

SPECIFICATION

TITLE OF THE INVENTION: PERMANENT MAGNET RELUCTANCE TYPE
ROTATING ELECTRIC MACHINE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2013-074958, filed on March 29, 2013; the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present embodiment relates to a permanent magnet reluctance type rotating electric machine.

BACKGROUND ART

[0003] Recently, in a rotating electric machine for vehicle, such as for railway or a hybrid car, high efficiency has been strongly desired. Accordingly, development of a rotating electric machine using permanent magnets which is a small size and can output a high power has been promoted.

[0004] In a rotating electric machine for vehicle, since high torque and high output are required in a space where a loading space is limited, high speed rotation is to be realized by increasing reluctance torque using a permanent magnet of high magnetic energy product. A permanent magnet reluctance type rotating electric machine has been required which enables high torque, high output, and high speed by properly arranging permanent magnets.

[0005] In a permanent magnet reluctance type rotating

electric machine, a permanent magnet reluctance type rotating electric machine has been proposed in which a cavity (a gap portion between magnetic poles) is arranged at the outer circumferential side of permanent magnets arranged in a V-shape, and its size/shape is numerically limited, to obtain high torque, and which can thereby output a high power and can perform a variable-speed operation. (Refer to Patent Document 1, for example). In addition, slits of a multilayer structure are provided inside a rotor core, and permanent magnets are arranged in the slit, and thereby high output and high speed are achieved. (Refer to Patent Document 2, for example).

PRIOR ART DOCUMENT

PATENT DOCUMENT

[0006] Patent Document 1: Japanese Patent Application
Publication No. 2001-339922

Patent Document 2: Japanese Patent Application
Publication No. 2000-270525

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0007] However, in the above-described conventional permanent magnet reluctance type rotating electric machine, there was a problem that torque property might decrease by the problems of magnet arrangement, magnetic barrier arrangement, and bridge.

[0008] The present invention is made to solve the above-

described problem, and makes it an object to provide a permanent magnet reluctance type rotating electric machine which can improve magnetic torque and reluctance torque, or can realize miniaturization.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

[Fig. 1] Fig. 1 is a diagram showing a whole structure (one pole portion) of a permanent magnet reluctance type rotating electric machine of a first embodiment.

[Fig. 2] Fig. 2 is a vector diagram of the permanent magnet reluctance type rotating electric machine of the first embodiment.

[Fig. 3] Fig. 3 is a diagram showing an example of torque-rotating speed properties of a case that overlapping of the permanent magnets is present and a case that the overlapping is not present in the permanent magnet reluctance type rotating electric machine of the first embodiment.

[Fig. 4] Fig. 4 is a diagram showing a whole structure (one pole portion) of a permanent magnet reluctance type rotating electric machine of a second embodiment.

[Fig. 5] Fig. 5 is a diagram showing a whole structure (one pole portion) of a permanent magnet reluctance type rotating electric machine of a second embodiment.

EMBODIMENTS TO PRACTICE THE INVENTION

[0010] Hereinafter, a permanent magnet reluctance type rotating electric machine of an embodiment will be described

with reference to the drawings.

[0011] (First embodiment)

A first embodiment will be described in detail with reference to the drawings. Fig. 1 is an overall view of a permanent magnet reluctance type rotating electric machine of a first embodiment. The first embodiment will be described using Fig. 1 - Fig. 3.

[0012] (Configuration)

Fig. 1 is a sectional view in the radial direction of the permanent magnet reluctance type rotating electric machine of the first embodiment. In Fig. 1, a stator 1 has a stator slot 11, a stator electromagnetic steel sheet 10, a stator core 7, an armature winding 3, stator teeth 2. The stator core 7 mainly composing the stator 1 is composed by laminating thin sheet materials called the stator electromagnetic steel sheets 10 which are made by adding silicon to iron. The stator slot 11 to house the armature winding 3 and the stator teeth 2 facing a rotor 5 are provided at the inner circumferential side of the stator core 7.

[0013] The rotor 5 is arranged opposite to the stator teeth 2 via a gap at the inner circumferential side of the stator 1. In Fig. 1, the rotor 5 has a rotor core 8, a permanent magnet 4, a rotor electromagnetic steel sheet 6, a magnetic barrier 12. The rotor 5 is mainly composed of the rotor core 8. The rotor core 8 is composed by laminating

thin sheet materials called the rotor electromagnetic steel sheets 6 which are made by adding silicon to iron. A plurality of the permanent magnets 4 are provided in the rotor core 8.

[0014] In the present embodiment, the permanent magnets 4 are composed of a first permanent magnet 4a and a second permanent magnet 4b.

[0015] The first permanent magnet 4a is located while being sandwiched between an outer magnetic barrier 12aa and an inner magnetic barrier 12a. At this time, the magnetic barrier 12aa is located at a more outer circumferential side (stator side) than the magnetic barrier 12a, and the lengths of the respective magnetic barriers are $12a > 12aa$. The above-described first permanent magnets are provided by two, so that they are symmetric with respect to a d-axis as a center line. This one pair is made a first permanent magnet group.

[0016] The second permanent magnet 4b is located while being sandwiched between an outer magnetic barrier 12bb and an inner magnetic barrier 12b, and at a more outer circumferential side (stator side) than the first permanent magnet 4a. At this time, the magnetic barrier 12bb is located at a more outer circumferential side (stator side) than the magnetic barrier 12b, and the lengths of the respective magnetic barriers are $12bb > 12b$. The above-described second permanent magnets 4b are provided by two, so

that they are symmetric with respect to the d-axis as a center line. This one pair is made a second permanent magnet group.

[0017] Further, the end portion at the magnetic barrier 12a side of the first permanent magnet 4a and the end portion at the magnetic barrier 12bb side of the second permanent magnet 4b are located at the equivalent positions or located so that they do not overlap with each other. In other words, the respective permanent magnets provided in the rotor 5 are configured to be arranged so as not to overlap with each other toward a direction of a rotor shaft 9.

[0018] In addition, a first bridge portion 13a is sandwiched between the magnetic barriers 12a which are symmetric with respect to the d-axis as a center. In addition, the vicinity of the first bridge portion 13a is made a first magnetic pass narrow portion. In addition, a second bridge portion 13b is sandwiched between the magnetic barriers 12b which are symmetric with respect to the d-axis as a center. In addition, the vicinity of the second bridge portion 13b is made a second magnetic pass narrow portion.

[0019] The rotor shaft 9 is provided at the inner circumferential side of the rotor 5. The rotor shaft 9 is supported rotatably by a bearing having a roller shaft, a ball shaft and so on which are not shown here in the drawing.

[0020] In addition, when a normal line on the outer circumferential face of the rotor shaft 9 is drawn toward the

outer circumferential face of the rotor 5, the first permanent magnet 4a and the second permanent magnet 4b may be arranged so that both of them are not present on this line all together.

[0021] In the armature winding 3 of the stator 1 of the permanent magnet reluctance type rotating electric machine with the configuration like this, a current flows, and thereby a rotating magnetic field is generated. The rotor 5 is sucked by the generated rotating magnetic field, and thereby rotates around the rotor shaft 9. The rotor core 8 has a magnetization easy axis (a portion where magnetic flux is easy to pass) q, and a magnetization difficult axis (a portion where magnetic flux is difficult to pass) d, which respectively extend in a radial direction or a radiation direction of the rotor core 8. These q-axis and d-axis are determined by the arrangement position of the permanent magnets 4. For the reason, these are formed alternately in a circumferential direction of the rotor core 8, and at a prescribed phase.

[0022] In the description of the first embodiment, the two-layer magnet arrangement has been described as an example, but the embodiment is not limited to the two-layer arrangement.

[0023] (Action)

Next, the property of this first embodiment will be described. A torque (T) which the permanent magnet

reluctance type rotating electric machine 100 generates is expressed by a vector diagram shown in Fig. 2.

[0024] On the q-axis and d-axis of Fig. 2, each property obtained from the permanent magnet reluctance type rotating electric machine 100 is shown. The torque (T) of the permanent magnet reluctance type rotating electric machine 100 is obtained by a magnet torque calculated from ϕ_a (an interlinkage flux on a d-q axis) and I_a (an armature current), and a reluctance torque which is generated from inductance difference of the d-q axis. The expression is shown by Number 1.

[Number 1]

$$T = P_n \{ \Psi_a i_q + (L_d - L_q) i_d i_q \} = T_m + T_r$$

T_m : magnet torque, T_r : reluctance torque, P_n : number of pole pairs.

[Number 2]

$$V_a = \sqrt{v_d^2 + v_q^2} = \sqrt{(Ri_d - \omega L_q i_q)^2 + (Ri_q + \omega L_d i_d + \omega \Psi_a)^2}$$

R : stator winding resistance, $\phi_a = \sqrt{3} \phi_e$, ϕ_e : effective value of stator interlinkage flux by permanent magnet, v_d , v_q : d, q-axis components of stator voltage, I_d , I_q : d, q-axis components of stator current, ω : electric angular velocity

[0025] From Number 1, a ratio L_q/L_d is made larger, and thereby the reluctance torque (T_r) can be made higher, and since the reluctance torque (T_r) is combined with the magnet

torque (T_m), it is found that high efficiency in torque generation to a current can be achieved. In addition, it is found from Number 2 that the terminal voltage is determined by the both influences of the inductance and the permanent magnet flux. In order to extract the best motor property in the given voltage and current, a configuration becomes necessary which ensures a magnet area in which the magnetic flux of the magnet can be properly controlled, in a rotor cross section.

[0026] In order to realize the confabulation as described above, the configuration becomes necessary in which the reluctance torque (T_r) and the magnet torque (T_m) are properly balanced. A shape which maximizes the ratio L_q/L_d is a rotor shape in which a magnetic pass is formed in the core so that a magnetic flux amount in the q-axis direction is maximum, and the permanent magnet 4 and the magnetic barrier 12 are provided so that a magnetic flux amount in the d-axis direction is minimum. In addition, in order to properly control the voltage, the magnet arrangement is to be made such that the magnetic flux of the magnet is weakened by the armature magnetic flux from the stator side.

[0027] Comparison between torque-rotating speed properties of a permanent magnet reluctance type rotating electric machine having an arrangement that the permanent magnets 4 are overlapped, and a permanent magnet reluctance type rotating electric machine having an arrangement that the

permanent magnets 4 are not overlapped is shown in Fig. 3. In Fig. 3, a torque-rotating speed property 81 having the arrangement that the permanent magnets 4 are overlapped, and a torque-rotating speed property 80 having the arrangement that the permanent magnets 4 are not overlapped. The Fig. shows that at the rotating speed of 5,000 or more, the torque-rotating speed property 80 in which the permanent magnets 4 are not overlapped can output larger torque than the torque-rotating speed property 81 in which the permanent magnets 4 are overlapped. That is, the permanent magnets 4 are arranged so as not to overlap with each other, and thereby the torque output at the time of middle to high speed can be improved.

[0028] (Effect)

According to the present embodiment, the permanent magnets 4 provided in the rotor core 8 are arranged so that they are not overlapped with each other seen from a direction via a gap with the stator teeth 2, and thereby it is possible to provide the permanent magnet reluctance type rotating electric machine which can properly balance the magnet torque and the reluctance torque and the voltage, and can realize miniaturization thereof.

[0029] (Second embodiment)

A second embodiment will be described in detail with reference to Fig. 4 to Fig. 5. Fig. 4 is a configuration diagram having a first rotor cutting portion, in a permanent

magnet reluctance type rotating electric machine of a second embodiment. Fig. 5 is a diagram showing an example of torque-rotating speed properties in a case that magnets for saturating a bridge portion are arranged in the vicinity of the bridge portion between the magnets, and in a case that the magnets are not arranged, in a permanent magnet reluctance type rotating electric machine 101 of the second embodiment.

[0030] In addition, the same symbols are given to portions with the same configuration as shown in Fig. 1 to Fig. 3, and the description thereof will be omitted.

[0031] (Configuration)

In the rotor 5 of the second embodiment shown in Fig. 4, a third permanent magnet 4c is provided at the d-axis side of the first permanent magnet 4a via a magnetic barrier 12c. A third bridge portion 13c is sandwiched between the third permanent magnets 4c which are symmetric with respect to the d-axis as a center. In addition, the vicinity of the third bridge portion 13c is made a third magnetic pass narrow portion.

[0032] In the description of the second embodiment, the case that the third permanent magnets 4c are provided at the both sides of the third bridge portion 13c has been described as an example, but the embodiment includes a case that the same measure is applied to a magnetic pass narrow portion between the magnets.

[0033] (Action)

Next, the property of the present embodiment will be described. The permanent magnet reluctance type rotating electric machine makes use of the magnet torque (T_m) and the reluctance torque (T_r), as described above. In order to make use of the magnet torque effectively, the leakage of the magnetic flux of the magnet in the bridge portion 13 has to be prevented. For this reason, the magnets are arranged in the vicinity of the bridge portion 13 (that is, the third magnetic pass narrow portion and the second magnetic pass narrow portion at the outer circumferential side of the rotor), and only the vicinity is magnetically saturated, to increase the magnetic resistance, and thereby it becomes possible to prevent the leakage flux. In addition, it becomes possible to obtain desired property, by making the magnetic force of the magnet variable.

[0034] Comparison between torque-rotating speed properties of a permanent magnet reluctance type rotating electric machine in which the third permanent magnets 4c are arranged in the vicinity of the third bridge portion 13c shown in Fig. 4, and a permanent magnet reluctance type rotating electric machine in which the third permanent magnets 4c are not arranged in the vicinity of the third bridge portion 13c is shown in Fig. 5. 82 of Fig. 5 is a torque-rotating speed property in a case that the third permanent magnets 4c are arranged in the vicinity of the

third bridge portion 13c. 83 is a torque-rotating speed property in a case that the third permanent magnets 4c are not arranged in the vicinity of the third bridge portion 13c. It is indicated by Fig. 5 that in the whole rotating speed area, the torque-rotating speed property 82 in a case that the third permanent magnets 4c are arranged in the vicinity of the third bridge portion 13c can output a larger torque than the torque-rotating speed property 83 in a case that the third permanent magnets 4c are not arranged in the vicinity of the third bridge portion 13c. That is, the magnets are arranged in the vicinity of the bridge portion 13, to improve the torque output.

[0035] (Effect)

According to the present embodiment, the magnets are arranged in the vicinity of the third bridge portion 13c (that is, the vicinity of the third magnetic pass narrow portion), and only this vicinity is magnetically saturated to increase the magnetic resistance, and the leakage flux is prevented, and thereby it is possible to provide the permanent magnet reluctance type rotating electric machine which can improve the torque, and can realize miniaturization thereof.

[0036] All embodiments described above have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the embodiments described herein may be embodied in a variety of other forms;

furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

DESCRIPTION OF THE SYMBOLS

[0037]

- 1 stator
- 2 stator teeth
- 3 armature winding
- 4 permanent magnet
- 4a first permanent magnet
- 4b second permanent magnet
- 4c third permanent magnet
- 5 rotor
- 6 rotor electromagnetic steel sheet
- 7 stator core
- 8 rotor core
- 9 rotor shaft
- 10 stator electromagnetic steel sheet
- 11 stator slot
- 12 magnetic barrier
- 13 bridge
- R stator winding resistance
- Ia armature current

ϕ_e effective value of stator interlinkage flux by
permanent magnet

v_d d-axis component of stator voltage

v_q q-axis component of stator voltage

i_d d-axis component of stator current

i_q q-axis component of stator current

ω electric angular velocity (rotating speed)

P_n number of pole pairs

L_d d-axis component of inductance

L_q q-axis component of inductance

V_a voltage

β phase angle of i_d and i_q

δ phase angle of i_q and V_a

80 permanent magnets do not overlap

81 permanent magnets overlaps

82 magnets are arranged in the vicinity of bridge

portion

83 magnets are not arranged in the vicinity of bridge

portion

SCOPE OF CLAIMS

[Claim 1] A permanent magnet reluctance type rotating electric machine comprising:

a stator having an armature winding in a stator core;
and

a rotor which is located at an inner circumferential side of the stator, and is provided with permanent magnets in a rotor core;

the permanent magnets being arranged in a multilayer, and arranged at positions so that end portions of the respective permanent magnets do not almost overlap with each other.

[Claim 2] The permanent magnet reluctance type rotating electric machine as recited in Claim 1 wherein:

the permanent magnets have a pair of a first permanent magnet group and a second permanent magnet group, each having a d-axis as a center line; and

the end portion at an inner side of the first permanent magnet group is arranged at a position not to almost overlap with the end portion at an outer side of the second permanent magnet group.

[Claim 3] The permanent magnet reluctance type rotating electric machine as recited in Claim 2 wherein:

the permanent magnet of the first permanent magnet group is located between magnetic barriers, and the magnetic barrier at an inner side is longer than the magnetic barrier

at an outer side; and

the permanent magnet of the second permanent magnet group is located between magnetic barriers, and the magnetic barrier at an outer side is longer than the magnetic barrier at an inner side.

[Claim 4] The permanent magnet reluctance type rotating electric machine as recited in Claim 1 wherein:

magnetic force of the permanent magnet is made variable.

[Claim 5] The permanent magnet reluctance type rotating electric machine as recited in Claim 1, characterized in that:

the stator has a stator slot to house the armature winding at an inner circumferential side of the stator core,

[Claim 6] The permanent magnet reluctance type rotating electric machine as recited in Claim 1, characterized in that:

the stator core is composed by laminating stator electromagnetic steel sheets of a thin sheet.

[Claim 7] The permanent magnet reluctance type rotating electric machine as recited in Claim 1, characterized in that:

the rotor is arranged opposite to the stator via a gap at an inner circumferential side of the stator;

a rotor shaft is provided at an inner circumferential side of the rotor; and

the permanent magnets are arranged so that they do not

overlap with each other seen from a direction via the gap with the stator.

[Claim 8] The permanent magnet reluctance type rotating electric machine as recited in Claim 1, characterized in that:

the rotor core is composed by laminating rotor electromagnetic steel sheets of a thin sheet.

[Claim 9] The permanent magnet reluctance type rotating electric machine as recited in Claim 1, characterized in that:

the permanent magnets are composed of a first permanent magnet and a second permanent magnet; and

the second permanent magnet is arranged at the stator side than the first permanent magnet.

[Claim 10] The permanent magnet reluctance type rotating electric machine as recited in Claim 9, characterized by further comprising:

a first outer magnetic barrier and a first inner magnetic barrier which are arranged to sandwich the first permanent magnet, to block magnetism; and

a second outer magnetic barrier and a second inner magnetic barrier which are arranged to sandwich the second permanent magnet, to block magnetism.

[Claim 11] The permanent magnet reluctance type rotating electric machine as recited in Claim 10, characterized in that:

magnetic path narrow portions are respectively provided in the vicinity of the first inner magnetic barrier and the second inner magnetic barrier.

[Claim 12] The permanent magnet reluctance type rotating electric machine as recited in Claim 10, characterized by further comprising:

a third permanent magnet at a d-axis side of the first permanent magnet, via the first inner side magnetic barrier.

[Claim 13] The permanent magnet reluctance type rotating electric machine as recited in Claim 12, characterized in that:

magnetic path narrow portions are respectively provided in the vicinity of the first inner magnetic barrier and the third permanent magnet.

[Claim 14] The permanent magnet reluctance type rotating electric machine as recited in Claim 8, characterized in that:

when a normal line on an outer circumferential face of the rotor shaft is drawn toward an outer circumferential face of the rotor, the first permanent magnet and the second permanent magnet are arranged so that both of them are not present on the normal line all together.