cross section, the permanent-magnet reference end portion of the permanent magnet at the position closest to the open end portion is, of end portions of the permanent magnet, an end portion at a position at the farthest distance in the circumferential direction from a straight line passing through a central position in the circumferential direction of a region of one pole including the permanent magnet, and the rotation axis line, and the distance in the circumferential direction from a straight line passing through the central position in the circumferential direction of the region of one pole including the permanent magnet, at the position closest to the open end portion, and the rotation axis line is a distance defined on a side, of the front side and the rear side in the rotation direction of the rotor core, in which the open end portion is present.

A rotor of the present invention includes the rotor core, and a plurality of permanent magnets installed in the rotor core.

A rotary electric machine of the present invention includes the rotor, and a stator.

BRIEF DESCRIPTION OF DRAWINGS

[0007] [Fig. 1] Fig. 1 is a view illustrating one example of a basic shape of an IPMSM.

[Fig. 2] Fig. 2 is a view illustrating a rotor cross section of the IPMSM illustrated in Fig. 1.

flowing out from the permanent magnets 112a to 112b to the permanent magnets 112. In the bridge portions 116a to 116b, 117a, an area of a cross section perpendicular to a traveling direction of the magnetic flux is smaller than that of the other region. Accordingly, magnetic resistances of the bridge portions 116a to 116b, 117a are larger than a magnetic resistance of the other region of the soft magnetic material forming the rotor core 111. Thus, providing the bridge portions 116a to 116b, 117a allows the suppression of the return of the magnetic flux flowing out from the permanent magnets 112a to 112b to the permanent magnets 112. The bridge portions 116a to 116b, 117a are present for securing mechanical strength of the rotor core 111. The magnetic flux passing through the bridge portions 116a to 116b, 117a flows back to the permanent magnets 112a to 112b, which has given a common general technical knowledge of hardly contributing to torque of the rotor 110 to a person skilled in the art so far. In the following explanation, a magnetic flux flowing out from one pole face of the permanent magnet, passing through the bridge portion, and returning (flowing back) to the other pole face of the permanent magnet is referred to as a reflux magnetic flux as necessary.

[0021] The present inventors designed a shape of the rotor core 111 according to the technique described in the specification of Japanese Laid-open Patent

[0023] The outer-peripheral-side flux barriers 113c to 113d illustrated in Fig. 3 reduce the reflux magnetic flux. In addition to this, the present inventors gave attention to a displacement of open end portions 310c to 310d of the outer-peripheral-side flux barriers 113c to 113d to a rear side in the rotation direction of the rotor core 111 (a side opposite to the rotation direction) as illustrated in Fig. 3. Then, the present inventors considered that the outer-peripheral-side flux barriers 113c to 113d play a role other than the reduction in reflux magnetic flux known as the common general technical knowledge so far.

[0024] Thus, the present inventors reviewed, of results of electromagnetic field analysis (magnetic flux density vector) in the IPMSM 100 in the optimum shape illustrated in Fig. 3, the result near the outer-peripheral-side flux barriers 113c to 113d. Note that in Fig. 3, r, θ represent a moving radius and an argument in polar coordinates (circular coordinates), respectively. In Fig. 3, a position of the rotation axis line 0 in a cross section of the rotor core 111 when cut perpendicularly to the rotation axis line 0 of the rotor core 111 is set as the origin 0 of the polar coordinates. Further, a direction from the origin 0 toward an outer side is a positive direction of a moving radius direction (a radial direction of the IPMSM 100), and a counterclockwise direction opposite to the sheet

paper (rotation direction) is set as a positive direction of the argument. Incidentally, the outer side is a side where the outer peripheral surface 115 of the rotor core 111 is present.

[0025] Fig. 4A to Fig. 4B are views for explaining a first result of the electromagnetic field analysis in the IPMSM 100 in the optimum shape. Fig. 4A is the view illustrating one example of the magnetic flux density vector in the IPMSM 100 in the optimum shape. Fig. 4B is the view for explaining one example of an outline of flows, of magnetic fluxes in the IPMSM 100 in the optimum shape, of magnetic fluxes near the outer peripheral surface 115 of the rotor core 111. In Fig. 4A, the magnetic flux density vector is represented by arrows each having a density corresponding to the magnitude thereof. However, for the convenience of notation, Fig. 4A cannot clearly illustrate characteristics of the magnetic flux density vector. Thus, for the convenience of explanation, Fig. 4B illustrates the outline of the flows, of the magnetic fluxes in the IPMSM 100 in the optimum shape, of magnetic fluxes necessary for the explanation. In Fig. 4B, "N" and "S" indicated in the permanent magnets 112a to 112b indicate magnetic poles (N pole and S pole) of the rotor 110. Accordingly, the pole faces 201a, 201c of the permanent magnets 112a, 112b are the pole faces of N pole, and the pole face 201b, 201d thereof are the pole faces of S pole.

permanent magnet 112a positioned on the front side in the rotation direction is referred to as the permanent magnet 112a on the front side as necessary. Further, the permanent magnet 112b positioned on the rear side in the rotation rear direction is referred to as the permanent magnet 112b on the rear side as necessary.

[0029] The outer-peripheral-side flux barrier 113c reduces the reflux magnetic flux flowing back from one pole face (for example, N pole) of the permanent magnet 112a on the front side via the outer-peripheral-side bridge portion 116a illustrated in Fig. 2 to the other pole face (for example, S pole). Similarly, the outer-peripheral-side flux barrier 113d reduces the reflux magnetic flux flowing back from one pole face (for example, N pole) of the permanent magnet 112b on the rear side via the outer-peripheral-side bridge portion 116b illustrated in Fig. 2 to the other pole face (for example, S pole).

[0030] Meanwhile, the torque of the rotor 110 is proportional to the inner product of a moving radius direction (the radial direction of the IPMSM 100) component B_r and a circumferential direction component B_θ of the magnetic flux density vector in a gap G between the rotor 110 (rotor core 111) and the stator 120 (stator core 121). In the following explanation, the moving radius direction (the radial direction of the IPMSM 100) component is referred to as a radial direction component as necessary. Accordingly, when

direction component B_θ of the magnetic flux density vector from the stator 120 toward the rotor 110 are negative, and a direction of this magnetic flux density vector is a direction greatly inclining to the radial direction of the IPMSM 100, the torque of the rotor 110 increases.

[0036] Further, as previously described, the result of the electromagnetic field analysis illustrated in Fig. 4A is the result when the exciting current flowing through the non-illustrated stator coil is the three-phase alternating current. Accordingly, the rotating magnetic field is generated in the IPMSM 100. A rotation period of the rotor 110 (rotor core 111) and a rotation period of the rotating magnetic field generated in the stator core 121 (teeth 123) are the same. Thus, a positional relationship between the rotor core 111 and the rotating magnetic field has no change even though the rotor core 111 rotates. Incidentally, the exciting current used in the present application is not limited to the three-phase alternating current.

[0037] Thus, in Fig. 4B, the recess portion 118a faces the teeth 123a, 123c with a high magnetic flux density (the teeth 123a, 123c in each of which the number of arrows are two) even though the rotor core 111 rotates. The magnetic flux $\phi 2$ from the teeth 123c of the stator core 121 toward the region on the rear side in the rotation direction of the IPMSM 100 further than the recess portion 118a in the region of

component B_r and the circumferential direction component B_θ of the magnetic flux density vector become negative and positive, respectively.

[0045] ((Third finding))

In Fig. 1 and Fig. 2, the inter-magnet bridge portion 117 is composed of the soft magnetic material. Accordingly, air is smaller in magnetic permeability than the inter-magnet bridge portion 117. Thus, air is larger in magnetic resistance than the inter-magnet bridge portion 117. Accordingly, if all inter-magnet bridge portions including the inter-magnet bridge portion 117a illustrated in Fig. 1 and Fig. 2 are flux barriers (gap portions), the region of the magnetic substance material composing the inter-magnet bridge portions is replaced with the gap portion. This replacement reduces the magnetic permeability in this region. Accordingly, the magnetic resistance in this region increases. According to the previously-described common general technical knowledge, the reflux magnetic flux is considered to be reduced. Therefore, the present inventors predicted that not only the outer-peripheral-side bridge portions 116a to 116b illustrated in Fig. 1 and Fig. 2 but also the inter-magnet bridge portion 117a becomes the flux barrier (gap portion). However, as a result, the IPMSM 100 in the optimum shape illustrated in Fig. 3 is different from this prediction. However, in the IPMSM 100 in the optimum shape illustrated in Fig. 3,

as illustrated by the inter-magnet flux barriers 114c to 114d, the inter-magnet flux barriers 114a to 114b illustrated in Fig. 1 and Fig. 2 are not coupled. That is, in the IPMSM 100 in the optimum shape illustrated in Fig. 3, as illustrated by the inter-magnet bridge portion 117b, a part of the inter-magnet bridge portion 117a illustrated in Fig. 1 and Fig. 2 remains. The IPMSM 100 in the optimum shape illustrated in Fig. 3 thus results in having the shape different from the previously-described prediction.

[0046] Further, in Fig. 1 and Fig. 2, the outer-peripheral-side bridge portions 116a to 116b are in positions closer to the stator 120 than the inter-magnet bridge portion 117a. Accordingly, the magnetic flux passing through the outer-peripheral-side bridge portions 116a to 116b heads for the stator 120 side more easily than the magnetic flux passing through the inter-magnet bridge portion 117a. Thus, the magnetic flux passing through the outer-periphery-side bridge portions 116a to 116b is considered to be less likely to become the reflux magnetic flux than the magnetic flux passing through the inter-magnet bridge portion 117a. Therefore, the coupled inter-magnet flux barriers 114a to 114b are considered to allow the magnetic flux heading for the stator 120 side to be increased more than the outer-peripheral-side flux barriers 113a to 113b reaching the outer peripheral surface 115 of the rotor core

adopted. For example, a so-called skew may be performed on the rotor core 111. Specifically, the skew is achieved by stacking a plurality of soft magnetic material blocks in the z-axis direction in a state of rotating them by a predetermined angle in the same direction with the z axis set as an axis. For this manner, the permanent magnets are installed in each soft magnetic material block. Accordingly, for example, as many permanent magnets as the product of the number of magnet holes of each soft magnetic material block and the number of the soft magnetic material blocks are required. Performing such a skew allows suppression of vibrations of a rotary electric machine.

[0052] Here, the soft magnetic material block is produced by stacking a plurality of soft magnetic material plates having the same size and shape in such a manner that their contours (an inner edge and an outer edge) coincide, for example. The soft magnetic material plates used for each soft magnetic material block may have the same shape and size or different shapes and sizes. However, when the plurality of soft magnetic material blocks are stacked, outer edges of the soft magnetic material blocks coincide. Further, the soft magnetic material blocks may have the same predetermined angle or different predetermined angles. Further, the soft magnetic material block may be formed without using the plate-shaped soft magnetic material.

800 when cut perpendicularly to a rotation axis line 0 of the IPMSM 800 (rotor 810). Similarly to Fig. 1, in Fig. 8, a range of a double arrow indicated as "one pole" is a section forming one pole of the IPMSM 800. This embodiment exemplifies a case where the IPMSM 800 has eight poles. However, the number of poles of the IPMSM 800 is not limited to eight. As previously described, when the number of poles of the IPMSM 800 is n, the IPMSM 800 has, on the whole, a relation of rotational symmetry of n-time symmetry in which the rotation axis line 0 of the IPMSM 800 is set as a rotation symmetry axis. n is an integer of two or more, and n is eight in the example illustrated in Fig. 8 (n = eight).

[0060] In Fig. 8, the IPMSM 800 includes a rotor 810 and the stator 120. The stator 120 is the same as the stator 120 illustrated in Fig. 1. Accordingly, here, the same reference sign as the reference sign given in Fig. 1 is given, and a detailed explanation of the stator 120 is omitted. The IPMSM 800 includes the stator 120 (the non-illustrated stator coil and the stator core 121) defined as follows, for example. The stator core 121 is formed of a yoke portion having a fixed width and 24 teeth portions, for example. The width of the yoke portion and a length of the teeth portion are each a length in a radial length of the IPMSM 800. A shape of the yoke portion is circular, for example. The 24 teeth portions are installed at regular intervals on an inner peripheral

front-side corner portion, a rear-side open-end front-side corner portion as necessary. Further, in the following explanation, the open end portion 1111a of the front-side magnet hole 817a and the open end portion 1111b of the rear-side magnet hole 817b are respectively referred to as the front-side open end portion 1111a and the rear-side open end portion 1111b as necessary.

[0084] The front-side open-end front-side corner portion 1131a is, of the two corner portions 1131a to 1131b in the circumferential direction of the rotor core 811 of the front-side open end portion 1111a which is the open end portion of a space 1123a included in the front-side magnet hole 817a and serving as the outer-peripheral-side flux barrier, the corner portion 1131a on the front side in the rotation direction of the rotor core 811.

[0085] The rear-side open-end front-side corner portion 1131c is, of the two corner portions 1131c to 1131d in the circumferential direction of the rotor core 811 of the rear-side open end portion 1111b which is the open end portion of a space 1123b included in the rear-side magnet hole 817b and serving as the outer-peripheral-side flux barrier, the corner portion 1131c on the front side in the rotation direction of the rotor core 811.

[0086] Further, in the rotor core cross section, the permanent-magnet reference end portions 841a to 841b have the front-side permanent magnet end portion 841a

and the rear-side permanent magnet end portion 841b. The front-side permanent magnet end portion 841a is, of the end portions of the permanent magnets 812a to 812b installed through the front-side magnet hole 817a, the end portion at a position on the foremost side in the rotation direction. The rear-side permanent magnet end portion 841b is, of the end portions of the permanent magnet 812b installed through the rear-side magnet hole 817b, the end portion at a position on the rearmost side in the rotation direction.

[0087] Further, in the rotor core cross section, the reference positions 831a to 831b have the front-side reference position 831a. The reference position 831a is a position at an intersection point of the straight line 1172 passing through the front-side permanent magnet end portion 841a and the rotation axis line 0, and the outer peripheral surface 818 of the rotor core 811.

[0088] Further, in the rotor core cross section, the reference positions 831a to 831b have the rear-side reference position 831b. The rear-side reference position 831b is a position at an intersection point of the straight line 1174 passing through the rear-side permanent magnet end portion 841b and the rotation axis line 0, and the outer peripheral surface 818 of the rotor core 811.

[0089] Here, from the viewpoint of certainly improving the torque of the rotor 810, positions of

straight line 1175 is preferably set to not less than θa/8 nor more than 25θa/24θa, and more preferably set within a range of 3θa/4 ± θa/12. The straight line 1176 is a straight line passing through a recess front-side corner portion 1161b and the rotation axis line 0 in the rotor core cross section. The recess front-side corner portion 1161b is, of the two corner portions 1161a to 1161b in the open end portion 1151a of the recess portion 815a, the corner portion on the front side in the rotation direction, in the rotor core cross section. The straight line 1175 is the straight line passing through the recess rear-side corner portion 1161a and the rotation axis line 0 in the rotor core cross section. In the following explanation, the angle θc is referred to as the recess opening angle θc as necessary.

[0096] Further, a maximum value Cd of a depth of the recess portion 815a is preferably set within a range of not less than 0.01 times nor more than 0.1 times a diameter of the rotor core 811, and preferably set within a range of not less than 0.04 times nor more than 0.07 times the diameter of the rotor core 811. In the following explanation, the maximum value Cd of the depth of the recess portion 815a is referred to as the maximum recess-depth value Cd as necessary.

[0097] Further, a shape of the recess portion 815a is not limited. Fig. 11A exemplifies a case where a planar shape (a shape of the rotor core cross section) of the recess portion 815a is a quadrangle

the magnet holes 817e, 817f from the corner portions 1131b, 1131c defining the first end portions 1111 to the corner portions 1132k, 1132m defining the second end portions 1112.

[0110] Back to the explanation of Fig. 11A, the fourth end portions 1114a to 1114b will be explained. The fourth end portions 1114a to 1114b are end portions positioned on the inner peripheral side in the magnetization direction Dm of the permanent magnets 812a, 812b. In the example illustrated in Fig. 11A, the fourth end portions 1114a, 1114b are regions along contours of the magnet holes 817a, 817b from the corner portions 1131a, 1131d positioned on outer sides, of the two corner portions 1131a to 1131b and the two corner portions 1131c to 1131d defining the first end portions 1111a, 1111b, to the corner portions 1132b, 1132d positioned on the inner peripheral side in the magnetization direction Dm of the permanent magnets 812a, 812b, of the two corner portions 1132a to 1132b and the two corner portions 1132c to 1132d defining the second end portions 1112a, 1112b. The outer side is a side close to an end in the circumferential direction of the region of one pole of the rotor. In the example illustrated in Fig. 11B, fourth end portions 1114c, 1114d are regions along contours of the magnet holes 817c, 817d from the corner portions 1131a, 1131d defining the first end portions 1111 to the corner portions 1132g, 1132j defining the second end portions 1112c, 1112d,

for example. In the example illustrated in Fig. 11C, fourth end portions 1114e, 1114f are regions along contours of the magnet holes 817e, 817f from the corner portions 1131a, 1131d defining the first end portions 1111 to the corner portions 1132l, 1132n defining the second end portions 1112.

[0111] In Fig. 11A to Fig. 11c, each two of the magnet holes 817a to 817b, 817c to 817d, 817e to 817f through which the permanent magnets 812a to 812b are installed have spaces 1121a to 1121b in which the permanent magnets 812a to 812b are installed. Further, the magnet holes 817a to 817b, 817c to 817d, 817e to 817f through each two of which the permanent magnets 812a to 812b are installed have spaces 1122a to 1122b, 1122c to 1122d, 1122e to 1122f serving as the inter-magnet flux barriers between the spaces 1121a and 1121b in which the permanent magnets 812a to 812b are installed, and each two of second end portions 1112a to 1112b, 1112c to 1112d, 1112e to 1112f. Further, each two of the magnet holes 817a to 817b, 817c to 817d, 817e to 817f through which the permanent magnets 812a to 812b are installed have spaces 1123a to 1123b, each serving as the outer-peripheral-side flux barriers 813a to 813b illustrated in Fig. 9 between the spaces 1121a and 1121b in which the permanent magnets are installed and the first end portions 1111a to 1111b.

[0112] In the following explanation, the spaces

1121a to 1121b in which the permanent magnets 812a to 812b are installed, the spaces 1122a to 1122b, 1122c to 1122d, 1122e to 1122f serving as the inter-magnet flux barriers, and the spaces 1123a to 1123b serving as the outer-peripheral-side flux barriers are respectively referred to as the magnet installation spaces 1121a to 1121b, the inter-magnet flux barrier spaces 1122a to 1122b, 1122c to 1122d, 1122e to 1122f, and the outer-peripheral-side flux barrier spaces 1123a to 1123b as necessary. The magnet installation spaces 1121a to 1121b, the inter-magnet flux barrier spaces 1122a to 1122b, 1122c to 1122d, 1122e to 1122f, and the outer-peripheral-side flux barrier spaces 1123a to 1123b will be explained.

[0113] In the front-side magnet hole 817a, the outer-peripheral-side flux barrier space 1123a is one example of the space serving as a front-side flux barrier. In the rear-side magnet hole 817b, the outer-peripheral-side flux barrier space 1123b is one example of the space serving as a rear-side flux barrier. Further, in the front-side magnet hole 817a, the inter-magnet flux barrier space 1122a is one example of the space serving as a rear-side flux barrier. In the rear-side magnet hole 817b, the inter-magnet flux barrier space 1122b is one example of the space serving as a front-side flux barrier. That is, in the front-side magnet hole 817a and the

the permanent magnets 812a to 812b is not fixed, the length in the width direction of the magnet installation spaces 1121a to 1121b may be equal to the length corresponding to the length in the magnetization direction Dm of the permanent magnets 812a to 812b. In this case, the length in the width direction of the magnet installation spaces 1121a to 1121b is not fixed.

[0116] When the permanent magnets 812a to 812b are installed, at least a part of the region of the magnet installation spaces 1121a to 1121b is occupied by the permanent magnets 812a to 812b, thereby serving as no space. The inter-magnet flux barrier spaces 1122a to 1122b correspond to the inter-magnet flux barriers 814a to 814b illustrated in Fig. 9, and remain spaces even though the permanent magnets 812a to 812b are installed. The outer-peripheral-side flux barrier spaces 1123a to 1123b correspond to the outer-peripheral-side flux barriers 813a to 813b illustrated in Fig. 9, and remain spaces even though the permanent magnets 812a to 812b are installed. Note that when a nonmagnetic material is installed in the inter-magnet flux barrier spaces 1122a to 1122f and the outer-peripheral-side flux barrier spaces 1123a to 1123b, at least a part of a region of the inter-magnet flux barrier spaces 1122a to 1122f and the outer-peripheral-side flux barrier spaces 1123a to 1123b is occupied by the nonmagnetic material.

[0117] Next, one example of a configuration of the

region surrounded by the straight line 1141a connecting the corner portions 1132a, 1132c on the outer peripheral side of the second end portions 1112a to 1112b of the magnet holes 817a to 817b, the straight line 1141b connecting the corner portions 1132b, 1132d on the inner peripheral side of the second end portions 1112a to 1112b of the two magnet holes 817a to 817b, and the second end portions 1112a to 1112b of the two magnet holes 817a to 817b. The inter-magnet bridge portion 821a coincides with the bridge outer edge portion 831a. Fig. 10 and Fig. 11A illustrate the reference signs 821a and 831a side by side, which means this.

[0121] Further, in the examples illustrated in Fig. 11B and Fig. 11C, the bridge outer edge portions are defined as follows.

In the example illustrated in Fig. 11B, the bridge outer edge portion 831b is a region surrounded by the straight line 1141c connecting the corner portions 1132e, 1132h on the outer peripheral side of the second end portions 1112c to 1112d of the magnet holes 817a to 817b, the straight line 1141d connecting the corner portions 1132g, 1132j on the inner peripheral side of the second end portions 1112c to 1112d of the two magnet holes 817a to 817b, and the second end portions 1112c to 1112d of the two magnet holes 817a to 817b. The inter-magnet bridge portion 821i coincides with the bridge outer edge portion 831b. Fig. 11B illustrates the reference

signs 821i and 831b side by side, which means this.

[0122] In the example illustrated in Fig. 11C, the bridge outer edge portion 831c is a region surrounded by the straight line 1141f connecting the corner portions 1132k, 1132m on the outer peripheral side of the second end portions 1112e to 1112f of the magnet holes 817a to 817b, the straight line 1141g connecting the corner portions 1132l, 1132n on the inner peripheral side of the second end portions 1112e to 1112f of the two magnet holes 817a to 817b, and the second end portions 1112e to 1112f of the two magnet holes 817a to 817b. The inter-magnet bridge portion 821j coincides with the bridge outer edge portion 831c. Fig. 11C illustrates the reference signs 821j and 831c side by side, which means this.

[0123] The outer side portion 822a is a region where the soft magnetic material is present in an outer-side outer edge portion. The outer-side outer edge portion is a region coupled to the inter-magnet bridge portion 821a on the outer peripheral side of the inter-magnet bridge portion 821a. In the examples illustrated in Fig. 10 and Fig. 11A, the outer-side outer edge portion is a region surrounded by the third end portions 1113a to 1113b of the two magnet holes 817a to 817b through which the permanent magnets 812a to 812b are installed and the outer peripheral surface 818 of the rotor core 811. In Fig. 10, this embodiment exemplifies a case where only the soft magnetic material is present in the outer-side

outer-side outer edge portion 832b is a region surrounded by the straight line 1141c connecting the corner portions 1132e, 1132h on the outer peripheral side of the second end portions 1112c to 1112d of the magnet holes 817c to 817d, the third end portions 1113c to 1113d of the two magnet holes 817c to 817d, and the outer peripheral surface 818 of the rotor core 811. The outer side portion 822i coincides with the outer-side outer edge portion 832b. Fig. 11B illustrates the reference signs 822i and 832b side by side, which means this.

[0126] In the example illustrated in Fig. 11C, the outer-side outer edge portion 832c is a region surrounded by the straight line 1141f connecting the corner portions 1132k, 1132m on the outer peripheral side of the second end portions 1112e to 1112f of the magnet holes 817e to 817f, the third end portions 1113e to 1113f of the two magnet holes 817e to 817f, and the outer peripheral surface 818 of the rotor core 811. The outer side portion 822j coincides with the outer-side outer edge portion 832c. Fig. 11C illustrates the reference signs 822j and 832c side by side, which means this.

[0127] The inner side portion 823a is a region where the soft magnetic material is present in an inner-side outer edge portion. The inner-side outer edge portion is a region of the soft magnetic material coupled to the inter-magnet bridge portion 821a on the inner peripheral side of the inter-magnet bridge

portion 821a. In the examples illustrated in Fig. 10 and Fig. 11A, the inner-side outer edge portion is a region surrounded by the fourth end portions 1114a to 1114b of the two magnet holes 817a to 817b through which the permanent magnets 812a to 812b are installed, the outer peripheral surface 818 of the rotor core 811, and the inner peripheral surface 819 of the rotor core 811. In Fig. 10, this embodiment exemplifies a case where only the soft magnetic material is present in the inner-side outer edge portion 833a. The presence of only the soft magnetic material means that the region except for the soft magnetic material, such as the flux barrier, is not included. Accordingly, the inner side portion 823a coincides with the inner-side outer edge portion 833a. However, the inner-side outer edge portion 833a may include the region except for the soft magnetic material, such as the flux barrier. In this case, the inner side portion 823a is a region eliminating the region except for the soft magnetic material from the inner-side outer edge portion 833a. Further, in the example illustrated in Fig. 10, the inner side portion 823a is one in number. Note that the inner side portion 823a need not necessarily be surrounded by the outer peripheral surface 818 of the rotor core 811. For example, when the rotor core 811 is formed in such a manner that the soft magnetic material is absent between the outer-peripheral-side flux barriers 813a to 813b(outer-peripheral-side flux barrier

spaces 1123a to 1123b) of the poles adjacent to each other, the inner side portion 823a is not surrounded by the outer peripheral surface 818 of the rotor core 811.

[0128] Specifically in the example illustrated in Fig. 11A, the inner-side outer edge portion 833a is a region surrounded by the straight line 1141b connecting the corner portions 1132b, 1132d on the inner peripheral side of the second end portions 1112a to 1112b of the two magnet holes 817a to 817b through which the permanent magnets 812a to 812b are installed, the fourth end portions 1114a to 1114b of the two magnet holes 817a to 817b, the outer peripheral surface 818 of the rotor core 811, and the inner peripheral surface 819 of the rotor core 811. The inner side portion 823a coincides with the inner-side outer edge portion 833a. Fig. 10 and 11A illustrate the reference signs 823a and 833a side by side, which means this.

[0129] Further, in the examples illustrated in Fig. 11B and Fig. 11C, the inner-side outer edge portions are defined as follows.

In the example illustrated in Fig. 11B, an inner-side outer edge portion 833b is a region surrounded by the straight line 1141d connecting the corner portions 1132g, 1132j on the inner peripheral side of the second end portions 1112c to 1112d of the two magnet holes 817c to 817d through which the permanent magnets 812a to 812b are installed, the fourth end portions 1114c to 1114d of the two magnet holes 817c

to 817d, the outer peripheral surface 818 of the rotor core 811, and the inner peripheral surface 819 of the rotor core 811. An inner side portion 823b coincides with the inner-side outer edge portion 833b. Fig. 11B illustrates the reference signs 823b and 833b side by side, which means this.

[0130] In the example illustrated in Fig. 11C, an inner-side outer edge portion 833c is a region surrounded by the straight line 1141g connecting the corner portions 1132l, 1132n on the inner peripheral side of the second end portions 1112e to 1112f of the two magnet holes 817e to 817f through which the permanent magnets 812a to 812b are installed, the fourth end portions 1114e to 1114f of the two magnet holes 817e to 817f, the outer peripheral surface 818 of the rotor core 811, and the inner peripheral surface 819 of the rotor core 811. An inner side portion 823c coincides with the inner-side outer edge portion 833c. Fig. 11C illustrates the reference signs 823c and 833c side by side, which means this.

[0131] Next, widths w of the inter-magnet bridge portions 821 will be explained. The widths w of the inter-magnet bridge portions 821 are indicated by lengths, of portions overlapping with the soft magnetic material, of bridge-width specified lines 1142a to 1142c in the rotor core cross section. As illustrated in Fig. 11A to Fig. 11C, the bridge-width specified lines 1142a to 1142c are each a straight line connecting each two of the second end portions

Table 1 reveal that even though only one or the other of the movement angle θf of the outer-peripheral-side flux barrier on the front side and the movement angle θb of the flux barrier on the rear side is in the ranges explained in this embodiment, the torque of the rotors can be improved.

[0156] However, in Table 1, the number 23 in which both the movement angle θf of the outer-peripheral-side flux barrier on the front side defined as indicated in the number 9 and the movement angle θb of the flux barrier on the rear side as indicated in the number 19 are set within the ranges defined in this embodiment demonstrates that a value of the increase and decrease in torque is larger than those in the numbers 2 to 16, 18 to 20, which allows further improvement in the torque of the rotor.

[0157] Further, as explained in this embodiment, the recess opening angle θc is preferably set to not less than θa/8 nor more than 25θa/24θa, and more preferably set within the range of 3θa/4 ± θa/12. In this calculation example, the reference-position movement angle θa is 2π/24 (rad) = 15(°). Accordingly, the recess opening angle θc is preferably set to not less than 1.975° nor more than 15.625°, and preferably set within a range of 11.25° ± 1.25°. Further, the maximum recess-depth value Cd is preferably set within the range of not less than 0.01 times nor more than 0.1 times the diameter of the rotor core. In this calculation example as

targeted for being analyzed in the number 36 in Table 2. Further, Fig. 12D is the view illustrating the configuration of the rotor (rotor cross section) targeted for being analyzed in the number 27 in Table 2 (the number 24 in Table 1) as previously described. The number 36 in Table 2 is different in the recess opening angle θc between the recess portions 1242a and 1242b from the number 27 in Table 2 (the number 24 in Table 1).

[0163] In this calculation example as previously described, the recess opening angle θc is preferably set to not less than 1.975° nor more than 15.625°, and more preferably set within the range of 11.25° ± 1.25°. Further, the maximum recess-depth value Cd is preferably set within the range of not less than 0.01 times nor more than 0.1 times the diameter of the rotor core.

[0164] In Table 2, a comparison between the number 23 and the number 25 reveals that the recess opening angle θc of less than 1.975° as in the number 25 fails to contribute to the improvement in the torque of the rotor even though the recess portion is provided. Similarly, a comparison between the number 23 and the number 33 reveals that the recess opening angle θc of more than 15.625° as in the number 33 fails to contribute to the improvement in the torque of the rotor even though the recess portion is provided. Further, a comparison between the number 23 and the number 39 reveals that the maximum recess-

depth value Cd of more than 0.1 times the diameter of the rotor core as in the number 39 fails to contribute to the improvement in the torque of the rotor even though the recess portion is provided.

[0165] On the other hand, in the numbers 26 to 32, 34 to 38 in each of which the recess opening angle θc is not less than 1.975° nor more than 15.625° and the maximum recess-depth value Cd is not less than 0.01 times nor more than 0.1 times the diameter of the rotor core, values of the increase and decrease in torque become larger than that in the number 23. Accordingly, the numbers 26 to 32, 34 to 38 demonstrate that the torque of the rotors can be further improved as compared with the number 23.

[0166] Further, the numbers 29 to 30 in each of which the recess opening angle θc is within the range of 11.25° ± 1.25° demonstrate that the torque of the rotors can be further improved. In particular, the number 30 in which the recess opening angle θc is 11.25° of the center value within the range of 11.25° ± 1.25°indicates the maximum value as the value of the increase and decrease in torque. Further, the numbers 35 to 37 in each of which the maximum recess-depth value Cd is within the range of not less than 0.04 times nor more than 0.07 times the diameter of the rotor core demonstrate that the torque of the rotors can be further improved. In particular, the number 36 in which the maximum recess-depth value Cd indicates a value near the center within the range of

magnet bridge portion flows in the rotor core cross section. The width of the inter-magnet bridge portion is the shortest length in this length in this inter-magnet bridge portion (the length in the direction perpendicular to the direction in which the magnetic flux flows).

[0175] In Fig. 12H, the soft magnetic material (an inter-magnet bridge portion 1232b) is present between permanent magnets 1221a and 1221b (inter-magnet flux barriers 1202d and 1202e). A shape and a size of each of outer-peripheral-side flux barriers 1201j to 1201k are the same as a shape and a size of the inter-magnet flux barrier 1202d to 1202e, illustrated in Fig. 12H. Further, in Fig. 12H, the outer-peripheral-side flux barriers 1201j to 1201k and the inter-magnet flux barriers 1202d to 1202e are disposed in such a manner that a width of each of outer-peripheral-side bridge portions 1231c to 1231d and a width of the inter-magnet bridge portion 1232b are roughly equal. Further, the width of each of the outer-peripheral-side bridge portions 1231c to 1231d and the width of the inter-magnet bridge portion 1232b, illustrated in Fig. 12H, are shorter than the width of each of the outer-peripheral-side bridge portions 1231a to 1231b and the width of the inter-magnet bridge portion 1232a, illustrated in Fig. 12G, respectively.

[0176] As previously described while referring to Fig. 11A to Fig. 11C, the width of the inter-magnet bridge portion is indicated by the length, of the

portion overlapping with the soft magnetic material, of the bridge-width specified line in the rotor core cross section. The bridge-width specified line is the straight line connecting the second end portions of the two magnet holes through which the permanent magnets are installed in such a manner as to make the length of the overlap with the soft magnetic material shortest. As previously described while referring to Fig. 11B and Fig. 11C, the second end portions include the positions at both ends of the straight line drawn so that the length of the overlap with the soft magnetic material composing the soft magnetic material portion has the shortest distance. Accordingly, in the example illustrated in Fig. 12H, a length of a straight line connecting a region between the inter-magnet flux barriers 1202d and 1202e at the shortest distance is the width of the inter-magnetic pole bridge portion.

[0177] Further, the outer-peripheral-side flux barriers 1201j to 1201k illustrated in Fig. 12H do not reach an outer peripheral surface 1211h of the rotor core, and are not open in the rotor core cross section. Further, the inter-magnet flux barriers 1202d to 1202e illustrated in Fig. 12H are not coupled. Accordingly, the soft magnetic material (inter-magnet bridge portion) is present between the inter-magnet flux barriers 1202 (1202d to 1202e).

[0178] The shape and the size of each of the outer-peripheral-side flux barriers 1201h to 1201i

illustrated in Fig. 12I are the same as the shape and the size of each of the outer-peripheral-side flux barriers 1201h to 1201i of the rotor illustrated in Fig. 12G. Accordingly, the shape and the size of each of the outer-peripheral-side bridge portions 1231a to 1231b illustrated in Fig. 12I are the same as the shape and the size of each of the outer-peripheral-side bridge portions 1231a to 1231b of the rotor illustrated in Fig. 12G. Further, in Fig. 12I, a flux barrier on the inner peripheral side in the left-right direction Ds further than the permanent magnets 1221a to 1221b (an inter-magnet flux barrier 1202f) is one in number.

[0179] Table 3 reveals that setting the width of each of the outer-peripheral-side bridge portions 1231a to 1231b and the width of the inter-magnet bridge portion 1232a to be the same as the width of the inter-magnet bridge portion 1132a illustrated in Fig. 12F and to be larger than the inter-magnet bridge portion 1232b illustrated in Fig. 12H, as illustrated in Fig. 12G, further decreases the torque of the rotor than the case of setting the width of each of the outer-peripheral-side bridge portions 1231c to 1231d and the width of the inter-magnet bridge portion 1232b to be smaller as illustrated in Fig. 12H. Further, providing the outer-peripheral-side bridge portions 1231a to 1231b and eliminating the inter-magnet bridge portion as illustrated in Fig. 12I causes the torque of the

rotor to increase more than the case of providing the outer-peripheral-side bridge portions 1231a to 1231b and the inter-magnet bridge portion 1232a as illustrated in Fig. 12G and setting the width of the inter-magnet bridge portion 1232a to be the same as the width of the inter-magnet bridge portion 1232a illustrated in Fig. 12F and to be larger than the inter-magnet bridge portion 1232b illustrated in Fig. 12H. However, eliminating the inter-magnet bridge portion as illustrated in Fig. 12I demonstrates that the torque of the rotor further decreases than the case of providing the outer-peripheral-side bridge portions 1231c to 1231d and the inter-magnet bridge portion 1232b as illustrated in Fig. 12H and setting the width of each of the outer-peripheral-side bridge portions 1231c to 1231d and the width of the inter-magnet bridge portion 1232b to be smaller than the width of each of the outer-peripheral-side bridge portions 1231a to 1231b and the width of the inter-magnet bridge portion 1232a, illustrated in Fig. 12G. Further, providing the inter-magnet bridge portion 1232a without providing the outer-peripheral-side bridge portion as illustrated in Fig. 12F demonstrates that the torque of the rotor increases more than the case of providing the outer-peripheral-side bridge portions 1231a to 1231b and the inter-magnet bridge portion 1232a as illustrated in Fig. 12G and a case of setting the width of each of the outer-peripheral-

to not less than 0.1 times nor more than 1.0 times the length L2 in the magnetization direction Dm of the permanent magnets 812a to 812b. Accordingly, the reflux magnetic flux can be surely suppressed.

[0188] Further, in this embodiment, the recess portion 815a is provided in the position opposite apart from the teeth 123a, 123b of the stator core 121 installed in the position opposite apart from the outer peripheral surface 818 of the rotor core 811. The teeth 123a, 123b are the teeth different from the teeth 123b, 123d having the lowest magnetic flux density of the teeth 123a to 123d. Accordingly, the torque of the rotor 810 can be further increased.

[0189] Further, in this embodiment, in the rotor core cross section, the recess opening angle θc is set to not less than θa/8 nor more than 25θa/24θa (θa is the reference-position movement angle). Accordingly, the torque of the rotor 810 can be surely increased.

[0190] Further, in this embodiment, the maximum recess-depth value Cd is set within the range of not less than 0.01 times nor more than 0.1 times the diameter of the rotor core 811. Accordingly, the torque of the rotor 810 can be surely increased.

[0191] Further, in this embodiment, the rotor core 811 has a plurality of magnet holes per one pole. Further, the plurality of magnet holes include the two permanent magnets 817a to 817b respectively having the first end portions 1111a to 1111b

in a cross section perpendicular to the rotation axis line, the front-side flux barrier is on a front side in a rotation direction of the rotor core than the rear-side flux barrier;

in the cross section, a position of an open-end front-side corner portion of at least one of the open end portions provided in the same pole of a rotor is on a rear side in a rotation direction of the rotor core further than a reference position relative to the magnet hole having the open end portion;

in the cross section, the open-end front-side corner portion is a corner portion on a front side in the rotation direction of the rotor core, of two corner portions in a circumferential direction of the rotor core, of at least one of the open end portions provided in the same pole of the rotor;

in the cross section, the reference position relative to the magnet hole having the open end portion is a position at an intersection point of a straight line passing through a permanent-magnet reference end portion which is one of end portions of the permanent magnet at a position closest to the open end portion, in the permanent magnet installed through the magnet hole, and the rotation axis line, and, the outer peripheral surface of the rotor core; and

in the cross section, the permanent-magnet reference end portion of the permanent magnet at the position closest to the open end portion is, of end

portions of the permanent magnet, an end portion at a position at the farthest distance in the circumferential direction from a straight line

passing through a central position in the circumferential direction of a region of one pole including the permanent magnet, and the rotation axis line, and the distance in the circumferential direction from a straight line passing through the central position in the circumferential direction of the region of one pole including the permanent magnet, at the position closest to the open end portion, and the rotation axis line is a distance defined on a side, of the front side and the rear side in the rotation direction of the rotor core, in which the open end portion is present.

[Disclosure 2]

The rotor core according to disclosure 1, wherein in the cross section, positions of the open-end front-side corner portions of all the open end portions provided in the same pole of the rotor are each on the rear side in the rotation direction of the rotor core further than the reference position relative to the magnet hole having the open end portion.

[Disclosure 3]

The rotor core according to disclosure 1 or 2, wherein:

the rotor core has a plurality of magnet holes per one pole;

the plurality of magnet holes have a front-side magnet hole positioned on the front side in the rotation direction, and a rear-side magnet hole

the front side in the rotation direction;

in the cross section, the front-side open end portion is the open end portion of the space serving as the front-side flux barrier included in the front-side magnet hole;

in the cross section, the rear-side open-end front-side corner portion is, of two corner portions in the circumferential direction of the rotor core of a rear-side open end portion, a corner portion on the front side in the rotation direction;

in the cross section, the rear-side open-end portion is the open end portion of the space serving as the rear-side flux barrier included in the rear-side magnet hole;

in the cross section, the permanent-magnet reference end portion has at least one of a front-side permanent magnet end portion and a rear-side permanent magnet end portion;

in the cross section, the front-side permanent magnet end portion is, of the end portions of the permanent magnet installed through the front-side magnet hole, the end portion at a position on the foremost side in the rotation direction;

in the cross section, the rear-side permanent magnet end portion is, of the end portions of the permanent magnet installed through the rear-side magnet hole, the end portion at a position on the rearmost side in the rotation direction;

in the cross section, the reference position has

is not less than θa/8 nor more than 25θa/24θa;

θa is the movement angle (rad) which is the angle around the rotation axis line from a rear-side reference position which is the position at an intersection point of a straight line passing through a rear-side permanent magnet end portion and the rotation axis line, and the outer peripheral surface of the rotor core, in the cross section;

the rear-side permanent magnet end portion is, of the end portions of the permanent magnet installed in the same pole, the end portion positioned on the rearmost side in the circumferential direction;

θa is calculated by $2\pi/N_{slot}$; and

N_{slot} is the number (piece) of slots in the stator core installed in the position opposite apart from the outer peripheral surface of the rotor core.

[Disclosure 10]

The rotor core according to disclosure 8 or 9, wherein a maximum value of a depth of the recess portion is within a range of not less than 0.01 times nor more than 0.1 times a diameter of the rotor core.

[Disclosure 11]

The rotor core according to any one of disclosures 1 to 10, wherein:

the rotor core has a plurality of magnet holes per one pole;

the plurality of magnet holes have a front-side magnet hole positioned on the front side in the rotation direction, and a rear-side magnet hole

positioned on the rear side in the rotation direction;

the space serving as the front-side flux barrier included in the front-side magnet hole is on the front side in the rotation direction further than the space serving as the rear-side flux barrier included in the front-side magnet hole;

the space serving as the front-side flux barrier included in the rear-side magnet hole is on the front side in the rotation direction further than the space serving as the rear-side flux barrier included in the rear-side magnet hole;

the soft magnetic material portion has an inter-magnet bridge portion disposed in a region between the space serving as the rear-side flux barrier included in the front-side magnet hole and the space serving as the front-side flux barrier included in the rear-side magnet hole;

the front-side magnet hole has a first end portion serving as the open end portion on the front side in the rotation direction relative to the permanent magnet installed through the front-side magnet hole;

the front-side magnet hole has a second end portion on the rear side in the rotation direction relative to the permanent magnet installed through the front-side magnet hole;

the rear-side magnet hole has a first end portion serving as the open end portion on the rear side in