PERMANENT MAGNET ROTOR AND PERMANENT MAGNET ROTATING ELECTRICAL MACHINE

FIELD

The present embodiments relates to a permanent magnet rotor and a permanent magnet rotating electrical machine.

BACKGROUND

A permanent magnet rotating electrical machine has a rotor and a stator. Flux barriers are formed in a rotor core provided outside a rotor shaft of the rotor radially. The flux barriers serve as magnetic barriers in each circumferential angle region of the rotor core. Permanent magnet is provided in a circumferential center region of each of the flux barriers. The permanent magnet has a cross-sectional shape of an arc shape or a rectangular shape as viewed in an axial section thereof.

FIG. 4 is a quarter part of a cross-sectional view of a conventional permanent magnet rotating electrical machine as viewed in a direction perpendicular to the rotary axis thereof, which illustrates a 1/4 range circumferentially. FIG. 5 is a partial sectional view illustrating through holes formed in the rotor core and permanent magnets in the example of the conventional permanent magnet rotating electrical machine, showing cross section as viewed in a direction perpendicular to the rotary axis thereof. In a permanent magnet rotating electrical machine 45 illustrated in FIGS. 4 and 5, the

flux barrier as a magnetic barrier is formed in each of circumferential angle regions of a rotor core 12 provided radially outside a rotor shaft 11 of a rotor 10. The flux barrier includes, in each of the circumferential angle regions of the rotor core 12, radially outer flux barriers 31a located radially outer position and radially inner flux barriers 31b located radially inner position.

A permanent magnet 41a is provided in a circumferential center of the radially outer flux barriers 31a, and a permanent magnet 41b is provided in a circumferential center of the radially inner flux barriers 31b. The permanent magnets 41a and 41b are those formed of the same material such as a ferrite magnet or a rare earth magnet.

The permanent magnet 41a is circumferentially divided into two parts interposing a bridge 42a. Similarly, the permanent magnet 41b is circumferentially divided into two parts interposing a bridge 42b. The bridges 42a and 42b are provided for compensating for reduction in a structural strength due to a cut portion formed for providing the respective permanent magnets 41a and 41b in the rotor core 12. Thus, the bridges 42a and 42b have lengths equal to the thicknesses of the respective permanent magnets 41a and 41b.

SUMMARY

According to a first aspect, there is provided a permanent magnet rotating electrical machine comprising: a rotor shaft rotatably supported and extending axially at its rotation axis; a rotor core, fixed to the rotor shaft, having a plurality of flat steel plates that are laminated axially, having flux barriers and permanent magnet spaces placed between the flux barriers formed in a convex curved shape in a direction toward the rotor shaft, and having bridges between the flux barriers and the permanent magnet spaces, wherein a width of the central region of the magnet space is thinner in a radial direction than a width of both end regions of the magnet space; permanent magnets disposed in the respective

central regions of the permanent magnet spaces, demagnetization resistance of the permanent magnets decreasing monotonically from outer side to inner side in the radial direction; a stator core disposed outside of the rotor core with a gap therebetween, the stator core including a plurality of stator teeth spaced apart from each other circumferentially and formed, the stator teeth extending axially and protruding radially inward; and armature windings wound around the stator teeth.

According to a second aspect, there is provided a permanent magnet rotor comprising: a rotor shaft rotatably supported and extending axially at its rotation axis; a rotor core, fixed to the rotor shaft, having a plurality of flat steel plates that are laminated axially, having flux barriers and permanent magnet spaces placed between the flux barriers formed in a convex curved shape in a direction toward the rotor shaft, and having bridges between the flux barriers and the permanent magnet spaces, wherein a width of the central region of the magnet space is thinner in a radial direction than a width of both end regions of the magnet space; and permanent magnets disposed in the respective central regions of the permanent magnet spaces, demagnetization resistance of the permanent magnets decreasing monotonically from outer side to inner side in the radial direction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a quarter part of a cross-sectional view of a permanent magnet rotating electrical machine according to an embodiment as viewed in a direction

perpendicular to a rotary axis thereof.

FIG. 2 is a partial cross-sectional view of through holes formed in the permanent magnet rotating electrical machine according to the embodiment, as viewed in the direction perpendicular to the rotary axis thereof.

FIG. 3 is a view illustrating an example of magnetic history curve of a permanent magnet.

FIG. 4 is a quarter part of a cross-sectional view of a conventional permanent magnet rotating electrical machine as viewed in the direction perpendicular to the rotary axis thereof, which illustrates a 1/4 range in a circumferential direction.

FIG. 5 is a partial sectional view illustrating a through hole formed in the rotor core and a permanent magnet in the example of the conventional permanent magnet rotating electrical machine, showing cross section as viewed in a direction perpendicular to the rotary axis.

DETAILED DESCRIPTION

It is known that the reluctance torque can be maximized when the radially outer flux barriers 31a and radially inner flux barriers 31b are formed into substantially elliptical arc shape following a flow of a q-axis magnetic flux as illustrated in FIG. 4. However, a reverse magnetic field generated by armature reaction generally becomes smaller at more radially inward. In a conventional approach, the radially inner magnet and the radially outer magnet are the same type, causing non-

uniformity in demagnetization resistance. That is, when the demagnetization resistance of a permanent magnet disposed radially outer side is ensured, the demagnetization resistance of the permanent magnet disposed inside radially becomes excessive. In particular, when a magnet having a high coercive force (neodymium magnet having a high Dy (dysprosium) content) is used in order to ensure the demagnetization resistance radially outside, a sufficient cost reduction cannot be achieved since such a magnet is expensive.

The present embodiment has been made to solve such a problem, and the object thereof is to achieve cost reduction while ensuring the demagnetization resistance of the permanent magnets in the permanent magnet rotating electrical machine.

According to an embodiment, there is provided a permanent magnet rotating electrical machine (100) comprising: a rotor shaft rotatably supported and extending axially at its rotation axis; a rotor core in which flux barriers are formed in each circumferential angle region so as to extend axially while spreading circumferentially toward the rotation axis center in a convex curved shape, and a permanent magnet spaces are formed in a circumferential direction center portion of each of the flux barriers, the rotor core being fixed to the rotor shaft and having a plurality of flat steel laminated plates laminated axially; permanent magnets disposed in the respective permanent magnet spaces, demagnetization resistance of the permanent magnets

decreasing monotonically from outer side to inner side in a radial direction; a stator core disposed outside of the rotor core with a gap therebetween, the stator core including a plurality of stator teeth spaced apart from each other circumferentially and formed, the stator teeth extending axially and protruding radially inward; and armature windings wound around the stator teeth.

According to another embodiment, there is provided a permanent magnet rotor comprising: a rotor shaft rotatably supported and extending axially at its rotation axis; a rotor core in which flux barriers are formed in each circumferential angle region so as to extend axially while spreading circumferentially toward the rotation axis center in a convex curved shape, and a permanent magnet spaces are formed in a circumferential direction center portion of each of the flux barriers, the rotor core being fixed to the rotor shaft and having a plurality of flat steel laminated plates laminated axially; and permanent magnets disposed in the respective permanent magnet spaces, demagnetization resistance of the permanent magnets decreasing monotonically from outer side to inner side in a radial direction.

Hereinafter, with reference to the accompanying drawings, permanent magnet rotating electrical machines of embodiments of the present invention will be described. The same or similar portions are represented by the same reference symbols and will not be described repeatedly.

FIG. 1 is a quarter part of a cross-sectional view

of a permanent magnet rotating electrical machine according to an embodiment as viewed in a direction perpendicular to a rotary axis thereof, which illustrates only a 1/4 sector, that is, a 1/4 circumferential angle region of a permanent magnet rotating electrical machine 100. In this case, the permanent magnet rotating electrical machine 100 has four poles. The permanent magnet rotating electrical machine 100 has a rotor 10 and a stator 20.

The rotor 10 has a rotor shaft 11 and a rotor core 12. The rotor shaft 11 extends in a direction along a rotary axis (axial direction) of the rotor 10. The rotor core 12 is disposed around the rotor shaft 11 radially and has a plurality of axially laminated steel plates. The rotor core 12 has a cylindrical outer shape.

FIG. 2 is a partial cross-sectional view of through holes formed in the permanent magnet rotating electrical machine according to the embodiment, as viewed in the direction perpendicular to the rotary axis thereof. FIG. 2 illustrates two through holes 13a and 13b formed radially in each circumferential angle region of the rotor core 12. The through holes 13a and 13b extend axially while spreading circumferentially in a convex curved shape toward a center of a rotation axis. The through holes 13a and 13b are formed in parallel to each other. Center regions of the respective through holes 13a and 13b serve as permanent magnet spaces 14a and 14b in which permanent magnets 51a and 51b (FIG. 1) each having a sectional area corresponding to each region are

provided. Regions on both sides of the permanent magnet space 14a in the through hole 13a are regions where radially outer flux barriers 31a are formed. Regions on both sides of the permanent magnet space 14b in the through hole 13b are regions where radially inner flux barriers 31b are formed.

In each of the radially outer flux barriers 31a, a bridge 52a is formed. The bridge 52a connects a radially inner portion of the rotor core 12 to the radially outer flux barrier 31a and a radially outer portion of the rotor core 12 to the radially outer flux barrier 31a with the radially outer flux barrier 31a interposed therebetween. That is, the radially inner portion of the rotor core 12 and the radially outer portion thereof of the radially outer flux barrier 31a are connected by the bridge 52a.

Similarly, in each of the radially inner flux barriers 31b, at the opposite sides of the permanent magnet 51b, a bridge 52b is formed. The bridge 52b connects a radially inner part of the rotor core 12 of the radially inner flux barrier 31b and a radially outer part of the rotor core 12 of radially inner flux barrier 31b with the radially inner flux barrier 31b interposed therebetween. That is, the inner part of the rotor core 12 and the outer part thereof in the radial direction of the radially inner flux barrier 31b are connected by the bridge 52b.

In the above example, the flux barriers and permanent magnets are each arranged in two rows in the

radial direction, but not limited thereto. The flux barriers and permanent magnets may each be arranged radially in three or more rows.

In the above-described conventional approach, the bridge has a length equal to the thickness of the permanent magnet, as illustrated in FIG. 5. In the present embodiment, the bridge has a length equal to the width of the flux barrier and larger than the width of the permanent magnet. Making the length of the bridge larger increases the magnetic resistance of the bridge. As a result, leakage flux can be reduced. Further, forming the bridge on both sides of the magnet eliminates the need of dividing the magnet.

As illustrated in FIG. 1, the permanent magnets 51a and 51b installed in the respective permanent magnet spaces 14a and 14b each have a flat plate-like shape and extend circumferentially and axially. The permanent magnet 51a and the permanent magnet 51b are arranged in parallel to each other and spaced apart from each other radially. Further, the inner permanent magnet 51b in the radial direction and outer permanent magnet 51a in the radial direction are arranged so as to have the same polarity. That is, the inner permanent magnet 51b and outer permanent magnet 51a are arranged in a first arrangement in which the radial direction inner surfaces of both the inner permanent magnet 51b and outer permanent magnet 51a have an N-pole and the radial direction outer surfaces thereof have an S-pole or in a second arrangement in which the radial direction inner

surfaces have an S-pole and the radial direction outer surfaces have an N-pole. Further, when one of permanent magnets adjacent to each other circumferentially has the first arrangement, the other thereof has the second arrangement.

The stator 20 has a stator core 21 and armature coils 24. The stator core 21 has flat plates laminated axially. Stator slots 23 extending axially are formed radially inside the laminated plates so as to be opposed to the outer surface of the rotor 10 radially with a gap 25 interposed therebetween. That is, a plurality of stator teeth 22 protruding inward are formed radially inside the stator core 21. The armature coils 24 are wound around each of the stator teeth 22.

Radial directions at both ends of the circumferential angle region in the circumferential direction are defined as q-axis directions, and a radial direction at a center of the circumferential angle region is defined as a d-axis direction. Further, in FIG. 1, a magnetic flux $\phi 1$ formed by the permanent magnets 51a and 51b is denoted by dashed double-dotted lines.

In FIG. 1, as the magnetic flux $\phi 1$, a clockwise magnetic flux and a counterclockwise magnetic flux are illustrated. For example, the clockwise magnetic flux $\phi 1$ forms closed clockwise magnetic flux lines with unillustrated permanent magnets provided in an unillustrated circumferential angle region positioned to the right of the illustrated circumferential angle region. Further, the counterclockwise magnetic flux $\phi 1$

forms closed counterclockwise magnetic flux lines with unillustrated permanent magnets provided in an unillustrated circumferential angle region positioned to the left of the illustrated circumferential angle region. In terms of the radial direction, the magnetic flux $\phi 1$ is formed along the d-axis.

On the other hand, a magnetic flux $\phi 2$ of a reluctance component formed by a rotating magnetic field generated in the stator core 21 does not pass through the radially outer flux barriers 31a and radially inner flux barriers 31b, which are formed in the rotor core 12 and serve as the magnetic resistance, but is formed along a pathway of the rotor core 12 between the radially outer flux barriers 31a and radially inner flux barriers 31b. Thus, in terms of the radial direction, the magnetic flux $\phi 2$ is formed in the q-axis.

The magnetic field formed by the reluctance component magnetic flux $\phi 2$ is reduced toward a farther side from the stator 20, that is, toward the radially inside. The magnetic field formed by the magnetic flux $\phi 2$ can be a reverse magnetic field having a demagnetization effect on the permanent magnets 51a and 51b. Thus, the strength of the reverse magnetic field acting on the radially outer permanent magnet 51a is greater than the strength of the reverse magnetic field acting on the radially inner permanent magnet 51b.

FIG. 3 is a view illustrating an example of magnetic history curve of a permanent magnet. The horizontal axis represents a strength of a magnetic field H, and the

vertical axis represents a magnetic flux density B. A part located in the second quadrant of a B-H curve (denoted by solid lines) having hysteresis characteristics, i.e., a demagnetization curve, shows a relationship between a magnetic field strength when a magnetic field is applied in the reverse direction and a total magnetic flux density. A magnetic field strength having a magnetic flux density of 0, that is, a coercive force H_{CB} which is an intersection with the horizontal axis corresponds to the demagnetization resistance which is a yield strength of the permanent magnet to the demagnetization effect and is thus called "demagnetization resistance".

When a magnetic polarization J calculated from a relationship of $B = \mu oH + J$ (μo is a permeability of vacuum) is plotted on the vertical axis, a J-H curve representing a relationship between the magnetic polarization J and the strength of the magnetic field H is obtained as denoted by dashed lines of FIG. 3. An inherent coercive force H_{CJ} which is an intersection of the demagnetization curve which is a part of the J-H curve located in the second quadrant and the horizontal axis line is a value inherent to a magnetic material and serves as an index of the demagnetization resistance of the magnetic material as a magnet. On the other hand, the coercive force H_{CB} depends not only on the magnetic material but also on the shape of the magnet.

Thus, in a region where the reverse magnetic field is large, it is necessary to use a permanent magnet

having a large coercive force H_{cB} or inherent coercive force H_{cJ}, that is, a large demagnetization resistance. Conversely, in a region where the reverse magnetic field is small, a magnet having a small coercive force H_{cB} or a small inherent coercive force H_{cJ} corresponding to the small reverse magnetic field may be used.

In the present embodiment, a permanent magnet having the coercive force H_{cB} or inherent coercive force H_{cJ} that satisfies a required demagnetization resistance at the both outside and inside in the radial direction is used. That is, a tolerance against a level required for the radially outer permanent magnet 51a is made almost equal to a tolerance against a level required for the radially inner permanent magnet 51b. Specifically, the coercive force H_{cB} or inherent coercive force H_{cJ} of the radially inner permanent magnet 51b is made smaller than the coercive force H_{cB} or inherent coercive force H_{cJ} of the radially outer permanent magnet 51a.

That is, the demagnetization resistance of the radially inner permanent magnet 51b is smaller than that of the radially outer permanent magnet 51a. The same can be said for a case where the permanent magnets are arranged radially in three or more rows. Basically, the demagnetization resistance monotonically decreases from the outermost permanent magnet to the innermost permanent magnet. For example, assume a case where four permanent magnets A (the outermost in the radial direction), B (the second in the radial direction), C (the third in the radial direction), and D (the innermost in the radial

direction) are provided. The demagnetization resistances of the permanent magnets A, B, C, and D are assumed to be Y_A, Y_B, Y_C, and Y_D, respectively. Examples of the monotonic decrease include a case where $Y_A > Y_B > Y_C > Y_D$, $Y_A > Y_B = Y_C = Y_D$, $Y_A = Y_B > Y_C = Y_D$, $Y_A = Y_B = Y_C > Y_D$, $Y_A > Y_B > Y_C = Y_D$, $Y_A > Y_B = Y_C > Y_D$, and $Y_A = Y_B > Y_C > Y_D$.

As a method of changing the inherent coercive force H_{CJ} of the permanent magnet, a method of changing the material type of the permanent magnet is known. Further, as a method of changing the coercive force H_{CB} of the permanent magnet, a method of changing the shape of the permanent magnet is known.

The types of the material for the permanent magnet include a neodymium magnet having a high Dy (dysprosium) content, a neodymium magnet having a low Dy content, a ferrite magnet, and the like. Among the above, the inherent coercive force H_{CJ} of the neodymium magnet having a high Dy content is the largest; however, it costs relatively high. Further, among the above, the inherent coercive force H_{CJ} of the ferrite magnet is the smallest; however, it costs relatively low. Thus, by using the ferrite magnet at least as the innermost permanent magnet and using the same as the permanent magnets outside the innermost one as much as possible, cost reduction can be achieved.

Further, by changing the thickness of the permanent magnet, the coercive force H_{CB} can be adjusted. In general, by increasing the magnet width and reducing the magnet thickness, a larger amount of magnetic flux can be

derived from a smaller amount of magnets. However, when the thickness of the permanent magnet is reduced, the coercive force H_{cB} is also reduced, so that a certain thickness or more needs to be ensured. Thus, in the radially outer permanent magnet 51a on which a large reverse magnetic field acts, the magnet thickness (size along the radial direction) is increased in accordance with the magnitude of the reverse magnetic field, and the magnet width (size along the circumferential direction) is reduced by that amount. On the other hand, in the radially inner permanent magnet 51b on which a small reverse magnetic field acts, the magnet thickness is reduced to the extent that demagnetization does not occur, and the magnet width is increased. The increase in the magnet width increases the amount of magnetic flux, thus allowing effective use of a magnetic torque.

In the above conventional approach, the radially inner magnet and the radially outer magnet are of the same type, so that when the type of the permanent magnet is selected so as to satisfy the demagnetization resistance of the radially outer permanent magnet, the demagnetization resistance of the radially inner permanent magnet becomes excessive. In the present embodiment, by changing the type of the magnet depending on the installation place, by appropriately selecting the magnet thickness and width, and by using the bridge having as large a magnetic resistance as possible, it is possible to achieve cost reduction while ensuring required demagnetization resistance of each permanent

magnet and maintaining equivalent characteristics to those of conventional permanent magnet rotating electrical machines.

[OTHER EMBODIMENTS]

The present invention is described above by way of an embodiment. However, the embodiment is presented only as an example without any intention of limiting the scope of the present invention.

Furthermore, the above-described embodiment may be put to use in various different ways and, if appropriate, any of the components thereof may be omitted, replaced or altered in various different ways without departing from the spirit and scope of the invention.

Therefore, the above-described embodiment and the modifications made to them are within the spirit and scope of the present invention, which is specifically defined by the appended claims, as well as their equivalents.

CLAIMS

1. A permanent magnet rotating electrical machine comprising:

a rotor shaft rotatably supported and extending axially at its rotation axis;

a rotor core, fixed to the rotor shaft, having a plurality of flat steel plates that are laminated axially, having flux barriers and permanent magnet spaces placed between the flux barriers formed in a convex curved shape in a direction toward the rotor shaft, and having bridges between the flux barriers and the permanent magnet spaces, wherein a width of the central region of the magnet space is thinner in a radial direction than a width of both end regions of the magnet space;

permanent magnets disposed in the respective central regions of the permanent magnet spaces, demagnetization resistance of the permanent magnets decreasing monotonically from outer side to inner side in the radial direction;

a stator core disposed outside of the rotor core with a gap therebetween, the stator core including a plurality of stator teeth spaced apart from each other circumferentially and formed, the stator teeth extending axially and protruding radially inward; and

armature windings wound around the stator teeth.

2. The permanent magnet rotating electrical machine according to claim 1, wherein

the permanent magnets include different materials from each other.

3. The permanent magnet rotating electrical machine according to claim 1 or 2, wherein

the permanent magnets at the radially innermost position at least include a ferrite magnet.

4. The permanent magnet rotating electrical machine according to any one of claims 1 to 3, wherein

the thickness of the permanent magnet disposed radially outer side is equal to or larger than the thickness of the permanent magnet disposed radially inner side, and the width of the permanent magnet disposed radially outer side is equal to or smaller than the width of the permanent magnet disposed radially inner side.

5. A permanent magnet rotor comprising:

a rotor shaft rotatably supported and extending axially at its rotation axis;

a rotor core, fixed to the rotor shaft, having a plurality of flat steel plates that are laminated axially, having flux barriers and permanent magnet spaces placed between the flux barriers formed in a convex curved shape in a direction toward the rotor shaft, and having bridges between the flux barriers and the permanent magnet spaces, wherein a width of the central