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(54) **ROTOR OF ROTARY ELECTRIC MACHINE AND ROTARY ELECTRIC MACHINE USING THE SAME**

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(52) **U.S. Cl.**
CPC ................................ ***H02K 1/2773*** (2013.01)

(57) **ABSTRACT**

An object is to provide a rotary electric machine capable of suppressing degradation of strength in high-speed rotation and reducing a torque ripple.

A rotor of a rotary electric machine according to the present invention includes a rotor core provided with a magnet insertion hole that forms a space into which a permanent magnet is inserted and a non-magnetic portion facing the space to form a part of the magnet insertion hole, wherein the non-magnetic portion is provided asymmetrically with respect to a d-axis.

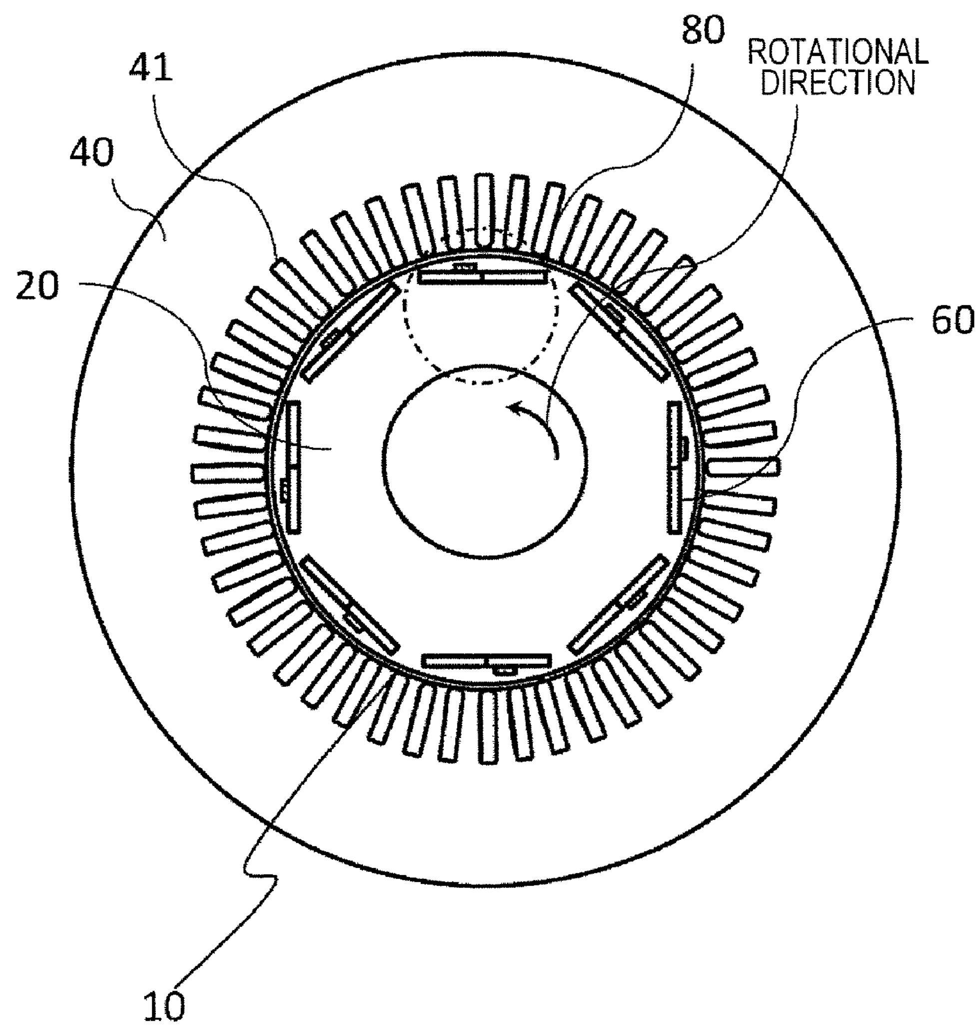


FIG. 1

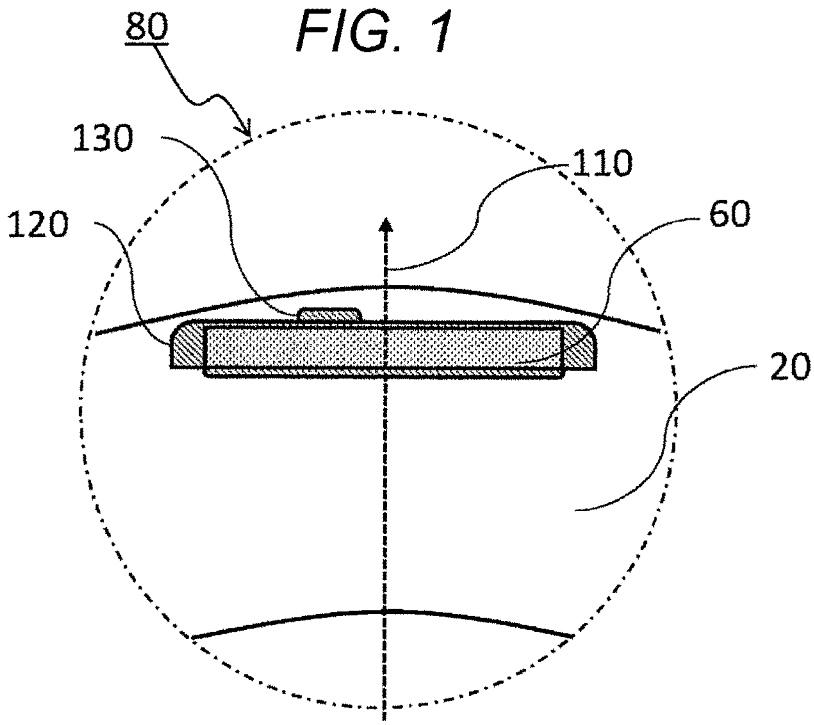

80
130
110
120
60
20

FIG. 2

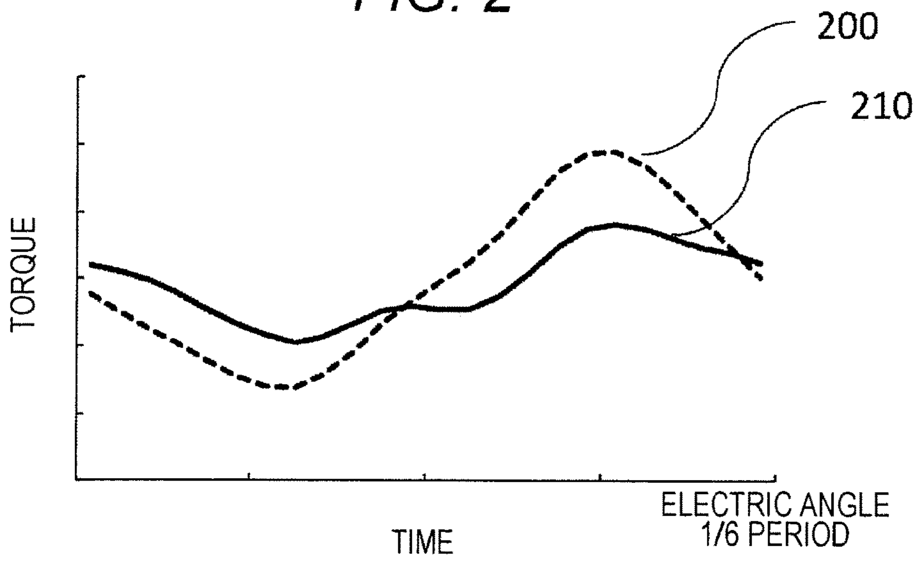

200
210
TORQUE
TIME
ELECTRIC ANGLE
1/6 PERIOD

FIG. 3

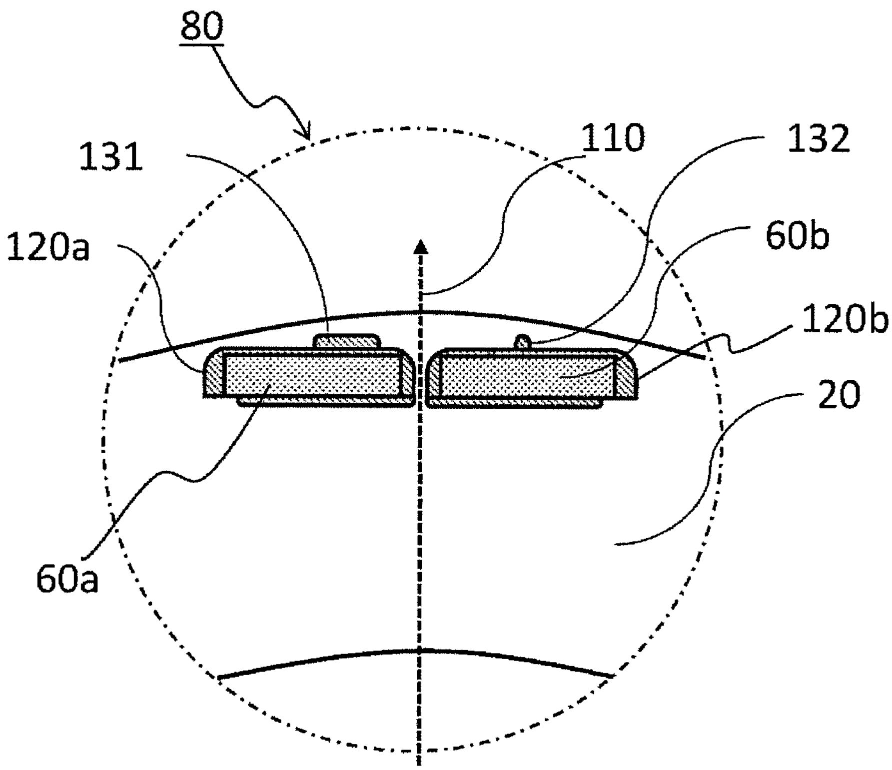


FIG. 4

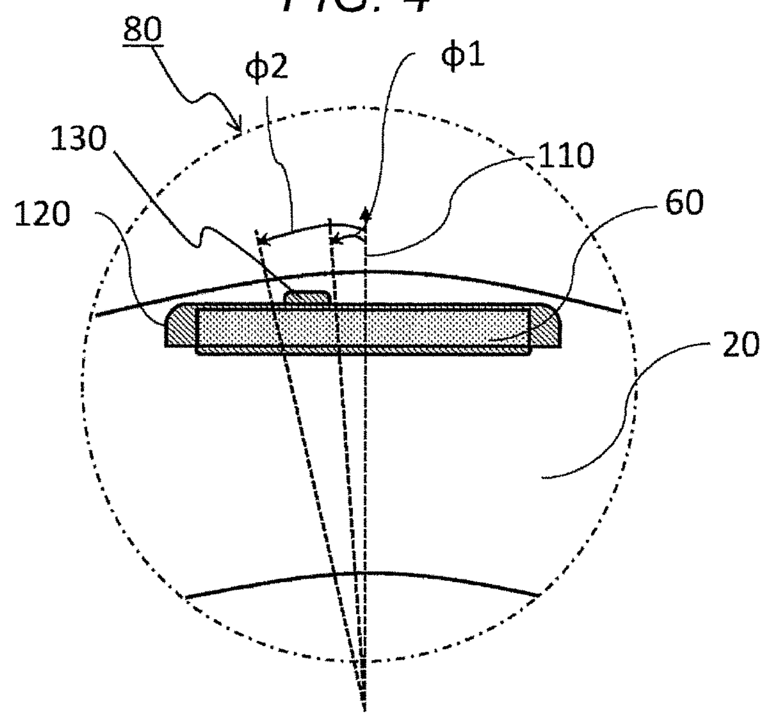

80
ϕ2
ϕ1
130
110
120
60
20

FIG. 5

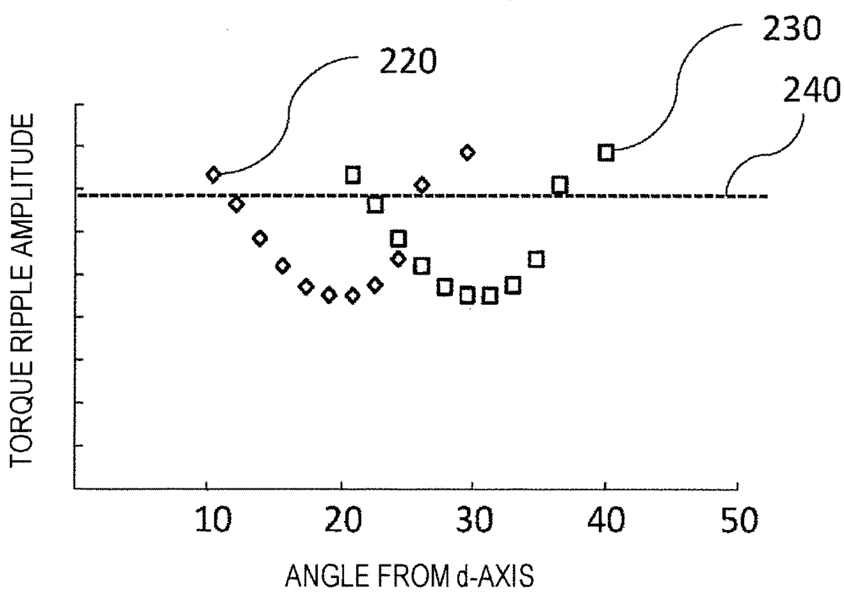

220
230
240
TORQUE RIPPLE AMPLITUDE
10
20
30
40
50
ANGLE FROM d-AXIS

FIG. 6

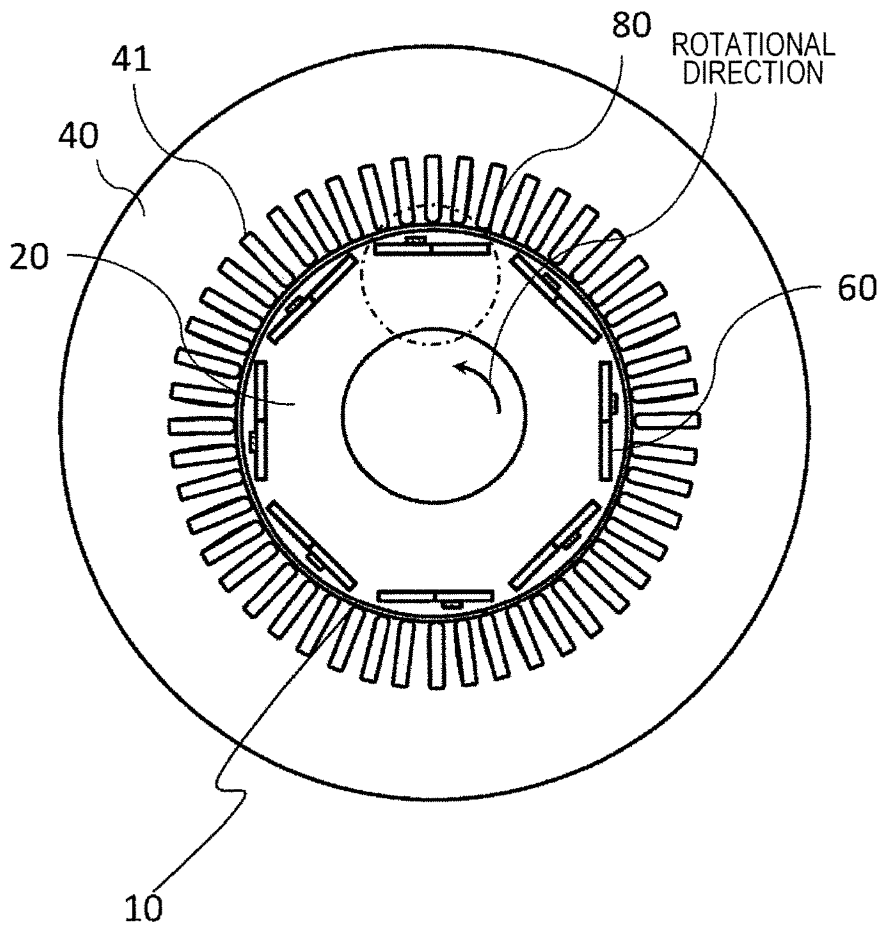



FIG. 7

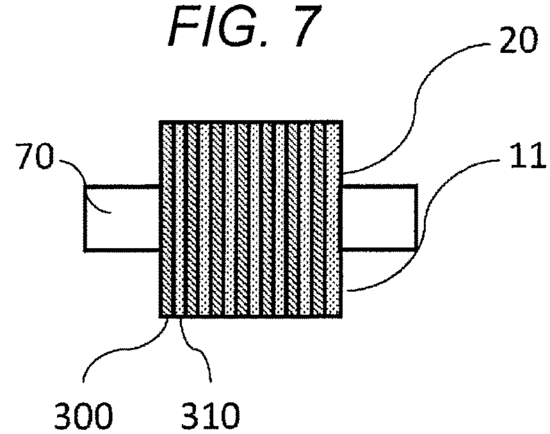


*FIG. 8*

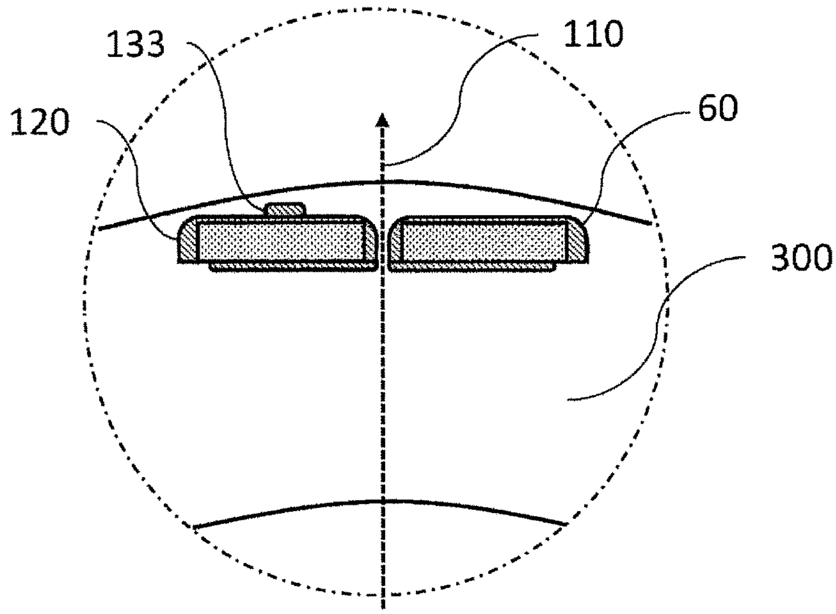



*FIG. 9*

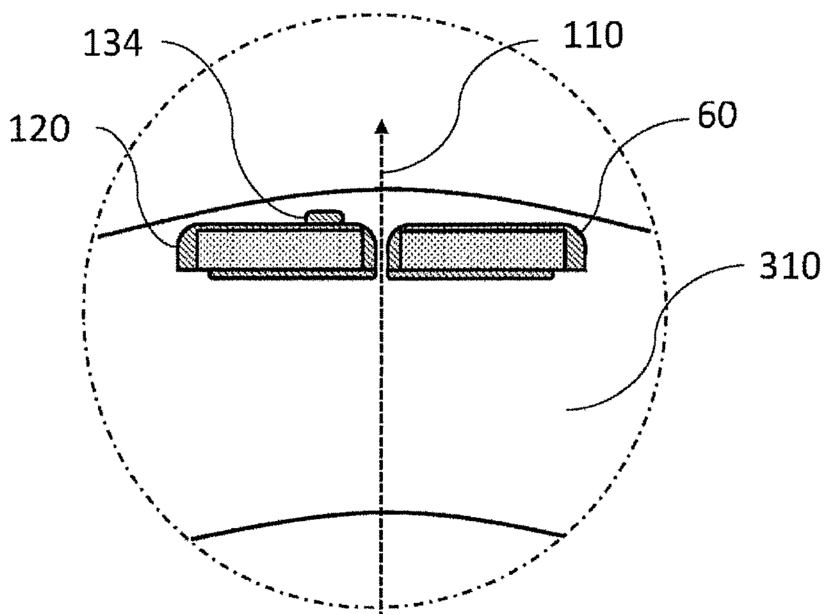


*FIG. 10*

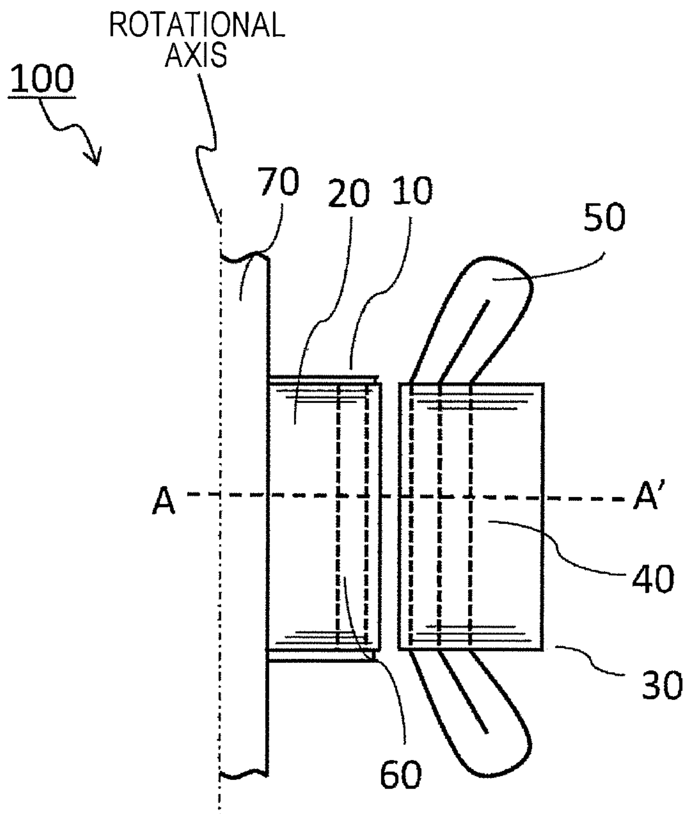


FIG. 11

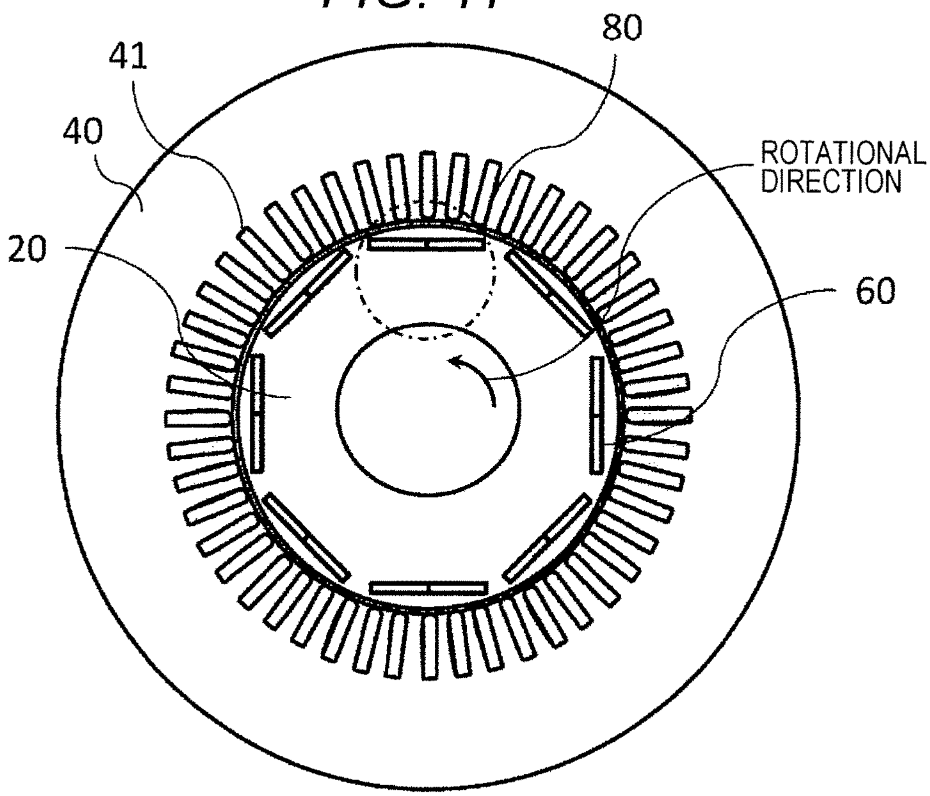



FIG. 12

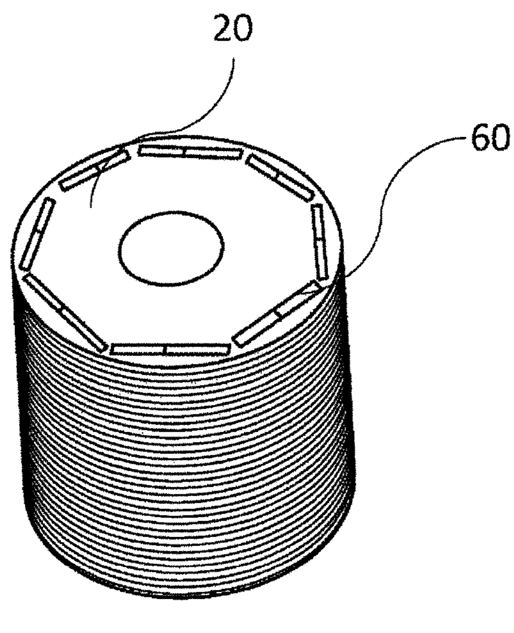


FIG. 13

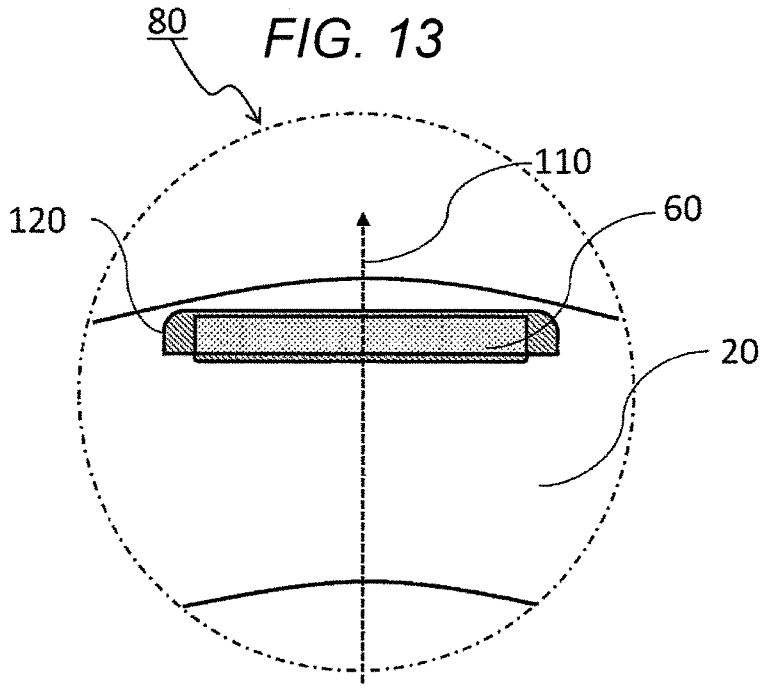
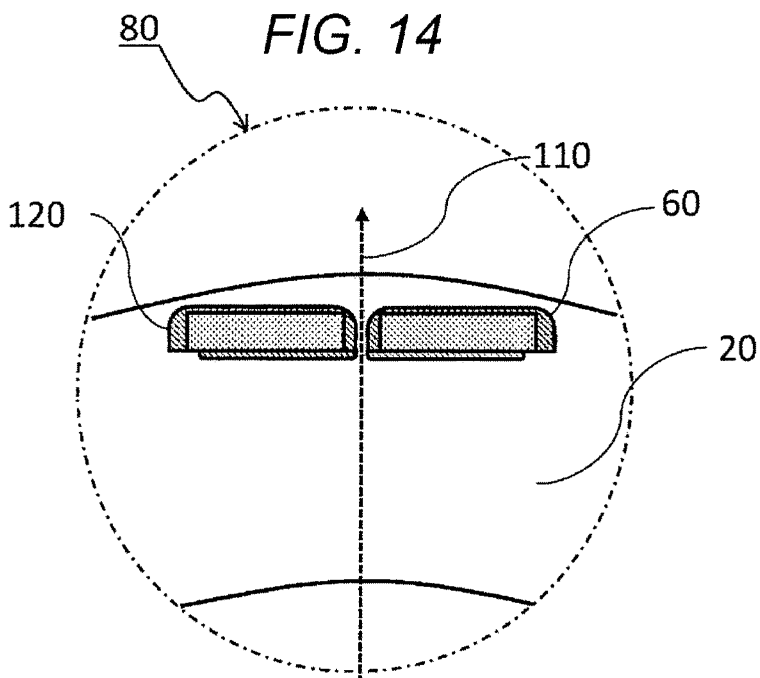



FIG. 14



# ROTOR OF ROTARY ELECTRIC MACHINE AND ROTARY ELECTRIC MACHINE USING THE SAME

## TECHNICAL FIELD

**[0001]** The present invention relates to a rotor of a rotary electric machine provided with a permanent magnet serving as a magnetic field source of the rotor and a rotary electric machine using the same.

## BACKGROUND ART

**[0002]** A rotary electric machine mounted on an electric vehicle, a hybrid vehicle, or the like is demanded to reduce a torque ripple. For example, PTL 1 discloses a stator structure of a rotary electric machine provided with a hole between a permanent magnet and the outer circumference in order to reduce a torque ripple.

## CITATION LIST

### Patent Literature

**[0003]** PTL 1: JP 2008-278591 A

## SUMMARY OF INVENTION

### Technical Problem

**[0004]** However, if a hole is provided between the permanent magnet and the outer circumference as disclosed in PTL 1, a portion where a core width is extremely narrow may be generated between the outer circumference of the rotor and the permanent magnet. This may generate degradation in strength or torque in high-speed rotation.

**[0005]** An object of the present invention is to provide a rotary electric machine capable of reducing a torque ripple while suppressing degradation of strength in high-speed rotation.

### Solution to Problem

**[0006]** In order to solve the problem, a rotor of a rotary electric machine according to the present invention includes a rotor core provided with a magnet insertion hole that forms a space into which a permanent magnet is inserted and a non-magnetic portion facing the space to form a part of the magnet insertion hole, wherein the non-magnetic portion is provided asymmetrically with respect to a d-axis.

### Advantageous Effects of Invention

**[0007]** According to the present invention, it is possible to reduce a torque ripple while suppressing degradation of strength in high-speed rotation. Other objects, configurations, and effects than those described above will become apparent by reading the following description of embodiments.

## BRIEF DESCRIPTION OF DRAWINGS

**[0008]** FIG. **1** is an enlarged view illustrating a region **80** of FIG. **6** according to a first embodiment.

**[0009]** FIG. **2** is a diagram illustrating torque ripple waveforms of a rotary electric machine according to the first embodiment and a rotary electric machine of the background art.

**[0010]** FIG. **3** is an enlarged view illustrating a rotor for one pole in a rotary electric machine according to a modification of the first embodiment.

**[0011]** FIG. **4** is an enlarged view illustrating a rotor **10** for one pole in a rotary electric machine according to a second embodiment.

**[0012]** FIG. **5** is a diagram illustrating torque ripple amplitudes of the rotary electric machine according to the second embodiment and the rotary electric machine of the background art.

**[0013]** FIG. **6** is a cross-sectional view illustrating a cross section as seen from an axial direction of the rotary electric machine according to the first embodiment.

**[0014]** FIG. **7** is a diagram illustrating a rotor **11** of a rotary electric machine according to a third embodiment.

**[0015]** FIG. **8** is an enlarged view illustrating a steel plate **300** for one pole in a rotor core **20** according to the third embodiment.

**[0016]** FIG. **9** is an enlarged view illustrating a steel plate **310** for one pole in the rotor core **20** according to the third embodiment.

**[0017]** FIG. **10** is a diagram illustrating main parts of a rotary electric machine **100** of the background art.

**[0018]** FIG. **11** is a cross-sectional view as seen in an axial direction of the rotary electric machine **100** of the background art.

**[0019]** FIG. **12** is an exterior view illustrating a rotor **10** in the rotary electric machine **100** of the background art.

**[0020]** FIG. **13** is an enlarged view illustrating the rotor **10** for one pole in the rotary electric machine **100** of the background art.

**[0021]** FIG. **14** is an enlarged view illustrating the rotor **10** for one pole in another configuration of the rotary electric machine **100** of the background art.

## DESCRIPTION OF EMBODIMENTS

**[0022]** Embodiments of the present invention will now be described with reference to the accompanying drawings. While a specific example of the contents of the present invention is discussed in the following description, the present invention is not limited such a description. Various changes or modifications may be possible for a person ordinarily skilled in the art within the scope and spirit of the present invention as disclosed in this specification. Note that, for description purposes, like reference numerals denote like elements throughout overall drawings, and they will not be repeatedly description.

**[0023]** FIG. **10** is a diagram illustrating main parts of a rotary electric machine **100** of the background art. FIG. **10** is a diagram as seen in a radial direction of the rotary electric machine **100** and shows only one side with respect to a rotational axis (illustrated as a one-dotted chain line). FIG. **11** is a cross-sectional view taken along a line A-A' of FIG. **10** in the axial direction. FIG. **12** is an exterior view illustrating a rotor core **20**. FIG. **13** is an enlarged view illustrating a configuration of a region **80** of FIG. **11** in the rotary electric machine **100** of the background art.

**[0024]** As illustrated in FIG. **10**, the rotary electric machine **100** includes a rotor **10**, a rotor core **20**, a stator **30**, a stator core **40**, an armature coil **50**, a permanent magnet **60**, and a shaft **70**.

**[0025]** A plurality of stator slots **41** are disposed in the stator core **40** approximately at equal intervals in a circumferential direction as illustrated in FIG. **11**, and the stator coil

**50** is wound inside the stator slots **41** as illustrated in FIG. **10**. As illustrated in FIG. **12**, the rotor **10** is coaxially disposed in the inner circumference side of the stator core **40**, and a plurality of permanent magnets **60** are disposed in the rotor **10** approximately at equal intervals in the circumferential direction. As illustrated in FIG. **13**, the permanent magnet **60** is inserted into a magnet insertion hole **120** provided in the rotor core **20**. A d-axis **110** is also illustrated.

**[0026]** Note that, as illustrated in FIG. **14**, the magnet insertion hole **120** may be bisected in the circumferential direction, so that two permanent magnets **60** are provided for one pole in the circumferential direction.

**[0027]** In the following example, the configuration will be described for the region **80** of the rotor for one pole. The other pole may be symmetrically provided to obtain the same effects of the present invention.

**[0028]** In the following examples, it is assumed that a rotation direction is counterclockwise as illustrated in FIG. **11**.

Example 1

**[0029]** FIG. **6** is a cross-sectional view illustrating a cross section as seen from the axial direction of the rotary electric machine according to the first embodiment. FIG. **1** is an enlarged view illustrating the region **80** of FIG. **6** according to the first embodiment.

**[0030]** The rotor **10** has a rotor core **20**, a permanent magnet **60**, and a shaft **70** (refer to FIG. **10**). The rotor core **20** is formed by stacking a plurality of steel plates. Each of the steel plates is provided with a magnet insertion hole **120** by punching or the like. The permanent magnet **60** is stored in this magnet insertion hole **120**. The stator **30** (not shown) is disposed in the outer circumference side of the rotor **10** (refer to FIG. **10**).

**[0031]** The rotor core **20** is provided with a non-magnetic portion **130** communicating with the magnet insertion hole **120**. In other words, the non-magnetic portion **130** is disposed in a position facing a space formed by the magnet insertion hole **120** to form a part of the magnet insertion hole **120**.

**[0032]** According to this embodiment, a rotational direction of the rotor **10** is counterclockwise as illustrated in FIG. **6**, and this counterclockwise direction is defined as a motor driving direction. As illustrated in FIG. **1**, a position of the non-magnetic portion **130** is in a leading side in the rotational direction from the d-axis **110** as a center of a magnetic pole. When a motor is driven, a magnetic flux density in the rotation leading side of the rotor **10** is high. In addition, since the non-magnetic portion **130** is provided in the rotation leading side, influence on a torque ripple is significant.

**[0033]** The non-magnetic portion **130** communicates with the magnet insertion hole **120** and can be provided without degrading manufacturability by forming integrally when punching from the steel plate.

**[0034]** By providing the non-magnetic portion **130** in communication with the magnet insertion hole **120**, a loss caused by air resistance at the outer circumferential portion does not increase. Even in oil immersion for lubrication or cooling, a loss caused by stirring does not increase.

**[0035]** The non-magnetic portion **130** is provided without forming an extremely narrow portion of the core width between the outer circumference of the rotor core **20** and the permanent magnet **60**. Therefore, it is possible to secure strength at high-speed rotation and avoid torque reduction because there is no intervention in the magnetic flux.

**[0036]** FIG. **2** is a computation result of the torque ripple waveform. Compared to the waveform **200** in the case where the non-magnetic portion **130** is not provided, the waveform **210** in the case where the non-magnetic portion **130** is provided has a smaller amplitude, so that the torque ripple is reduced. Meanwhile, an average torque value does not change nearly between both cases. The cause of the torque ripple is the change in the magnetic resistance by the stator slot **41** shown in FIG. **6**. However, by providing the non-magnetic portion communicating with the magnet insertion hole **120** according to this embodiment, an abrupt change of the magnetic resistance is alleviated. Therefore, as illustrated in FIG. **2**, it is possible to reduce the torque ripple while maintaining the average torque value.

**[0037]** FIG. **3** is an enlarged view illustrating the rotor for one pole of the rotary electric machine according to a modification of the first embodiment. The magnet insertion hole is bisected into a first magnet insertion hole **120*a*** and a second magnet insertion hole **120*b*** with respect to the d-axis **110** in the circumferential direction. In addition, the first permanent magnet **60*a*** is stored in the first magnet insertion hole **120*a***, and the second permanent magnet **60*b*** is stored in the second magnet insertion hole **120*b***.

**[0038]** The non-magnetic portion **131** is formed to communicate with the first magnet insertion hole **120*a*** in the leading side in the rotational direction. The non-magnetic portion **132** is formed to communicate with the second magnet insertion hole **120*b*** in the lagging side in the rotational direction. The non-magnetic portion **131** is formed to be larger than the non-magnetic portion **132** in the circumferential direction. As a result, it is possible to effectively reduce the torque ripple.

**[0039]** Note that a place where the non-magnetic portions **130** to **132** are disposed communicates with the magnet insertion hole **120**. Therefore, resin or the like may be filled in order to hold the permanent magnet **60**.

Example 2

**[0040]** FIG. **4** is an enlarged view illustrating a rotor **10** for one pole in the rotary electric machine according to a second embodiment.

**[0041]** In this embodiment, assuming that the rotational direction is counterclockwise, that is, a motor driving direction, a circumferential position of the non-magnetic portion **130** is set to an electric angle range between $\phi\mathbf{1}=12^\circ$ and $\mathbf{2}=38^\circ$ in a rotation leading direction from the d-axis **110** as a center of the magnetic pole. When a motor is driven, a magnetic flux density in the rotation leading side of the rotor **10** is high. In addition, since the non-magnetic portion **130** is provided in the rotation leading side, influence on the torque ripple is significant.

**[0042]** FIG. **5** illustrates a relationship between electric angle positions from the d-axis in the rotation leading side end and the rotation lagging side end of the non-magnetic portion **130** and the torque ripple amplitude. It is recognized that, when the electric angle from the d-axis is smaller than 12° in the torque ripple amplitude **220** of the rotation leading side end position of the non-magnetic portion **130**, and the electric angle from the d-axis is larger than of 38° in the torque ripple amplitude **230** of the rotation lagging side end position of the non-magnetic portion **130**, the torque ripple amplitudes **220** and **230** in both cases are higher than the torque ripple amplitude **240** in the case where no non-magnetic portion is provided.

**[0043]** According to this embodiment, the circumferential position of the non-magnetic portion **130** has an electric angle range between 12° and 38° in the rotation leading direction from the d-axis **110**. As a result, it is possible to effectively reduce the torque ripple.

Example 3

**[0044]** FIG. **7** is a diagram illustrating a rotor **11** of a rotary electric machine according to a third embodiment. As illustrated in FIG. **7**, the rotor core **20** is formed by alternately stacking a plurality of steel plates **300** and **310**.

**[0045]** FIG. **8** is an enlarged view illustrating the steel plate **300** for one pole in the rotor core **20** according to the third embodiment. FIG. **9** is an enlarged view illustrating the steel plate **310** for one pole in the rotor core **20** according to the third embodiment.

**[0046]** The non-magnetic portion **133** of the steel plate **300** is disposed in the rotation leading side relative to the non-magnetic portion **134** of the steel plate **310**. The non-magnetic portion **134** of the steel plate **310** is disposed in the rotation lagging side relative to the non-magnetic portion **133** of the steel plate **300**.

**[0047]** Comparing FIGS. **8** and **9**, FIG. **8** is a cross-sectional view illustrating the non-magnetic portion **133** having a slightly wide width provided in the rotation leading side, and FIG. **9** is a cross-sectional view illustrating the non-magnetic portion **134** having a slightly narrow width provided in the rotation lagging side. By alternately stacking them, it is possible to obtain the rotor core **20** having an intermediate characteristic between both cross sections.

**[0048]** According to this embodiment, it is possible to reduce a desired order harmonic component when the torque is affected overlappingly by the harmonics in addition to the slot due to an influence of the power source and the like.

**[0049]** Note that the circumferential position of the non-magnetic portion and the number of the combined non-magnetic portions may be determined by performing computation and measurement depending on a desired characteristic. In addition, the number of the stacks is not limited to one, but a plurality of stacks may be provided. Furthermore, in order to secure a holding strength of the permanent magnet, the number of the stacked steel plates may be determined without providing the non-magnetic portion.

REFERENCE SIGNS LIST

**[0050]** **10** . . . rotor
**[0051]** **20** . . . rotor core
**[0052]** **30** . . . stator
**[0053]** **40** . . . stator core
**[0054]** **41** . . . stator slot
**[0055]** **50** . . . armature coil
**[0056]** **60** . . . permanent magnet
**[0057]** **60***a* . . . first permanent magnet
**[0058]** **60***b* . . . second permanent magnet
**[0059]** **70** . . . shaft
**[0060]** **80** . . . region
**[0061]** **100** . . . rotary electric machine
**[0062]** **110** . . . d-axis
**[0063]** **120** . . . magnet insertion hole
**[0064]** **120***a* . . . first magnet insertion hole
**[0065]** **120***b* . . . second magnet insertion hole
**[0066]** **130** . . . non-magnetic portion
**[0067]** **131** . . . non-magnetic portion
**[0068]** **132** . . . non-magnetic portion
**[0069]** **200** . . . torque waveform in case where no non-magnetic portion **130** is provided
**[0070]** **210** . . . torque waveform in case where non-magnetic portion **130** is provided
**[0071]** **220** . . . torque ripple amplitude in rotation leading side end position of non-magnetic portion
**[0072]** **230** . . . torque ripple amplitude in rotation lagging side end position of non-magnetic portion
**[0073]** **240** . . . torque ripple amplitude in case where no non-magnetic portion is provided
**[0074]** **300** . . . steel plate
**[0075]** **310** . . . steel plate

**1**. A rotor of a rotary electric machine comprising a rotor core provided with a magnet insertion hole that forms a space into which a permanent magnet is inserted and a non-magnetic portion facing the space to form a part of the magnet insertion hole,

wherein the non-magnetic portion is provided asymmetrically with respect to a d-axis.

**2**. The rotor of the rotary electric machine according to claim **1**, wherein the non-magnetic portion is provided in an electric angle position between 12° and 38° from the d-axis.

**3**. The rotor of the rotary electric machine according to claim **1**, wherein the d-axis passes through a center of the magnet insertion hole.

**4**. The rotor of the rotary electric machine according to claim **1**, wherein the magnet insertion hole includes a first magnet insertion hole that forms a first space into which the first permanent magnet is inserted and a second magnet insertion hole that forms a second space into which the second permanent magnet is inserted,

the non-magnetic portion includes a first non-magnetic portion facing the first space to form a part of the first magnet insertion hole, and a second non-magnetic portion facing the second space to form a part of the second magnet insertion hole, and

the first non-magnetic portion is formed to be larger than the second non-magnetic portion in a circumferential direction with respect to the d-axis.

**5**. The rotor of the rotary electric machine according to claim **1**, wherein the rotor core is formed by alternately stacking steel plates having different positions of the non-magnetic portions.

**6**. A rotary electric machine comprising:

the rotor according claim **1**; and

a stator provided in an outer circumference side of the rotor by interposing a gap.

* * * * *