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(54) IMPROVEMENTS IN OR RELATING TO ELECTRIC MOTORS

(71) We, HORSTMANN CLIFFORD MAGNETICS COMPANY LIMITED, A British Company, of Newbridge Works, Bath BA1 3EF Avon, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to electric motors.

The invention seeks to provide an efficient electric motor of simple inexpensive construction which can be driven from an alternating current supply.

According to the invention there is provided an alternating current rotary electric motor comprising a rotor of magnetic material having a radial face with a plurality of segments which are angularly distributed around the axis of rotation of the rotor, a stator including a plurality of permanent magnet poles having polefaces spaced apart and distributed around the axis of rotation of the rotor, all of which polefaces are spaced from and face said radial face of the rotor and present the same magnetic polarity thereto, and a winding wound upon the stator and so arranged that on energisation of the winding by an alternating current the relative flux density of adjacent ones of the polefaces is caused to alternate without polarity change about a mean value so that a segment is attracted towards the adjacent poleface of greater flux density thereby to induce rotation of the rotor.

Since the flux density of the polefaces alternates without polarity change about a mean value there are no reversals of magnetic flux in operation of the motor, and accordingly a high efficiency with minimal magnetic losses can be achieved.

The stator poles are preferably arranged at equal angular intervals around the axis of rotation of the rotor and superimposed upon a core carrying the motor winding or

windings. The magnetic flux from the stator poles, after passing through a rotor vane, returns to the core through an air path externally of the core, while the alternating component of magnetic flux produced by the or each winding has a substantially closed magnetic circuit.

The core preferably comprises an annular outer core element coaxial with the axis of rotation of the rotor and an inner core element concentric with the outer element and defining therewith an annular gap in which the or each winding is located. In a preferred embodiment of the invention stator pole segments are superimposed on the inner and outer core elements so that the pole segments carried by the inner core element alternate with those carried by the outer core element around the axis of the core. The stator pole segments may have equal angular width, in which case the rotor vane preferably has a number of segments of the same angular width as the pole segments. Thus in one practical embodiment of the invention the number of rotor vane segments is one half the number of stator pole segments, the rotor vane segments being spaced apart by segmental spaces of the same angular width as the rotor segments themselves.

The invention will now be further described, by way of example only, with reference to the accompanying purely diagrammatic drawings, in which:

Figure 1 is an axial cross section of an electric motor according to one embodiment of the invention;

Figure 2 is an end view of the stator of the motor, with the rotor shown dotted, and taken in the direction of arrow II of Figure 1;

Figure 3 is a plan view of the rotor of the motor shown in Figures 1 and 2;

Figure 4 is an axial cross sectional view of a second embodiment of electric motor

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constructed in accordance with the invention;

Figure 5 is an end view of the stator of the motor of Figure 4, taken in the direction of arrow III of Figure 4, and

Figure 6 is a plan view of the rotor of the motor shown in Figures 4 and 5.

The motor of Figures 1 to 3 has a stator assembly 1 comprising a pot core of magnetic material having an annular outer core element 2 and an inner core element 3 concentric with the outer element 2 and defining with the latter an annular gap, the two core elements being interconnected at one end of the stator by annular portion 4. The stator assembly 1 further comprises a number of permanent magnet stator pole segments 5A, 5B arranged at equal angular intervals about the axis of the core, alternate pole segments 5A, 5B around the core axis being carried by the outer and inner core elements 2, 3 respectively.

The permanent pole segments 5A, 5B subtend equal angular widths at the centre of the core assembly (Figure 2). Each pole segment 5A, 5B is formed from a layer, approximately 1mm thick, of permanent magnet material such as barium ferrite or samarium cobalt magnetised through its thickness, the direction of magnetisation of all the pole segments 5A and 5B being identical, as indicated in Figure 1. The thickness of the pole segments can be less than 1mm if constructed from samarium cobalt. The pole segments 5A and 5B superimposed on the outer and inner core elements 2, 3 respectively have flat coplanar polefaces 6 which lie in a plane perpendicular to the axis of the stator assembly 1. A rotor in the form of a flat vane 7 (Figure 3) of soft magnetic material is mounted with bearings spaced from the stator assembly 1 for rotation about an axis which is coaxial with the axis of the stator assembly and which is perpendicular to the polefaces 6. The rotor vane 7 is cut or stamped from a single sheet of magnetic material such as softened Mumetal (Registered Trade Mark), the rotor vane 7 being formed with a number of sector-shaped segments 8 of the same angular width as the pole segments 5A, 5B, spaced apart by segmental spaces 9 of the same angular width as the rotor segments themselves. Thus the number of rotor vane segments 8 will be half the total number of stator pole segments 5A, 5B - in the illustrated embodiment the rotor vane has four segments 8 and there are eight stator pole segments made up of four outer segments 5A alternating with four inner segments 5B (Figure 2).

Conveniently the inner core element 3 of the stator assembly is of hollow tubular construction and houses in its interior a non-magnetic bearing assembly 10, for ex-

ample of brass, supporting a rotor shaft 11, rotatable about the axis of the stator assembly 1, carrying the rotor vane 7. In a typical practical embodiment the rotor vane 7 will be spaced from the stator polefaces 6 by a narrow air gap of substantially the same width as the rotor vane thickness.

A motor winding 12 is wound concentrically in the annular space between the inner and outer core elements 2, 3. In a practical example of the invention the rotor winding 12 would comprise 4000 turns having a resistance of 1600 ohms. The stator core 2, 3, 4 provides a nearly closed magnetic circuit for the flux of the winding 12 in conjunction with the rotor 7, while the flux of the permanent magnetic pole segments 5A, 5B, after passing through the rotor vane 7, has an air return path.

When the rotor vane 7 is fitted to the motor, and in the rest condition of the latter, the rotor assumes a position in which its vane segments 8 each cover one half of an outer stator pole segment 5A and one half of an adjacent inner pole segment 5B, as illustrated diagrammatically by a broken outline in Figure 2. This is an ideal position for self-starting of the motor when an alternating current is applied to the motor winding 12.

Upon applying alternating current to the motor winding 12, that is, upon switching on the motor, the magnetic flux density of each of the pole segments 5A, 5B will alternate, without polarity change, about a mean value, by virtue of the alternating magnetic field of the winding 12 superimposed upon the permanent magnetic flux of the pole segment magnets 5A, 5B. For example, the flux density at the pole faces 6 may alternate cyclically between a minimum of 1450 lines per square centimetre and a maximum of 1550 lines per square centimetre.

Commencing with the rotor vane 7 in the starting position shown in broken outline in Figure 2, the flux from one of the two sets of pole segments; for example the outer pole segments 5A, will increase as the flux from the other set of pole segments (5B) decreases in one half cycle of the alternating supply. The rotor vane segments 8 will in consequence be displaced angularly so as to align themselves with the stronger magnetic flux from the outer pole segments 5A, and hence rotation of the rotor vane 7 will commence with a starting torque determined by the force of magnetic attraction between the rotor segments 5A and the rotor vanes 8. In the next half cycle of the supply the inner pole segments 5B will be stronger than the outer pole segments 5A, and the rotor vane 7 will therefore continue its rotation in an attempt to align its segments 8 with the inner pole segments 5B. The rotation of the rotor vane 7 continues,

at a rate proportional to the frequency of the alternating current supply.

It has been found that a four pole motor according to the invention is self-starting up to a supply frequency of 30 Hz, and it is envisaged that rotors having more poles, for example twenty poles, will be self-starting at higher frequencies, of the order of 50 Hz or more.

If we assume that ϕ_A is the alternating torque producing flux and ϕ_P is the permanent magnet flux, then

(a) If no permanent magnet flux, Torque = $K_1 \phi_A^2$

(b) If permanent magnets present, Torque = $K_2(\phi_P + \phi_A)^2 - (\phi_P - \phi_A)^2$ and if the geometry is the same for both there will be no change in K i.e. $K_2 = K_1$. (b) expands into $4\phi_A \phi_P$ so even if ϕ_P only equalled ϕ_A there would be a four fold gain in torque.

Experiments indicate that highest efficiency is obtained when $\phi_P = \phi_A$ but extra torque at lower efficiency can be obtained by making ϕ_P greater than ϕ_A .

It has been found that slightly higher efficiency is achieved if the ends of the segments 8 are bent substantially at right angles so that the rotor to stator reluctance is reduced by making it of greater area in reluctance = μ length/area.

Also higher efficiency is achieved by making circumferential cuts in the rotor segments to interrupt the path of the unwanted eddy currents.

It has been found that the rotor can also be provided with magnetic pole segments similar to the pole segments 5A and 5B and which each present the same polarity face to the stator. The displacement of such an armature upon application of an alternating current to the stator winding can be effected by attraction or repulsion. Such a rotor may be constructed of soft iron or any other suitable magnetic material.

An alternative embodiment of the invention is shown in Figures 4, 5 and 6 which employs a stator assembly 21 similar to the stator 1 but having pairs of stator pole segments 25a and 25b similar to segments 5A and 5B mounted in alignment on axes extending radially of the stator. In this case a rotor 7 formed from a disc of magnetic material is employed which disc is provided at its periphery with four equangularly displaced slots 29 which extend inwardly to a pitch circle diameter of approximately $\frac{2}{3}$ of the radius of the disc and subdivide the disc into four peripheral segments 28a. Four apertures 30 are also provided in the disc, have ends in radial alignment with opposite ends of the segments 28a and extend from a pitch circle diameter of just less than $\frac{2}{3}$ of the diameter of the disc to a position close to the centre of the disc. The apertures 30 subdivide the inner portion of the disc into four

segments 28b disposed inwardly of the segments 28a and staggered relative thereto. Such a rotor is known as a "staggered rotor". As can be seen from Figure 6 the segments 28a and 28b are disposed alternately around the rotor. The rotor segments can also be provided with pole segments which present the same magnetic polarity to the stator.

Instead of forming the rotor as a flat vane it could be formed of cup or bell shape in which case the stator could be mounted inside the bell or cup.

The segments of the rotors of Figures 3 or 6 may be provided with portions along their radial extending edges which are bent substantially at right angles to the face of the rotor along a radial axis. This can provide for improved efficiency of operation in some circumstances.

WHAT WE CLAIM IS:

1. An alternating current rotary electric motor comprising a rotor of magnetic material having a radial face with a plurality of segments which are angularly distributed around the axis of rotation of the rotor, a stator including a plurality of permanent magnet poles having polefaces spaced apart and distributed around the axis of rotation of the rotor, all of which polefaces are spaced from and face said radial face of the rotor and present the same magnetic polarity thereto, and a winding wound upon the stator and so arranged that on energisation of the winding by an alternating current the relative flux density of adjacent ones of the polefaces is caused to alternate without polarity change about a mean value so that a segment is attracted towards the adjacent poleface of greater flux density thereby to induce rotation of the rotor.

2. An electric motor as claimed in Claim 1, wherein the rotor segments all extend radially outwardly in a spoke-like arrangement to the same radial distance from the axis of rotation.

3. An electric motor as claimed in Claim 2, wherein the rotor segments are substantially sector shaped.

4. An electric motor as claimed in any one of the preceding claims wherein the stator polefaces are angularly distributed around the axis of rotation and are staggered alternately radially outwardly and inwardly.

5. An electric motor as claimed in Claim 4, wherein the outward polefaces of the stator are of truncated sector shape and the inner polefaces are substantially of sector shape.

6. An electric motor as claimed in Claim 1, wherein the rotor segments are angularly distributed around the axis of rotation and are staggered alternately radially outwardly and inwardly.



at a rate proportional to the frequency of the alternating current supply.

It has been found that a four pole motor according to the invention is self-starting up to a supply frequency of 30 Hz, and it is envisaged that rotors having more poles, for example twenty poles, will be self-starting at higher frequencies, of the order of 50 Hz or more.

If we assume that ϕ_A is the alternating torque producing flux and ϕ_P is the permanent magnet flux, then

(a) If no permanent magnet flux, Torque = $K_1 \phi_A^2$

(b) If permanent magnets present, Torque = $K_2(\phi_P + \phi_A)^2 - (\phi_P - \phi_A)^2$ and if the geometry is the same for both there will be no change in K i.e. $K_2 = K_1$. (b) expands into $4\phi_A\phi_P$ so even if ϕ_P only equalled ϕ_A there would be a four fold gain in torque.

Experiments indicate that highest efficiency is obtained when $\phi_P = \phi_A$ but extra torque at lower efficiency can be obtained by making ϕ_P greater than ϕ_A .

It has been found that slightly higher efficiency is achieved if the ends of the segments 8 are bent substantially at right angles so that the rotor to stator reluctance is reduced by making it of greater area in reluctance = μ length/area.

Also higher efficiency is achieved by making circumferential cuts in the rotor segments to interrupt the path of the unwanted eddy currents.

It has been found that the rotor can also be provided with magnetic pole segments similar to the pole segments 5A and 5B and which each present the same polarity face to the stator. The displacement of such an armature upon application of an alternating current to the stator winding can be effected by attraction or repulsion. Such a rotor may be constructed of soft iron or any other suitable magnetic material.

An alternative embodiment of the invention is shown in Figures 4, 5 and 6 which employs a stator assembly 21 similar to the stator 1 but having pairs of stator pole segments 25a and 25b similar to segments 5A and 5B mounted in alignment on axes extending radially of the stator. In this case a rotor 7 formed from a disc of magnetic material is employed which disc is provided at its periphery with four equangularly displaced slots 29 which extend inwardly to a pitch circle diameter of approximately $\frac{2}{3}$ of the radius of the disc and subdivide the disc into four peripheral segments 28a. Four apertures 30 are also provided in the disc, have ends in radial alignment with opposite ends of the segments 28a and extend from a pitch circle diameter of just less than $\frac{2}{3}$ of the diameter of the disc to a position close to the centre of the disc. The apertures 30 subdivide the inner portion of the disc into four

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The segments of the rotors of Figures 3 or 6 may be provided with portions along their radial extending edges which are bent substantially at right angles to the face of the rotor along a radial axis. This can provide for improved efficiency of operation in some circumstances.

WHAT WE CLAIM IS:

1. An alternating current rotary electric motor comprising a rotor of magnetic material having a radial face with a plurality of segments which are angularly distributed around the axis of rotation of the rotor, a stator including a plurality of permanent magnet poles having polefaces spaced apart and distributed around the axis of rotation of the rotor, all of which polefaces are spaced from and face said radial face of the rotor and present the same magnetic polarity thereto, and a winding wound upon the stator and so arranged that on energisation of the winding by an alternating current the relative flux density of adjacent ones of the polefaces is caused to alternate without polarity change about a mean value so that a segment is attracted towards the adjacent poleface of greater flux density thereby to induce rotation of the rotor.

2. An electric motor as claimed in Claim 1, wherein the rotor segments all extend radially outwardly in a spoke-like arrangement to the same radial distance from the axis of rotation.

3. An electric motor as claimed in Claim 2, wherein the rotor segments are substantially sector shaped.

4. An electric motor as claimed in any one of the preceding claims wherein the stator polefaces are angularly distributed around the axis of rotation and are staggered alternately radially outwardly and inwardly.

5. An electric motor as claimed in Claim 4, wherein the outward polefaces of the stator are of truncated sector shape and the inner polefaces are substantially of sector shape.

6. An electric motor as claimed in Claim 1, wherein the rotor segments are angularly distributed around the axis of rotation and are staggered alternately radially outwardly and inwardly.



7. An electric motor as claimed in Claim 6 wherein the outward rotor segments extend between the periphery of the rotor and a pitch circle diameter intermediate the periphery and the axis of rotation and the inward rotor segments extend from a position at or near said intermediate pitch circle diameter to a smaller pitch circle diameter.

8. An electric motor as claimed in Claim 6 or 7, wherein the outward rotor segments are of truncated sector shape and the inward rotor segments are of substantially sector shape.

9. An electric motor as claimed in any one of Claims 1, 6, 7 or 8, wherein the stator polefaces are arranged in pairs which are in radial alignment, the relative flux density of which pairs is arranged to alternate without polarity change to induce said rotation.

10. An electric motor as claimed in any one of the preceding Claims, wherein the stator poles lie in a plane perpendicular to the axis of rotation of the rotor.

11. An electric motor as claimed in any one of the preceding Claims, wherein the rotor is in the form of a flat vane spaced by an air gap from the stator polefaces.

12. An electric motor as claimed in Claim 11, wherein the rotor vane is spaced from the stator by an air gap of width substantially equal to the thickness of the rotor vane.

13. An electric motor as claimed in any one of the preceding Claims, wherein the rotor segments are provided at their radially extending edges with portions which extend substantially at right angles to the radial face of the rotor.

14. An electric motor as claimed in any one of the preceding Claims, wherein the extremities of the segments of the rotor are bent to reduce the air gap reluctance between rotor and stator.

15. An electrical motor as claimed in any one of the preceding Claims, wherein the segments of the rotor are provided with one or more circumferential cuts.

16. An electric motor as claimed in any one of the preceding Claims, wherein the stator poles are equiangularly displaced around the axis of rotation.

17. An electric motor as claimed in any one of the preceding Claims wherein the stator poles are arranged to subtend equal angular intervals around the axis of rotation of the rotor.

18. An electric motor as claimed in Claim 17, wherein the stator comprises permanent magnet segments superimposed upon a core carrying the motor winding.

19. An electric motor as claimed in Claim 18, wherein the core has an annular outer core region coaxial with the axis of rotation of the rotor and an inner core region concentric with the outer region and

defining therewith an annular gap in which the or each winding is located, the pole segments being superimposed on the core regions.

20. An electric motor as claimed in any one of the preceding Claims, wherein the rotor segments are of the same angular width as the polefaces.

21. An electric motor as claimed in any one of the preceding Claims, wherein the number of rotor segments is one half the number of stator polefaces, the rotor segments being spaced apart by segmental spaces of the same angular width as the rotor segments themselves.

22. An electric motor as claimed in any one of the preceding Claims wherein the polefaces are arranged to provide a flux density bias of said like polarity of magnitude substantially equal to the amplitude of alternating flux produced by said alternating current.

23. An electric motor substantially as described herein with reference to, or as illustrated in, the drawings.

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