or coils 35A and 35B may be held in place in the respective stator slots 64 by special insulation pieces, such as wedges, which are fitted into the grooves 65 provided on each side of the stator slots 64 adjacent to the opening 63 in the stator core 90.

In order to provide bearing support for the rotor member 39 and mounting support for the stator core 90 and the rotor member 39, as well as for certain other parts of the induction regulator 30, the upper and lower stator end bell members 132 and 134, respectively, are provided at the upper and lower ends, respectively, of the stator core 90. The upper and lower stator end bell members 132 and 134, respectively, are rigidly secured to the stator core 90 by suitable fastening means such as the through bolts or rivets 176, as best shown in FIGS. 2 and 4. The through bolts or rivets 176 which pass through the holes 68 provided at the corners of the stator core 90 may be provided with associated insulating tubes or sleeves in order to reduce the eddy current losses which would otherwise result in the stator core 90.

In order to prevent relative movement of the upper and lower stator end bell members 132 and 134, respectively, with respect to the stator core 90, the stator core 90 which is substantially rectangular in cross section includes the projecting portions 180 at the respective corners thereof which are adapted to be received by the corresponding openings 179 in the corners of the associated stator end bell members and prevent movement of the latter type after said end bell members are assembled with the stator core 90.

The corners of the stator core 90 are curved or formed as arcuate portions 130 which match and fit the inner periphery of the upper and lower stator end bell members 132 and 134, respectively, where the latter members are in contact with the stator core 90.

In order to provide mounting support for the stator core 90, the rotor member 39 and certain other parts of the induction regulator 30 as previously indicated, the upper and lower stator end bell members 132 and 134, respectively, are provided with the mounting arms 135 and 137, respectively, as best shown in FIGS. 2, 3, and 4. From this instance, the upper and lower mounting arms 135 and 137, respectively, include openings to receive the upper and lower supporting stud members 182 and 186, respectively. The upper and lower stud members 182 and 186, respectively, are supported by the bracket member 172 which is rigidly secured to the inside of the casing 28 by suitable means, such as welding or bolts. The lower stud members 186 are secured or fastened to the bracket member 172 by suitable means, such as small brackets 183 and bolts 185, to facilitate assembly of the stator core 90 on the bracket 172.

In order to reduce the ambient temperature range to which the control circuit 50 is subjected during the operation of the induction regulator 30 and to reduce the temperature compensation required in said control means, the inside of the casing 28 is divided into first and second compartments or portions by the barrier or partition members 162 and 163, which are disposed or mounted as best shown in FIGS. 2 and 3 on the side of the bracket member 172 away from the stator core 90. The barrier members 162 and 163 are preferably formed from a material, such as pressboard, which is both electrically and thermally insulating, in order to reduce the circulation of the fluid dielectric between the two compartments formed by said barrier members and to reduce the heat transfer between the fluid dielectric which is disposed in both of the compartments inside the casing 28. The control circuit or means 40 which is disposed in the compartment on the side of the barrier members 162 and 163 away from the compartment in which the stator core 90 and the rotor member 39 are disposed is, therefore, subjected to a smaller and lower operating range of temperatures. It is also to be understood that the control means 40 may be disposed in a separate compartment inside the casing or tank 28 underneath the drive motors 60 and 70 and the control transformer with a thermal barrier disposed between the control means 40 at the bottom of the casing and the balance of the regulator parts. In certain applications, the control means 40 may be disposed in a separate compartment which is attached or secured to the outside of the casing 40. In an arrangement of the latter type, the additional compartment would not have to be filled with the same fluid dielectric as the casing 28.

In order to provide mounting support for the drive motors 60 and 70 and the mechanical coupling between said drive motors and the rotor member 39, the channel member 174 is secured to the lower stator end bell member 134 by suitable fastening means, such as screws or bolts. The drive motors 60 and 70 are secured to one end of the channel member 174 by similar fastening means, such as the bolt 175, while the transformer 50 is secured to the other end of the channel member 174 by suitable fastening means, such as the rivets 177. The lug portions 143 which extend downwardly from the lower stator end bell member 134 after it is assembled with the stator core 90 may include openings to provide bearing support for the worm 122, which forms part of the mechanical coupling between the rotor member 39 and the drive motors 60 and 70. The upper stator end bell member 132 may be also provided with corresponding lug portions 159 in order to make the upper stator end bell member interchangeable with the lower stator end bell member 134. It is to be understood that the lug portions 139 of the upper stator end bell member 132 may be omitted in a particular application.

In order to reduce any vibration which results during the operation of the induction regulator 30 and which might originate with the driving means associated with the rotor member 39 from being transmitted to the bracket member 172 and inside the casing 28, the upper and lower supporting stud members 182 and 186, respectively, which support the upper and lower stator end bell members 132 and 134, respectively, are provided with the sleeve or vibration isolating members 184, which are formed from a suitable resilient, elastomeric, rubber-like material, such as the type known to the trade as nitrile rubber. The sleeve members 184 function to struc-
 turally isolate the vibration which would otherwise be transmitted to the casing 28 and which might cause an objectionable sound level during the operation of the regulator 30. Due to the resilient nature of the spring 40 from which the sleeve members 184 are formed, the vibrations which result during the operation of the induction regulator 30 are either partially or completely absorbed by the sleeve members 184. Similarly to the stator core 90, the rotor member 39 comprises a plurality of stacked laminations or punchings formed from a suitable magnetic material such as hot rolled silicon steel or other magnetic materials of the type mentioned previously in connection with the stator core 90. After the laminations which make up the rotor member 39 are stacked or assembled, the laminations are preferably impregnated with a suitable thermosetting resin, such as an epoxy resin, which is then cured in place to form a unitary member in which the different laminations which make up the rotor member 39 are maintained in proper alignment.

The rotor member 39 is provided with at least one pair of substantially rectangular slots 49 and 51 which are disposed on opposite sides of the rotor member 39, the terminal 32 and 34 of the induction regulator 30 displaced from one another by an angle of substantially 180° with respect to a central longitudinal axis of the rotor member 39. The width of each of the rotor slots 49 and 51 is greater than the circumferential spacing around the opening 53 in the stator core 90 between the adjacent stator slots 32 and 34 in order to increase the effective magnetic reluctance in each of the magnetic paths around the portion of the conductor turns of the secondary winding sections 35A and 35B which are disposed in each of the stator slots 64, as will be explained in detail hereinafter, for certain operating positions of the rotor member 39.

Since the rotor member 39 is not provided with a through shaft for reasons which will be discussed hereinafter, the upper and lower rotor end bell members or spider members 190 and 192, respectively, are disposed at the upper and lower ends, respectively, of the rotor member 39. The upper and lower end bell members 190 and 192 are secured to the upper and lower ends of the rotor members 39 through bolts or rivets 157 which pass through the openings 57 provided in the laminations which make up the rotor member 39. The through bolts or rivets 157 may also be provided with associated insulating tubes or sleeve members 158 in order to reduce any eddy current losses in the rotor members 39. The upper and lower shaft stub portions 110 and 112, respectively, of the rotor member 39 may be formed as integral axial extensions of the rotor end bell members 190 and 192, respectively, or said shaft portions may be formed separately and then assembled with said rotor end bell members.

Similarly to the secondary winding sections 35A and 35B, the primary winding 37 includes a plurality of conductor turns which are disposed in the slots 49 and 51 of the member 39 to form a closed loop, the ends of said primary winding being connected by the flexible leads 43 to the terminals 32 and 34 of the induction regulator 30. The absence of a shaft through the laminations which make up the rotor member 39 results in an increased cross-sectional area of the magnetic material in the central portion of the rotor member 39 around which the conductor turns of the primary winding 37 are wound and, along with the increase in diameter of the rotor slots 49 and 51, permits a more compact primary winding structure and a more compact rotor member 39 to thereby reduce the overall size and weight of the induction regulator 30. It is to be noted that upper and lower insulating channel members 46 and associated insulating side channel members 47 may be provided in the slots 49 and 51 of the rotor member 39 to electrically insulate the primary winding 37 from the laminations which make up the rotor member 39. When current flows through the primary winding 37, magnetic poles are formed at the opposite ends of the rotor member 39 between the adjacent rotor slots 49 and 51, as best shown in FIGS. 13 and 14.

In order to support the rotor member 39 in proper alignment inside the openings or bore 53 in the associated stator core 90, the upper and lower bearing members 146 and 148, respectively, are disposed in the upper and lower housing housings 142 and 146, respectively, of the upper and lower stator end bell members 132 and 134, respectively. The upper and lower bearing members 146 and 148, respectively, are of the split ring sleeve type and include the internally tapered portions 113 and 115, respectively. The tapered portions 113 and 115 of the upper and lower bearing members 146 and 148, respectively, bear against the matching tapered portions 111 and 117 of the upper and lower shaft stub portions 110 and 112, respectively, in order to apply a frictional force to said shaft portions which results in a frictional torque which opposes or attenuates the vibratory torque which results during the operation of the induction regulator 30. The latter reductively or subtractively reduces the net vibratory torque which might otherwise be transmitted to the casing 28 of the induction regulator 30 results in an overall reduction in the sound level of the regulator 30. In order to maintain the tapered portions 113 and 115 of the upper and lower bearing members 146 and 148, respectively, in contact with the tapered portions 111 and 117, respectively, of the upper and lower shaft portions 110 and 112, respectively, the biasing spring 144 is provided around the upper shaft portion 110 and is restrained by the upper bearing housing 142 to exert a downward force against the upper bearing member 146 and the rotor member 39.

The upper and lower bearing members 146 and 148, respectively, are formed from a suitable material, such as high temperature molded nylon, and are arranged to be self-adjusting or self-centering with respect to the rotor member 39 and its associated upper and lower shaft portions 110 and 112, respectively. In the bearing arrangement shown in FIG. 4, the clearances between the outer diameter or circumference of the bearing members 146 and 148 and the inside diameter or circumference of the associated bearing housings 142 and 146, respectively, are arranged to be negligible. Because of the tapered inner portions 113 and 115 of the bearing members 146 and 148, respectively, and because of the split or saw cut in each of the bearing members 146 and 148, the bearing members 146 and 148 are adapted for axial movement with respect to the upper and lower shaft portions 110 and 112, respectively, in order to maintain the rotor member 39 in vertical and radial alignment with the inside opening or bore 53 of the stator core 90. It is to be noted that where the dielectric fluid provided in the casing 28 is an insulating oil, adequate lubrication would be assured for the bearing members 146 and 148 since said bearing members are immersed in the fluid dielectric.

Referring to FIGS. 6 through 9, two different bearing arrangements are illustrated which may be substituted for the bearing arrangement shown in FIG. 4 in certain applications. In particular, referring to FIGS. 6 and 7 the first alternate bearing arrangement is shown which is similar to the bearing arrangement shown in FIG. 4 except that means are provided for the upper shaft portion 110 and the rotor member 39 with respect to the inner opening or bore 53 of the stator core 90. The bearing member 146' is similar to the bearing member 146 shown in FIG. 4 and may include the saw cut or split, indicated at 147 in FIG. 7, to permit axial movement of the bearing member 146'. A metallic ring or sleeve is provided around the outer or periphery of the bearing member 146', as indicated at 145 in FIGS. 6 and 7, to prevent damage to the bearing member 146' by the adjusting screws 140 and the
3,189,856 9 radially biasing spring 149, which are disposed in the bearing housing 142 to exert radially inward forces against the outer periphery or circumference of the bearing member 146' and its metallic supporting ring or sleeve 145. The bearing member 146' also includes an internally tapered portion 113' which is maintained in contact with the tapered portion 111 of the upper shaft portion 110 by the axially biasing spring 144 to substantially eliminate axial or axial clearance between the bearing member 146' and the tapered portion of the upper shaft portions 110. It should be noted that the sleeve or ring 145 permits axial movement of the bearing member 146' in response to the downward force exerted against it by the biasing spring 144. A radial clearance is provided, shown 1, between the outer diameter or circumference of the metallic ring 145 and the inner diameter or circumference of the modified bearing housing 142', as shown in FIGS. 6 and 7, to permit positioning of the bearing member 146' and the upper shaft portion 110 by means of two adjusting screws 140 and the radially biasing spring 149 to thereby position the rotor member 39 in the stator core 90. The lug portions 141 on the metallic ring 145 are provided on each side of the upper adjusting screw 140 to prevent rotation of the bearing member 146' in place. In summary, the bearing arrangement shown in FIGS. 6 and 7 provides means for adjusting the position of the upper shaft portion 110 and the rotor member 39 and for centering said rotor member within the inner opening or bore 53 of the stator core 90.

Referring now to FIGS. 8 and 9, a second alternate bearing arrangement is illustrated which is similar to the bearing arrangement shown in FIGS. 6 and 7 except that the bearing member 146' does not include an internally tapered portion like that of the bearing member 146'. In other words, the bearing member 146' is a tapered bearing rather than a tapered bearing and includes three adjusting screws 140, rather than a radially biasing spring and two adjusting screws as does the bearing arrangement shown in FIGS. 6 and 7. The bearing member 146'' also includes a saw cut or split 136, as shown in FIG. 9, to permit tightening of the bearing member 146'' around the modified upper shaft portion 110 by means of the adjusting screws 140 spaced at 120° angles around the bearing. Similarly to the bearing arrangement shown in FIGS. 6 and 7, the bearing member 146'' includes lug portions 141' which are disposed on opposite sides of the upper adjusting screw 140 shown in FIG. 9 to prevent rotation of the bearing member 146'' within the modified bearing housing 142''. Similarly to the bearing arrangement shown in FIGS. 6 and 7, the bearing arrangement shown in FIGS. 8 and 9 permits manual centering of the rotor member 39 within the inner opening or bore 53 of the stator core 90 by adjustment of the adjusting screws 140.

Referring now to FIGS. 4 and 5, the mechanical coupling between the drive motors 60 and 70 and the rotor member 39 will now be described. The drive motors 60 and 70 are capable of driving a common tandem rotor member 178 in opposite directions when actuated by the control circuit or means 40. The tandem drive shaft 178 is mechanically coupled to the shaft 181 by the gear train 126, as best shown in FIG. 5. The worm 122 is pinned or otherwise secured to the shaft 181 for rotation therewith. The worm 122 also provides supports for the shaft 181 which are disposed in the lug portions 143 of the lower stator end bell member 134 as previously mentioned. The worm 122, in turn, drives a conventional worm gear 124 which is secured or pinned to the lower shaft portion 112 of the rotor member 39 for when either the drive motor 60 or the drive motor 70 is energized by the control circuit or means 40, the rotor member 39 is driven through the mechanical coupling or linkage just described to rotate substantially 90° in either one or the other direction from a neutral position of the rotor member 39 with respect to a central vertical axis of the rotor member 39. In order to limit the angular travel of the rotor member 39 by either the drive motor 60 or the drive motor 70, as previously mentioned, the first and second limit switches LS1 and LS2, respectively, are provided to be actuated by the projecting members 159 which extend downwardly from the lower rotor end bell member 192 to engage either the limit switch LS1 for the limit switch LS2 in case predetermined operating positions of the rotor member 39. In particular, the limit switches LS1 and LS2 as shown in FIGS. 10 through 12 each includes a stationary contact member 187 and a movable contact member 188 which are held in a normally closed position with respect to each other by an overcenter biasing spring 196 until the limits of rotor travel of the rotor member 39 are reached and then said contact members become open circuited or disengaged with respect to each other to thereby prevent the control circuit or means 40 from continuing to energize either the drive motor 60 or the drive motor 70. The movable contact member 188 is actuated by a spring arm 197 which is engaged by one of the projections 195.

In order to provide a resilient mounting for the drive motors 60 and 70 and to substantially eliminate any alignment requirements in the mechanical coupling between the drive motors 60 and 70 and the rotor member 39, the drive motors 60 and 70 are mounted on or between two layers or blocks 129 formed from a resilient, elastomeric, rubber-like material, such as sponge neoprene synthetic rubber which are held in place between the channel member 174 and the lower supporting plate 136 by the bolt 175, as previously explained. The layers or blocks 129 also serve to absorb at least a portion of the sound level that would otherwise be transmitted to the casing 28 of the induction regulator 30.

Referring now to FIGS. 13 and 14, the operation of the induction regulator 30 will be considered for four different operating positions of the rotor member 39 with respect to the stator core 90. Referring first to FIG. 13 and the schematic diagram of FIG. 16, the rotor member 39 is shown for the position when the mutual inductance between the primary winding 37 and the secondary winding 35 is at a maximum value. In other words, when a voltage is applied at the input terminals 32 and 34 of the induction regulator 30 and current flows through the primary winding 37 and the secondary winding sections 35A and 35B, the magnetic axes of the primary winding 37 and the secondary winding sections 35A and 35B will be substantially in line, and the voltages induced in the secondary winding sections 35A and 35B will be at maximum values and either additive or subtractive with respect to the voltage applied at the input terminals 32 and 34 of the induction regulator 30. The position of the rotor member 39 in FIG. 13 is the maximum boosting position, since the voltages induced in the secondary winding sections 35A and 35B will be additive and at substantially maximum values for the assumed instantaneous magnetic flux directions indicated by the dotted and solid arrows shown in FIG. 13. The magnetic fluxes represented by the solid arrows are those produced by the current flow through the primary winding 37 which is disposed on the rotor member 39. The dotted arrows shown in FIG. 13 represent the magnetic fluxes produced by the currents which flow through the conductor turns of the respective secondary winding sections 35A and 35B and which are induced in said secondary winding sections by the current which flows in the primary winding 37 and the corresponding magnetic fluxes produced thereby. The maximum bucking position of the rotor member 39 will result when the rotor member 39 is rotated about its central axis substantially 180° from the position shown in FIG. 13. The induced voltages in the secondary winding sections 35A and 35B would then also be at maximum values and opposing with respect to the voltage applied at the input.
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terminals 32 and 34 of the induction regulator 30. For positions between the maximum boosting and maximum bucking positions of the rotor member 39, the voltages induced in the air gaps of the secondary winding sections 35A and 35B will be correspondingly reduced to provide a continuous stepless variation in the output voltage of the induction regulator 30. It is to be noted that when mutual inductance exists between the primary winding 37 and the secondary winding sections 35A and 35B such as in the maximum boosting or maximum bucking positions, the ampere-turns produced by the current flow in the primary winding 37 to thereby reduce the effective impedance of the induction regulator 30 and the corresponding voltage drop produced across the effective impedance of said regulator by the load current flow through said regulator to the load circuit at the load conductors L1 and L2.

Referring to FIG. 14, the rotor member 39 is shown in the neutral position when the mutual inductance between the primary winding 37 and the secondary winding sections 35A and 35B is substantially negligible, since the magnetic axes of the primary winding 37 and the secondary winding sections 35A and 35B are disposed at substantially right angles or 90° with respect to one another. If it were not for the improved construction of the induction regulator 30, when load current flowed in the secondary winding sections 35A and 35B in the neutral position of the rotor member 39 shown in FIG. 14, the ampere-turns of the secondary sections would be unopposed and the effective through impedance of the induction regulator 30 would therefore be greatly increased and the corresponding voltage drop in the induction regulator 30 would also be increased. The instantaneous assumed directions of the magnetic fluxes produced by current flow in the primary winding 37 are indicated by the solid arrows while the instantaneous magnetic flux directions produced by current flow in the secondary winding sections 35A and 35B are indicated by the dotted arrows. Considering the magnetic paths around the portion of the conductor turns of the secondary winding sections 35A and 35B in each of the stator slots 64, it will be seen that the effective magnetic reluctance in each of the latter magnetic paths will be substantially increased by the air gaps 77 which are introduced in the latter magnetic paths by the positions of the rotor slots 49 and 51 and the relative position of the stator slots 64 and the conductor turns of the secondary winding sections 35A and 35B which are disposed therein. In other words, the magnetic flux which may surround the portion of the conductor turns of each of the secondary winding sections 35A and 35B in each of the stator slots 64 is reduced and the corresponding self-impedance or leakage reactance of each of the secondary winding sections 35A and 35B is effectively reduced to thereby reduce the through voltage drop in the induction voltage regulator 30 without the use of tertiary windings, as employed in a conventional induction regulator structure.

It is also to be noted that the magnetic fluxes produced by current flow in the upper portion of the conductor turns in the upper stator slot 64 in each of the secondary winding sections 35A and 35B are opposed by the magnetic fluxes produced by current flow in the portion of the conductor turns in each of said winding sections in the lower stator slots of the stator core 90 to thereby increase the effective reluctance of the magnetic paths which would otherwise be available through the rotor member 39 to increase the effective impedance of the regulator 50 in the neutral position. In summary, the through voltage drop of the induction regulator 30 is reduced in the neutral position without the use of tertiary windings by reducing the magnetic flux which is permitted to surround the individual conductor turns of each of the secondary winding sections 35A and 35B by increasing the relative width of the rotor slots 49 and 51 as compared with the circumferential distance between the symmetrically disposed stator slots 64. In addition, the position of the stator slots 64 is arranged to introduce an air gap in the indicated portion of the secondary winding sections 35A and 35B by the increased width of each of the stator slots 64 in cooperation with the increased width of the rotor slots 49 and 51.

Referring to FIG. 15, the variation of the induced voltage in one of the secondary winding sections 35A and 35B from the starting turn to the finishing turn of said secondary winding sections 35A and 35B is substantially the same as the curve 220 for the maximum boosting maximum bucking and neutral positions, respectively. It is to be noted that the voltage drop resulting in the secondary winding sections in the neutral position as indicated by the curve 220 is substantially negligible from the starting turn to the finishing turn because of the rotor and stator core structure just described.

Referring now to FIG. 16, the control circuit or means 40 will now be described in detail. The control circuit or means 40 includes the voltage sensing or error detecting circuit SC and the raise and lower circuits RC and LC, respectively, for energizing the drive motors 60 and 70, respectively, in response to the output voltage of the induction regulator 30 to thereby maintain said output voltage at substantially a predetermined value or within a substantially predetermined operating range. As previously mentioned, the control circuit or means 40 is disposed inside the casing 28 on the side of the barrier members 162 and 163 away from the stator core 90 and the rotor member 39 and is connected in circuit relation with the drive motors 60 and 70 and the transformer 50 by the disconnect plug member 80, which includes a male portion or plug 80A and a female portion or receptacle 80B. The disconnect plug member 80 permits replacing or disconnecting the control circuit or means 40 without disturbing the balance of the induction regulator 30. The disconnect plug member includes a plurality of terminals M1 through M9 on the male portion thereof and a plurality of corresponding terminals F1 through F9, respectively, on the female portion thereof, as best shown in FIG. 16. It should be noted that all the components of the control circuit or means 40 which will be described may be disposed in a container and then impregnated or potted with a suitable thermostetting resin, such as an epoxy resin and then cured in place to provide a completely weatherproof sealed unitary member which is immersed in the dielectric fluid inside the casing 28.

More specifically, the sensing circuit SC comprises a full wave rectifier 312 whose input terminals are connected across the secondary winding 58 of the transformer 50 through the current limiting resistor 323 to obtain an input signal which varies with or is proportional to the output voltage of the induction regulator 30 at the terminals 36 and 38. The output terminals of the full wave rectifier 312 are connected in circuit relation with a filtering network which includes the capacitors 326 and 324 and the resistors 322 and 328. The filtered unidirectional output voltage of the full wave rectifier 312 is then applied to the conductors CL1 and CL3 through a temperature compensating network, which includes the temperature compensating device 336 and the resistor 338. The temperature compensating device may be of any conventional type, such as a thermistor, and serves in cooperation with the resistor 338 to temperature compensate the entire control circuit 40. The unidirectional voltage or signal which appears at the conductors CL1 and CL3 is therefore a measure of the output voltage of the induction regulator 30 at the terminals 36 and 38.

In order to obtain an error or difference signal which is a measure of the deviation of the output voltage of the induction regulator 30 from a desired regulated value, the unidirectional voltage at the conductors CL1 and CL3 of the sensing circuit SC is applied across a first series circuit which includes a voltage reference device,
more specifically the semiconductor diode 320 and the current limiting resistor 352 which are connected in series circuit relationship with one another. The voltage across each of the conductors CLI and CL2 is equal to the difference between the output voltages of the diode 320 and the resistor 352. The second voltage dividing network includes the resistors 344 and 345 which are connected in series circuit relationship with one another. Since the difference between the output voltages of the diode 320 and the resistor 352 remains substantially constant, the difference between the output voltages of the induction regulators 30 and 30a varies with the output voltage of the induction regulator. A difference signal will result between the conductors CL1 and the arm of each of the potentiometers 346 and 345.

The setting of the potentiometer arm of the potentiometer 346 will be adjusted to establish a lower limit for the output voltage of the induction regulator 30. In the absence of input voltage, the setting of the potentiometer arm of the potentiometer 346 will be adjusted to establish an upper limit for the output voltage of the induction regulator 30. In other words, the settings of the potentiometers 346 and 345 are adjusted to establish a bandwidth or operating range of the output voltage of the induction regulator 30. In the operation of the induction regulator 30, when the output voltage of the regulator 30 tends to decrease, the difference between the output voltages of the diode 320 and the resistor 352 is restored to the lower limit of the desired operating range. On the other hand, when the output voltage of the regulator 30 tends to increase, the difference between the output voltages of the diode 320 and the resistor 352 is restored to the upper limit of the desired operating range.
The effective impedance of the emitter-collector path of the transistor T3 will therefore decrease to a value below that necessary to maintain the first transistor T1 in a conducting state in which the base and the emitter of the transistor T11 and T14 are directly connected to the negative terminal of the full-wave rectifier 316. The emitter of the transistor T14 is directly connected to the capacitors 359 and the movable contact 389 of the latter limit switch to the positive terminal of the full-wave rectifier 316. The base of the transistor T14 is connected directly to the negative terminal of the full-wave rectifier 316. The emitter of the transistor T14 is connected to the diode 356, the stationary contact 187 of the second limit switch L52, and the movable contact 188 of the latter limit switch to the positive terminal of the full-wave rectifier 316. The base of the transistor T14 is connected to the collector CL2 through the resistor 398, while a voltage suppression or stabilizing network, which includes the resistor 392 and the capacitor 398 connected in series, is connected between the base and the emitter of the transistor T14. The switching transistors T12 and T14 are normally arranged to be substantially non-conducting or cut off in the absence of a sufficient input signal between the base and the emitter of the switching transistor T11. The effective impedance between the emitter and collector of the final switching transistor T14 of the lower circuit LC, therefore, similarly provides an effective relatively high impedance between the negative and positive terminals of the full-wave rectifier 316 and introduces an effectively high impedance in series with the main winding 72 of the motor 60 and the winding 62 of the motor 60 will be energized from the transformer 50. The drive motor 60 will then rotate the rotor member 39 of the induction regulator to increase the output voltage of the regulator 30 at the terminals 36 and 38 below a predetermined desired upper limit, the latter difference voltage is sufficient to maintain the first switching transistor T11 in an "on" condition in which it is conducting substantially saturation current between the emitter and the collector thereof. When, however, the output voltage of the induction regulator increases to a value above the desired upper limit, the input voltage applied to the switching transistor T11 decreases to a value below that necessary to maintain the switching transistor T11 in an "on" condition in which it is conducting saturation current between the emitter and collector thereof. During the latter operating condition, the following switching transistors are actuated to opposite conduction states so that the switching transistors T11 and T14 are turned off or begin to conduct saturation current between the emitter and collector thereof, while the switching transistor T13 is actuated to substantially a non-conducting or cut off condition. When the switching transistor T14 is turned "on" and begins to conduct saturation current between the emitter and collector thereof, the effective impedance between the emitter and collector is reduced to a relatively low value, the corresponding impedance across the input terminals of the full-wave rectifier 316 is also reduced to a relatively low value, so that the voltage applied to the main winding 72 of the drive motor 60 is sufficient to energize the drive motor 70. The drive motor 70 then rotates the rotor member 39 of the induction regulator 30 until the output voltage of the regulator 30 has decreased to a value below the desired upper limit. The difference input voltage between the base and the emitter of the switching transistor T11 then increases to the value necessary to store the switching transistor to an "on" condition and the following switching transistors are actuated to opposite conduction states, the switching transistor T14 being restored to a substantially non-conducting or cut off condition and the motor 70 is deenergized. It should be noted that the additional switching stage required in the lower circuit LC since the output voltage of the induction regulator is changing in a direction which is opposite to that which actuates the raised circuit RC and the additional switching transistor stage is necessary to provide the proper output phase from the lower circuit LC. It should also be noted that the switching transistors T1 through T3 and T11 through T14 may be described as NOT logic elements since each of said switching transistors is arranged to provide an effective output in the absence of a particular input and to provide an output when the input is of a particular value.

In control circuits 320 from surge or abnormal voltages which might result in the induction regulator 30 during certain operating conditions, the diodes which make up each of the full-wave rectifiers 315, 314 and 316 are preferably semiconductor diodes. In other words, diode-semiconductor diodes which make up each of the latter full-wave rectifiers, such as those of the silicon type, include a substantially constant voltage region in their reverse voltage-current characteristics so that when the applied voltage exceeds substantially a predetermined breakdown voltage, the output voltage across the diodes remains substantially constant or at a limited value. In addition, the current limiting resistor 323 cooperates with the diodes which make up the full-wave rectifier 312.
to limit the surge or abnormal voltages which are applied to the control circuit 40, while the windings 62 and 72 of the drive motors 60 and 70, respectively, cooperate with the diodes which make up the full-wave rectifiers 314 and 316, respectively, to also limit the surge or abnormal voltages which are applied to the control circuit 40 from the voltage transformer 49, whose design reduces the magnitude of any abnormal voltages which might be transmitted from the load circuit at the load conductors L1 and L2 from the induction regulator 30.

It is to be understood that the induction regulator 30 as described be applied either of two single-phase load circuits or on three-wire single-phase load circuits, as previously indicated, since the use of the first and second secondary winding sections 35A and 35B permits substantially balanced regulation of the voltages in a three-wire load circuit in which the voltage between the outer conductors thereof is substantially twice the voltage between the grounded or mid-tapped conductor. It is also to be understood that other types of static switching devices may be substituted for the switching transistors T1 through T3, and T11 through T14 in a particular application, such as those of the magnetic amplifier type, or of the electron tubes.

It is also to be understood that other types of conventional limit switches may be substituted for the first and second limit switches LS1 and LS2 which are connected to interrupt the emitter-collector circuits of the final switching transistors T3 and T14 of the raise and lower circuits RC and LC, respectively, as shown in FIG. 16 or that projecting members could be provided on the rotor member 39 which would engage corresponding projecting members on the stationary parts of the regulator to mechanically stop the rotation of the rotor member in certain limiting positions to eliminate the need for the limit switches LS1 and LS2. It is to be understood that other types of control circuits may be substituted for the control circuit 40 shown in FIG. 16 in an overall induction regulator equipment embodying certain features of the invention.

The apparatus embodying the teachings of this invention has several advantages. For example, the through voltage drop of the induction regulator 30 is reduced to a relatively low value in the neutral position without requiring the use of a separate tertiary winding on the rotor member thereof as employed in a conventional induction regulator. The latter construction feature permits a much more compact design in which both the size and weight of the induction regulator are reduced. In addition, the temperature compensation problems which would otherwise be greater in the control circuit 40 are reduced by the separation of the casing of the induction regulator 30 into at least first and second compartments as disclosed. The various bearing arrangements disclosed for the induction regulator 30 also provide certain advantages with respect to the elimination or facilitation of alignment, both radial and axial, of the rotor member 39 with respect to the inner opening of bore 53 of the stator core 90 in the induction regulator 30. Finally, the control circuit by means 40 is protected against the abnormal or surge voltages which might be introduced into the circuit by the various circuit arrangements disclosed.

Since numerous changes may be made in the above-described apparatus and circuits, and different embodiments of the invention may be made without departing from the spirit and scope thereof, it is intended that all the matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

We claim as our invention:

1. An induction voltage regulator comprising a laminated hollow stator core having at least four longitudinal slots therein, said slots being circumferentially displaced from one another around the inner periphery of said stator core by substantially equal distances, a rotor member disposed for angular rotation inside said stator core and having at least one pair of longitudinal slots therein, primary windings disposed in the slots of said rotor member, said primary winding having only one magnetic axis, a secondary winding including at least first and second winding sections disposed in the slots of said stator core, said secondary winding having only one magnetic axis, one end of each of said secondary winding sections being connected to different ends of said primary winding, said rotor having a neutral position in which the magnetic axes of the primary winding is perpendicular to the magnetic axis of the secondary winding, the width of each of the slots in said rotor member being greater than the distance between the adjacent slots of said stator core to reduce the leakage reactance of each of said secondary winding sections in the neutral position of said rotor member.

2. An induction voltage regulator comprising a laminated hollow stator core having four longitudinal slots therein, said slots being circumferentially displaced from one another around the inner periphery of said stator core by substantially equal distances, a rotor member disposed for angular rotation inside said stator core and having at least one pair of longitudinal slots therein, a primary winding disposed in the slots of said rotor member, said primary winding having only one magnetic axis, and a secondary winding having at least on pair of winding sections disposed in the slots of said rotor core, said secondary winding having only one magnetic axis, the winding sections of said secondary winding being connected in circuit relation with said primary winding, the width of the slots of said rotor member being greater than the distance between the adjacent slots of said stator core to reduce the voltage drop in said secondary winding when current flows therethrough and when the magnetic axes of said primary and secondary windings are at substantially right angles with respect to one another.

3. An induction regulator comprising a laminated stator core having a substantially circular opening there through and four slots therein, said slots being displaced from one another around said opening by an angle of substantially 90 degrees with respect to a central axis, a rotor member disposed for angular rotation inside the opening of said stator core and including two longitudinal slots thereon on opposite sides of said rotor member, a primary winding disposed in the slots of said rotor member, said primary winding having only one magnetic axis, a secondary winding having first and second winding sections disposed in the slots of said stator core and connected in circuit relation with said primary winding, said secondary winding having only one magnetic axis, said rotor having a neutral position in which the magnetic axis of the primary winding is perpendicular to the magnetic axis of the secondary winding, the width of each of the slots of said rotor member being greater than the circumferential distance between the adjacent slots of said stator core to reduce the leakage reactance of said secondary winding when said rotor is in said neutral position and the magnetic coupling between said primary and secondary windings is negligible.

4. An induction regulator comprising a stator, a rotor including tapered shaft portions at each end thereof, said rotor being subjected to a vibratory torque during operation of the regulator, a bearing in which each of said tapered shaft portions is supported by said stator, a split ring bearing member disposed in each bearing housing and including an inner tapered portion to match that of the associated shaft portion, a biasing spring disposed in the bearing housing at one end of said rotor to bear against one of the bearing members, said torsion spring being subjected to a vibratory torque.

5. An induction regulator comprising a stator formed from a plurality of stacked laminations of magnetic material, a rotor formed of a plurality of stacked laminations of magnetic material and including tapered segments disposed inside said stator core and having at least one pair of longitudinal slots therein, a primary winding disposed in the slots of said stator core, said primary winding having only one magnetic axis, a secondary winding including at least first and second winding sections disposed in the slots of said stator core, said secondary winding having only one magnetic axis, one end of each of said secondary winding sections being connected to different ends of said primary winding, said rotor having a neutral position in which the magnetic axes of the primary winding is perpendicular to the magnetic axis of the secondary winding, the width of each of the slots in said rotor member being greater than the distance between the adjacent slots of said stator core to reduce the leakage reactance of each of said secondary winding sections in the neutral position of said rotor member.
together with a thermosetting resin, a bearing housing disposed around each of said tapered shaft portions and supported by said stator, a split ring bearing member disposed in each bearing housing and including an inner tapered portion to match that of the associated shaft portion, a biasing spring disposed in the bearing housing at one end of said rotor to bear against one of the bearing members to apply a frictional force to said shaft portions and oppose said vibratory torque.

6. An induction voltage regulator comprising a stator core having a substantially circular opening therethrough with a plurality of longitudinal slots therein, a generally cylindrical rotor member having at least one pair of longitudinal slots on its outer periphery, a primary winding disposed in the slots of said rotor member, a secondary winding disposed in the slots of said stator core, an end bell member secured to each end of said rotor member at the outer periphery thereof beyond the slots in the rotor member, each of said end bell members having a stub shaft extending therefrom, said end bell members being shaped to provide clearance spaces between the end bell members and the ends of the rotor member to permit winding of said primary winding in the slots in the rotor member and in the clearance spaces provided by the end bells.

7. An induction voltage regulator comprising a stator core formed from a plurality of laminations of magnetic material and having at least one pair of longitudinal slots on its outer periphery, the laminations of said stator core member being bonded together with a thermosetting resin, the laminations of said rotor member being bonded together with a thermosetting resin, a primary winding disposed in the slots of said rotor member, a secondary winding disposed in the slots of said stator core, an end bell member secured to each end of said rotor member at the outer periphery thereof beyond the slots in the rotor member, each of said end bell members having a stub shaft extending therefrom, said end bell members being shaped to provide clearance spaces between the end bell members and the ends of the rotor member to permit winding of said primary winding in the slots in the rotor member and in the clearance spaces provided by the end bell members.

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