(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 September 2015 (24.09.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/139080 A1

(51) International Patent Classification:
H02K 21/24 (2006.01) *H02K 1/27* (2006.01)

(21) International Application Number:
PCT/AU2015/000165

(22) International Filing Date:
20 March 2015 (20.03.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2014900988 21 March 2014 (21.03.2014) AU

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

WO 2015/139080 A1

(54) Title: ROTOR FOR AN ELECTRICAL MACHINE

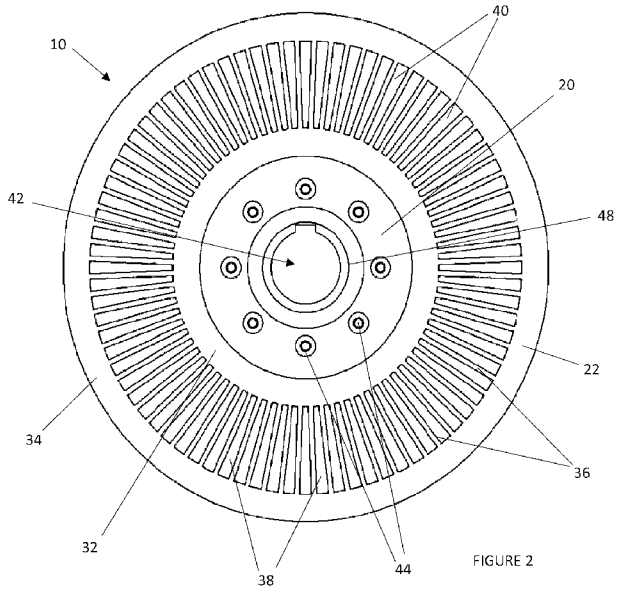

FIGURE 2

(57) Abstract: A rotor (10) for an axial-flux electrical machine (12) is provided. The rotor (10) comprises an annular disc-shaped central frame (20) formed of a ferromagnetic material and having first and second opposing surfaces (26, 28). Each of the first and second opposing surface (26, 28) has shaped protrusions (40) extending therefrom. The rotor (10) further comprises a first and a second outer frame (22, 24) formed of a non-ferromagnetic, electrically conducting material. Each outer frame (22, 24) has an inner periphery portion (32) and an outer periphery portion (34) and a plurality of bars (36) galvanically connecting the inner and outer periphery portions (32, 34). Gap portions (38) are defined between adjacent bars (36) and the inner and outer periphery portions (32, 34). The gap portions (38) are shaped complementary to the shaped protrusions (40) of the central frame (20).

ROTOR FOR AN ELECTRICAL MACHINE

Field of the Invention

[001] The present invention relates to a rotor for use in an electrical machine and in particular to a rotor for use in an axial flux induction electrical machine.

[002] The invention has been developed primarily for use in/with electrical motors for electric/hybrid vehicles and will be described hereinafter with reference to this application. However, it will be appreciated that the invention is not limited to this particular field of use.

Background of the Invention

[003] In nearly all hybrid vehicles, it is desirable to minimise the size and weight of the automotive components. At the same time, it is also desirable to maximise the power output of electrical machines used in hybrid vehicles.

[004] Thus, for hybrid vehicles it is desirable to use electrical machines with high power output per unit mass (often referred to as “power density” and measured in kW/kg). Unfortunately, however, existing electrical machines do not satisfy these requirements and so do not lend themselves well to use in hybrid vehicles.

[005] Similar considerations apply to electrical machines used to power purely electric vehicles.

[006] Electrical machines that are of the axial-flux type are in several ways best suited for use in hybrid vehicles and purely electric vehicles. One reason for this is because they can be designed to have a high power density. However, the design of axial-flux machines insofar as it relates to their assembly and operation is not optimized. Assembly can be difficult and operation can be unreliable. This is particularly the case in relation to the rotors of such machines.

[007] An object of the claimed invention is to provide a rotor for an axial-flux electrical machine which will overcome or substantially ameliorate at least some of the deficiencies of the prior art, or to at least provide an alternative.

[008] It is to be understood that, if any prior art information is referred to herein, such reference does not constitute an admission that the information forms part of the common general knowledge in the art, in Australia or any other country.

Summary of the Invention

[009] According to a first aspect of the present invention, a rotor for an axial-flux electrical machine is provided. The rotor the rotor comprises:

[0010] an annular disc-shaped central frame formed of a ferromagnetic material and having first and second opposing surfaces, wherein each of the first and second opposing surfaces have shaped protrusions extending therefrom;

[0011] a first and a second outer frame formed of a non-ferromagnetic, electrically conducting material, each outer frame having an inner periphery portion and an outer periphery portion and a plurality of bars galvanically connecting the inner and outer periphery portions, wherein gap portions are defined between adjacent bars and the inner and outer periphery portions, the gap portions being shaped complementary to the shaped protrusions of the central frame;

[0012] wherein the first outer frame is affixed to the first surface of the central frame and the second outer frame is affixed to the second surface of the central frame with the shaped protrusions extending through the gap portions of the outer frames.

[0013] Preferably, the central frame is integrally formed.

[0014] Preferably, each outer frame is integrally formed.

[0015] Preferably, the plurality of bars extend radially between the inner and outer periphery portions.

[0016] Preferably, each outer frame further includes at least one intermediary portion arranged between the inner and outer periphery portions and intersecting the plurality of bars.

[0017] Preferably, ferromagnetic material is steel and the non-ferromagnetic material is aluminium or copper.

[0018] Preferably, the central frame and the outer frames are formed by a process of milling, laser cutting, water jet cutting, electrical discharge machining or casting.

[0019] Preferably, the number of bars is selected on the basis of a ratio with the number of slots on the stator of the axial-flux electrical machine. Ideally, the ratio is a high ratio with more bars compared to stator slots such as 1.666:1.

[0020] According to a second aspect of the present invention, there is provided rotor for an axial-flux electrical machine, the rotor comprising:

[0021] an annular disc-shaped central frame formed of a ferromagnetic material and having first and second opposing surfaces, wherein each of the first and second opposing surfaces have shaped protrusions extending therefrom;

[0022] a first and a second outer frame formed of a non-ferromagnetic, electrically conducting material, each outer frame having an inner periphery portion, an outer periphery portion and at least one intermediary portion between the outer and inner periphery portions; a plurality of bars galvanically connect the inner and the at least one intermediary portions and the outer periphery portions, wherein gap portions are defined between adjacent bars and the inner, the at least one intermediary and the outer periphery portions, the gap portions being shaped complementary to the shaped protrusions of the central frame;

[0023] wherein the first outer frame is affixed to the first surface of the central frame and the second outer frame is affixed to the second surface of the central frame with the shaped protrusions extending through the gap portions of the outer frames.

[0024] Other aspects of the invention are also disclosed.

Brief Description of the Drawings

[0025] Notwithstanding any other forms which may fall within the scope of the present invention, a preferred embodiment / preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of an axial flux induction machine incorporating a rotor in accordance with a preferred embodiment of the present invention;

Fig. 2 is a plan view of a rotor in accordance with a preferred embodiment of the present invention;

Fig. 3 is a cross-sectional view of the rotor of Fig. 2;

Fig. 4 is a plan view of a rotor in accordance with another preferred embodiment of the present invention;

Fig. 5 is a cross-sectional view of the rotor of Fig. 4;

Fig. 6 is a plan view of a rotor in accordance with another preferred embodiment of the present invention; and

Fig. 7 is a cross-sectional view of the rotor of Fig. 6.

Description of Embodiments

[0026] It should be noted in the following description that like or the same reference numerals in different embodiments denote the same or similar features.

[0027] The invention relates to a rotor 10 for an axial flux induction electrical machine 12. Referring to Fig. 1, the machine 10 includes a first stator 14 and a second stator 16 in a symmetrical mirrored relationship to the first stator 14 such that a gap 18 is defined intermediate the first and second stator 14, 16. A rotor 10, in the shape of a thin annular disc, is disposed in the gap 18. The thickness of the disc is substantially smaller than the radius of the disc.

[0028] Referring to Figs. 2 and 3, the rotor structure 10 is comprised of a central ferromagnetic material frame 20 and two outer non-ferromagnetic material frames 22, 24 affixed to opposing surfaces 26, 28 of the central frame 20.

[0029] The non-ferromagnetic frames 22, 24 are fabricated with high electrically conducting material such as aluminium or copper. The non-ferromagnetic frames 22, 24 comprise an inner periphery 32 and an outer periphery 34. Conducting bars 36 fabricated of the same material are galvanically connected to the peripheries 32, 34. The conducting bars 36 together with the inner and outer peripheries 32, 34 form the cage winding of the rotor 10. As shown, the conducting bars 36 are arranged extending radially from the inner 32 to the outer periphery 34. However, other configurations of the conducting bars will also work. For example, figs. 4 and 5 show an alternative embodiment of a rotor 110 in which the conducting bars 136 have a skewed arrangement.

[0030] The number of conducting bars 36 is ideally selected on a ratio basis of the number of slots on the stator 14, 16. It is been found that by having a high ratio (i.e. more conducting bars compared with number of stator slots) there is a reduction in differential leakage compared with using a low ratio. The ideal ratio has been found to be 1.666:1. In the embodiment illustrated this ratio equates with 80 conducting bars for use with a stator having 48 stator slots.

[0031] The construction of the non-ferromagnetic frames 22, 24 provides gap portions 38 defined between adjacent conducting bars 36 and the inner 32 and outer 34 peripheries.

[0032] In order to provide the disc rotor 10 with a high level of structural rigidity, to allow the rotor 10 to retain dimensional stability and withstand both axial and radial structural stresses and moment stress, the central frame 20 is fabricated with a ferromagnetic material such as steel. The ferromagnetic frame 20 is integrally formed as a single piece.

[0033] On the opposing sides 26, 28 of the central frame 20, integrally formed shaped protrusions 40 extend from the frame 20. The protrusions 40 are shown as wedge shaped which match the shape of the gap portions 38 in the non-ferromagnetic frames 22, 24.

[0034] The non-ferromagnetic frames 22, 24 are placed respectively on each side 26, 28 of the central frame 20 with the wedge-shaped protrusions 40 fitting in and extending through the gap portions 38 of the non-ferromagnetic frames 22, 24. The non-ferromagnetic frames 22, 24 can be secured in place using a suitable epoxy, for example.

[0035] The arrangement enhances the flux carry capacity of the rotor 10 and provides a magnetic flux path between the first and second stator 14, 16 due to the plurality of ferromagnetic wedge-shaped protrusions 40 extending through the non-ferromagnetic frames 22, 24 and being spaced apart from each other at an appropriate distance so that the radial non-ferromagnetic conductor bars 36 are appropriately located between the protrusions 40.

[0036] The central frame 20 has a central hole 42, in which is received a separate hub member. The hub member is used to fix the rotor to be mounted on a shaft 11 of the machine 12, for example by way of radial grub screws and a shaft key. A number of

additional holes 44 surround the central hole 42 for receiving bolts, screws or other suitable means in order to secure the rotor 10 to the hub member .

[0037] The hub member is not shown on the alternative embodiments illustrated in Figs. 4 to 7.

[0038] Figs. 6 and 7 show an alternative embodiment of the rotor 210. In this embodiment the non-ferromagnetic frames 222, 224 have an intermediary portion 250 arranged between the inner 232 and outer 234 periphery. Conducting bars 236 extend between the inner periphery 232 and the intermediary portion 250; and between the intermediary portion 250 and the outer periphery 234. Again, this arrangement provides gap portions 238 and the central frame 220 has complementary shaped protrusions 240 for fitting and extending through the gap portions 238. In tests it has been found that the rotor 210 incorporating the intermediary portion 250 improves performance by providing an improved magnetic circuit and reduced torque ripple.

[0039] The ferromagnetic and non-ferromagnetic rotor parts 20, 22, 24 may be fabricated from sheet metal using material removal methods by means of milling, laser cutting, water jet cutting or electrical discharge machining. Alternatively, the rotor parts 20, 22, 24 could be fabricated using direct metal sintering 3D printing methods.

In preferred embodiments, the central frame 20 is formed by a casting process. Potentially, the non-ferromagnetic frames 22, 24 could be formed by die-casting onto the central ferromagnetic frame 20 using the ferromagnetic frame as a form within the die cast tooling.

Interpretation

Embodiments:

[0040] Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be

apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0041] Similarly it should be appreciated that in the above description of example embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the Detailed Description of Specific Embodiments are hereby expressly incorporated into this Detailed Description of Specific Embodiments, with each claim standing on its own as a separate embodiment of this invention.

[0042] Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

Different Instances of Objects

[0043] As used herein, unless otherwise specified the use of the ordinal adjectives “first”, “second”, “third”, etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

Specific Details

[0044] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

Terminology

[0045] In describing the preferred embodiment of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, the invention is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar technical purpose. Terms such as "forward", "rearward", "radially", "peripherally", "upwardly", "downwardly", and the like are used as words of convenience to provide reference points and are not to be construed as limiting terms.

Comprising and Including

[0046] In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” are used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

[0047] Any one of the terms: including or which includes or that includes as used herein is also an open term that also means including at least the elements/features that follow the term, but not excluding others. Thus, including is synonymous with and means comprising.

Scope of Invention

[0048] Thus, while there has been described what are believed to be the preferred embodiments of the invention, those skilled in the art will recognize that other and further modifications may be made thereto without departing from the spirit of the invention, and it is intended to claim all such changes and modifications as fall within the scope of the invention. For example, any formulas given above are merely representative of procedures that may be used. Functionality may be added or deleted from the block diagrams and operations may be interchanged among functional blocks. Steps may be added or deleted to methods described within the scope of the present invention.

[0049] Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

Industrial Applicability

[0050] It is apparent from the above, that the arrangements described are applicable to the electrical machine industries.

Claims

The claims defining the invention are as follows:

1. A rotor for an axial-flux electrical machine, the rotor comprising:

an annular disc-shaped central frame formed of a ferromagnetic material and having first and second opposing surfaces, wherein each of said first and second opposing surface has shaped protrusions extending therefrom;

a first and a second outer frame formed of a non-ferromagnetic, electrically conducting material, each outer frame having an inner periphery portion and an outer periphery portion and a plurality of bars galvanically connecting the inner and outer periphery portions, wherein gap portions are defined between adjacent bars and the inner and outer periphery portions, the gap portions being shaped complementary to the shaped protrusions of the central frame;

wherein the first outer frame is affixed to the first surface of the central frame and the second outer frame is affixed to the second surface of the central frame with the shaped protrusions extending through the gap portions of the outer frames.

2. The rotor of claim 1, wherein the central frame is integrally formed.

3. The rotor of claim 1 or 2, wherein each outer frame is integrally formed.

4. The rotor of any one of the preceding claims, wherein the plurality of bars extend radially between the inner and outer periphery portions.

5. The rotor of any one of the preceding claims, wherein each outer frame further includes at least one intermediary portion arranged between the inner and outer periphery portions and intersecting the plurality of bars.

6. The rotor of any one of the preceding claims, wherein said ferromagnetic material is steel.

7. The rotor of any one of the preceding claims, wherein said non-ferromagnetic material is aluminium.

8. The rotor of any one of claims 1 to 6, wherein said non-ferromagnetic material is copper.

9. The rotor of any one of the preceding claims, wherein said central frame is formed by a process of milling, laser cutting or water jet cutting.

10. The rotor of any one of claims 1 to 8, wherein said central frame is formed by a casting process.

11. The rotor of any one of the preceding claims, wherein each outer frame is formed by a process of milling, laser cutting or water jet cutting.

12. The rotor of any one claims 1 to 10, wherein each outer frame is formed by a casting process.

13. The rotor of claim 12, wherein each outer frame is cast directly onto the central frame.

14. The rotor of any one of the preceding claims, wherein the number of bars is selected on the basis of a ratio with the number of slots on the stator of the axial-flux electrical machine.

15. The rotor of claim 14, wherein the ratio is a high ratio with more bars compared to stator slots.

16. The rotor of claim 15, wherein the ratio is 1.666:1.

17. A rotor for an axial-flux electrical machine, the rotor comprising:
an annular disc-shaped central frame formed of a ferromagnetic material and having first and second opposing surfaces, wherein each of said first and second opposing surface has shaped protrusions extending therefrom;

a first and a second outer frame formed of a non-ferromagnetic, electrically conducting material, each outer frame having an inner periphery portion, an outer periphery portion and at least one intermediary portion between the outer and inner periphery portions; a plurality of bars galvanically connect the inner and the at least one intermediary portions and the outer periphery portions, wherein gap portions are defined between adjacent bars and the inner, the at least one intermediary and the outer periphery portions, the gap portions being shaped complementary to the shaped protrusions of the central frame;

wherein the first outer frame is affixed to the first surface of the central frame and the second outer frame is affixed to the second surface of the central frame with the shaped protrusions extending through the gap portions of the outer frames.

18. The rotor of claim 17, wherein the central frame is integrally formed.

19. The rotor of claim 17 or 16, wherein each outer frame is integrally formed.

20. The rotor of any one of claims 17 to 19, wherein the plurality of bars extend radially from the inner periphery portion.

21. The rotor of any one of claims 17 to 20 wherein said ferromagnetic material is steel.

22. The rotor of any one of claims 17 to 21, wherein said non-ferromagnetic material is aluminium.

23. The rotor of any one of claims 17 to 21, wherein said non-ferromagnetic material is copper.

24. The rotor of any one of claims 17 to 23, wherein said central frame is formed by a process of milling, laser cutting, water jet cutting or electrical discharge machining.

25. The rotor of any one of claims 17 to 23, wherein said central frame is formed by a casting process.

26. The rotor of any one of claims 17 to 25, wherein each outer frame is formed by a process of milling, laser cutting, water jet cutting or electrical discharge machining.

27. The rotor of any one of claims 17 to 25, wherein each outer frame is formed by a casting process.

28. The rotor of claim 27, wherein each outer frame is cast directly onto the central frame.

29. The rotor of any one of claims 17 to 28, wherein the number of bars is selected on the basis of a ratio with the number of slots on the stator of the axial-flux electrical machine.

30. The rotor of claim 29, wherein the ratio is a high ratio with more bars compared to stator slots.

31. The rotor of claim 30, wherein the ratio is 1.666:1.

32. An axial flux electrical machine including a rotor according to any one of the preceding claims.

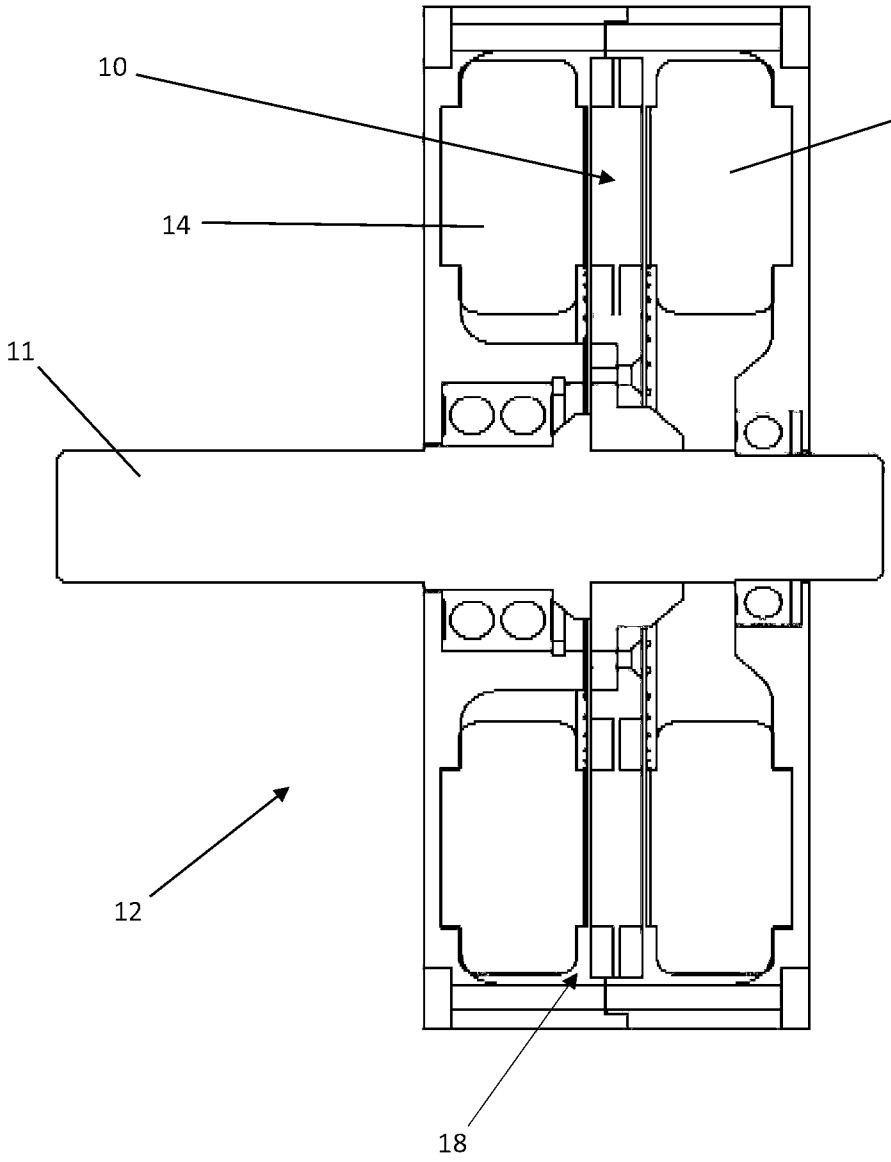

FIGURE 1

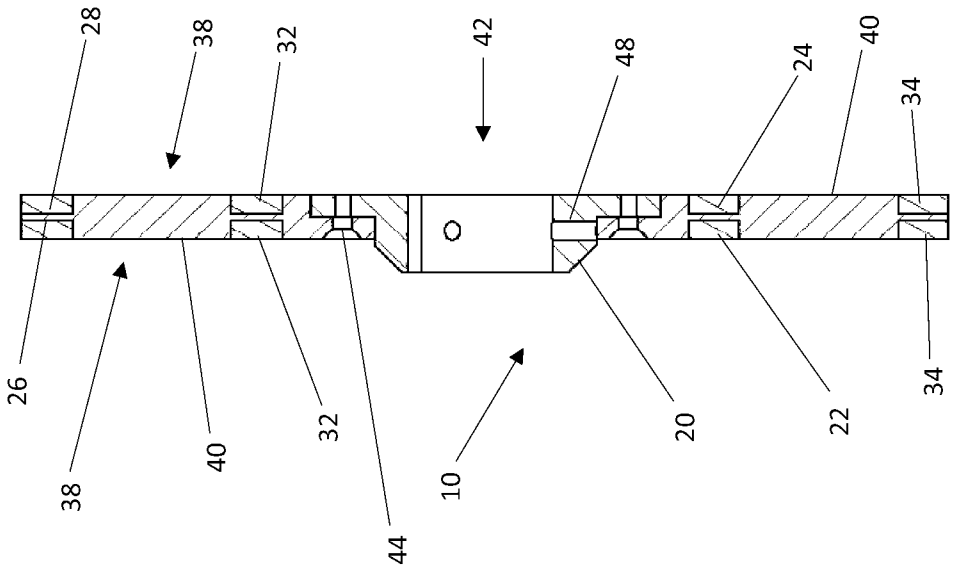

FIGURE 3

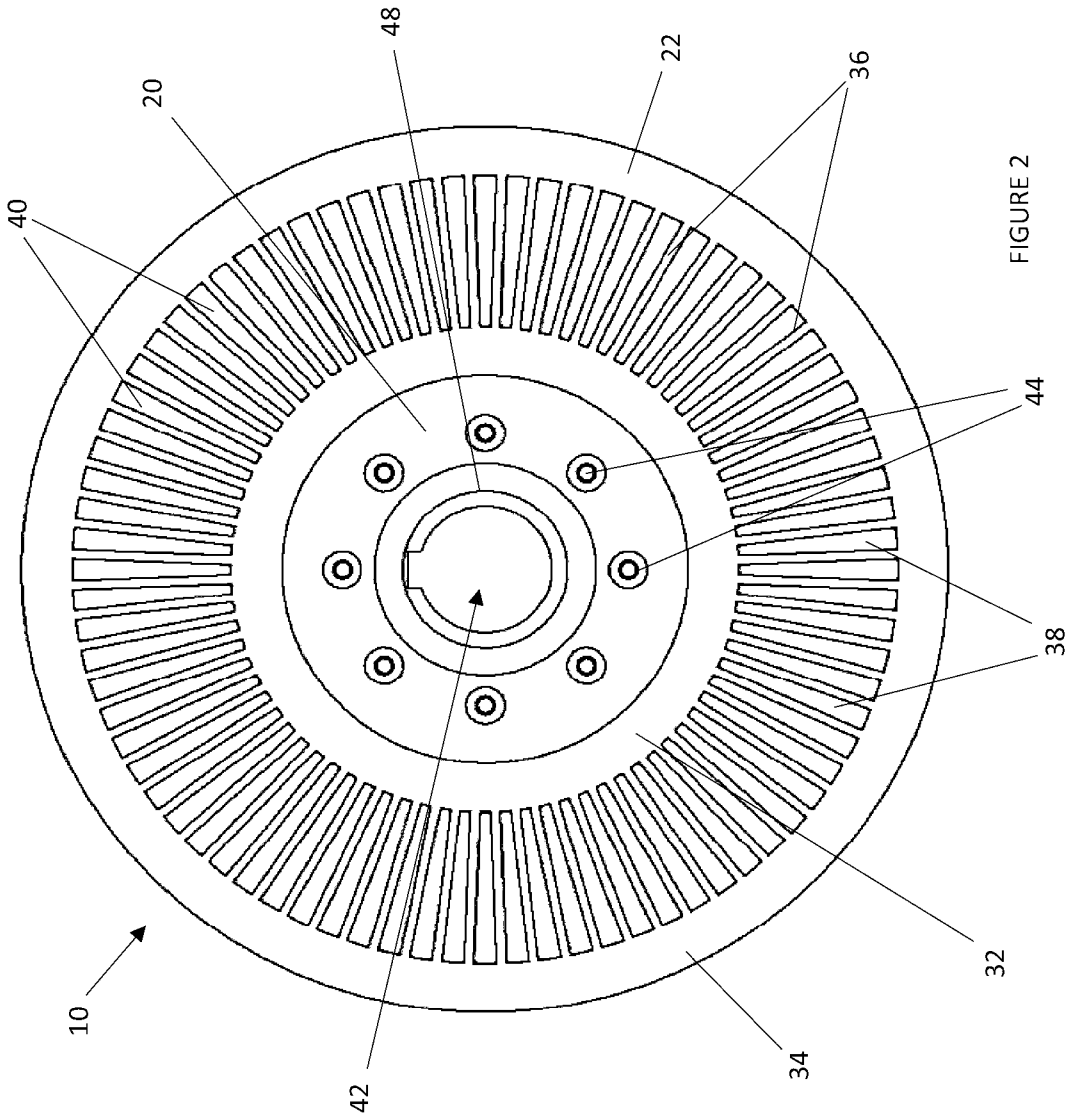

FIGURE 2

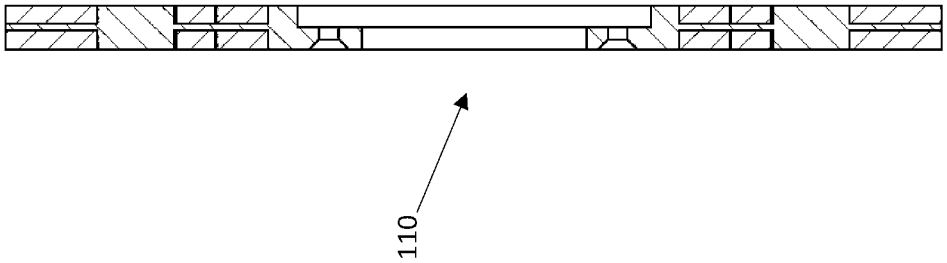

FIGURE 5

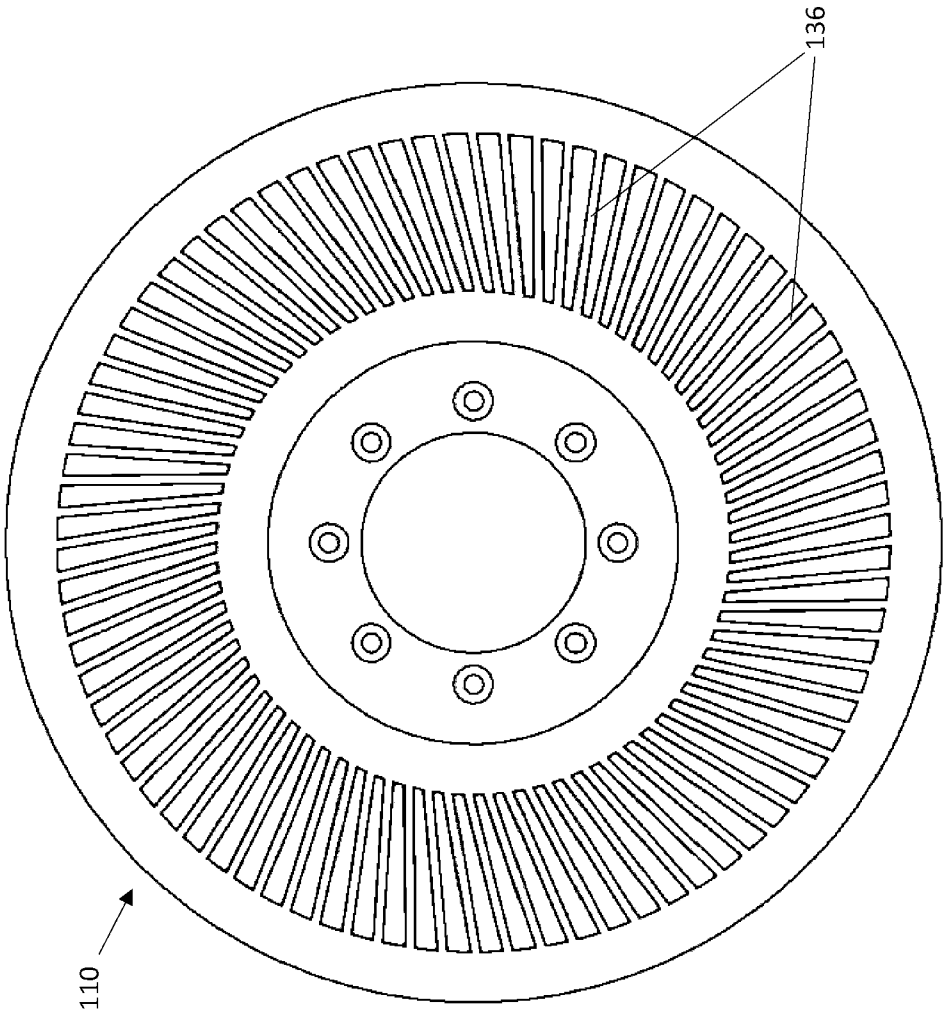

FIGURE 4

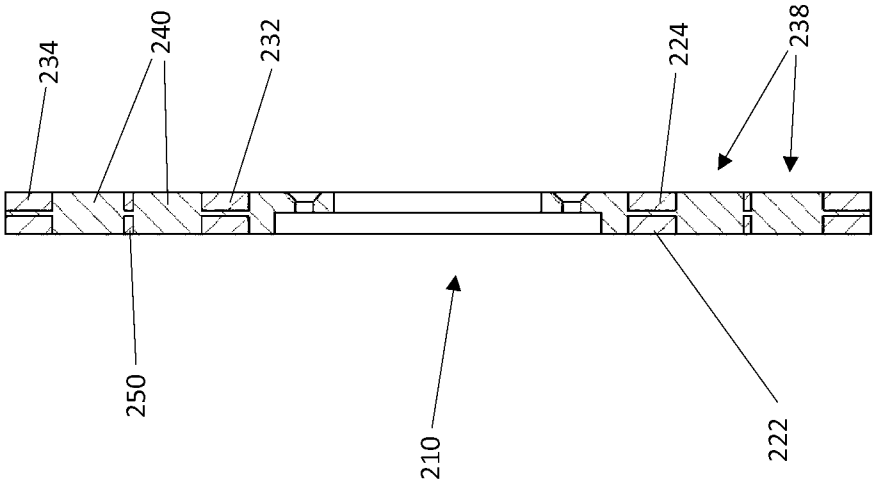

FIGURE 7

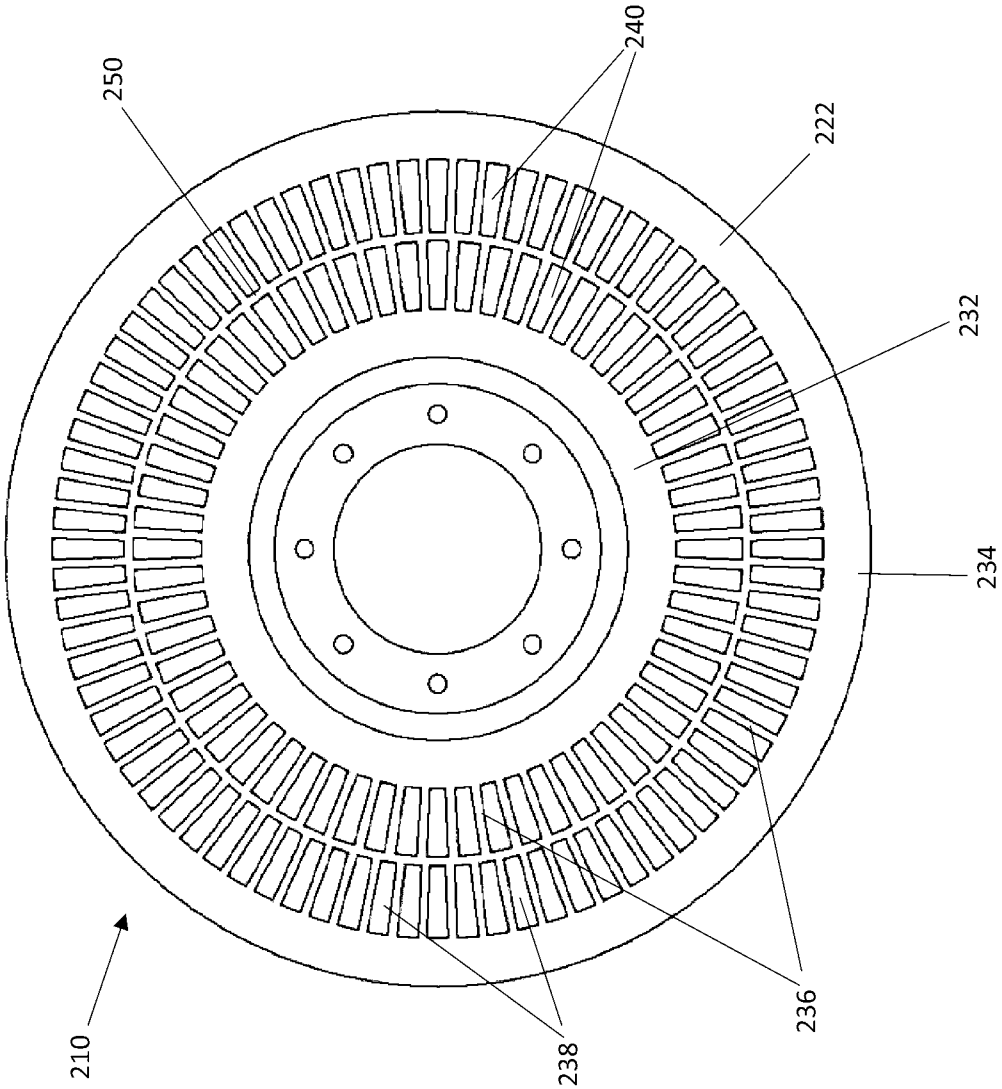

FIGURE 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2015/000165

A. CLASSIFICATION OF SUBJECT MATTER

H02K 21/24 (2006.01) H02K 1/27 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC and WPI with keywords axial motor, annular, magnetic, protrusion, central, frame, IPC H02K21, H02K1 and similar terms.

GOOGLE PATENTS with the following keywords – axial, motor, rotor, frame, protrusion, plate, protruding, gap, and similar terms.

ESPACENET: Applicant/ Inventor search.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 April 2015	29 April 2015
Name and mailing address of the ISA/AU	**Authorised officer**
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Vinod Menon AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0262832763

INTERNATIONAL SEARCH REPORT C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		International application No. **PCT/AU2015/000165**
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2006-345627 A (NISSAN MOTOR CO LTD) 21 December 2006 Abstract, paragraph [0013]-[0016], [0025], figs 2, 4	1-32
A	JP 2011-172385 A (DAIKIN INDUSTRIES LTD) 01 September 2011 Whole document especially the abstract, paragraph [0058]-[0059], figs 4-5	1-32

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2015/000165**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
JP 2006-345627 A	21 December 2006		
JP 2011-172385 A	01 September 2011		

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

摘要

提供了一种用于轴向磁通电机(12)的转子(10)。所述转子(10)包括：由铁磁材料制成并具有相对的第一表面和第二表面(26，28)的环形盘状中心框体(20)。该第一表面和第二表面(26，28)中的每个表面具有伸出的成形突起(40)。转子(10)还包括由导电的非铁磁材料制成的第一外框体和第二外框体(22，24)，每个外框体(22，24)具有内周部(32)和外周部(34)，多个导条电(36)连接该内周部和该外周部(32，34)。在相邻的导条(36)与该内周部和该外周部之间(32，34)形成间隙部(38)，该间隙部(38)与该中心框体(20)的该成形突起(40)的形状互补。